# 7TH

# SUMMARY OF RESEARCH
## AT
# BOULDER LABORATORIES

FOR YEAR ENDING JUNE 30, 1961

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
BOULDER LABORATORIES
Boulder, Colorado

# THE NATIONAL BUREAU OF STANDARDS

## Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. Research projects are also performed for other government agencies when the work relates to and supplements the basic program of the Bureau or when the Bureau's unique competence is required. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

## Publications

The results of the Bureau's research are published either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three periodicals available from the Government Printing Office: The Journal of Research, published in four separate sections, presents complete scientific and technical papers; the Technical News Bulletin presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: Monographs, Applied Mathematics Series, Handbooks, Miscellaneous Publications, and Technical Notes.

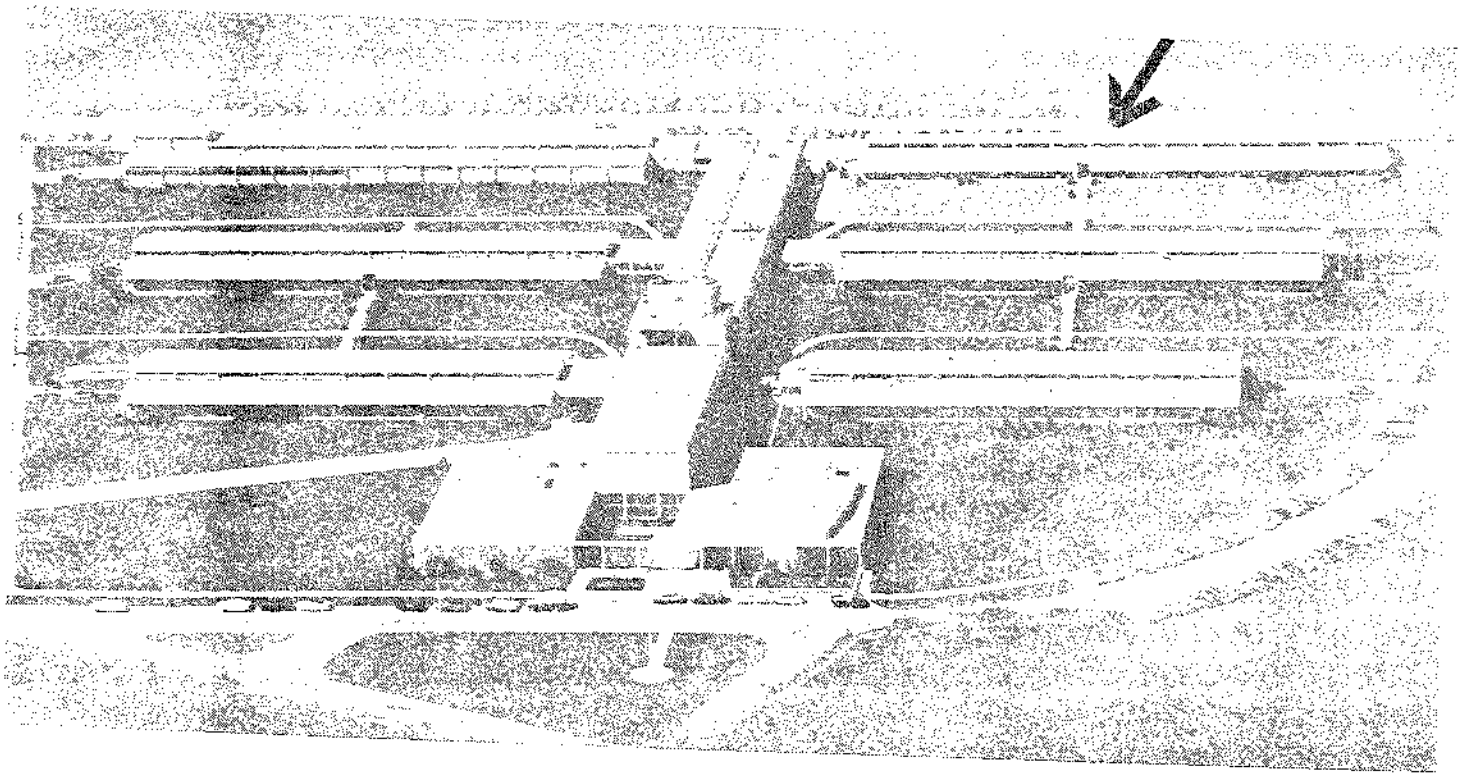
A complete listing of the Bureau's publications can be found in National Bureau of Standards Circular 460, Publications of the National Bureau of Standards, 1901 to June 1947 ($1.25), and the Supplement to National Bureau of Standards Circular 460, July 1947 to June 1957 ($1.50), and Miscellaneous Publication 240, July 1957 to June 1960 (Includes Titles of Papers Published in Outside Journals 1950 to 1959) ($2.25); available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

# SEVENTH
# SUMMARY OF RESEARCH
# AT
# BOULDER LABORATORIES

FOR YEAR ENDING JUNE 30, 1961

NBS

**U. S. DEPARTMENT OF COMMERCE**
**NATIONAL BUREAU OF STANDARDS**
**BOULDER LABORATORIES**
**Boulder, Colorado**



Radio Building, Boulder Laboratories, National Bureau of Standards. Arrow indicates Wing 5 under construction.

U.S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS

# BOULDER LABORATORIES, BOULDER, COLORADO

Telephone Hillcrest 2-2161

| Code | | | Building | Room | Ext. |
|---|---|---|---|---|---|
| 79 | DIRECTOR'S OFFICE | | | | |
| 79.00 | Director | Dr. F. W. Brown | Radio | 2010 | 211 |
| | Secretary | Josephine S. Krantz | Radio | 2010 | 211 |
| | Executive Officer | S. W. J. Welch | Radio | 2010 | 212 |
| | Communication Liaison Officer (Washington, D. C.) | Allen Barnabei | Commerce | 5104 | Sterling 3-9200 -X 4198 & 4019 |
| | Administrative Assistant | George Reynolds | Radio | 2013 | 340 |
| 79.10 | Chief, Office of CRPL Liaison & Program Development | A. H. Shapley | Radio | 2019 | 228 |
| 79.20 | Technical Information Officer | J. R. Craddock | Radio | 1201 | 245 |
| 79.25 | Librarian | Mrs. Victoria Barker | Radio | 1202 | 271 |
| 79.30 | Consultant, Math-Analysis Group & Computation Facility | Dr. J. J. Sopka | Radio | 2013 | 200 |
| 79.40 | Consultant-Mathematical Physics & Education Director | E. H. Brown | Radio | 2022 | 248 |
| 79.50 | Consultant - Statistics | Dr. E. L. Crow | Radio | 2217 | 452 |
| 79.60 | Consultant - Astrophysics | Dr. R. N. Thomas | Radio | 3024 | 525 |
| | Consultant - Astrophysics | Dr. J. T. Jefferies | Radio | 3024 | 336 |
| 79.70 | Consultant - Radio Wave Prop. | Dr. J. R. Wait | Radio | 2213 | 549 |
| 79.80 | Consultant - Physics of the Atmosphere | Dr. D. M. Gates | Radio | 2031 | 214 |
| 80 | ADMINISTRATIVE | | | | |
| 80.00 | Chief | S. W. J. Welch | Radio | 2010 | 212 |
| | Secretary | Mrs. Nathelle Steimetz | Radio | 2010 | 212 |
| 80.10 | Management Planning | Mrs. Jessie Berkley | Radio | 2010 | 212 |
| 80.20 | Fiscal | H. D. Stansell | Radio | 2016 | 242 |
| 80.30 | Personnel | R. W. Stockwell, Jr. | * | 504 | 204 |
| | Health Unit | Mrs. Thelma G. Haydon | Radio | 1209 | 473 |
| 80.40 | Supply | B. F. Betts | * | 511 | 653 |
| 80.50 | Engineering Services | P. S. Ballif | Radio | 3343 | 201 |
| 80.60 | Office Services | R. G. Bulgin | Radio | 2021 | 233 |
| | Drafting | Harman, J. C. | Radio | 1205 | 323 |
| | Photo Lab | Benedict, C. M. | Radio | 2208 | 604 |

*Colorado Insurance Group Building

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| 81 | CRYOGENIC ENGINEERING LABORATORY | | | | |
| 81.00 | Chief | R. B. Scott | Cryogenics | 2 | 237 |
| | Secretary | Mrs. Evelyn Kenny | Cryogenics | 1 | 237 |
| | Assistant Chief | B. W. Birmingham | Cryogenics | 30E | 226 |
| 81.10 | Cryogenic Equipment | Dr. R. B. Jacobs | Cryogenics | 8 | 254 |
| 81.20 | Cryogenic Processes | B. W. Birmingham | Cryogenics | 30E | 226 |
| 81.30 | Properties of Materials | Dr. R. J. Corruccini | Cryogenics | 5 | 255 |
| 81.40 | Cryogenic Technical Services | V. J. Johnson | * | 508 | 258 |

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| 82 | IONOSPHERE RESEARCH AND PROPAGATION | | | | |
| 82.00 | Chief | Dr. E. K. Smith, Jr. | Radio | 3050 | 311 |
| | Secretary | Alice E. McRae | Radio | 3050 | 311 |
| | Assistant Chief | T. N. Gautier | Radio | 3055 | 505 |
| | Assistant Chief | R. W. Knecht | Radio | 3050 | 312 |
| | Assistant to Chief for Technical Planning and Coordination | J. A. Kemper | Radio | 3050 | 313 |
| | Consultant | D. K. Bailey | Radio | 3003 | 464 |
| | Administrative Assistant | E. F. Dooley | Radio | 3050 | 314 |
| 82.10 | LF and VLF Research | A. G. Jean | Radio | 3420 | 418 |
| 82.20 | Ionosphere Research | Dr. K. Davies | Radio | 3015 | 569 |
| 82.30 | Prediction Services | W. B. Chadwick | * | | 231 |
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| 82.50 | Field Engineering | H. G. Sellery | Radio | 3047 | 224 |
| 82.60 | Radio Warning Services | J. Virginia Lincoln | Radio | 3015 | 321 |
| 82.70 | Vertical Soundings Research | J. W. Wright | Radio | 3047 | 624 |

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## 83 RADIO PROPAGATION ENGINEERING

| | | | | | |
|---|---|---|---|---|---|
| 83.00 | Chief | K. A. Norton | Radio | 2030 | 623 |
| | Secretary | Mrs. Gertrude Qvale | Radio | 2030 | 623 |
| | Assistant Chief for Research and Development | J. W. Herbstreit | Radio | 2030 | 501 |
| | Consultant - Terminal Equipment | E. F. Florman | Radio | 2241 | 472 |
| | Administrative Officer | V. Beck | Radio | 2030 | 501 |
| 83.10 | Data Reduction Instrumentation | W. E. Johnson | Radio | 2237 | 414 |
| 83.40 | Radio Noise | W. Q. Crichlow | Radio | 2125 | 291 |
| 83.50 | Tropospheric Measurements | M. T. Decker | Radio | 2245 | 413 |
| 83.60 | Tropospheric Analysis | P. L. Rice | Radio | 2218A | 459 |
| 83.70 | Propagation-Terrain Effects | R. S. Kirby | Radio | 2243 | 589 |
| 83.80 | Radio Meteorology | B. R. Bean | Radio | 2210 | 481 |
| 83.90 | Lower Atmosphere Physics | Dr. M.C. Thompson, Jr. | Radio | 2237 | 513 |

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| 84.00 | Chief | Dr. J. M. Richardson | Radio | 4066A | 268 |
| | Secretary | Mrs. Patricia Murdock | Radio | 4066 | 268 |
| | Assistant Chief for Radio Frequencies | W. D. George | Radio | 4068 | 269 |
| | Assistant Chief for Microwave Frequencies | Dr. D. M. Kerns | Radio | 4070 | 485 |
| | Assistant Chief for Technical Planning & Coordination | E. C. Wolzien | Radio | 4063 | 301 |
| | Consultant | W. W. Brown | Radio | 4023 | 453 |
| | Consultant | Dr. P. F. Wacker | Radio | 4652 | 550 |
| | Administrative Assistant | Mrs. Pauline W. Smith | Radio | 4065 | 302 |
| 84.10 | HF Electrical Standards | M. C. Selby | Radio | 4035 | 283 |
| 84.20 | Radio Broadcast Service | A. H. Morgan | Radio | 4031 | 281 |
| 84.30 | Radio and Microwave Materials | J. L. Dalke | Radio | 4055 | 440 |
| 84.40 | Atomic Frequency & Time Stds. | Dr. R. C. Mockler | Radio | 4013 | 294 |
| 84.50 | Electronic Calibration Center | H. W. Lance | Radio | 4643 | 289 |
| 84.70 | Millimeter-Wave Research | Dr. L.Y. Beers, Actg. | Radio | 4011 | 486 |
| 84.80 | Microwave Circuit Standards | R. W. Beatty | Radio | 3063 | 644 |

## 85 RADIO SYSTEMS

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| 85.00 | Chief | R. C. Kirby | Radio | 3419 | 266 |
| | Secretary | Mrs. Marilyn Hoisington | Radio | 3419 | 266 |
| | Assistant Chief | D. W. Patterson | Radio | 3415 | 562 |
| | Consultant | G. W. Haydon | Radio | 3411 | 583 |
| | Administrative Officer | Helen R. Machin | Radio | 3419 | 267 |
| 85.20 | HF and VHF Research | W. F. Utlaut | Radio | 3443 | 223 |
| 85.40 | Modulation Research | W. C. Coombs | Radio | 3451 | 536 |
| 85.50 | Antenna Research | H. V. Cottony | Radio | 3451 | 276 |
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| 87.00 | Chief | Dr. C. G. Little | Radio | 3001 | 218 |
| | Secretary | Mrs. M. Joyce Benedict | Radio | 3001 | 218 |
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| | Consultant | D. K. Bailey | Radio | 3001 | 464 |
| | Administrative Officer | R. T. Frost | Radio | 3001 | 216 |
| 87.10 | Upper Atmosphere & Plasma Physics | R. M. Gallet | Radio | 3007 | 460 |
| 87.50 | Ionosphere & Exosphere Scatter | Dr. K. L. Bowles | Radio | 4073A | 296 |
| 87.70 | Airglow and Aurora | Dr. F. E. Roach | * | | |
| 87.80 | Ionospheric Radio Astronomy | R. S. Lawrence | Radio | 2131 | 450 |

*Fritz Peak Observatory Nederland 258-3231

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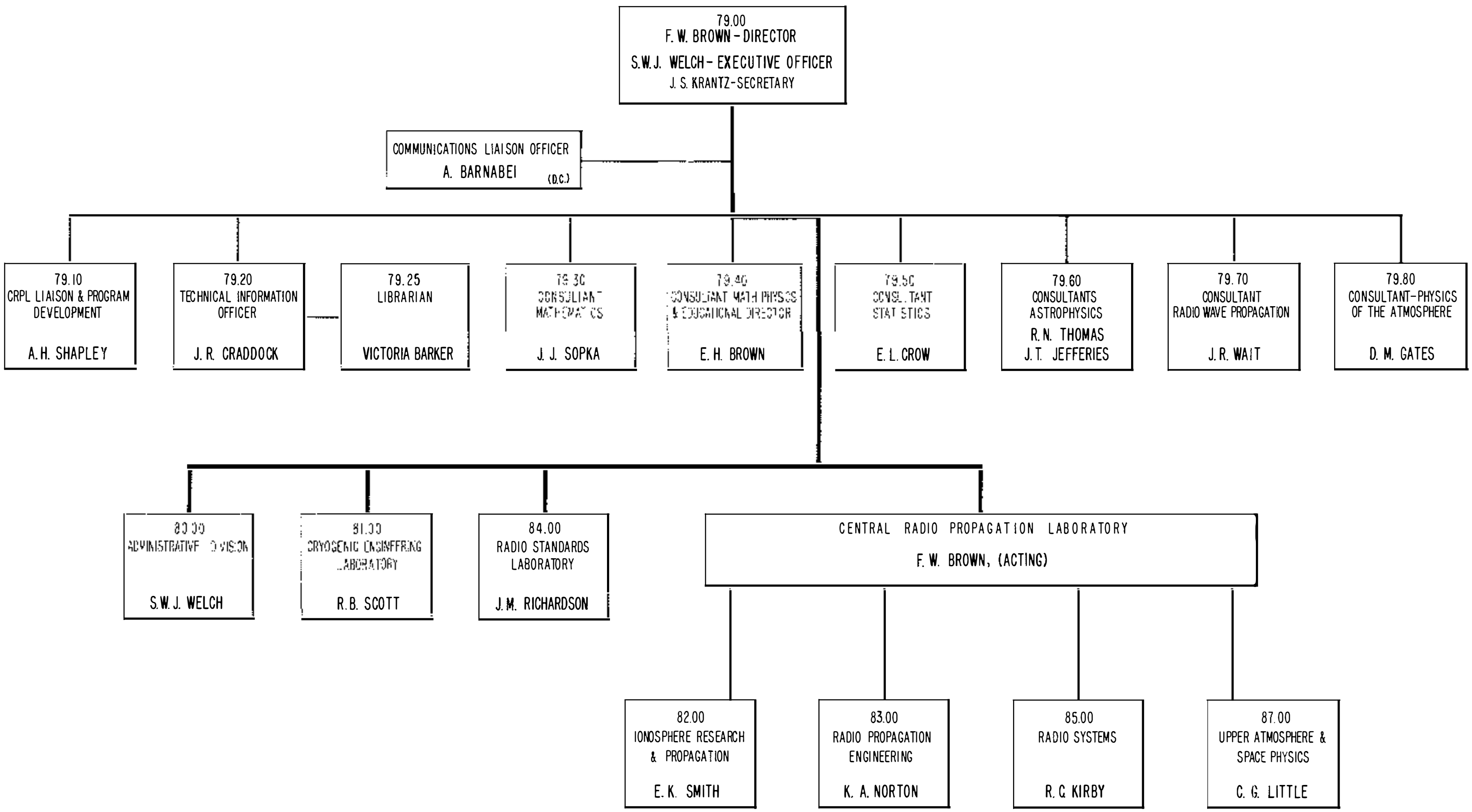
# OFFICE OF THE DIRECTOR

DIVISION 79

# NATIONAL BUREAU OF STANDARDS
# BOULDER LABORATORIES



# OFFICE OF THE DIRECTOR

The Director of the Boulder Laboratories is also acting director of the Central Radio Propagation Laboratory. In this capacity, he heads a technical division staffed by outstanding individuals who perform basic research in areas of their individual competence and provide consulting services to all of the Boulder Laboratories. Under his personal directions are:

CRPL Office of Liaison and Program Development, responsible for maintaining an effective relationship between CRPL and the various national and international societies and committees whose activities influence the CRPL programs and for advising the Director on program emphasis in relation to these influences. This Office also directs the activities of the IGY World Data Center A for Airglow and Ionosphere, and the Airglow and Ionosphere Data Service.

CRPL Math-Analysis Group and Computation Facility, responsible for research and consultation to the Boulder Laboratories in mathematical analysis and computation procedures. The section conducts studies in pure and applied mathematics in support of the research programs, provides consultation and advice on large-scale computer and numerical analysis procedures, and has overall responsibility for operation of a large-scale computer and data processing facility.

Consultant in Mathematical Physics, who conducts basic research and provides consultation services for the Boulder Laboratories in mathematical physics and their applications to cryogenics, thermodynamics, and ionospheric physics. This Office also provides direction for the Laboratories' educational and formal training programs; its chief serves as permanent chairman of the Education Committee, and as director of the Graduate School conducted for the benefit of the professional staff.

Consultant in Statistics, who provides consultation services and performs basic research in design and analysis of experiments, mathematical statistics, and related mathematical fields.

Consultants in Astrophysics, whose basic research and consultation services are concerned with diagnostic methodology to infer the state of a gaseous atmosphere from stellar spectroscopic studies, with particular regard to ways of describing a gas where cyclic processes in the energy balance occur; the interrelations between the phenomena of non-equilibrium thermodynamics, and the field of aerodynamic motions which may exist in the atmosphere. Liaison is also provided, under the cross-divisional program of NBS in Astro- and Plasma-Physics, between work in laboratory astrophysics and statistical physics within NBS and several astrophysical observatories outside NBS.

Consultant in Radio Wave Propagation, who conducts basic research and provides consultation service in the field of theoretical radio wave propagation: electromagnetic theory, antenna theory, and low frequency, very low frequency, and extremely low frequency. The chief of this activity served as editor of Section D, Radio Propagation, of the Journal of Research of the National Bureau of Standards until July 1961.

Consultant in physics of the atmosphere, whose basic research and consultative service is concerned with the properties of the middle and upper atmosphere, as determined by spectroscopic techniques. Since July 1961, the chief of this group has taken over the post of Editor of Section D, Radio Propagation, of the Journal of Research of the National Bureau of Standards.

## DASA Assistance

79411 and 85404

Under these projects, the CRPL collectively serves in a broad advisory capacity to the Defense Atomic Support Agency in connection with its program concerned with electromagnetic propagation. This includes participation in various panel meetings, consulting with the DASA headquarters staff and incidental analyses in areas of DASA interest where CRPL has suitable experience. This work is appropriate to the mission of CRPL as the centralizing laboratory for its field. It lends assistance with problems of considerable scientific importance to other government agencies.

During the past year, two senior CRPL staff members attended four meetings of technical panels of DASA and participated in numerous smaller conferences. An ad hoc meeting of the panel on the lower ionosphere was held under CRPL auspices, and numerous specific ionospheric studies were carried out. A number of visits were made to laboratories concerned with DASA-sponsored work. Contributions were made by many senior members of the CRPL staff with direct contact maintained by the two principals, A. H. Shapley and W. F. Utlaut.

## Office of CRPL Liaison and Program Development

79115

This office serves in a staff capacity to the Director in maintaining an effective relationship between the Central Radio Propagation Laboratory (CRPL) and the various national and international organizations and agencies whose activities influence those of CRPL, and in matters of emphasis and balance of the CRPL program itself. The office is in charge of the IGY World Data Center, serves as a focal point for many scientific visitors to CRPL, and for certain other activities which concern all four of the CRPL technical divisions as a whole.

During the year ending June 30, 1961, the chief of the office participated in several international meetings and symposia, including the XII General Assembly of the International Union of Geodesy and Geophysics (IUGG), the VIII General Assembly of the International Scientific Radio Union (URSI), the Fourth meeting of the Special Committee on Antarctic Research (SCAR), the Third meeting of the International Committee on Geophysics (CIG), and the Fourth meeting and symposium of the Committee on Space Research (COSPAR). In association with some of these meetings were meetings of specialized committees, notably the URSI World-Wide Ionospheric Soundings Committee (Chairman) and the ICSU International World Day Service (Spokesman). All of these activities are organized under the International Council of Scientific Unions (ICSU) and in many instances the status was that of representative of the U. S. National Academy of Sciences. In addition to the meetings themselves, much of the work of the specialized committees has been, as in the past, carried on by active correspondence.

Contact has been maintained with work and plans of interest to CRPL at a national level through membership on the Space Science Board, Committee on Polar Research, and the U. S. National Committee for IGY, all under the auspices of the National Academy of Sciences. A new activity undertaken during the year was the chairmanship of the Panel on International Exchange of Geophysical Data of the Academy's Geophysical Research Board; this Panel is developing policies and recommendations for the maturation of the concept of Data Centers in geophysics established for the IGY. Activities continued with committees of the various Academy organizations concerned with planetary atmospheres, antarctic science, and particularly international cooperation in scientific programs.

Ties have been continued or developed with appropriate committees in National Science Foundation, Air Force, Department of Defense, NASA, and other public and private organizations whose areas of interest overlap those of CRPL. These aid in suggesting the availability of CRPL's broad experience and attitudes to cope with their problems.

A series of visits was made to scientific laboratories throughout South America which cooperate in ionospheric research with CRPL, or other U. S. organizations, in order to achieve more direct contacts and indirectly assist the furtherance of cooperation. This trip culminated in an international symposium on space research in Buenos Aires.

The office has attempted to assist in certain aspects of coordination among the CRPL technical divisions, since this is a problem which becomes more important as the size and diversity of the CRPL activity increases. To a certain extent the problem extends beyond CRPL, including several other organizations in the Boulder area with a degree of common interest. As an example, an attempt is made to keep track of the growing number of scientific visitors to the Boulder community and to help arrange in some cases for conferences of visiting groups.

In the area of CRPL program planning, the office has contributed to both formal and informal program reviews and long-range plans. In an organization of this size, it is inevitable that there be some accidental duplication of program details and some unintentional gaps in the total CRPL program.

In addition to the liaison and program activities, there has been some opportunity to undertake scientific investigations. These have largely concerned study of some individual ionospheric disturbances of particular interest, the undisturbed polar ionosphere, and the study of the distinctive types of Es, all largely based on the world-wide ionospheric soundings data.

The Office of CRPL Liaison and Program Development comprises A. H. Shapley, Chief, and Mrs. R. Schultze, with, however, indirect assistance from staff members throughout CRPL.

IGY World Data Center A Airglow and Ionosphere

79412

The objectives of this project are to maintain files of data in ionospheric physics and airglow taken under the IGY and IGC programs; to copy and reproduce the data in accordance with IGY agreements; to exchange copies of data with other World Data Centers; to prepare catalogues and indexes of received data; to make available copies of data and records to scientists, organizations, and others requiring their use; to assist scientists in obtaining ionosphere and airglow data not in the Data Center files; and to maintain the Data Center as a place where research scientists and graduate students can come for periods of study and research using material in the Data Center files.

The vast world-wide effort of the IGY and the smaller, but still large, effort of the IGC, would largely be lost without effective arrangements for the collection, filing, cataloguing, and exchange of the data, with effective arrangements for scientists to obtain copies of the data, or to visit and use the Data Center files for study and research. These data and records will provide material and opportunities for important research for many years to come. The availability of the extensive NBS collection of pre-IGY data adds immensely to the usefulness of the Data Center. The IGY World Data Center program, making IGY and IGC data available to the entire world scientific community, has proved so useful in current research that the international data exchange and filing program will continue indefinitely for current and future observing programs. It has already been anticipated that the World Data Centers will participate in the collection of data from the coming Year of the Quiet Sun.

During the past year, the Data Center has continued to receive data at a high rate. A great deal of the new data is post-IGC. Every effort is being made to complete the collection and cataloguing of missing

IGY data. Of the total expected data for the IGY, 5.2% of the Hourly Values, 2.9% of the Monthly Medians, 9% of the Ionogram Film, and 11% of the f-plots have not been received. For the IGC-59, 16% of the Hourly Values, 11.4% of the Monthly Medians, 23% of the Ionogram Films, and 14% of the f-plots are still outstanding. Although there was some decrease in programs after the IGY, the volume of incoming data continues at a high comparable level.

The Data Center received 89 visitors during the past year. Of these, 25 occupied space in the guest offices of the Data Center. The length of stay per visitor ranged from one day to one year. There was a marked increase in orders for data from scientists outside of the National Bureau of Standards during the past year. A large part of the increased use was made by scientific industry. A number of requests were for very large orders of data. Some included complete sets of IGY publications. In total, there were 104 requests for data from individuals, universities, Government agencies, and industrial concerns.

During the year, the Data Center has become more active in the collection and cataloguing of research papers in the field of Airglow and Ionosphere, particularly those which are important data sources and those deriving from the IGY/IGC Programs. In connection with its function as a permanent archive, the Data Center has accepted historical data and similar materials from Drs. Lloyd Berkner and Harlan Stetson. The Data Center prepared and distributed three catalogues of the various data on file.

In the coming year, the Data Center will begin the systematic collection and cataloguing of reprints and reports in the fields of Airglow and Ionosphere. It has long been anticipated that the collection and exchange of such reprints and reports would increase the usefulness of the data now being exchanged. It is expected that the data will continue to flow into the World Data Center A at an increased rate. In addition, it is expected that the demand for data will increase significantly as more scientists become aware of the wealth of scientific data available at the World Data Center.

Personnel contributing to the project were S. M. Ostrow (Project Leader), G. A. Lira, L. S. Wilson, P. A. Pardi, and F. M. Stryker.

## Data Center Reimbursable

79627

The objective of this project is to make available to scientists and research groups copies of ionosphere and airglow data and records; the cost of reproduction to be reimbursed to NBS.

In order that maximum benefit may be realized from the International Geophysical Year, International Geophysical Cooperation, 1959, and succeeding observing programs, the resulting scientific data and records must be available to all the scientific community. Part of the responsibility of the IGY World Data Center A for Airglow and Ionosphere is to provide copies of data and records, on request, at approximately the cost of duplication.

During the year, 104 orders for data were filled for a total charge of $5,160. This was a significant increase in number of orders over the past one-year period. The orders ranged from a single booklet to a vast order amounting to $830, in photostats and ionogram film, for an eastern aircraft company. This was the largest single order ever filled by the Data Center.

Future plans include making and sending copies of data and records, as ordered, making charges according to schedule.

Personnel contributing to the project were S. M. Ostrow (Project Leader), G. A. Lira, L. S. Wilson, P. A. Pardi, and F. M. Stryker.

## Mathematics Analysis Group and Computation Facility

79103

The objective of this project is to perform research and analysis in mathematics and computation procedures in support of the Boulder Laboratories program.

Major activity, since July 1960, has been centered on installation and utilization of a new, large-scale binary computer. An operating system of executive-utility programs has been prepared. This system includes input-output routines buffered directly with main frame processing, diagnostic dump, and trace routines. Also included are peripheral processing routines, allowing card to magnetic tape and magnetic tape to printer or punch operations to run simultaneously with independent main frame computations. Similar peripheral processing routines were prepared to work with the algebraic compiler and its run programs.

A library of mathematical subroutines has been established and is being enlarged. More than three dozen computer program descriptions and write-ups have been prepared and distributed by this group. Staffing the facility has been essentially completed during the last few months. A considerable amount of consultation, advice on programming problems, debugging, and mathematical analyses have been provided to the scientific staff. An advanced course in Numerical Analysis was taught through the academic year.

This project, through its contributions in mathematics and computation procedures, provides a basis for more effective theoretical analyses and computation in radio and cryogenics projects. Professional preparation of computer procedures increases the volume and complexity of computations performed by the laboratory projects.

Future activity will include: Improvement and expansion of mathematical and utility procedures for the present computer; preparation of suitable utility procedures for the peripheral equipment system scheduled to arrive in November 1961; increased activity in mathematical studies; planning and preparation for transfer of the Mathematics Group and Computation Facility to Wing 5 in the spring or summer of 1962.

## Research and Services in Mathematical Statistics

79950

Research and consulting services in mathematical statistics are provided in the Director's Office for the Boulder Laboratories as a whole. During this year, a greater proportion of time was devoted to research than in previous years, but consultations included a productive application to atomic standards.

In contrast to previous years, no formal courses were taught. Instead, the supervision of work on an individual doctorate (mostly out of hours) was concluded. George E. Bardwell, Assistant Professor of Statistics at the University of Denver, received his Ph.D. with his dissertation, "Certain discrete distributions."

A major area of research is the sampling properties of stationary time series. In the case of independent observations from a statistical population, the sampling properties of the mean, the median, the empirical distribution function, the percentiles, and the regression estimates are well known. However, in data observed over time there is usually some correlation among observations. A general investigation was carried out to obtain sampling properties of the statistics calculated from such correlated observations. The results of the study are embodied in papers published and to be published in the NBS Journal of Research, Section B, and the Annals of Mathematical Statistics.

A project was undertaken to predict a whole curve of future sunspot numbers with a prescribed confidence. In recent years, a "best" estimate of such a curve has been obtained using the McNich-Lincoln method and, under certain assumptions, an interval prediction for a single time. If such intervals are calculated for several times, and the points are connected to obtain a prediction band for some finite period in the immediate future, it can then be said that the confidence that the future curve would fall in the band will be less than the confidence for a single time. How much less, however, cannot be said. An approximation may be obtainable as a multivariate normal integral, but these integrals are difficult to evaluate for more than 2 or 3 dimensions. Some approximations were obtained, and it is hoped to extend them to higher dimensions. This work led to organizing a session on multivariate normal probabilities at the annual meeting of the Institute of Mathematical Statistics in Seattle, June 14-17, 1961, as considerable work on them in general has been done in recent years.

Another undertaking of general statistical interest is the determination of the efficiency of the very useful distribution-free confidence intervals for the median of a random sample. When these are used on populations which are in fact normal (Gaussian), it is well known that their asymptotic efficiency is $2/\pi$. The present work determines the efficiency for small samples (2 observations and up) and is almost completed. Other purely statistical papers, now submitted for publication, include a numerical study of an approximation technique for the evaluation of the moments of the sample median and a problem on games associated with renewal processes.

Probably the most fruitful consultation resulted from a request by the Radio Standards Laboratory for the application of analysis of variance to the interlaboratory comparison of atomic standard frequencies transmitted by radio to a common receiver. Results are contained in a report to the April 1961 meeting of the Consultative Committee for the Definition of the Second of the International Congress of Weights and Measures.

Other consultations considered error rates for communication links in tandem and derivations of various probability distributions.

A substantial increase in the number of papers refereed was noted. E. L. Crow continued his associate editorship of Section B (Mathematics and Mathematical Physics) of the Journal of Research. During the 2 years of existence of Section B, there have been 55 papers, totaling 557 pages. Of these, 9 papers, totaling 100 pages, have been from the Boulder Laboratories.

An enlarged and updated study of promotion rates of professional personnel neared completion.

In the coming year, it is proposed to evaluate the probability density functions of the complete class of "stable" distributions, a class of some interest in probability theory and physics. It is also proposed to make a thorough study of random processes and statistical inference for them, in accordance with the program submitted and approved under the Government Employees Training Act of 1958 for the training and research of E. L. Crow at University College, London (mainly), University of Paris, and University of Stockholm from August 1961 to September 1962.

Personnel consist of mathematical statisticians, Dr. E. L. Crow and Dr. M. M. Siddiqui; mathematician, Mrs. Nancy F. Carter (WAE, about 1 man-month total); and secretary, Mrs. Charlotte S. Landay (part-time).

## Theoretical Astrophysics

79105 and 79401

The general objective of the program in theoretical astrophysics is the development: (a) of the diagnostic methodology to infer the state of a gaseous atmosphere from spectroscopic studies; and (b) of an understanding of the inferred physical phenomena occurring in such an atmosphere. Particular interest lies in: (1) the methods of describing a gas where cyclic processes in the energy balance occur, so that there exist significant departures from configurations of Local Thermodynamic Equilibrium (LTE); (2) investigations of the interrelation between such non-LTE configurations of the gaseous atmosphere and the field of aerodynamic motions which may exist in the atmosphere; (3) discussion of the various radiative and mechanical transport phenomena arising in connection with (1) and (2).

The theoretical astrophysics group at Boulder also aims at providing a liaison (under the umbrella of the NBS Laboratories cross-divisional program in Astrophysical and Plasmal research) between the work in laboratory astrophysics and in statistical physics carried out at the NBS Laboratories, and several astrophysical observatories outside NBS. Because of the great detail possible in solar studies, particular emphasis lies on collaborative solar programs with the Sacramento Peak Observatory and the High Altitude Observatory. A strong collaborative program on theoretical studies exists with groups at the Institut d'Astrophysique - Observatoire de Meudon; and on atomic parameters of astrophysical interest applied to stellar atmospheres with a group at University College, London.

The following specific programs have been in progress during the last year:

(i) J. T. Jefferies left CSIRO, Australia, to join the astrophysics group at Boulder permanently, and continue the series of investigations "Source-function in a non-LTE Atmosphere" initiated by him and Thomas.

(ii) The monograph: "Physics of the Solar Chromosphere," by R. G. Athay of the High Altitude Observatory and Thomas, has been published by Interscience Press. The monograph essentially summarizes the non-LTE methodology developed to date, and applies it to the analysis of the structure of the lower solar chromosphere.

(iii) F. Q. Orrall and J. B. Zirker of the Sacramento Peak Observatory have each spent 4 months at BL-NBS on collaborative investigations. Orrall and Jefferies have continued a series of papers on the physical structure of solar prominences; Zirker and Thomas initiated investigations on an atmospheric shell of finite opacity, such an atmosphere being the kind producing the solar rocket spectra. Jefferies, Orrall, and Zirker presented summaries of the temperature measurement in stellar atmospheres at the NBS-sponsored program on Temperature Measurements in Science and Industry.

(iv) During the summer of 1961, a collaborative program with W. A. Rense of the Colorado University Physics Department on the analysis of his solar rocket spectra has been renewed, under the direction of Charlotte W. Pecker of the Institut d'Astrophysique in Paris. Also, Dr. Pecker presented one of the three summary papers on application of atomic cross-sections at the Second International Conference on Atomic Collision Problems held in Boulder; her subject was Atomic Cross-sections and the New Spectroscopy.

(v) Thomas spent Februrary - March in Paris, working with Dr. Pecker on the interpretation of solar coronal and rocket spectra, and gave a series of lectures on "Non-equilibrium Thermodynamics in the Presence of a Radiation Field."

(vi) A summary, by J-C. Pecker of the Meudon Observatory and Thomas, on the analysis of spectra produced in an atmosphere having velocity fields, was presented at the Fourth Symposium on Cosmical Gas Dynamics at Varenna, Italy. Thomas was secretary of the Symposium and edited the Proceedings, which will be published late in 1961.

(vii) Jefferies and Thomas have been appointed Professors-Adjoint in the Department of Astrogeophysics of Colorado University, and Thomas was Visiting Professor at the University of Paris.

During the coming year, work will continue on the above lines. We hope to gain more insight into the kind of emission from finite emitting shells observed variously in solar prominences, flares, and the undisturbed corona, and coronal condensations. Also, we hope to go more systematically into the effects of velocity fields on spectral line-profile formation. Finally, we would like to relate the astrophysical investigations of non-equilibrium thermodynamics to those more usually studied in physics where the effect of the radiation field has not been so important.

Personnel: John T. Jefferies, Charlotte W. Pecker (Part-time), Richard N. Thomas, assisted by Anne Taylor - Toggenberger, and Nancy H. Potter.

## Electromagnetic Theory*

79111 - 79402

a) Anisotropic Media - A plasma, consisting of a neutral mixture of electrons, ions, and molecules, in the presence of a constant magnetic field $H_0$, possesses a dielectric constant which is in the form of a tensor. A medium such as this, is anisotropic in its electrical properties. The ionosphere is a good example. Exact solutions of boundary value problems involving such media have been obtained for two-dimensional configurations. Explicit results were given for the reflection coefficients of stratified plasma in planar and cylindrical geometry.

It has been shown that a thin plasma sheet will support a trapped surface wave. The presence of the constant and uniform magnetic field modifies the phase velocity and polarization of the surface wave. The essential features have been illustrated by numerical results for selected values of the electron density, collision frequency, and gyro-frequency. The effect of locating the plasma sheet near and parallel to a conducting plane has also been considered. In this situation other modes of a wave-guide type are possible in addition to the surface wave.

The excitation of the thin plasma by dipole sources has also been treated in some detail. Under the previous assumption that the thickness of the slab is very small, expressions for the resultant fields have been obtained. As a result of the anisotropy of the sheet, it was indicated that the fields are elliptically polarized in general. On carrying out a saddle-point evaluation of the integrals in the formal solution, it was shown that the far fields may be split into "radiation" and "surface wave" components.

b) Waves on Interfaces - The excitation and propagation of surface waves on a spherical inductive boundary has been considered. The source was taken to be a vertical electric dipole. The circumferential attenuation rates of the various modes were discussed where it was indicated that the dominant mode was very similar to the trapped surface wave for a plane inductive boundary. The results appear to conflict with those of H. E. M. Barlow, but are in agreement with some numerical data of R. S. Elliott for the circumferential attenuation rate of the dominant mode. These results are of a fundamental importance to the further development of surface wave antennas.

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*James R. Wait (Project Leader), Alyce M. Conda. Work sponsored, in part, by Air Force Cambridge Research Laboratories.

A related problem concerns the resonance characteristics of a corrugated cylinder excited by a magnetic dipole. Radiation from an axial magnetic current element in the presence of the corrugated cylinder was considered. It was indicated that the power radiated in a given mode depends on the surface reactance, the circumference of the cylinder and elevation angle. For certain values of the parameters, particular modes may be strongly excited, corresponding to a resonance condition of the circumferential (or spiral) surface waves.

Some further attention has also been given to the theory of ground waves on a spherical earth when the surface is inhomogeneous. The problem formulated concerns the mutual impedance between two vertical dipole antennas, A and B, located near the surface of a spherical smooth earth. The path between A and B is made up of a number of homogeneous segments where the surface impedance is constant. Various formulas were developed for two- and three-section paths which are suitable for computation. Certain limiting cases were treated in a more explicit fashion to facilitate a physical interpretation of the results. This study is continuing in collaboration with J. R. Johler of the Radio Systems Division.

A related problem is when an antenna is mounted over an inhomogeneous ground plane. The ground plane may be characterized by a variable surface impedance such as in the case of a radial-wire screen. The problem was formulated in terms of the mutual impedance between two vertical dipoles, one which is raised, and the other, located on the ground plane. The ground screen was taken to be in the combined form of a circular disc and a concentric sector. An approximate solution of the problem was obtained. Results were compared with previous investigations of closely related work. It is planned to extend this work in the near future and, in particular, to compare the results with experimental data recently obtained by A. C. Wilson.

c) Propagation in Conducting Media - A general analysis for the electromagnetic response of conducting media due to pulse excitation was carried out. The treatment was based on the Laplace transform theory. First, a survey of the field was made and the limitations and scope of the previous work were pointed out. The theory of propagation of a plane wave pulse in a conducting and homogeneous medium of infinite extent was then reviewed. The form of these results enables one to evaluate the relative importance of the conductivity and the dielectric constant. It was indicated, for sufficiently large times in the transient response, that displacement currents may be safely neglected for sea water and for most geological media. Under this assumption, the wave-form of the electric field in a conducting medium is illustrated for the case where the source is an electric dipole energized by a step-function current. Results were also presented for exponential and bell-shaped source functions. It was found that the pulse shape of the field components is profoundly modified as they propagate through the medium. It was suggested that this property may be utilized in measuring distances in the earth's crust. The more difficult problem of propagation in non-infinite conducting media was also considered. To account for the presence of the interface in a conducting half-space (i.e., homogeneous flat ground), a rather involved analytical expression for the transient fields was required. Certain special cases, such as a horizontal electric dipole at the interface, were illustrated by numerical results. The transient excitation of a wire loop lying on the surface of a homogeneous ground was also considered. Finally, transient coupling between pairs of parallel insulated wires grounded at their end points was treated as an extension of the earlier results.

## Long Wave Propagation Theory*

79112 - 79471

a) VLF Modes - A simplified treatment of propagation in the earth-ionosphere waveguide has been developed as an adjunct to more sophisticated methods. It was shown that, if the field intensity (i.e., field amplitude squared) is averaged over the width of the waveguide, a very simple formula for the averaged intensity is obtained. This result was used to discuss some of the broad features of VLF propagation in a relatively concise fashion.

Influence of earth curvature and the terrestrial magnetic field on VLF propagation has also been studied. Taking note of the fact that the important modes for long-distance propagation are near grazing, suitable approximate forms of the wave functions were introduced at the outset, rather than at the end, of the analysis. It was thus possible to account for the influence of earth curvature in a relatively concise manner. The influence of the earth's magnetic field was also treated in a concise manner. Finally, numerical results for the attenuation and the phase velocity of the dominant modes were prepared.

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J. R. Wait (Project Leader), Kenneth Spies. Work sponsored by Advanced Research Projects Agency.

Initially, the ionosphere was assumed to be a sharply bounded and homogeneous ionized medium. It was indicated that earth curvature increases the attenuation rate by as much as a factor of 2 as compared with the corresponding attenuation for a flat earth. The influence of the earth's magnetic field was also shown to be important. In fact, east-to-west propagation paths suffer much greater attenuation than west-to-east paths. These theoretical results appear to agree well with the experimental data of W. L. Taylor.

Long distance propagation of VLF radio waves is characterized by only a few low-order waveguide modes. This results from the excessive attenuation of the higher order modes. In navigational systems this is a desirable characteristic since the phase velocity approaches a constant at very great ranges when only one mode is predominant. Unfortunately, the second-order mode still exerts its influence for ranges as great as 4000 km. The possibility that this second-order mode could be discriminated against at the transmitting antenna is being investigated from an analytical viewpoint. At the same time, it is hoped that this might shed some light on the behavior of antenna arrays at VLF.

b) ELF Modes - The mode theory of propagation of electromagnetic waves at extremely low frequencies (ELF) (1.0 to 3000 cycles per second) has been treated in some detail. Starting with the representation of the field as a sum of modes, approximate formulas were derived for the attenuation and phase constants. Certain alternate representations of the individual modes were also developed. These were used as a basis for describing the physical behavior of the field at large distances from the source, particularly near the antipode of the source. At the shorter distances, where the range is comparable with the wavelength, the spherical-earth mode series was transformed to a series involving cylindrical wave functions. This latter form was used to evaluate the near field behavior of the various field components.

The effect of the earth's magnetic field was also evaluated, using a quasi-longitudinal approximation. In general, it is indicated that if the gyro-frequency is less than the effective value of the collision frequency, the presence of the earth's magnetic field may be neglected for ELF. When this condition is not met the attenuation may be increased somewhat. The influence of an inhomogeneous ionosphere was also briefly considered and, finally, the propagation of ELF pulses was treated. It is suggested that certain observed characteristics of ELF waveforms may be attributed to the inclination of the current channel in the lightning discharge.

Some interesting features in the propagation of radio waves occur in the ELF range when the distance from the source to the observer is comparable with the wavelength. Under such a condition, it is not permissible to assume that the wavefronts are plane; consequently, the ratio of the electric and magnetic field components orthogonal to the direction of propagation are no longer equal to 377 ohms. This question has been considered, in some detail, from an analytical viewpoint.

The propagation of the slow-tail portion of atmospherics was also considered from the waveguide-mode viewpoint. This source, which is a lightning discharge, was represented by a vertical dipole. The transient response of the distant electric field was then computed for various forms of the source current waveform. The results are then employed to reinterpret the experimental data of F. Hepburn. As suggested by the present theory, it was found that the observed separation, $t_s$, between the oscillatory head of the atmospheric and the maximum of the slow-tail amplitude varies with distance, $\rho$, to the source, according to a law of the form;

$$(t_s)^{\frac{1}{2}} = A + B\rho$$

The constant, A, is related to the pulse width of the source, and the constant, B, depends on ionospheric parameters. Values of effective ionospheric conductivities deduced from the theory were consistent with earlier results for the VLF band. The influence of nonvertical currents in the discharge channel has also been considered.

c) <u>LF Sky Waves</u> - A diffraction theory for LF sky-wave propagation has recently been developed. The concept that radio waves propagate from transmitter to receiver via discrete ionospheric reflections (i.e., hops) has been put on a sound theoretical basis. The earth and the ionosphere were represented by two (smooth) concentric spherical surfaces. The (local) reflecting characteristics of these boundaries were assumed to be known. It was shown that the m'th hop sky-wave may be generally represented by a complex integral. The geometrical-optical representations for the field were retrieved as a special case. For low-order-frequencies, it was shown that these optical-type formulae, which are often used, have severe limitations. Generally, they are not valid near the caustic points. Techniques for evaluating the complex integral for the sky-waves near and beyond the caustics were then treated in some detail. In some cases, a clear physical interpretation of the results has been found. The results have been applied to study the quantitative behavior of the first hop sky-wave near its geometrical horizon. The results should be useful for sky-wave field computations at low frequencies and in the interpretation of measured field-strength data.

The investigations mentioned above (under a, b, and c) are being carried out in close collaboration with A. G. Jean, Chief of the VLF Research Section in CRPL.

## Office of the Communications

## Liaison Officer

79405

The Communications Liaison Officer and his deputy represent the Department of Commerce on the Interdepartment Radio Advisory Committee (IRAC), its Frequency Assignment Subcommittee (FAS), and its Subcommittee on Frequency Allocations (SFA). IRAC formulates and recommends policies, plans, and actions to the Director of the Office of Civil and Defense Mobilization in connection with the management and usage of radio frequencies by Government agencies; supervises the application and execution of such policies, plans, and actions pertaining to radio frequency usage as have been approved by the Director; and, pursuant to executive order authorizes, subject to the Director's approval, interim or temporary operation by Government agencies on any frequency, pending the issuance of a new executive order assigning frequencies to Government radio stations.

The activity of the Communications Liaison Officer is of particular importance because of the Department of Commerce's statutory responsibility in the field and the number of agencies making use of the radio spectrum. Proper, accurate, and detailed technical justification is required in order to insure that radio frequency requirements of the Department are satisfied.

The IRAC, in concert with the FCC, is also concerned in developing U.S. positions and providing U.S. delegates for international conferences on radio matters. Of particular interest are national and international allocation of radio frequencies, operating procedures and technical standards for the same, and formulation of governing rules and regulations. In this connection, the Liaison Officer or deputy represent 6 different agencies or organizations on 9 national, international, and government/industry committees.

Activities in radio frequency management included the streamlining of the List of Frequency Assignments to Government Radio Stations, the amendment of the IRAC Table of Frequency Allocations Above 25 Mc/s as needed, and the drafting of a Table of Frequency Allocations below 25 Mc/s. The Government has had no such table below 25 Mc/s. When adopted, it will become a valuable guide in frequency management. Considerable progress was made in clearing the band 136-137 Mc/s of non-space operations. The band 132-135 Mc/s for air traffic control communications was implemented without major interference. In company with the FCC, an interference protection procedure was evolved for the Harvard University radio astronomy observatory at Ft. Davis, Texas. In addition, a notice was prepared for all Federal agencies concerned with radio astronomy observations documenting the steps which have to be taken nationally in their interest.

The necessary documentation and planning was completed by IRAC for the international meeting of the Panel of Experts at Geneva, September 1961, which will be concerned with allocation of frequencies for space telecommunications. Weather Bureau requirements for meteorological uses were included in the U. S. proposal. Work is continuing on the U.S. position for the ICAO 4th NAT-RAN Meeting, September 1961, Paris; and the ICAO 7th COM Division Meeting, in Montreal, February 1962.

During FY 62, the matter of effecting radio frequency assignments and changes of assignments to the radio stations of the Federal Government will continue to be a basic task. Special meetings will look toward formulating location proposals for the radio astronomy group. Increasing emphasis will be given to preparing for the September meeting of the Panel of Experts in Geneva. Progress is expected on the long-range planning program upon receipt of the NBS report on wave propagation studies.

Personnel participating in this project were: A. Barnabei (Project Leader), Ellery Estes, Miss Anna Meyer, and Mrs. Norma Stotlemyer.

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# Radio Propagation

OFFICE OF THE DIRECTOR-- from Administration to Wallops Island . . .

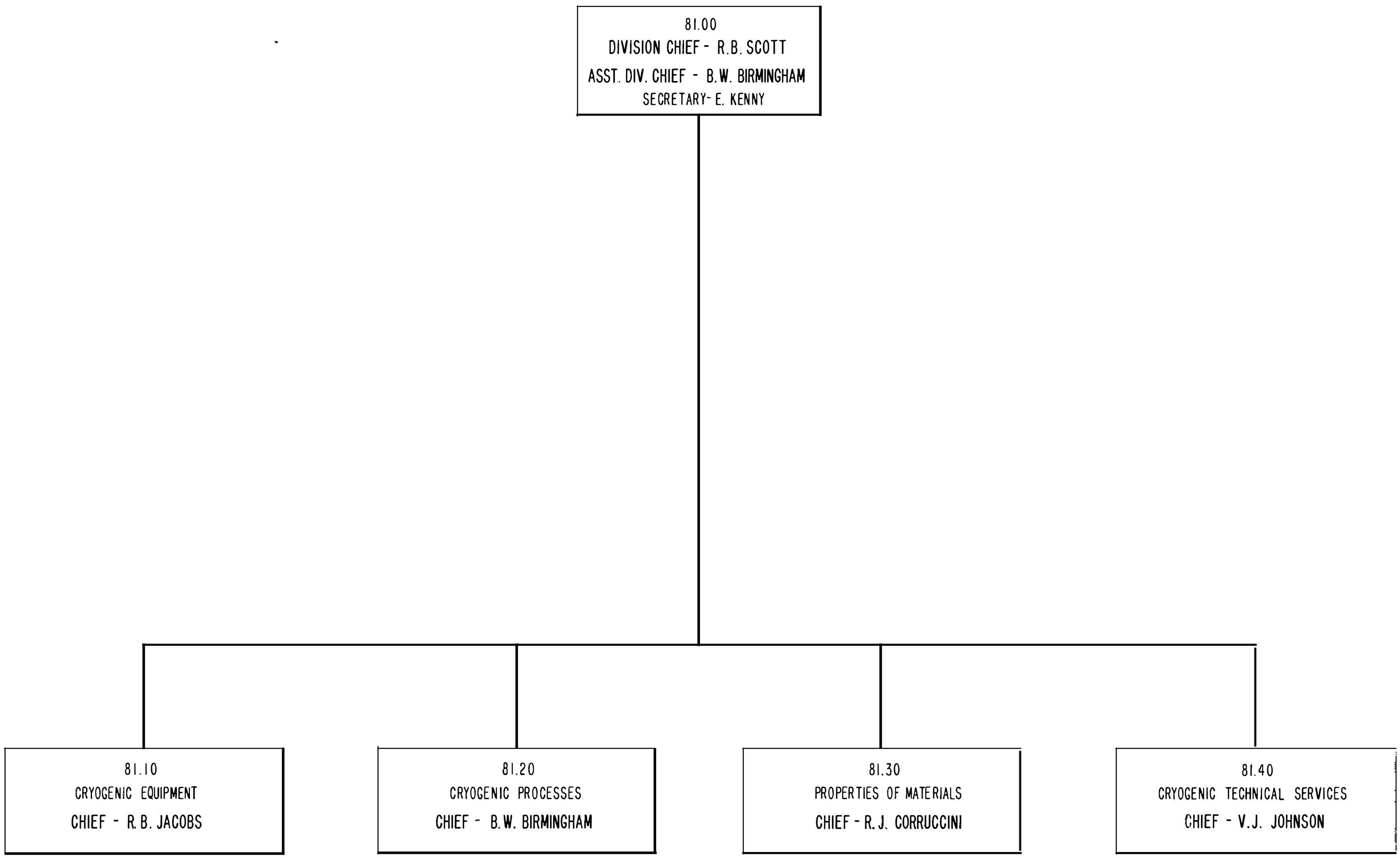
SECTION D
JOURNAL OF RESEARCH

1. NBS fosters international relationships. 2. Dr. A. V. Astin (left), Director of NBS, and Dr. F. W. Brown, Director of Boulder Laboratories. 3. Construction of sixth wing. 4. Rocket test of satellite instruments.

# CRYOGENIC ENGINEERING LABORATORY

DIVISION 81

CRYOGENIC ENGINEERING LABORATORY



# CRYOGENIC ENGINEERING LABORATORY

The Bureau's Cryogenic Engineering activities, centralized at the Boulder Laboratories, are designed to provide information needed for practical applications at low temperatures, and to assist Government and industry with problems in this rapidly growing specialized field.

To carry out these activities, the laboratory conducts research on the physical properties of materials, properties of fluids, cryogenic processes, and cryogenic equipment. In addition, it maintains a national Cryogenic Data Center in which information of importance in Cryogenic Engineering is collected and organized for use by other Government agencies and the public. Equally important are the advisory services furnished to both industry and other Government agencies to help establish the field of Cryogenic Engineering. The demand for such help was greatly increased as a result of missile and space programs which rely on cryogenic liquids as propellants. Also the techniques of cryogenic engineering have application to fundamental physical research. This is illustrated by the work of CEL on the liquid hydrogen bubble chambers and refrigerators reported in previous years.

Another application of cryogenic engineering now under development is the use of cooled electromagnets to provide the intense magnetic fields which confine the plasma for experiments on controlled thermonuclear fusion (Project Sherwood). It appears that the total power required to maintain a given magnetic field will be less if part of the power is used to cool the coils of the electromagnet to a very low temperature. Very recently this work has been further stimulated by the discovery at the Bell Telephone Laboratories of a superconductor that remains superconducting in intense magnetic fields. CEL has a major program on cooled magnets, both normal and superconducting. The work comprises magnet design, magnet materials and efficient cooling processes.

The laboratory has recently undertaken a new task in support of basic physical research. This is the design of a neutron moderator to be installed in experimental reactors. The moderator will probably consist of a mass of "heavy ice", solid $D_2O$, maintained by continuous refrigeration at a temperature of about 20° K. The objective is to provide an intense beam of slow neutrons.

Work on the properties of materials has continued at a high level. Perhaps the most notable accomplishment has been the completion of the measurements on the P-V-T relations for parahydrogen in the liquid and gaseous states at temperatures up to 100°K and pressures to 350 atmospheres. Also measurements have been started on the specific heat of parahydrogen in the same region of temperatures and pressures. These data are needed by the designers of missile propellant systems using parahydrogen.

Russell B. Scott, Chief
Cryogenic Engineering Laboratory

## Consultative and Advisory Services

81101

This project has been established to support consultative and advisory services offered to government and industry, and not directly related to existing projects of the laboratory.

To properly disseminate cryogenic engineering information to the scientific community, it is desirable to have a separate project supported from the Bureau's basic appropriation. The need for this is evident when considering the steady stream of visitors from both government and industry who visit the Cryogenic Engineering Laboratory and request information.

Consultative and advisory services have been provided to visitors from both government and industry who are recognized to have a definite requirement for cryogenic engineering information. Several visitors a week have been received on a regular basis throughout the year.

This project will be continued and funded at a slightly higher level during the next fiscal year.

## Cryogenic Data Center

81102

This project's purpose is to develop an organized index of all published literature, reports and patents of interest in the cryogenic engineering field; to provide NBS Staff, other agencies and the cryogenic industry with a bibliography service in the field of cryogenics; to obtain cryogenic literature (reprints, reports, microfilm, photo copies, etc.) needed by staff members for division projects and to maintain a central file of such literature when no longer needed on a project; and to evaluate cryogenic data and compile data sheets in areas of primary interest.

The Cryogenic Engineering Laboratory is the government's primary laboratory for cryogenic engineering research and development. Many inquiries (in person, by telephone and by letter) are received requesting information on various aspects of research and development in the low temperature field. Much of this type of work is connected with national defense programs. The Cryogenic Data Center is expected to increase the effectiveness of the Laboratory by furnishing requested information from centrally organized technical files, thus minimizing time required of senior staff members in obtaining technical information and in answering requests. In addition, a much broader coverage of the field can be accomplished through central operation, especially as more of the literature is reviewed and coded.

There was a notable increase in literature procurement for Division personnel during the year. This type of service is considered quite justifiable although the primary objective of the Data Center is to develop a comprehensive bibliography service. The acquisition of over two thousand documents for the staff contributed considerably to the primary list of references.

The conversion of the storage and retrieval system for references from the manual punch cards to a mechanized system was undertaken. Not as much progress was made as expected because of a shortage of technical coding help; however, category 3 (Properties of Fluids) was recoded for machine retrieval. The services of a key punch and operator were obtained near the end of the fiscal year which should make it possible soon to check out the machine retrieval system, using the Boulder Laboratories digital computer facility

Typing of the first 8000 listings for the "Catalog of References" was completed about mid-year. Subsequent references are being punched on cards for machine printing with the same format as set up for the typed portion. The catalog will be reproduced as soon as all the references have been proof read, checked, and corrections made. Only a nominal number of copies (500 or less) will be made since the machine bibliography service will incorporate a catalog tape from which specific citations can be printed out as required.

Literature searching and coverage of new literature sources is by no means complete or adequate as yet. Regular review of a few good sources was instituted, such as Chemical Abstracts, International Institute of Refrigeration Abstracts, ASTIA Abstracts and Dissertation Abstracts. A program for voluntary review of a number of current periodicals by Division staff members was also instituted, resulting in an input of 50 to 100 new references per week. This input will have to be more than doubled to provide comprehensive coverage of the cryogenic engineering field of interest.

The task of distributing CEL reprints and reports was turned over to the Data Center during the year. The mailing list has been up-dated and expanded so that a better awareness of CEL literature can be provided. The acquisition of modern photocopying equipment has made it possible to provide single copies of material after the original supply is exhausted. About ten thousand pages a month of this type of material is being furnished on a cost reimbursement basis, (Project 81626).

The evaluation of cryogenic data and compilation of data sheets was supported mostly with other agency funds and the accomplishments are described under Projects 81404 and 81450.

Primary emphasis will continue to be placed on the conversion of the storage and retrieval system to computer operation. Category 2 (Properties of Solids), Category 6 (Cryogenic Processes) and Category 8 (Cryogenic Equipment) will be the next in order for recoding. Two additional professional staff members, recently recruited, are expected to help accelerate the recoding appreciably. Increased activity in the literature procurement and distribution is also expected. Because of the ever increasing volume of literature and professional interest in the cryogenic engineering field, emphasis will be placed on additional mechanization of Data Center operations to increase its productivity and service.

Personnel contributing to the Cryogenic Data Center operations during the fiscal year are: Robert G. Smith, Virginia Hinchman, Jo Ann Kirby, Marjorie Tomhave, Eunice Fairless, Nellie Kifer, Billie Greene, Jan Elting (summer), Victor Selby (summer), Arthur Bashford (P/T), William Longfellow (WAE), Richard Trembath (WAE), R. B. Stewart, and V. J. Johnson.

## Compilation of Thermal Data

81404

The objective of this project, sponsored by the Air Force, is: (1) to search the published literature and reports for thermophysical properties of fluids and solids of interest in cryogenic engineering for design and development of cryogenic processes and equipment; (2) to compile an extensive bibliography of references, cross-indexed for convenient use; and (3) to evaluate and select data for compilation of data sheets to be presented in compendium form.

Considerable data are available for low temperature work but are not conveniently available or in good agreement. By making a thorough and systematic search for low temperature data, selecting "best values" and compiling and arranging them in an organized compendium, the engineer and scientist have been greatly aided in the design and development of cryogenic equipment and processes. This project should provide much needed information, at considerable saving of time and effort, to persons engaged in current defense and space programs.

The sponsorship of this project was transferred to NASA early in January, 1961. At that time substantial progress had been made on the data sheets for Phase II of the compendium for four additional properties of cryogenic fluids and two additional properties of solids at low temperatures. During this period the scope of the data analysis was increased, and the data sheets reflect this in an increased coverage of the literature, in more extensive comparisons of alternate sources of data, and in the use of many more data points for the preparation of graphs and tables of values. This improvement was made possible both by an increase in the full-time staff associated with the project as well as the availability of a large, high-speed computer. The final page proofs of this second phase of the compendium have recently been transmitted to the sponsors for publication as a report on the work completed on this project.

Personnel contributing to this project are: Robert McCarty, James Cunningham (summer and WAE), Dr. F. E. E. Germann (P/T), David Millhiser, Robert Smith, Genevieve Michela (P/T), W. W. Bulla, L. J. Ericks, Richard Weekley, Don Harrison, Patricia Rice, V. J. Johnson and R. B. Stewart (Project Leader).

## Transfer of Liquefied Gases

81111

The general objectives of this project are to investigate basic phenomena encountered in the transfer of liquefied gases. At the beginning of the past year two-phase fluid flow phenomena, with emphasis on critical flows, were being studied; because of the loss of the project leader, this work was suspended, and two investigations, initiated with other agency funds, were supported on this project. These studies are hydrogen pressurization and flow studies initiated by the AEC, and theoretical frost formation studies initiated by the Army Ballistic Missile Agency. This report is therefore divided into three sections.

### Two-Phase Flow Studies

The general objective of this program is to provide basic understanding and predictive information in the field of two-phase, single-component fluid flow. Data from the study should expand the general knowledge of flow phenomena and provide design engineers with working charts and equations.

Cryogenic fluid flow applications are currently very numerous and are increasing at a rapid rate. Some examples are liquefied gas propellants for missile and space vehicles, the use of cryogenic fluids to cool materials to favorably control their electrical and magnetic properties and to preserve vegetable and animal tissue. In cryogenic flow problems one must be concerned with the vapor-liquid flow phenomena to a greater degree than most fluid flow systems because cryogenic fluids are very near or at their vapor pressure in most applications.

Earlier studies in this project have been concerned with two-phase, single-component flow in constant area pipes with particular emphasis on pressure drop determination.

Some investigations during the past two years have been concerned with understanding and developing a system for predicting the point of choking or mass limiting two-phase flow. Designers of flow systems, flow measuring devices, etc need information which will enable them to predict this point accurately.

Experimental investigations of choking flows began about December of 1959 and continued to August of 1960. Analytical and data reduction studies have continued. The program was suspended in December of 1960 when M. R. Hatch, project leader, transferred from the section. About 400 runs were completed in the experimental choking studies and these data have been reduced to charts which indicate the mass limiting flow conditions.

R. V. Smith began in June of 1961 as project leader on the choking studies. The first phase of the current study will be to develop an analytically predictive system from basic principles of fluid mechanics, thermodynamics and heat transfer utilizing also, of course, theoretical and experimental data reported in the literature and that produced in previous studies on this project.

The second phase of the project will be to refine and confirm the results of the first phase study by experimental tests.

The personnel contributing to this project during the past year were M. R. Hatch (former project leader), R. B. Jacobs, F. H. Ammer, and E. G. F. Brentari (WAE).

The current project is being conducted by R. V. Smith (project leader), R. B. Jacobs, and E. G. F. Brentari (WAE).

## Hydrogen Pressurization and Flow.

Initial objective of this study was to assist the Los Alamos Scientific Laboratory in the solution of cryogenic problems associated with the AEC's nuclear-powered rocket (Rover) program. The pressurization and flow studies described here were originally supported by the AEC in connection with the forthcoming Rover KIWI-B tests to be held in Nevada late in 1961. Because the pump development associated with this program progressed more rapidly than anticipated, the AEC's interest in pressurization and pressurized flow terminated. As essentially all of the equipment had been procured, as all liquid required for the experiments had been provided by the original contractor, and as the results of the investigation have wide applicability, a decision was made to use Bureau funds to provide the labor required for completion of the project.

Results of this work are directly applicable to the development of nuclear-powered and chemically-powered rockets using liquid hydrogen, and to all applications where large quantities of liquid hydrogen are handled and transferred. This project directly affects the missile and space technology competence of the United States.

Although the test facility and equipment have been ready to use for more than six months, experiments have been delayed due to the unavailability of a suitable liquid hydrogen storage container (original plans included the use of an AEC vessel). A dewar is now available for this work.

The project's specific objectives for the coming year are: to determine the amount of pressurization gas required to attain various pressure levels, up to 600 psia, with liquid level and outflow rate of liquid hydrogen as parameters; to conduct temperature surveys throughout the fluid under both static and flow conditions; to determine the effect of emptying spherical containers on density gradients; to obtain an insight into the heat transfer mechanisms occurring during pressurization and outflow; and to obtain performance information for Venturi tubes operating in the supercritical pressure region. It is anticipated that this study will be completed by November 30, 1961.

Personnel contributing to this project were, A. F. Schmidt (Project Leader), M. D. Atwood, J. D. Evans, and J. R. Purcell.

## Frost Formation

The primary objective of this project is to determine theoretically the rate of frost formation on surfaces at liquid oxygen temperature.

With the increasing use of liquid oxygen in space vehicles and industry, the need to predict heat transfer to, and frost formation on, uninsulated equipment and heat exchangers is very great. These theoretical studies are designed to assist in fulfilling this need by providing a sound basis for the extrapolation of limited empirical information to all atmospheric conditions likely to be encountered.

A general two-dimensional, non-steady mathematical model, designed to predict the rate of condensation of water from the atmosphere onto a surface at liquid oxygen temperature, has been set up. This model, which consists of 5 differential equations that describe the "conservation" laws and 17 additional equations, has been reduced to four equations with four unknown functions. The solution of these equations for the region between the atmospheric temperature and condensation temperature isotherms is now being sought by numerical analysis on the CD-1604 computer.

This work will be supported by NASA under the contract for Liquid Oxygen Studies (project 8110-12-81411) next year. It is anticipated that the contract will include funds for frost studies. The plan is to complete these theoretical studies next year.

Personnel contributing to this project are M. D. Bunch and R. B. Jacobs.

## Heat Transfer Studies

81112

The objectives of this project are (1) to determine the heat transfer from air at ambient conditions to solid surfaces at a cryogenic temperature (20 to 90 degrees Kelvin) and (2) to verify the theoretical work being done on frost formation.

In essentially all cryogenic equipment, heat transfer occurs; if the behavior of this equipment is to be satisfactorily predicted, the heat transfer itself must be adequately predicted. This project, therefore, undertakes problems which are necessary to the satisfactory solution of problems encountered by both government and industry, problems which, in a great many instances, are directly connected with both the defense and space technology efforts of the country.

During the past year an experimental apparatus has been designed and partially built. The design consists of a wind tunnel in which the solid surface at a cryogenic temperature will be placed. Air temperature, humidity and velocity will be controlled in the tunnel. Temperature of the solid surface and rate of liquid vaporized will be measured for the heat transfer studies. Instrumentation for the frost studies have been completed.

In the coming year construction of the wind tunnel and controls will be completed. Test runs with liquid nitrogen, liquid hydrogen and liquid oxygen will be started.

Personnel contributing to the project are R. J. Richards, D. K. Edmonds, Jr., and R. B. Jacobs.

## Cryopumping

81115

The general objective of this project is to study problems encountered in cryopumping. The specific objective for the past year has been to evaluate the characteristics of cryopumps as an item of vacuum pumping equipment.

This project is of great importance because cryopumping is the only technique that has been described which can produce the low pressures encountered in interplanetary space and which can produce low pressures required for some basic scientific research. It is therefore the technique which will probably be used to produce the pressures desired in environmental chambers to simulate conditions of outer space.

During the past year the equipment was modified and some components were rebuilt as indicated by the initial cryopumping runs. In the earliest runs, outgassing and changing temperature gradients influenced the data, but a moderate baking improved the performance. The results of preliminary runs provoked an analysis of the "residual gases" which revealed an undesirable level of non-condensable gases. Although the calibrated variable leak was adequate for the preliminary runs, it has proved unsatisfactory in current experiments. An approach, which will allow constant monitoring of the flow of inlet gases and will provide a means to obtain the desired purity by a distillation process, is being perfected.

The general objectives of this task for the coming reporting period are not altered. We shall continue our evaluation of cryopumps as pumps, and evaluate a possible solution to reduce outgassing.

Project personnel for the past year have been Lewis O. Mullen, R. B. Jacobs, and E. G. Brentari.

## NASA Instrumentation

81410

The principal objectives of this project, sponsored by NASA, are as follows: (1) to determine the status of cryogenic instrumentation in the areas of pressure, temperature, liquid level and flow measurement; (2) to conduct investigations which will yield the low temperature behavioral patterns of existing instrumentation; (3) to improve upon existing instrumentation, and to engage in research and development necessary to the achievement of the sponsor's cryogenic instrumentation requirements.

The importance of this project lies in the assistance provided, in the instrumentation areas mentioned, to organizations engaged in the development of advanced propulsion systems for use in future space missions.

During the Fiscal Year 1960 an extensive survey was made to establish the state-of-the-art in the four areas previously mentioned. Information was secured from two basic sources. The first, and most helpful, came from a review of technical publications dating back to 1955, while the second came from letters of inquiry sent to various industries and laboratories known to be working in cryogenics. A compilation of the information and data obtained has been made and is presently being prepared for distribution.

As part of the test phase of the project an apparatus for testing commercial pressure transducers was designed and built and is now in operation. The intent of this phase is to establish such characteristics as repeatability, zero shift and linearity in addition to temperature cycling and hysteresis effects. Commercial units are being tested and the results will be issued as a supplement to the survey.

Two separate test rigs are being worked on for determining the dynamic characteristics of temperature sensors. The first unit, employing a spring loaded plunger will move a sensor from one control temperature to another during a known time interval. This unit has been built and is now undergoing checkout before being put into use. The second test unit utilizes the principle of adiabatic compression to produce a step change in temperature and is now in the construction stage.

A liquid level test unit is being designed and tests are being conducted on a primary standard.

In the area of development a project was started to investigate the feasibility of using a vibrational system as a means of measuring fluid densities. A prototype densitometer was built and preliminary tests indicate the densitometer will provide simple and reliable means of measuring single-phase, and possibly two-phase, fluid densities with a maximum error of less than 1%.

The objectives of the project have not been changed and plans for Fiscal Year 1962 are to continue the existing program with the main emphasis on the experimental phase of the program rather than on the survey. It is planned that the above program will yield information that will permit an accurate evaluation of the present status and future needs in cryogenic instrumentation in the areas mentioned, thereby assisting in the formulation of long range cryogenic research projects.

The staff contributing to this project are J. Macinko (Project Leader), P. Smelser, C. E. Miller, R. C. Muhlenhaupt, R. B. Jacobs.

## Liquid Oxygen Studies

81411

The objective of this project is to study problems encountered by the ABMA (now NASA - MSFC) in the use of liquid oxygen in connection with missile and space applications. The specific problem under study is concerned with the bulk density of boiling liquid oxygen, and with the determination of the liquid level and mass of the boiling fluid.

Results of this work will be directly applicable to the missile and space technology of the United States.

During the past year work on this project has consisted of analyzing data from test runs using a 2 ft. diameter by 16 ft. tall cylindrical tank. Installation of a 3 ft. diameter by 16 ft. tall tank and revision of instrumentation has occupied the balance of the year. Check runs on the larger tank, using liquid $N_2$, have been completed and liquid $O_2$ runs will start in the near future.

Preliminary work on a theoretical approach resulted in acceptance of a paper to be delivered at the 1961 Cryogenic Engineering Conference.

It is anticipated that tests at 1 atmosphere pressure will be completed and a program involving tank pressures up to 40 psig will be undertaken during the coming year.

The staff contributing to this project are R. W. Arnett (project leader), W. H. Probert, D. R. Millhiser, F. W. Windmoeller, R. B. Childs (WAE).

## Cavitation Studies

81414

The primary objective of this project is to provide basic theory and data which will lead to a better and more thorough understanding of cavitation inception and mechanisms of cavitation. Information compiled would provide design criteria for prediction of inception of cavitation for any fluid. Specific data obtained will pertain only to cryogenic fluids.

This investigation of the inception and mechanisms of cavitation is necessary in order to improve the "state of the art" in the design of equipment for handling liquids. Existing information and knowledge concerning cavitation are not adequate for the designer to accurately predict cavitation inception. The effect of cavitation on various equipment designed to handle liquids may be to (1) drastically reduce the efficiency of the equipment, (2) reduce the equipment life expectancy, (3) induce errors in instrumentation or any combination of the three. Much more information and basic understanding is needed to avoid the occurrence of cavitation. Accomplishments of this study would be utilized in various fields of interest: missile industry (liquid propellant pumps, valves, instrumentation), hydroelectric plants (water turbines), industrial process control plants (valves, instrumentation, pumps), nuclear reactors (pumps), propeller-driven ships, underwater ballistics, etc.

A comprehensive literature survey has been conducted to determine the present status of basic cavitation research in both conventional and cryogenic fluids. Preliminary experimental tests have been conducted to prove the feasibility of a study plan. From these preliminary tests have evolved the design of an all-glass test apparatus to study the metastability characteristics of cryogenic fluids. An analytical study intended to predict the fluid conditions required for the inception of cavitation in various cryogenic fluids contained in the all-glass test apparatus is well underway. This test apparatus is essentially a small bubble chamber and hopefully will provide a "super-heat limit curve" for each cryogenic fluid. This limit curve will indicate the pressure and temperature conditions at which nucleation will occur in an ideal system. All of the materials of construction for the test apparatus have not yet been received.

The project will attempt to obtain a better understanding of cavitation through theoretical analysis and experimentation in the coming year. The proposed study plan is divided into two phases of interest as outlined below.

<u>Phase A:</u> Static-analysis (non-flow)

1. The theoretical analysis of metastability will be completed in an effort to predict the fluid conditions required for formation of a cavity.

2. Experimental data to verify or disprove theory of 1 above.

Phase B: Dynamic Analysis (flow)

1. A paper study shall be conducted in an effort to predict the effect of fluid velocity, system geometry, system cleanliness, and fluid properties on nucleation such that modifying factors could be applied to static nucleation theory (Phase A. 1).

2. Some rather simple experimental tests are visualized, utilizing either a venturi or smooth approach restricted diameter test section in a flow tunnel.

Personnel contributing to this project are J. Hord (project leader) and R. B. Jacobs.

## Cooldown of Cryogenic Transfer Lines

81415

The objectives of this project are to investigate theoretically and experimentally the phenomena occuring in cryogenic transfer lines during the period of cooling down from ambient to operating temperature. The purpose of the theoretical phase is to derive and solve equations which predict the operating characteristics such as cooldown time, flow rates, gas venting rates, temperatures, and pressures for insulated or uninsulated cryogenic transfer lines of any geometry or construction material. The experiments propose to verify the theoretical calculations as well as to supply forced convection boiling and non-boiling heat transfer coefficients, two-phase pressure drop, etc. which are used in the theoretical calculations. A range of transfer line sizes, driving pressures, and two different fluids will be covered by the tests.

Cryogenic fluids are often transported from one point to another (e. g. from a supply tank to a rocket's fuel tanks) by means of pipes called transfer lines. When these low-boiling-temperature fluids are driven by pumps or pressurized gas into warm transfer lines high rates of heat transfer, boiling, and evolution of gas occur. Pressures may surge higher than the driving pressure and the flow may even reverse momentarily. A means of predicting pressures to which a transfer line will be subjected, the flow rates which may be achieved, the rates at which gas must be vented, and the time required for cooldown are essential to the proper design of equipment using cryogenic transfer lines. These means have not been available; however, this project is attempting to provide them.

During the past year a numerical solution to a system of twelve partial differential equations describing the cooldown process has been devised and is being tested and perfected by a hand calculation. Special instrumentation for the experiments has been tested in the laboratory. The test apparatus has been designed and constructed, and is now being assembled.

During this year the $LO_2$ servicing container optimization project was completed. Modification and repair of a cracked nozzle on a 50 gallon $LO_2$ vessel was completed. The unit was tested for thermal performance and showed an improvement over production model units by approximately four to one. After testing the vessel was shipped to the sponsor for further evaluation. A WADD Technical Report was prepared and submitted as the final phase of this work.

The numerical calculation will be programmed for an electronic computer and solutions to cover a range of the parameters will be sought. The testing of the experimental transfer lines will cover a wide range of the parameters as permitted by the experimental apparatus. The results will be submitted to the sponsor in the form of a final report which will include graphs showing the relationships between the various parameters and conclusions concerning the surges in flow and pressure, optimum line geometry for various applications, and the nature of the flow passing through the transfer line at each stage of cooldown.

Personnel contributing to this project were: W. G. Steward, T. T. Nagomoto, J. H. Wilson (WAE), R. W. Arnett, W. H. Probert, R. B. Childs (WAE), R. B. Jacobs.

## Lox Storage Tank Review

81417

The object of this project was to provide consultation for the Army Corps of Engineers in connection with $LO_2$ tankage used at ICBM complexes in the Denver area.

Analyses and recommendations were made regarding thermal performance, design and vibration susceptibility of the tankage. An informal report was prepared and furnished to the Army.

This project was completed.

Personnel contributing to this project were R. B. Jacobs, A. F. Schmidt, E. H. Brown, and R. W. Arnett.

## Magnet Research

81418

This project is concerned with advancing the technology of electromagnetic field production by developing highly efficient cryogenic solenoids.

The competitive nuclear age is demanding extremely efficient production of intense magnetic fields as high-energy particle accelerators and the proposed thermonuclear reactors are critically dependent on large volumes of these force fields. Prior to the consideration of low-temperature solenoids, the projected electrical power input needed to sustain the aligning field in a fusion reactor was in the 50 to 200 megawatt range. This figure can be reduced by a factor of over 1000 by using cryogenic electromagnets.

A high purity aluminum foil magnet has been designed that should produce a 100 kilogauss, steady-state field over a cylindrical volume 3 inches in diameter and 8 inches long. Forced convection cooling through radial grooves with sub-cooled $LH_2$ will dissipate the anticipated 4 kilowatts of joule heating. The solenoid will draw 135 amps from a D.C. power supply consisting of a variac, an isolation current transformer, and two silicon rectifiers. Assembly is almost complete and actual testing of the electromagnet will begin in July 1961.

Testing and evaluating the present system, then using the results to design larger and stronger cryogenic magnets are the goals of this project for the coming year. Studies will be made on properties of materials and the behavior of instruments in intense magnetic fields at low temperatures.

Personnel contributing to this project were J. R. Purcell (Project Leader), J. D. Evans, E. G. Payne, M. D. Atwood, and R. B. Jacobs.

## Physical Equilibria

81124

The main objectives of this project are to provide data and to develop methods which will enable the cryogenic engineer to accurately determine the best design for the purification of gases for liquefaction. The aim of research in this area is to predict the properties of multiphase, multicomponent, cryogenic systems given only the properties of the pure constituents.

A major problem in the liquefaction of gases, in particular hydrogen or helium, is to provide adequate purification continuously to eliminate plant shut-downs due to collection of frozen impurities in liquefier heat exchangers. Impurity levels, ranging from hundreds of parts per million to several percent in gases of various sources, must be reduced to essentially zero since amounts as low as one part per million can eventually lead to plant blockage. Research in physical equilibria is necessary to establish accurate design criteria for impurity removal.

Besides providing solutions to this exacting technical problem, physical equilibria research necessarily yields information on the nature of forces between molecules of different species. This information is vital to understanding mixtures and solutions.

During fiscal year 1961, the thorough literature search of physical equilibria and related properties of some cryogenic systems was brought up to date, and existing data were extracted from the literature for five binary systems containing hydrogen. The data for each system are being compiled in such a manner to provide a virtual map for the researcher and a convenient source of available design information for the engineer.

Theoretical studies of physical equilibria were carried out to develop a thermodynamic consistency test to determine the probable validity of experimental phase equilibria data.

An experimental and theoretical program to study adsorption of impurities at low temperatures was continued. The studies, concentrated primarily on the adsorption of methane on silica gel, uncovered a significant anomaly in respect to adsorptive capacity versus temperature for this particular system. A refined experimental apparatus was developed to study this effect more precisely on silica gel as well as other adsorbents.

Other efforts have been concentrated on the calculation of vapor pressures of condensed gases below the normal boiling point from a minimum of information. Calculations have been completed for nitrogen and are in progress for methane and ethylene. This work was accomplished at the Georgia Institute of Technology under a contract from NBS.

During fiscal year 1962 the compilation of data of the physical equilibria and related properties of the binary systems containing hydrogen will be completed in the first half of the year.

Theoretical studies on physical equilibria will be conducted within the framework of the second virial coefficient. Initially data for about ten cryogenic fluids will be examined in an effort to obtain characterizing parameters which eventually can be extended to mixtures. Studies on multicomponent adsorption theory will also be continued.

Systems will be selected for experimental physical equilibria investigations based on compilations, theoretical studies, and desirability of data for technical designs. Both pure component and impurity adsorption experiments will be extended to other adsorbents.

Personnel contributing to this project were: T. M. Flynn (Project Leader,first half year), M. J. Hiza, (Project Leader), A. J. Kidnay, D. E. Drayer and W. T. Ziegler (Georgia Institute of Technology).

## Refrigeration Processes

81125

The development of methods of providing refrigeration and liquefied gases in the cryogenic temperature range is of considerable importance in present day military, industrial and research programs. Such fields as missiles, fuels, cryogenic magnets, bubble chambers, masers and high speed computer elements, require refrigeration methods of diverse quantity and quality.

Calculation of refrigeration cycles to provide low temperatures is considerably facilitated by using a high speed digital computer. In addition basic programs can be developed to handle wide limits of input parameters making possible quick design studies consistant with the changing component "state of the art."

The general objective of the project is to analyze refrigeration processes for cryogenic temperatures.

During the past year work was centered on the compilation correlation and tabulation of the thermodynamic properties of nitrogen gas.

A modified Benedict-Webb-Rubin equation of state was developed to express the P-V-T data and was used to generate the thermodynamic property data for nitrogen. The results were tabulated on magnetic tape and used as input data to the digital computer during refrigeration cycle calculations.

Several simple refrigeration cycles have been calculated and the performance plotted in graphical form.

Personnel contributing to the project were D. B. Mann (Project Leader), and T. R. Strobridge.

## Friction, Wear and Lubrication

81126

The objective of this program was to continue the study of supporting rotating equipment in cryogenic applications.

Rotating equipment for use at cryogenic temperatures requires bearings that will operate reliably at these temperatures in the absence of normal lubrication or bearings that are placed in warm regions on extended shafts. The need for bearings that will operate successfully in cryogenic environments is steadily increasing with the growing missile programs, food freezing industries, etc. because the extended shaft design is not as practical or efficient as equipment designed with the bearings located in the cold environment. This program was initiated to determine the requirements necessary for successful operation of bearings in low temperature environments.

The work on this program has been limited to the testing of ball bearings operating in cryogenic environments. The testing was done on bearings running in either gaseous hydrogen or submerged in liquid nitrogen. Ball separator materials were evaluated at speeds up to 9200 rpm in liquid nitrogen and the most promising material was then tested in gaseous hydrogen. Through this screening process it was possible to find some materials for the ball separator that would give bearing life in liquid nitrogen in excess of the rated minimum life. Bearings with these separators also gave satisfactory results when tested in gaseous hydrogen.

Work on this program during the early part of the fiscal year will be concerned with (1) a parameter study on bearings operating in gaseous environments at cryogenic temperatures and (2) testing a few new separator materials in liquid nitrogen. At the completion of these two phases of the program additional work will be done on an as needed basis.

Personnel contributing to the project were J. A. Brennan, W. A. Wilson, R. Radebaugh, and W. H. German.

## Cryogenic Design Principles and Materials Utilization

81420

The objective of the program is to provide assistance to the Centaur and Rover missile programs in the broad area of cryogenic design principles and materials utilization.

Missile development programs, both chemical and nuclear, are now using and are planning more extensive use of liquid hydrogen. The physical properties of hydrogen are sufficiently different from other fuels to present many new problems to the industry. Although many of the solutions are not unique to the field, the applications are often difficult. Other problems require research to aid in their solution. It is hoped that the initiation of the present program will help provide suitable answers to many component development problems and will improve component reliability.

Primary assistance efforts have been concerned with Project Centaur. Numerous contacts have been made with General Dynamics - Astronautics (GDA) and various co-contractors and subcontractors associated with the main program. Emphasis on the GDA portion of the program has been focused on the development of cryogenic seals for the liquid hydrogen fuel line flanges, on the cryogenic testing of ball bearings operating in hydrogen gas for the zero-gravity centrifugal vent device, on the design of observation windows for cryogenic containers, and on insulation problems associated with the flight vehicle and propulsion test vehicle. In addition, general assistance was given on other matters of cryogenic importance such as properties of materials, instrumentation, liquid oxygen density, gas detection and thermometry.

It is anticipated that general assistance on Project Centaur will continue. To date, minor assistance has been given to the Rover program. Although several contacts have been made with Los Alamos Scientific Laboratory personnel, a course of action has not yet been established. It is hoped that contributions can be made in this area during the next reporting period.

Personnel contributing to the project were: D. B. Chelton (Project Leader), L. E. Scott, B. W. Birmingham, J. A. Brennan, R. H. Kropschot, R. N. Herring and D. H. Weitzel.

## Argonne Cold Moderator

81421

The object of this project is to provide engineering assistance in the design of cryogenic facilities for the production of cold neutrons.

Low energy neutrons are useful for the investigation of the nature of matter. Such neutrons are produced by the use of a suitable moderator placed within a nuclear reactor, i. e. $D_2O$ ice maintained near 20°K. The thermalization of neutrons liberates energy within the moderator that may be removed by a cryogenic refrigeration system.

Two refrigeration processes are being considered for this application. The first system is a conventional Joule-Thompson hydrogen refrigerator coupled with a helium loop for input service; the second system utilizes a turbo expander with gas lubricated bearings in a helium refrigerator circuit. Theoretical performance for both systems have been analyzed and flow sheets drawn. The specifying of major components has been started.

A heat transfer study of the inside cryostat has been performed in order to help define the cryostat configuration. It was found that the thermal conductivity of $D_2O$ ice near 20°K was needed. Since no data was available in the literature, an existing apparatus was modified to make some measurements. Measurements of the thermal conductivity of $H_2O$ ice at liquid nitrogen temperature have been made.

Specifications will be written and cost estimates made for both refrigeration processes. Measurements of $D_2O$ ice thermal conductivity will be completed at liquid hydrogen temperatures.

Personnel contributing to the project are John W. Dean and K. D. Timmerhaus.

## Edwards AFB Consulting

81422

The objectives of this project are to provide consultation and assistance to EAFB on cryogenic problems as required. The project emphasis is mainly directed toward liquid helium storage and handling.

The transportation of helium in liquid form offers economic and strategic advantages over normal ambient temperature compressed gas shipment. The experience of NBS in this field has aided EAFB in the planning and purchase of equipment for their helium program. NBS also assists and augments the technical capability of the sponsor in certain areas of cryogenics where NBS has unique qualifications.

During the past year, a large liquid helium semi-trailer and a mechanical discharge device have been purchased by the Air Force. Some preliminary testing of the transport unit was accomplished using a Navy liquefier. Operation difficulties of this small liquefier prevented a full evaluation and the lack of a liquefier of suitable size prevents further testing and use of the equipment. Temporarily, this equipment will be placed in liquid hydrogen service, until such time as a suitable liquefier is available.

NBS was also consulted on a problem concerning the sampling and impurity analysis of liquid oxygen in large storage tanks. An EAFB contract to develop apparatus for obtaining a representative sample was placed with a commercial firm. The technical aspects of this contract have been monitored by NBS.

Personnel contributing to the project were: L. E. Scott and D. B. Mann.

## Study of Helium Liquefaction

81424

The project objective is to establish equipment and techniques for producing, storing and transporting large quantities of helium in liquid form.

The shipment and handling of helium in liquid form, would allow a substantial savings in transportation and handling cost to large users compared to ambient temperature compressed gas transport. The relative size and performance of the equipment needed demands a higher degree of optimization of equipment and techniques than previously required. The data and proven feasibility obtained through this effort is of great benefit to other industries who have requirements for large quantities of helium.

Technical assistance was provided to the sponsor on several items of equipment. A 35,000 scf/day liquefier has been purchased and installed by BuWeps. Considerable difficulty has been experienced by the contractor in overcoming difficulties associated with the transfer of liquid from the liquefier. NBS has provided assistance in several tests. The cause has been determined and is being corrected by the contractor. In addition a large liquid helium semi-trailer, a smaller air transportable dewar, and a high pressure liquid helium pump and vaporizer are presently being procured by BuWeps. NBS is representing BuWeps in technical matters with the respective contractors, and directing the testing and evaluation of the finished product.

The design of a liquid helium tank car has been completed under NBS contract. The design has been approved by the American Association of Railroads and a freight rate has been established.

Activity will be reduced in Fiscal Year 1962. NBS-CEL will provide technical assistance to continuing contracts and prepare a report covering the total work on the project.

Personnel contributing to the project were: L. E. Scott, D. B. Mann, and B. W. Birmingham.

## Liquid Hydrogen Bubble Chamber

81427

The development of liquid hydrogen bubble chambers is of continued importance in the study of fundamental particle physics. The number of such bubble chambers being planned, designed and constructed throughout the world is increasing rapidly. In recent months, considerable interest has been generated in the application of superconducting magnets to bubble chambers and to other associated high energy physics problems.

The objective of the project is to give general assistance to the University of California, Lawrence Radiation Laboratory (LRL) at Berkeley, California, in these areas. The project is a continuation from the previous year.

During the past year assistance was given in a number of miscellaneous problem areas. These have mainly been in conjunction with the design of a 25-inch chamber that will incorporate a liquid expansion system.

The feasibility of adapting the 300 watt refrigerator (previously designed within the project) for use with the 25-inch chamber was considered. The refrigeration requirements for the larger chamber may be as much as 500 watts. It was concluded that with minor modifications of the refrigerator system, the 67 percent increase in capacity is feasible.

Since the new chamber will be of the liquid expansion type, it is necessary to make better estimates of the adiabatic compressibility of liquid hydrogen. PVT data for para-hydrogen, now being measured at the laboratory by another project, were used in an effort to arrive at more reliable compressibility information.

In addition to the above assistance, a meeting was held in Berkeley to discuss the design and development of superconducting magnets for high energy physics applications. We are presently making measurements of the superconducting characteristics of the $Nb_3Sn$ wire in magnetic fields up to 185,000 gauss at temperatures below 20°K. Particularly, the effects of mechanical stress on the critical field and critical current transitions are being studied.

Personnel contributing to the project were: D. B. Chelton (project leader), R. H. Kropschot (project leader), B. W. Birmingham, J. W. Dean and D. B. Mann.

## Magnet Refrigeration

81428

The object of this project is to develop refrigeration cycles capable of producing refrigeration in the 1.5 to 30°K temperature range. This development work involves a theoretical study of feasible cycles adaptable to such an application and consideration of the components necessary to provide a reliable, maintenance free refrigeration unit. A vital component which requires additional development is the expansion device required to produce the required refrigeration. For all practical purposes a turbine expander would be the most feasible expansion device to use. Consequently, a secondary object is to develop a turbine expander that will operate continuously with no maintenance required.

Because of recent developments in the areas of electromagnet and superconductor applications, the need for an adequate and reliable source of refrigeration is increasing rapidly. The nature of the application requires that not only must the hazard of using liquid hydrogen as a pre-coolant be eliminated, but that a minimum of supporting equipment be used to produce the required refrigeration.

In the area of turbine expander design and operation, considerable progress has been made in the development of a reliable expander. The high speeds involved in a turbine expander can be obtained by using gas-lubricated bearings to support the turbine shaft. A flat plate test apparatus was provided and experiments completed to provide data applicable to gas-lubricated bearing design. These experiments provided data on load-carrying capacity and stiffness of both nitrogen and helium gas films over a wide range of conditions.

An actual turbine expander was fabricated and tested using helium gas as the process fluid. This expander was operated for a number of hours up to speeds of 180,000 rpm. The expander itself and the gas-lubricated bearings performed as expected over a wide range of conditions. Sufficient testing was performed to insure that the expander unit will run indefinitely with very little attention or maintenance required.

The work on thermodynamic refrigeration cycle calculation and analysis has centered on the compilation, correlation, and tabulation of the properties of helium, hydrogen, nitrogen and neon gas. A digital computer is being used to facilitate and speed the cycle investigations and the thermodynamic data has been listed on magnetic tape for input to the machine.

Properties of helium and nitrogen gas have been correlated and calculated using a modification of the Benedict-Webb-Rubin equation of state developed within the project. Neon and hydrogen properties were generated from existing published data.

With the completion of the property tabulations a systematic investigation of low temperature refrigeration cycles was begun.

Testing of the turbine expander proved that the design approach is sound and reliable. Future plans will include the application of these design principles to specific refrigeration requirements. The design of such a turbine expander is applicable to a wide range of operating conditions.

A refrigeration cycle incorporating the turbine is to be developed. This cycle will provide a significant refrigeration effect at 20°K, 10°K, 4.2°K and 1.5-2.0°K, and great care will be exercised to design a system of high reliability.

The systematic investigation of refrigeration processes will continue and will be extended to more complex component arrangements. Transport properties of the refrigerants will also be correlated and tabulated to provide data for the calculation of heat exchangers.

Personnel contributing to this project were: D. B. Mann, W. A. Wilson (Project Leaders), T. R. Strobridge, H. Sixsmith, J. A. Brennan, B. W. Birmingham.

## Low Temperature Seals

81429

The project has two related objectives. The first of these is the design and testing of static and sliding seals for use in all types of cryogenic equipment. The second objective is the determination and study of mechanical properties of elastomers and plastics, with emphasis on those properties which can be related to the performance of these materials as seals or in other applications at cryogenic temperatures.

There are numerous applications for seals which must operate at all temperatures from normal to cryogenic in missiles, rockets, satellites, and high flying aircraft. Any vehicle which uses a cryogenic fuel or oxidizer must also depend upon an elaborate ground support system which includes cryogenic pumps, valves, transfer lines, and storage dewars. This equipment contains many demountable seals, both static and moving, which must perform at all temperatures from ambient to cryogenic. In addition, there are important applications wherever cryogenic equipment is used in industrial and research activities.

The mechanical behavior of plastics and elastomers, which are derived from chain polymers, is in itself a subject of great interest. Many aspects of this behavior have not been thoroughly investigated; this is particularly true under conditions of high compressive stress and extreme low temperature. Thus the measurement of physical properties, which constitutes about 50% of the total effort of this project, will be of fundamental interest. The compounding variables of the test samples are being controlled as carefully as possible; it is hoped that meaningful correlations can be established between these variables and measurable properties at cryogenic temperatures.

It has been clearly demonstrated that several readily available elastomers and plastics can be used to make simple flange type static seals which are high vacuum tight at pressures to 1000 PSIG and temperatures from above room temperature to 20°K. During the past year it has been shown that simple flat flanges can be substituted for the tongue and groove design previously thought necessary. This development, together with the use of O-rings of smaller cross section, has resulted in significant reduction in flange loading as well as machining costs. The importance of spring loads resulting from stretching of bolts and flexing of flanges has been recognized, and equipment has been designed to make critical studies of this factor.

A constant load dilatometer has been constructed for the study of thermal expansion, creep, and relaxation of highly stressed elastomers at temperatures from about 10°K to room temperature. This equipment has been in use for several months and is yielding valuable information. Under construction are two additional apparatus for the properties study. One of these will measure and record change of length with temperature for an unstressed sample from room temperature to about 10°K. The other will use a preloaded sample and will measure the variation of force with temperature at constant length.

The third phase of the seals program is concerned with seals around low and high-speed rotating shafts which operate at all temperatures from ambient to cryogenic. A tester for the first class of rotating seals has been constructed and is in use; a tester for high speed rotating seals has been designed but may not be constructed unless the level of funding is increased.

As indicated above the work on properties of elastomers will be expanded during FY 62 with the addition of two more tests. The work on functional static seals will be concerned with the establishment of correlations between properties and sealability under conditions of a standardized seal test, and with a critical study of spring loads resulting from straining of flange parts during seal assembly. Tests with the slow speed rotating shaft tester will continue and detailed shop drawings of the high speed rotating seal tester will be prepared. If additional funding is made available, the high speed test unit will be fabricated and tests begun.

Personnel assigned to this project during FY61 have been D. H. Weitzel, R. F. Robbins, R. N. Herring, and P. L. Barrick (consultant). Air Force Monitor of the program is R. E. Headrick of Wright Patterson Air Force Base.

Low-Temperature Properties

81131

This is a continuing project in which various physical properties useful in low temperature applications are measured. Data on physical properties of materials of construction and process materials are essential to the intelligent engineering design of low temperature devices and processes. Data obtained by this project are being applied to industrial and military technology and to the techniques of basic research.

Multi-component non-metallic powder insulations have been tested, the components of which were selected so as to provide a continuum of low transmission throughout the spectral region, 8-100μ, where thermal radiation is important. Promising results were obtained. Though the effective thermal conductivities were not as low as those of the best mixtures containing metals, such non-metallic mixtures may be of value in insulating vessels containing reactive oxidants.

The Fabry-Perot dilatometer has been completed, and the expected fringe patterns have been obtained. Difficulties in maintaining the fringe pattern during thermal cycling have been encountered.

The thermal conductivities of two irradiated graphites have been measured from 4° to 100°K. Order of magnitude decreases in conductivity due to lattice damage were found. The results are relevant to the design of nuclear reactors for missile propulsion using a cryogenic working fluid.

The thermoelectric characteristics of some common commercial thermocouples were determined down to 4°K. The stability and calibration of newly available commercial germanium resistance thermometers were studied in the liquid hydrogen region using techniques of vapor pressure control and thermometry that are precise to a few hundred-thousandths of a degree. The germanium thermometers were stable within a few millidegrees throughout extensive thermal cycling. Joule heating effects in carbon thermometers at radio frequencies were investigated and were found to present no unusual features. Interpolation techniques for platinum resistance thermometers were evaluated using calibration data furnished by Div. 3. A simple interpolation technique was found to suffice down to 20°K for thermometers of the kind regularly calibrated by NBS.

Plans for Fiscal Year 1962 are to continue exploration of mixed powder insulations, to complete the measurements of thermal conductivity of reactor graphites, to support an extension of the research on magnetic core materials after termination of project 81433, and to calibrate the germanium resistance thermometers in the liquid helium range.

The principal contributors to this project were V. D. Arp, W. J. Bell, L. P. Caywood, D. B. Cline, R. J. Corruccini (Project Leader), J. L. Harden, R. H. Kropschot, R. L. Powell, and J. H. Wilson.

## Hydrogen Properties NASA

81430

The objective of this project is to measure the PVT relations, specific heat, thermal conductivity, dielectric constant, viscosity, and sonic velocity of fluid hydrogen at low temperatures and at pressures up to 300 atm. and to calculate derived thermodynamic properties. In order to achieve the highest specific impulse, chemical rockets must use hydrogen as a fuel, and nuclear rockets must use it as a propulsion fluid. The above properties data are now required with higher accuracy and over wider ranges of temperature and pressure than hitherto available in order to permit improved design and prediction of hydrogen-handling equipment such as refrigerators, liquifiers, pumps, turbines, and gages for density and liquid level.

Progress and plans for the first three of the tasks above are reported under project 81531 since these tasks were initiated under that project and continue to be partially supported by it. The remaining tasks above have been inactive due to inability to recruit competent personnel.

Plans for Fiscal Year 1962 are to initiate experimental work on the viscosity, provided a scientist can be recruited for this.

Personnel contributing to this project were R. J. Corruccini (Project Leader), D. E. Diller, R. D. Goodwin, W. J. Hall, H. M. Roder, L. A. Weber, and B. A. Younglove.

## Engineering Properties of Cryogenic Materials

81431

The objective of this project is to prepare a handbook of mechanical properties data and certain physical properties data on cryogenic materials. The data are to be taken from the literature where possible and are to be supplemented by experimental measurements where this is desirable or necessary. The project is sponsored by Air Force Ballistic Missile Division. The immediate goal is to permit the achievement of improved reliability of valves and other control components of missiles that use cryogenic fluids. The importance of this will hardly need stressing, since many missile failures have been attributed to malfunction of such minor components. As a by-product, the whole field of cryogenic engineering will be enriched by the data to be made available.

The Handbook now contains over 500 data sheets. Tensile, impact, and shear modulus measurements that were planned for the original list of metals are nearly complete. Thermal expansions have been measured for half of the materials. The compilation of data from the literature has been completed for the years, 1940-1959, inclusive.

Plans for Fiscal Year 1962 are to complete the measurements of modulus of elasticity and thermal expansion, and to measure the tensile properties of certain plastics. On about Jan. 1, 1962, supervision and support will be taken over by Wright-Patterson AFB.

Preliminary discussions with its representatives indicate that a less varied list of properties will be measured in the future, but that additional materials will be introduced into the program.

Personnel contributing to this project included T. H. Durham, R. L. Greeson, R. P. Mikesell, G. W. Pickering, R. P. Reed (Project Leader), and K. A. Warren.

## Properties of Air

81432

The objective of this project was to determine the thermal conductivity of air at low temperatures and pressures. It was sponsored by Arnold Engineering Development Center. The results were needed in order to analyze and correlate test data obtained with wind tunnels.

See project 81531 for a report of progress with the apparatus. This project has been terminated.

W. J. Hall and R. L. Powell (Project Leader) were contributors.

## ARPA Properties of Materials

81433

This project consists of three unrelated tasks: (1) To study the magnetic properties of soft ferromagnetics at low temperatures; (2) To study phase transformations and the mechanical properties of certain austenitic steels at low temperatures; (3) To study various factors affecting the performance of cryogenic adhesives and to develop improved adhesives.

(1) The increasing use of electric motors, generators, transformers, transducers, and electrical instruments operating at low temperatures has created an urgent need for engineering data on ferromagnetic materials at low temperatures. Such data are practically non-existent. (2) Austenitic stainless steels play an important role in cryogenic equipment because of their generally good ductility, work-hardenability, and phase stability at low temperatures. Thus it is important to establish the conditions under which some deterioration of these good characteristics can occur. Also the mechanical properties of some of the less-familiar alloys of this type should be investigated in the hope of finding steels of superior characteristics or of lower cost. (3) Adhesives can be used to join structures or to seal against leaks in situations where conventional metal-joining techniques are prohibited. There is need for a systematic study leading to optimization of adhesive performance.

Accomplishments during the year are summarized as follows: (1) A considerable body of data has been accumulated on hysteresis loss, eddy-current loss, resistivity, and permeability of commercial core materials. Domain patterns have been observed on polycrystalline materials at room temperature using magneto-optic rotation. (2) A simple nitrogen-shielded cryostat has been built for tensile testing. The thermal performance is excellent and permits long tests at 4°K. The tensile and notch-tensile data on stainless 304, 304L, and 310 have been extended to 4° using this cryostat. The irreversible production of martensite in 304L by thermal cycling and its effect on the mechanical properties have been determined. The transformation in 202, 304, and 304L steels has been followed as a function of strain by metallographic, magnetic, and X-ray techniques. The formation of a transitional HCP phase has been verified by X-ray diffraction. (3) Inactive.

Plans for Fiscal Year 1962 are as follows: (1) The magnetic measurements program has been enlarged relative to the original plans. It will continue until funds expire and will then be supported by RTS. (2) Complete except for writing reports and papers. (3) Because of administrative limitations on staff, no work will be done on adhesives. The funding of this task will have been used to extend tasks (1) and (2) in scope and duration.

Personnel contributing to this project were J. J. Gniewek (Project Leader, Part 1), R. L. Greeson, C. J. Guntner, and R. P. Reed (Project Leader, Part 2).

## Magnet Materials

81438

The objective of this project is to develop and investigate materials suitable for high-intensity refrigerated solenoids. It is supported by AEC. High magnetic fields have important applications for particle deflection in nuclear fusion reactors (Project Sherwood), accelerators, particle detection devices, magneto-hydrodynamic power converters, etc.

Niobium-clad $Nb_3Sn$ wire was produced by Sec. 8.02. The quenching of superconductivity in this material as a function of current and external field was measured to nearly 200 kgauss in cooperation with the University of Colorado, where a pulse magnet was available. While some details of the results are not yet clear and may ultimately be attributed to transient effects, it appears that solenoids can be made of this material that will produce fields of over 100 kgauss and possibly as high as 200 kgauss. An extensive review paper on superconducting magnets was completed.

Plans for Fiscal Year 1962 are to perfect the pulse technique for studying quenching of superconductivity at high fields, to measure other superconductors having high transition temperatures, to fabricate small pilot models of solenoids and study their behavior, and to study critical field enhancement in thin films.

Personnel who contributed to this project were V. D. Arp, D. B. Cline, R. H. Kropschot (Project Leader), J. H. Wilson, and members of the Chemical Metallurgy Section, 8.02.

## Properties of Hydrogen

81531

The project objectives are to produce detailed data on the PVT relations, specific heat, and thermal conductivity of fluid hydrogen between 20° and 100°K and at pressures as high as 300 atmospheres. The sponsor is the Air Force. Absolute accuracies required are dictated by the computational procedures, by which the first two types of data are to be combined and converted into so-called thermodynamic networks, useful for engineering design work. As it is generally integrals of the first and second derivatives of the mechanical properties or compressibilities which enter into thermodynamic computations, these properties must be obtained experimentally with precision and absolute accuracy roughly one magnitude better than required for direct use as mechanical properties.

These properties are required by engineers for the design of devices such as missiles and missile components which must employ cryogenic fluids at temperatures and pressures for which data are insufficient, conflicting or totally lacking. Such lack of data arises from the unusual difficulties of conducting precise measurements simultaneously at cryogenic temperatures and at pressures of hundreds of atmospheres.

The experimental PVT measurements have been completed. The results have been smoothed and the second and third virial coefficients have been calculated.

The $C_v$ calorimeter has been completed, and some preliminary measurements have been made along the saturation line. Excellent precision is indicated by these results.

Careful and laborious checks of the precision and self-consistency of the thermal conductivity apparatus have been carried out using nitrogen. These have suggested certain minor improvements in the apparatus which have been made.

Plans for Fiscal Year 1962 are to prepare smooth self-consistent tables of the thermodynamic functions derivable from the PVT data and thermal data from other sources, to complete experimental measurement of specific heats and incorporate the latter into the thermodynamic data network, and to measure the thermal conductivities. (See project 81430 for related research).

Contributors to this project were D. E. Diller, R. D. Goodwin (Project Leader), W. J. Hall, H. M. Roder, L. A. Weber, and B. A. Younglove.

## Liquefied Gases for Rocky Flats

81443

The objective of this project is to furnish liquid nitrogen to Dow Chemical Company, Rocky Flats operation. The liquid nitrogen furnished was used in research for the Atomic Energy Commission. This research is vital to the interests of the United States. 81,291 liters of liquid nitrogen were furnished during the fiscal year. This is nearly a 40% increase over the fiscal year 1960.

The project is expected to continue at the same level of activity at least for the first part of the fiscal year. Dow may install a liquid nitrogen storage facility and purchase liquid from a private source.

## Liquefied Gases for Fitzsimmons Army Hospital

81444

The objective is to furnish liquid nitrogen to Fitzsimmons Army Hospital, Denver, Colorado. The liquid nitrogen was used in connection with the research activities of the hospital. 1,755 liters of liquid nitrogen were furnished during the period September-December 1960.

This project has been terminated.

## Liquid and Gaseous Hydrogen for the Martin-Denver Co.

81446

The objective is to furnish liquid and gaseous hydrogen to the Martin Company as needed until such time as Martin is able to obtain these products from a private source.

The liquid and gaseous hydrogen furnished was used in research and development work in connection with National Defense and space programs. 4,200 liters of liquid hydrogen and 24 cylinders (4200 scf) of gaseous hydrogen were furnished during the period August-December 1960. Dollar-wise, this is about 30% of the activity for the fiscal year 1960.

This project has been terminated as Martin is now being supplied by a commercial company.

## Liquid Nitrogen for Colorado State College

81447

The objective is to furnish liquid nitrogen to Colorado State College. The liquid nitrogen was used for research work done by the College. 1,120 liters of liquid nitrogen were furnished during the fiscal year. This is about double the amount furnished during the fiscal year 1960.

It is expected that this project will continue at about the rate of 100 liters per month.

## Liquid Nitrogen for Ball Brothers

81448

The objective is to furnish liquid nitrogen to Ball Brothers Research Corporation. The liquid nitrogen was used for research and development activities, some of which were in connection with government contracts. 5,980 liters of liquid nitrogen were furnished during the period July 1960 to February 1961. Dollar-wise, this is twice the value of the products furnished during the fiscal year 1960.

This project has been terminated. Ball Brothers is now being supplied from a commercial source.

## Liquid Nitrogen for Colorado State University

81449

The objective is to furnish liquid nitrogen to Colorado State University as needed. The liquid nitrogen was used for research work in connection with the activities of the University. 165 liters of liquid nitrogen were furnished during the period March-June 1961.

It is expected that this project will continue and that small amounts of liquid nitrogen will be furnished.

## Low Temperature Data Compilation

81450

The objective of this project, sponsored by the National Aeronautics and Space Administration, is: (1) to search the published literature and reports for thermophysical properties of fluids and solids of interest in cryogenic engineering for design and development of cryogenic processes and equipment; (2) to compile an extensive bibliography of references, cross-indexed for convenient use; and (3) to evaluate and select data for compilation of data sheets to be presented in compendium form.

Considerable data are available for low temperature work but are not conveniently available or in good agreement. By making a thorough and systematic search for low temperature data, selecting "best values" and compiling and arranging them in an organized compendium, the engineer and scientist have been greatly aided in the design and development of cryogenic equipment and processes. This project should provide much needed information, at considerable saving of time and effort, to persons engaged in current defense and spacc programs.

This activity is a continuation of the work undertaken in Project 81404, sponsored by Wright Air Development Division - USAF, which was terminated early in January 1961. This former project had resulted in the production of two compendiums, Phase I and Phase II, on the properties of materials at low temperature. This project was then started early in January 1961, at the time the former project was terminated. Because of increased emphasis in more thorough and detailed data evaluation as well as the preparation of more comprehensive data sheets, many of the tasks undertaken in Phase II of the compendium were only partially completed. The efforts in this project have been directed at continuing these tasks. In addition, as a result of this increased scope of data analysis, it has been possible to pursue the development of Temperature-Entropy charts for some of the fluids.

Current plans for this project are to complete the tasks on Compressibility, Compressibility Factor, and Temperature-Entropy charts for the remaining fluids. In addition, work will be undertaken on additional data sheets on the equilibrium concentration of two-phase, binary systems in which the liquid-vapor, solid-vapor and liquid-solid systems will be considered. Additional tasks such as Prantl number, specific heat ratios, thermoelectric properties, physical transformations, etc. will be undertaken as rapidly as work assignments can be made.

Personnel contributing to this project are: Robert McCarty, Dr. F. E. E. Germann (P/T), Genevieve Michela (P/T), Albert Cosman (Summer), Lynda Wallace (Summer), W. W. Bulla, L. J. Ericks, Richard Weekley, Don Harrison, V. J. Johnson, and R. B. Stewart (Project Leader).

Liquid Helium for the Sandia Corporation

81540

The objective is to furnish liquid helium for the Sandia Corporation, Albuquerque, New Mexico. The liquid helium was used in research work for the Atomic Energy Commission. 176.5 liters of liquid helium were furnished under this project during July and August 1960. No liquid has been furnished since.

It is expected that this project will be terminated.

Liquid Nitrogen and Helium, and Gaseous Hydrogen for Colorado University

81541

The objective is to furnish liquid nitrogen, liquid helium and gaseous hydrogen to the University of Colorado. The products furnished were used for research activities at the University, many of which are on government contracts having to do with National Defense. 21,113 liters of liquid nitrogen, 294 liters of liquid helium and 3 cylinders (525 scf) of gaseous hydrogen were furnished during the year. This is approximately the same level of activity as in the fiscal year 1960.

It is expected that this project will continue at about the same level of activity.

Gaseous Hydrogen for Beech Aircraft Corporation

81542

The objective is to furnish gaseous hydrogen to Beech Aircraft Corporation. The gas furnished was used on research and development projects in connection with government contracts. 31 cylinders (5425 scf) of hydrogen gas were furnished during December 1960 and January 1961.

It is expected that this project will be terminated. Beech is now being supplied by private industry.

## Liquid Helium for the University of California

81543

The objective is to furnish liquid helium to the University of California as needed. No liquid was supplied during the year.

It is not known whether this project will be terminated, or continued for another year with the liquid being supplied as originally planned.

## Liquid Helium for Mellon Institute

81544

The objective is to furnish liquid helium to Mellon Institute. The liquid helium was used on research projects in connection with government contracts. 215 liters of liquid helium were furnished by air transportation during the year. This is approximately 50% of the amount furnished in fiscal year 1960.

It is expected that this project will continue at about the same level.

## Liquid Helium for the Argonne National Laboratories

81547

The objective is to furnish liquid helium to the Argonne Laboratories. The liquid helium was used on research projects in connection with government contracts. 49 liters of liquid helium were furnished by air transportation during the period April-June 1961.

It is expected that small amounts of liquid helium may be supplied to Argonne during fiscal year 1962.

## Liquid Helium for Wyandotte Chemical Company

81548

The objective is to furnish liquid helium to the Wyandotte Chemical Company. The liquid helium was used on research projects in connection with government contracts. 146 liters of liquid helium were furnished by air transportation during the year.

It is expected that this project will continue at about the same level of activity.

## Miscellaneous Reimbursable Cryogenic Services

81625

The objective is to furnish liquid and gaseous hydrogen, liquid and gaseous nitrogen, and liquid helium to various non-government users* on an individual order basis. The various products furnished were used on research and development activities, some of which were in connection with government contracts. The products supplied were:

| | |
|---|---|
| Liquid Hydrogen | 825 liters |
| Gaseous Hydrogen | 4 cylinders (800 scf) |
| Liquid Nitrogen | 700 liters |
| Gaseous Nitrogen | 1 cylinder (200 scf) |
| Liquid Helium | 349 liters |

It is expected that this project will continue. The level of activity is undetermined.

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* Armour Research Foundation, Chicago, Illinois; Bell Laboratories, Murray Hill, New Jersey; Hofman Laboratories, Inc., Newark, New Jersey (Boulder delivery); Ramo-Wooldridge, Denver, Colorado (Boulder delivery); Stanford University, Palo Alto, California; University of Chicago, Chicago, Illinois; University of Missouri, Columbia, Missouri.

## Cryogenic Data Services

81626

This reimburseable project was established to furnish technical literature, data and bibliographic service to NBS projects and others as requested.

The greatly increased activity in the cryogenic engineering field has resulted in a demand for literature and data of such a specialized nature that libraries are unable to handle it. The Cryogenic Data Center was instituted to meet these specialized demands.

This project was set up during this fiscal year for cost reimbursement of service charges in supplying cryogenic information and was only used the last few months of the year. The activity has amounted to slightly over $2,000, principally for the reproduction of documents and the sale of tabulated data on magnetic tape.

A considerable increase in the activities of this project is expected. Plans for providing the cryogenic engineering industry with more information as to availability of cryogenic literature and data, and the introduction of a bibliographic service will incur a much greater demand for service. A total dollar volume of $25,000 may easily develop.

## Liquefaction of Gases

81645

The objectives of this project are: (1) to produce or procure liquid hydrogen and liquid nitrogen as required for the Boulder Laboratories; (2) to produce liquid helium and pure hydrogen and nitrogen gas as needed, for use in NBS research and development projects, and for use by other agencies and qualified non-government activities; and (3) to provide facilities for the development and testing of cryogenic equipment and materials, and for the evaluation of cryogenic processes.

Liquefied and pure gases are essential in conduction of many of the research and development projects of the Cryogenic Engineering division and for a few projects in other divisions of the Boulder Laboratories. In the production, handling and distribution of cryogenic fluids, it is important that experienced personnel and suitable facilities be used. This can best be assured under a centralized service responsibility.

Approximately 20,000 liters of liquid hydrogen were produced during the year and about 20,000 liters were received from outside sources. Likewise, approximately 190,000 liters of liquid nitrogen were produced and about 360,000 liters were purchased. Now that both liquid hydrogen and liquid nitrogen are commercially available at reasonable prices, they are being purchased rather than produced except when for other reasons than merely providing a liquid supply, it is feasible to operate the liquefier facility.

Liquid helium production amounted to about 3000 liters requiring procurement of 88,000 scf of helium gas for this purpose. An additional 35,000 scf of helium gas was distributed to laboratory projects. Pure hydrogen and nitrogen gas produced was 20,000 scf and 44,000 scf respectively. Some heavy water was electrolyzed for the University of California with a total of 10,500 scf of deuterium gas being produced. (See Project 81427.)

The following projects list the type and amount of cryogenic fluids furnished to non-NBS activities: 81443, 81444, 81446, 81447, 81448, 81449, 81540, 81541, 81542, 81543, 81544, 81547, 81548, and 81625.

The practice of recovering boil-off hydrogen gas is still being followed. Over 750,000 scf was recovered during the year. Accordingly, no hydrogen gas was purchased for liquefaction purposes. About 80,000 scf was procured, however, for direct use on project 81420.

The liquefaction facilities were used for development, testing and evaluation of cryogenic equipment and processes for various CEL projects. One phase of project 81428, Magnet Refrigeration, was completed using portions of the hydrogen liquefier flow system. Work is still in progress on a phase of project 81420, Design Criteria and Materials Utilization, using space provided in the hydrogen liquefier plant area.

It is expected that requirements for liquefied gases within CEL will remain at the same level or increase slightly, while the requirements for activities outside CEL will decrease even more than in FY 1961. All liquid hydrogen and liquid nitrogen requirements will be met with liquids purchased from commercial sources with the exception of those requirements where it is not feasible to use commercial products. Until liquid helium becomes commercially available at a reasonable price, it will still be liquefied at CEL as required.

The plant facilities will become more available for the testing and evaluation of cryogenic equipment, materials and processes as more liquefied gases are procured commercially.

Personnel contributing to the liquefaction of gases projects are: C. G. Goodner (Project Engineer), Maurice Bergh (Plant Superintendent), Peter Smelser, Frank Mouffe, William German, Arthur Bashford (P/T), Dan Schock, Arthur Kidnay, Douglas Covington (WAE), Willard Bell, James Draper, Thomas Anderson (summer), Lewis Mullen, Russell Potts, Signe Hartley (Secretary), V. J. Johnson (Section Chief) and others.

# CENTRAL RADIO PROPAGATION LABORATORY

IONOSPHERE RESEARCH AND PROPAGATION

DIVISION 82

RADIO PROPAGATION ENGINEERING

DIVISION 83

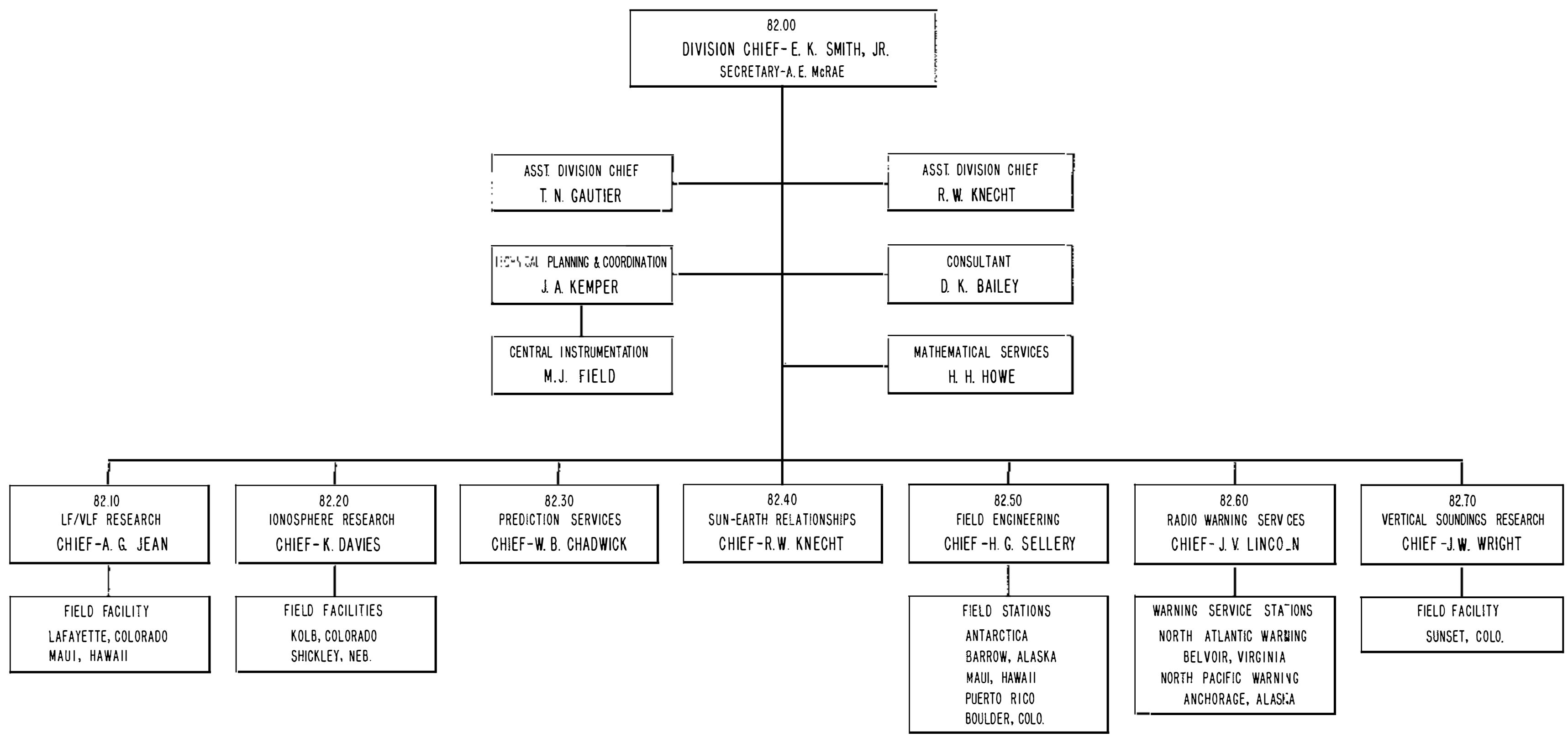
RADIO SYSTEMS

DIVISION 85

UPPER ATMOSPHERE AND SPACE PHYSICS

DIVISION 87

IONOSPHERE RESEARCH AND PROPAGATION



# IONOSPHERE RESEARCH AND PROPAGATION
# DIVISION 82

## Introduction

Within the Central Radio Propagation Laboratory, the Ionosphere Research and Propagation Division acts as the primary agency for the conduct and coordination of basic research on the propagation of radio waves as affected by the ionosphere and on the special factors which can give rise to large departures from the normal behavior; conducts basic research on the nature of the media through which these radio waves are transmitted and the interaction of radio waves with the media; prepares predictions of radio wave propagation and warnings of disturbances; acts as a central repository for data, reports, and information in the field of ionospheric radio wave propagation, and maintains a staff of experts on the characteristics of the ionosphere and on radio wave propagation in it for consultation when needed by other government agencies and industry.

Toward the end of Fiscal Year 1961, the Sun-Earth Relationships Section (82.40) was split to form a new section, Vertical Soundings Research Section (82.70).

## Consulting and Advisory Services

82101

The Ionosphere Research and Propagation Division provides advice and information on technical problems relating to ionospheric radio propagation and ionospheric phenomena and cooperates with scientific and technical societies in the dissemination of technical information and in the formulation of specifications, methods of testing, codes, and standards of practice.

An important mechanism for increasing the Bureau's service to the nation is the provision of advice and information on technical problems within the competence of the Bureau's scientists and engineers. The Bureau therefore recognizes an important responsibility for consultation and collaboration with other government agencies, industrial organizations, research institutions, professional and scientific societies, and technical organizations.

The staff of the Division continues to provide consulting and advisory services to many government, university, and private organizations concerned with ionospheric radio propagation and ionospheric phenomena. Many of these have to do with particular aspects of problems which, in general, are covered by the regular ionospheric frequency predictions services and radio disturbance warning services. The Division is very frequently called upon by institutions throughout the world for guidance and advice as regards vertical soundings of the ionosphere; both on the equipmental aspects, and on the reduction and interpretation of ionograms. Other advisory services are concerned with the new areas of space science and technology, VLF communication, and ionospheric electron density distribution. Several agencies and contractors concerned with satellite and space probe experiments came for advice and assistance in the ionospheric or wave propagation aspects of their problems.

Members of the staff participated in certain international activities, particularly the International Scientific Radio Union (URSI) where one member is serving on the True Heights Working Committee; another is a consultant to the International World Day Service. Three members of the Division delivered invited papers at the URSI Thirteenth General Assembly in London in September, 1961. Two staff members have been very active in the URSI World-wide Soundings Committee, one serving as secretary and the other as consultant, both greatly assisting the Chairman, another CRPL staff member. Other international activities involve the International Astronomical Union, the International Union of Geodesy and Geophysics and the Comite Internationale Geophysique (successor to the international IGY committee) of the International Council of Scientific Unions.

Another aspect of international collaborative work in which the Division has played a role is the International Radio Consultative Committee (CCIR) of the International Telecommunication Union (ITU). In addition to preparatory work at the national level, both the International U. S. Chairman and Vice-Chairman of the CCIR Study Group VI (Ionospheric Propagation) are members of the Division. One member is the U. S. representative of the International CCIR Working Group on HF Field Intensity. Two members of the staff were delegates to the NATO Advisory Group for Aeronautical Research and Development (AGARD) Symposium on Effect of Solar Disturbances on Radio Communication, held in Naples, Italy, May 1961.

On the national scene the Division has one member serving on the Science Advisory Group of the Voice of America. He has participated actively as a member of the Propagation Subcommittee and earlier as Chairman of the Dwindling Spectrum Subcommittee. Other members of the Division participated in work of the Rocket and Satellite Research Panel, and the NASA Topside Sounder Working Group, and various other NASA advisory groups. One member is serving on the Administrative Committee of the IRE Professional Group on Antennas and Propagation.

## Revision of Circular 462

82102

The objective of this project is to provide an up-to-date manual on ionospheric radio propagation emphasizing the relation of ionospheric propagation characteristics to practical communication systems. NBS Circular 462, "Ionospheric Radio Propagation" is now over 12 years old. The practical applications of ionospheric characteristics given in the 1948 version need revision in the light of new knowledge. The treatment needs expanding to include newer modes of propagation (i.e., scatter and meteoric), and to show the relationship of the propagation characteristics to the design and functioning of modulation.

Preparation of the revision was combined with preparation of a two-week course in ionospheric radio propagation (part of the three-week course described under Project 79629). The course consists of 42 lectures prepared and presented by thirty individuals on the regular staff plus one WAE consultant and one expert from the Canadian Defence Research Telecommunications Establishment. A monograph will be prepared based on the lecture notes for the ionospheric propagation course.

This work has been under the direction of T. N. Gautier.

## VOA Science Advisory Group

82402

The objectives of the Group are to advise the Director of the Voice of America on technical problems. The U. S. Information Agency sponsors this work. It is in the national interest to see that the Voice of America, which is perhaps the best known source of information on U. S. policy overseas, is kept abreast of technological developments which might enhance its position in the highly competitive field of international broadcasting.

The Science Advisory Group held its semi-annual meeting May 9 - 11, 1961 in Boulder at the invitation of Dr. F. W. Brown. The second meeting of the Dwindling Spectrum Subcommittee was held in Boulder in July of 1960. The CRPL representative also attended meetings of the SAG in Washington and of the Propagation Subcommittee in Los Angeles and Stanford. In addition, the CRPL member participated in a fact-finding mission on equatorial propagation effects, visiting the proposed VOA Relay Base in Liberia and discussing problems with U.K. experts at Department of Scientific and Industrial Research (DSIR - Slough), Cable and Wireless, the Post Office, and particularly the BBC in London. The subcommittee will continue to hold meetings and to gather and review material on the current technological developments in the fields of engineering and propagation of interest to the VOA; these to be reviewed by the full Group at its bi-annual meetings. A problem of major importance is the optimum use of frequencies during the oncoming period of low solar activity.

Dr. E. K. Smith is a CRPL member of the VOA Science Advisory Group.

# LF AND VLF RESEARCH SECTION

## VLF Propagation

82117

The objective of this work is to study ionospheric propagation at frequencies from about 1 kc/s to 100 kc/s. Atmospherics are utilized as a source of signals in lieu of suitable man-made transmissions. Particular emphasis is placed on the band of frequencies from 3 kc/s to 30 kc/s. This study consists of determining propagation attenuation, phase velocity, and ionospheric reflection coefficients as a function of frequency, distance, time of day, season, magnetic activity, and direction of propagation.

This work is of basic scientific importance. Through complex spectral analysis of the waveforms of atmospherics recorded by a network of stations, certain propagation phenomena are revealed; for example, the reflection height of the ionosphere, the complex ionospheric reflection coefficients and propagation attenuation, and phase velocity of the ground and skywave modes of propagation. With these experimentally determined results, it is possible to test certain ionospheric models; i.e., to estimate values of electron density and collisional frequency as a function of height, and to determine the effect of other parameters involved in VLF propagation, such as the direction and magnitude of the earth's magnetic field, solar flares, magnetic disturbances, and variations of ground constants.

Special equipment was constructed and placed into operation at Miami, Gainesville, and Cross City, Florida, to record the waveforms of atmospherics. This equipment was designed to record the groundwave and first hop skywave for purposes of determining the complex ionospheric reflection coefficients at VLF.

Equipment to improve the data recorded at other NBS field sites was placed in operation. With these improved recording techniques, the broadband field from atmospherics can be recorded over a bandwidth extending from a few hundred cycles per second to above 100 kc/s at free space field strengths ranging from a few millivolts per meter to about 100 volts per meter on both the vertical and loop antenna channels.

Simultaneous observations were made at the NBS recording stations starting in March, 1961. These data are in the process of being analyzed. Analyses consist of tracing and scaling the broad waveform of atmospherics, photographed from the oscilloscope cathode ray tubes by 35 mm continuously moving film cameras, and computing the amplitude and phase spectra and the energy density with the aid of an electronic computer. Other necessary analysis includes the measurement of time of reception and direction of arrival for each lightning discharge.

Analysis of distant waveform data was completed relative to determining phase velocity of propagation. A report, "Daytime phase characteristics in the VLF band deduced from atmospheric waveforms," was presented at the Fall URSI meeting in Boulder, Colorado.

First hop skywave analysis was continued to determine the complex ionospheric reflection coefficients as a function of frequency and direction of propagation with respect to the earth's magnetic field lines.

Observations were made utilizing the radiation from an "atmospherics pulse generator" (Newman-Lightning and Transients Labs) in the Florida area. Pulses from this generator were recorded at the Miami site (approximately equal to 300 km) and the Boulder Labs site (approximately equal to 3000 km).

Recording sites were operated by NBS personnel near Boulder, Colorado, and on Maui, Hawaii, and under contract by University of Utah near Salt Lake City, Utah; New Mexico Institute of Mining and Technology near Socorro, New Mexico; University of Florida near Gainesville and Cross City, Florida; and University of Miami, near Miami, Florida.

In the continuing program, particular attention will be placed on determining variation of VLF propagation conditions relative to the effects produced by path direction, solar flares and magnetic disturbances. Attenuation rates and phase velocities for the dominant waveguide mode propagation concept, will be computed as a function of path conditions. Normal and abnormal components of the first hop skywave will be recorded through the use of improved recording techniques recently developed. Vertical electric field reflection coefficient of the ionosphere ($_{\|}R_{\|}$) and the conversion coefficient ($_{\|}R_{\perp}$), i.e., from normal or parallel electric field to horizontal or perpendicular electric field, will be computed from these data. The practicability of utilizing the "atmospherics pulse generator" technique for VLF propagation work will be studied. It is planned to design and construct equipment which will continuously monitor particular paths, utilizing atmospherics to indicate gross changes in propagation conditions produced by solar flares and magnetic storms.

Personnel contributing to this work were: W. L. Taylor (project leader), H. M. Burdick, L. W. Eichacker, and L. A. Pollock.

## VLF Phase Stability

82118

The objective of this program is to study the propagation characteristics of phase-stabilized transmissions in the VLF band of the radio spectrum. This involves the collection of data on the variations in phase and amplitude of VLF signals received at great distances, and the interpretation of the data in terms of propagation stabilities and ionospheric parameters.

This investigation provides information regarding the propagation medium, the state of the lower ionosphere, and the precision with which a measurement of frequency and time can be made at intercontinental ranges.

During the fiscal year 1961, a new and improved (transistorized) equipment has been developed for recording the phase and amplitude of a VLF transmission. This equipment is small and compact and has the capability of following a 180-degree shift in phase with a time constant of 1 second. Equipments of this type are now in use at Boulder, Colorado, recording the phase-stabilized transmissions of GBR (16 kc/s), NBA (18 kc/s), NLK (18.6 kc/s), and WWVL (20 kc/s); at Maui, Hawaii, recording NBA and WWVL; and at Barrow, Alaska (to be moved to College, Alaska), recording NBA and GBR.

Since February 1960, continuous records of the phase and amplitude of the 16 kc/s transmission GBR, radiated from Rugby, England, have been obtained at Boulder, Colorado (7400 km). These records reveal the regular diurnal and seasonal variations as well as anomalies. In addition, phase and amplitude recordings of NBA, 18 kc/s, radiated from Balboa, Panama, have been made at Boulder, Colorado (4300 km) for approximately one year, and at Maui, Hawaii (8300 km), for about six months.

Sudden phase anomalies (SPAs) associated with solar flares, observed simultaneously along different propagation paths, are being studied in detail. An unusually large SPA was produced on the recording of GBR made at Boulder by the solar cosmic ray flare of 4 May, 1960. Only ten such solar flare cosmic ray events have been observed in the period from February 1942 to December 1960. An account of this event is being prepared for publication.

Anomalous phase variations in the GBR signal received at Boulder have been observed, coincident with meteor shower activity. The observation of VLF phase shifts is apparently a sensitive indicator of the gross ionizing effects of meteors in contrast to the fine structure of meteor ionization observed by VHF forward scatter, radar, and optical observations. A comprehensive study of the meteor shower effect has begun, utilizing data obtained during 1 1/2 years of observation at Boulder of the GBR transmission.

A preliminary study has revealed good correlation between "isolated magnetic bays" observed in the local Boulder magnetometer records, and variations in the phase of the GBR signal observed at Boulder.

Recording of the above-mentioned VLF transmissions will continue until the seasonal variations have been established and the precision of frequency measurement is known as a function of distance. This will necessitate a comprehensive study of ionospheric disturbance effects on a number of recorded frequencies and paths, utilizing various equipment time constants.

Personnel contributing to this work were: C. J. Chilton (project leader), R. F. May, A. H. Diede, and A. C. Murphy.

## Sferics & VLF

82411

The objective of the work is to study the characteristics of the electromagnetic energy radiated from lightning discharges (atmospherics) and to study propagation characteristics at frequencies from about 1 kc/s to 100 kc/s. The primary end result is to furnish necessary information to the sponsor so that VLF interference from atmospherics can be determined at great ranges. The Air Force Technical Applications Center is the sponsor.

This work is important to those agencies using the VLF region of the radio spectrum for communications or for various other specialized purposes. It is also of basic scientific importance. The characteristics of lightning discharges, relative to meteorological and topographical factors, can be determined through the study of the groundwave waveforms from atmospherics. The characteristics of VLF propagation relative to the direction and magnitude of the earth's magnetic field, magnetic disturbances, sunrise and sunset conditions, solar flares, and variations of ground constants can be determined through the study of atmospheric waveforms at great distances.

An experiment was designed to determine the characteristics of the electromagnetic radiation produced by lightning discharges (atmospherics) occurring at and near sea level elevations. Special equipment was designed and constructed to meet the requirements of the experiment. Three recording units, containing the equipment, were placed in operation at Miami, Gainesville, and Cross City, Florida. Personnel to operate these units, under contract at each location, were instructed in the basic experimental requirements and operational techniques.

New equipment, using loop antennas for recording atmospheric waveforms and their directions-of-arrival, was designed and constructed. With this improved equipment for the loop antenna channels, the transfer characteristics, i.e., amplitude and phase, of the vertical antenna (responding to the vertical electric field), and the two crossed loop antennas (responding to the orthogonal horizontal magnetic fields), are identical at all recording sites. The broadband field from atmospherics can be recorded over a bandwidth extending from a few hundred cycles per second to above 100 kc/s at free space field strengths of a few millivolts per meter to over 100 volts per meter on all waveform channels.

Simultaneous observations were made at the NBS recording stations, starting in March, 1961. This data is in the process of being analyzed. Analyses consist of tracing and scaling the broad waveform of atmospherics photographed from the oscilloscope cathode ray tubes by 35 mm continuously moving film cameras, and computing the amplitude and phase spectra, and the energy density with the aid of an electronic computer. Other necessary analysis includes the measurement of time of reception and direction of arrival for each lightning discharge.

Analyses of the groundwave portions of atmospheric waveforms recorded in the Texas-Oklahoma area from past operations were completed. A report, "Radiation field characteristics of lightning discharges in the band 1 kc/s to 100 kc/s," was completed and presented at the Spring URSI meeting in Washington, May 1961.

Analyses of atmospherics associated with whistlers and other unusual phenomena were continued. First hop skywave analysis was continued for purposes of determining the complex ionospheric reflection coefficients and delay times.

Recording sites were operated by NBS personnel near Boulder, Colorado, and on Maui, Hawaii, and under contract by University of Utah near Salt Lake City, Utah; New Mexico Institute of Mining and Technology near Socorro, New Mexico; University of Florida near Gainesville and Cross City, Florida; and University of Miami, near Miami, Florida.

Continuing work will be focused on determining the characteristics of lightning discharges occurring at low elevations. Atmospheric waveforms data, recorded at Miami, Gainesville, and Cross City, Florida sites, from atmospherics within about 500 km of these locations, will be analyzed to fully determine the variations in characteristics associated with meteorological conditions. Analyses of atmospherics associated with whistlers will continue, with emphasis on study of other large energy atmospherics, particularly those with initial negative half-cycles, to determine, if possible, the meteorological conditions necessary for their occurrence. Because of their larger energy content (about an order of magnitude above an "average" atmospheric), these two types of atmospherics propagate to very great distances and are likely to produce a severe interference problem at great distances from the source. Determination of attenuation rates and phase velocities will continue for various paths and times not previously studied with particular attention to the effects of path orientation, solar flares and magnetic storms on propagation conditions. Analysis of the first hop skywave will be expanded to determine the characteristics of this portion of atmospheric waveforms and to compute the ionospheric reflection coefficients.

The following personnel worked on this project: W. L. Taylor (project leader), H. M. Burdick, L. W. Eichacker, and L. A. Pollock.

## Sferics Studies

82412

The details of this project are similar to those outlined in Project 82411 except that the Advance Research Projects Agency via Air Force Technical Applications Center is the sponsor.

Personnel contributing to this work were: W. L. Taylor (project leader), H. M. Burdick, L. W. Eichacker, and L. A. Pollock.

## Extremely Low Frequency Studies

82413

The objective of this project is to determine the propagation characteristics of the earth-ionosphere waveguide in the zero-order mode, including the propagation attenuation rates and relative phase velocities. This will be done through the simultaneous reception of atmospherics at different locations. The work is sponsored by the Advance Research Projects Agency. The results of this work will enable testing of the validity of existing theories concerning the propagation of radio waves, and will permit evaluating the effective heights and conductivity of the lower ionosphere.

Three recording stations are being installed in Florida, Colorado, and British Columbia. Vertical electric field fluctuations from atmospherics will be simultaneously recorded at these stations during the summer of 1961. The waveform analysis of the recorded signals is scheduled to begin in the fall or winter. Future research will include observations of the polarization of the waves at ELF. Construction of loop antennas, required in the polarization observations, has been initiated.

Operation of a three-station network will commence during the latter part of the 1961 summer, with possible extensions to provide data on propagation at greater distances and polarization measurements.

Personnel contributing to this work were: W. H. Campbell (project leader), D. F. Wasmundt, M. D. Littlefield, A. C. Murphy, and A. G. Jean.

## VLF Phase Perturbations

82415

The objective of this work, sponsored by the Advance Research Projects Agency, is to obtain information on variations in the phase of VLF signals reflected from the ionosphere at steep and at oblique incidence. Variations in the phase, or the time of arrival of VLF signals, are associated with changes in the apparent height of the ionosphere. Variations in the time of arrival of signals disclose the manner in which the reflection height of the lower ionosphere varies with solar illumination and unusual events, including solar flares, bombardment of the ionosphere by high-energy electrons, auroral disturbances, disturbances in the geomagnetic field, the passage of meteor showers, et cetera. An understanding of the natural phase variations is necessary to fully exploit long-range communications systems making use of the carrier phase, such as, radio aids to navigation, standard frequency broadcasts, et cetera. Systems recording variations in the phase of the received signal can provide information on the occurrence of solar flares, and perhaps detect changes in the lower ionosphere resulting from the detonation of nuclear devices at high altitudes.

Equipment was placed in operation at Maui, Hawaii, to record the 20 kc/s signal transmitted from WWVL, Boulder, and the 18 kc/s signal transmitted from NBA, Canal Zone. It is possible to receive the 14-watt signal transmitted from Boulder at certain hours of the day at Maui, and this information promises to be of value in steering the standard oscillators at Maui. The signal-to-noise ratio does not permit detecting solar flare effects.

The NBA recordings at Maui, at a range of 10,000 km, reveal sudden phase anomalies, SPAs, associated with solar flares of low importance, provided an appreciable portion of the transmission is illuminated by the sun.

Observations were commenced at a distance of 100 km of the skywave received after one ionospheric reflection, from the (20 kc/s) WWVL transmission at Boulder. The measurements are made using the "abnormal" loop technique to reject the groundwave component and to respond to a component of the magnetic field reflected from the ionosphere. In this experiment, the diurnal phase shift is observed to be about 720° (or about 100μsec) which compares favorably with the results of similar observations made at the Cavendish Laboratory at 16 kc/s some years ago. The latter observations were made of transmissions from GBR which radiates a power of about 30 KW. The Boulder observations were made of transmissions from WWVL which radiates a power of 14 watts. The Boulder observations of the 14-watt signal were made possible through the use of phase-coherent detection.

Studies are being made of the types of phase perturbations, as seen at oblique and steep incidence, and their relationship to other geophysical events.

Improved equipment is planned for Maui to provide continuous records of phase and amplitude of the NBS signal, together with a second recorder of this type to receive GBR signals. Extension of steep-incidence observations are planned to provide information on the reflection coefficient of the lower ionosphere along paths of different magnetic orientation, and a study of the "blobiness" of the lower ionosphere through the use of two stations with variable spacing.

The following personnel worked on this project: A. G. Jean (project leader), C. J. Chilton, R. F. May, A. H. Diede, and A. C. Murphy.

## Micropulsations

82417

A magnetic field micropulsation program was recently initiated for the purpose of determining the origin and physical extent of the unique current systems associated with micropulsations. An immediate objective is to test for a possible correlation between the arrival of primary electrons in the atmosphere and the period of micropulsations. The Air Force Technical Applications Center is sponsoring this program.

The micropulsation study should help to clarify the role of rapid magnetic fluctuations in the behavior of the ionosphere and the outer atmosphere. This past year, sensitive field detectors have been developed for amplitude and direction-of-arrival measurements of micropulsations in the broad period range of several hundred seconds to a fraction of a second.

(This corresponds to a frequency spectrum extending between frequencies measured by the magnetometer and ELF equipment.) These magnetic pulsations occur at times when the earth is bombarded by high energy solar-terrestrial electrons which create large disturbances in the ionosphere. Micropulsation measurements are being made in Alaska, during June and July, cooperatively with Dr. R. R. Brown, of the University of California, who is conducting observations of x-radiation by balloons. The x-ray detectors provide a direct indication of the bremsstrahlung from the incoming electrons.

Micropulsation observations will be carried out at College, Alaska, and MacQuarie Island, New Zealand, located roughly at magnetic conjugate points, to assist in determining the role of the outer atmosphere in micropulsation behavior. Measurements are planned at high, middle, and equatorial latitudes to determine the position and dimensions of the ionospheric currents associated with micropulsations.

Personnel contributing to this work were: W. H. Campbell (project leader), D. F. Wasmundt, M. D. Littlefield, and A. F. Moser.

## Night-Sky Coruscations

82418

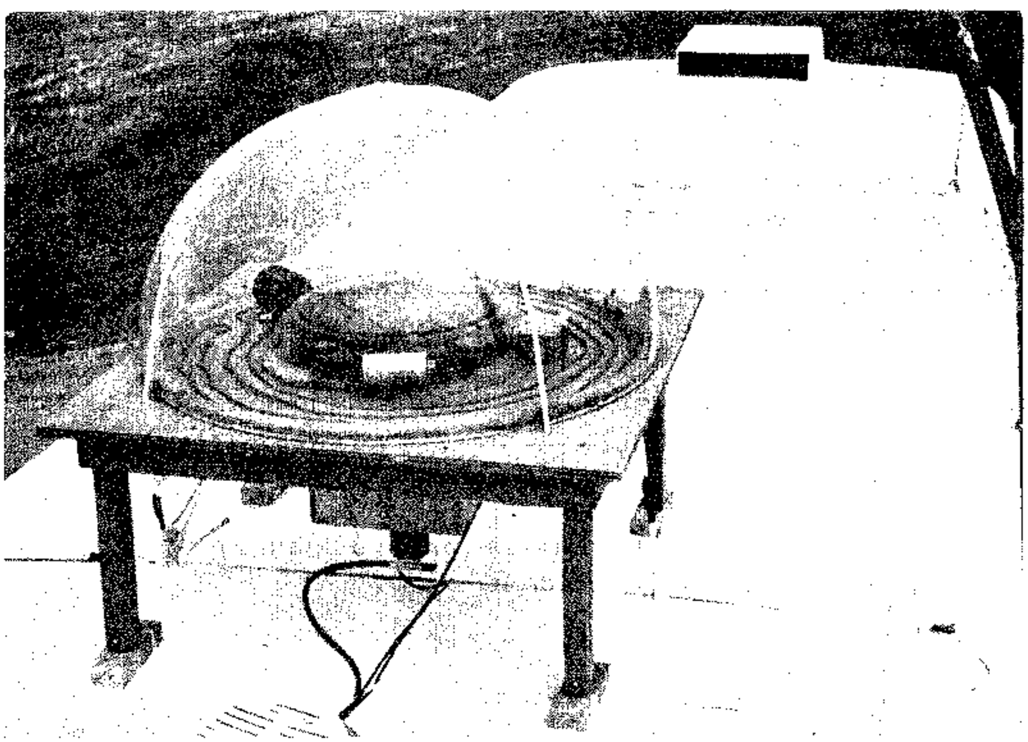
The objective of this project is to record the short-period fluctuations of the 5577 A and the 6300 A atomic oxygen emissions in the illumination of the mid-latitude night sky, and to determine the degree of correlation, if any, existing between these fluctuations , the occurrence of magnetic field micropulsations, and short-period variations of cosmic radio noise absorption. The Advanced Research Projects Agency is sponsor for this project.

Correlation of the above-named effects has been observed in the northern auroral zone during auroral displays, and the luminosity fluctuations have been associated with variations of electron density and changes in current systems in the atmosphere at ionospheric heights. It is of great interest to extend observations of such effects to lower latitudes, and possibly to relate them to disturbances in VLF radio transmissions.

A detecting unit (coruscatometer) has been designed, for mounting on an existing tracking radio telescope, which observes radio noise emissions from extra-terrestrial sources. The coruscatometer has approximately the same field of view as the radio telescope, and thus will observe directly correlations between scintillations in the radio noise signals and those in the oxygen emissions in the same discrete regions of the night sky. Arrangements have been made to coordinate the work with that of Dr. Franklin Roach of NBS and that of Dr. James Warwick of the University of Colorado, High Altitude Observatory.

Actual recording of coruscations will begin as soon as development and mounting of the equipment on the radio telescope are completed. These data will be analyzed for correlations with simultaneously observed radio noise scintillations and occurrence of micropulsations observed at the Lafayette site.

The following personnel worked on this project: W. H. Campbell (project leader).



Photometer system (coruscatometer) for measurements of short period fluctuations in auroral luminosity.

# IONOSPHERE RESEARCH SECTION

## Oblique Studies

### 82121

This project was set up to provide for the analysis of data collected during the CRPL sweep-frequency pulse experiment, and thus, to improve the present methods used in the computation of HF propagation conditions, and also to extend the theory of oblique propagation to include effects due to the earth's magnetic field. Most of the world's long distance communication is still carried out via HF ionospheric propagation. This project is aimed at improving the means of applying ionospheric data to radio communication problems.

During the past year, the data have been scrutinized for the effects of solar and magnetic disturbances on oblique propagation records. A paper on this aspect of the work was read at an AGARD Conference held at Naples, Italy, in May 1961.

A study is also proceeding of the relation between vertical and oblique propagation in the presence of the earth's magnetic field. Ray-tracing programs have been written for a binary computer, partly supported under this project, and partly under 82423. A ray-tracing program for vertical propagation has proven particularly useful in checking the accuracy of electron-density profiles which are used for oblique ray-tracing. It has also been used extensively for computations involved in the work on the topside sounder.

Future plans call for consolidation of this project with 82123 as it is felt that the main emphasis, in the next few years, will be on the experimental side.

Project personnel were: K. Davies (project leader), V. Agy, A. K. Saha, R. Schieber, and K. Kildahl.

## Africa Ionosphere Studies

82122

The objective of this project is to study high-frequency propagation conditions near the magnetic equator and between the United States and West Africa. In particular, F-scatter and flutter fading are to be studied. This project is part of a joint NBS-USIA investigation of radio propagation conditions between the USA and Africa and within Africa. In frequency prediction work it is necessary to know the dominant modes of propagation which, near the magnetic equator, may be F-scatter and sporadic-E. It is desirable to determine whether propagation conditions over Africa are similar to those over South America and in the Far East, which have already been studied.

Fixed frequency pulse studies were carried out over a two-month period, March and April 1961, over the 8000 km path between Sterling, Virginia, and Accra, Ghana, which is an important circuit for communications between the United States and West Africa. In addition, signals from WWV20 were also recorded. Over a similar period c. w. signals on frequencies of 20 and 50 Mc/s, from the NBS transmitters at Wheelus Air Base, Libya, were recorded in Accra (3300 km path). These data are now in process of analysis.

The experimental work was shut down at the end of April 1961. However, it is planned to reopen the observing program for about a six-week period around September 1961. After this, the equipment will be returned to Boulder.

The cooperation of the 1950th AACS Squadron, USAF, and the staff of the Department of Physics of the University College of Ghana has been invaluable.

The following personnel contributed to this project: K. Davies (project leader), V. Agy, D. Brooks, J. DeGregorio, R. M. Fisher, K. Kildahl, H. Petrie, K. Wood, and G. Weber.

## Oblique Experiment

82123

The purpose of this project is to carry out oblique propagation studies with a view to applying the data to the improvement of prediction methods. The gathering of propagation data, using the sweep-frequency pulse technique, is particularly valuable in the solution of long-distance radio communication problems. Up to the present time, the sweep-frequency technique has been used in the United States over intermediate distances, and its extension to longer distances is desirable.

A step frequency gear was purchased during the year which is compatible with similar equipment employed by other agencies. Some preliminary observations have been made at Boulder of signals from Resolute Bay and Ottawa, Canada, and from the SHAPE laboratory in The Hague. These measurements were interrupted to send the equipment to Tripoli, Libya, and Accra, Ghana, and so, for most of the year, the work on this project has been combined with Projects 82122 and 82125.

After the completion of the present program in Africa, the equipment will be returned to Boulder and the recordings of Resolute Bay, Ottawa and The Hague will recommence. In future years this project will be consolidated with Project 82121.

Project personnel were: K. Davies (project leader), D. Brooks, R. M. Fisher, K. Kildahl, and G. Weber.

## Sporadic-E Studies

82125

The aim of this project is to investigate the sporadic-E mode of propagation at both vertical and oblique incidence with a view to understanding the sporadic-E ionization as a physical entity as well as its effect on radio communications. Sporadic-E propagation has been quite extensively studied with regard to its temporal and geographic variations; yet little is known about the propagation medium itself, or how it is formed and then maintained for hours at a time. With the increased use of the radio spectrum and the diminution of the spectrum due to decreasing sunspot activity, the relative importance of sporadic-E is increasing.

A multiple-station experiment, designed to investigate the motion of sporadic-E ionization in terms of its velocity and direction, was the primary experimental work performed during the past fiscal year. The signal intensity of transmissions at 50 Mc/s from Long Branch, Illinois, was recorded at Boulder, Colorado, about 140 km east of Boulder, and approximately the same distance south of Boulder. The midpoints of these three paths formed a right triangle, having its vertex at the Shickley, Nebraska, ionosonde site, and legs of 70 km each. Longer legs were added to the triangle by recording 30 Mc/s transmissions from Long Branch and Norman, Oklahoma, at the Shickley site. The equivalent vertical-incidence frequency, according to the secant law, was nominally 10 Mc/s for all circuits. The gross features of the sporadic-E enhancements recorded over all paths were examined for any displacements in time, and this information was used to calculate the velocity and direction of the motion.

The analysis of the sporadic-E data obtained during the IGY over the Long Branch to Boulder path has been completed. It indicates that the correspondence between the intensity of the Es propagated signal and foEs observed at the path midpoint is dependent on the type of Es and the beamwidth of the antennas used on the oblique circuit.

Work on the sporadic-E monograph has continued throughout the year. Most contributions have been received and edited.

Future plans include study of the equatorial sporadic-E belt by means of a network of vertical-incidence sounders located in Africa. Of particular interest is the geographic extent of this region in latitude which has not been fully resolved. Analysis will be continued of the sporadic-E data contained in the vast amount of ionospheric records taken during recent years.

Personnel who contributed to the project are: J. W. Finney (project leader), E. K. Smith, and Hope Leighton.

## CCIR Studies

82127

The purpose of the project is to take up the study of various subjects of interest to the CCIR. Study Group VI of CCIR (Ionospheric Propagation) requires information on many topics in the field of interest to the Ionosphere Research and Propagation Division. An attempt is made to gather that information and to work on specific items which will serve to satisfy this need.

Early in the year, NBS Technical Note 2-2, "Supplementary World Maps of F2 Critical Frequencies and Maximum Usable Frequency Factors," by D. H. Zacharisen, was published which, with Technical Note 2, provides F2-layer prediction charts for all twelve months of the year.

Material was submitted for inclusion in a U. S. contribution to a CCIR report on oblique-incidence tests.

Time was spent in the further analysis of blackout data with the aim of preparing a "final" report on the subject for the purpose of assessing the need and direction of future related work. It is found that there is little detailed agreement between propagation loss over paths between Bismarck, N. D., and Alaska, and the presumed occurrence of (vertical-incidence) blackout at points along the path.

The project has given partial support to continuation of the study of frequency variations of WWV transmissions observed at Boulder. Interesting variations at the times of solar flares and sudden commencements have been seen which indicate that F-layer effects occur.

An attempt will be made to exploit the technique used in the WWV frequency variations study for investigation of the fading of ionospherically propagated signals. The results of other studies -- primarily, those dealing with the tropical ionosphere -- will be applied to CCIR problems. In particular, study of frequency variations of various highly stable transmissions will be made at Accra, Ghana.

Personnel who worked on this project were: Vaughn Agy (project leader), Donald H. Zacharisen, Gerald G. Weber, and Katherine Wood.

## Ray Tracing

82423

The objective of this program is to utilize a high speed computer for the determination of the paths of energy flow through the ionosphere in the presence of the earth's magnetic field and of large scale inhomogeneities. Data on the world wide distribution of electron density have shown that large clouds of high electron density exist in the equatorial regions which distort the ray paths. In such an ionosphere, the angles of take-off and arrival may differ substantially, and so these angles are determined by the computer. The project is sponsored by the U. S. Information Agency.

A program of ray tracing for vertical propagation in the presence of the earth's magnetic field has proven to be of considerable value to the work of other sections. For instance, it has been used to check the accuracy of electron-density profiles and for studies involving the "topside" sounder.

Ray paths for vertical propagation at Boulder have been made at a number of frequencies. On frequencies just below the gyrofrequency, the point of reflection of the extraordinary ray may be far to the north whereas, on frequencies well removed from the gyrofrequency, the reflection point is to the south of the transmitter.

A program has been written for the computer in which are given the geographical coordinates of the transmitter and receiver together with the electron-density profiles at arbitrary points along the path. For an initial angle of elevation at the transmitter, rays are traced through the ionosphere in the presence of the dipole magnetic field. The following quantities are computed: Real path, lateral deviation, time of flight of a pulse, phase path, and angles of take-off and arrival.

The encoding of the program for the computer will be completed, and computations for specific ionosphere profiles will be carried out.

The project personnel were: K. Davies (project leader), J. W. Finney, A. K. Saha, C. E. Hoff, D. McKinnis, V. Rios, and R. Schieber.

## Ionosphere Studies

82424

This project, sponsored by the U. S. Information Agency, is concerned with the study of applied propagation problems of particular interest to the operations of the Voice of America. In order to fulfill its mission, the Voice of America has a need for propagation information which will allow for the efficient use of the ionosphere for communication and broadcasting. Tropical conditions are especially important and knowledge of these conditions during sunspot low will be useful.

A beginning was made on a comparison of F2 and Es MUF's, based on the D-series predictions of these parameters. Although it appears that, during daylight hours for paths in African equatorial regions (for sunspot low), sporadic-E will provide the higher MUF; the work should be carried out in greater detail, using observed values from 1954 to 1958, rather than predicted values for this period.

The project gave partial support to the Doppler frequency variations of WWV as recorded at Boulder (see Project 82127).

Further work on ionospheric propagation conditions during sunspot low (especially in tropics) will be carried out. Contributions to the general problem should be forthcoming from analysis of data from the African Ionosphere study (Project 82425).

Personnel who contributed to this project were: Vaughn Agy (project leader), Kenneth Davies, Donald H. Zacharisen, Hope I. Leighton, and Gerald G. Weber.

## Africa Ionosphere Studies

82425

This project, under U. S. Information Agency sponsorship, shared in the funding of the research reported in detail in Project 82122.

## Blackout Studies

82426

This project was set up by the U. S. Information Agency for the purpose of extending our knowledge of blackout phenomena. In particular, analysis of vertical-incidence data was to be carried out to examine statistical occurrences of blackout as well as the sequence of events during specific periods.

The greatest single problem confronting the user of high frequency communications in the Arctic is the effect of the frequent occurrence of polar blackout. Recent observations have indicated that at least two "types" of high absorption events must be considered: those of relatively long duration which occur in the polar regions primarily, and the shorter period, more localized blackouts characteristic of the auroral zone. It appears that further classification may be possible and should be made to get the most meaning from the statistical studies. The relationships between the various types should be delineated, in order first, to understand the phenomena, and second, to predict and circumvent their effects on ionospheric communications.

Statistical studies to date have turned up nothing new. General confirmation of the results of earlier work has been obtained, and the conclusion has been reached that we cannot as yet define a variation in the statistical occurrence of blackout with sunspot number.

The film, "Polar Blackouts during the International Geophysical Year," finished and first shown just before the beginning of Fiscal Year 1961, has since been shown at the IRE Convention in New York (March 1961). Copies have been purchased by the University of Paris (France), Radio Research Station (Slough, England), the Defence Research Telecommunications Establishment (Ottawa, Canada), the AVCO Corporation, the Naval Research Laboratory, the Laboratory of Applied Science (University of Chicago), and the Rand Corporation.

"Spiral Patterns in Geophysics" by V. Agy was published in J. Atmos. and Terrest. Phys. 19, 136 (1960).

The report on work to date will be completed, and a study made of the feasibility of making a synoptic study by the use of riometer data. The film and a survey paper on blackout will be presented at the Conference on the Earth Storm, Kyoto University, in September. Further work on the definition of the existence and effect of the "auroral absorption zone" is planned.

Project personnel were: Vaughn Agy (project leader), Kenneth Davies, Katherine Wood, and Gerald G. Weber.

## Ray Path Calculations

82428

This project, under Air Force Cambridge Research Center sponsorship, supports research similar to that reported in detail in Project 82423 but for different ray paths.

Blackout pattern over the northern hemisphere at 8:30 a.m., GMT, October 21, 1957, deduced from data supplied by 48 stations. The grey portion of the polar projection map indicates the demarcation between sunlight and darkness.

# PREDICTIONS SERVICES SECTION

## Data Analysis

82131

Statistical analysis of ionospheric data is necessary to prepare the data for use in other projects, with emphasis on current analysis of data for immediate use in predictions studies. An additional objective is the preparation of data for dissemination to other Government agencies, scientists, laboratories, as well as official agencies in other countries who collaborate in the exchange of data.

In order to prepare predictions of the best sky-wave operating frequencies for communication paths all over the world, it is necessary to collect and analyze ionospheric data from stations having a world-wide geographical distribution. Since it is impossible to do this without cooperation from scientists and scientific organizations in foreign countries, it is necessary to have a system for the dissemination of ionospheric data from the United States and its possessions, in order that NBS may receive foreign data in exchange for United States data. The Central Radio Propagation Laboratory is the designated official U. S. agency for the reception, coordination, and exchange of ionospheric data, and for liaison with corresponding agencies in other countries. Thus, data are received, analyzed, and the results disseminated to other Government agencies, scientists and laboratories in this country, and abroad to those organizations which collaborate with CRPL in the exchange of data with mutual benefit. In addition to their role in predictions of maximum usable frequency, these data are used in research studies carried on to further knowledge of the upper atmosphere and of solar-terrestrial relationships. A large part of the task of dissemination, both within and without the U. S., is accomplished through the monthly publication of the CRPL-F Series, Part A, "Ionospheric Data," and Part B, "Solar-Geophysical Data."

The statistical analysis of ionospheric data and their publication, together with their dissemination, were continued during the past year. Twelve monthly issues of the CRPL-F Series, Part A, "Ionospheric Data," were prepared, Nos. 191-202, July 1960 through June 1961. Corresponding issues of the CRPL-F Series, Part B, "Solar-Geophysical Data," were published. The distribution at the end of the year of this publication, which is in general available only on an exchange basis, was: Part A - 420 copies;

Part B - 505 copies per issue. Provision is made, through the IGY World Data Center A for Ionospheric Physics and Airglow, to make the type of data in these publications available on a cost-of-duplication basis to those not entitled to the F-Series on an exchange basis.

All expected data from ionosphere sounding stations sponsored by the United States during International Geophysical Cooperation Year - 1959 have now been received; the last, for Byrd Base, Nov. and Dec. 1959, arriving in June 1961. During the year, 152 station-months of data from this group of stations were processed by the computing laboratory. Funds for this purpose were split among four different projects, the bulk of the money coming from outside the Section. A backlog of 103 station months of data, for which funds were not available for processing, has been built up. Although direct support ceased from the National Science Foundation, most of the money used came from World Data Center A for Airglow and Ionosphere.

During the year ionospheric data were received from two new French stations, Garchy and Paris-Saclay. It is estimated that there is sufficient backlog of data on hand (both U. S.-sponsored and foreign) to permit publication of at least 15 supplementary issues of the CRPL-F Series, "Ionospheric Data."

The following programs will be continued in Fiscal Year 1962: (1) Analysis of ionospheric data and preparation of graphs for immediate use in making basic radio propagation predictions. (2) Publication of data in CRPL-F Series, "Ionospheric Data." (3) Analysis of ionospheric data and preparation in forms suitable for use by research groups. (4) Reception and dissemination by teletype, telegram, and airmail of daily, weekly, and monthly reports of provisional radio propagation data. (5) Maintenance of ionospheric data files. As far as available funds will allow, current vertical incidence data will be processed for as many as possible of the 24 U. S. and U. S.-sponsored ionosphere sounding stations expected to obtain data during FY 1962. (6) As funds permit, additional supplementary issues of the CRPL-F Series, "Ionospheric Data," will be prepared and published, thus reducing the large backlog of material which has accumulated since the International Geophysical Year.

Personnel contributing to work on this project were: L. Gillespie (project leader), S. G. Jones, L. Williams, M. E. Chamberlin, M. Whetstine, E. Renlund, E. G. Neill, L. L. Sherman, M. E. O'Neill, and B. Snyder.

## Basic Radio Propagation Prediction Services

82132

The objective of this project is the compilation, on a monthly basis, of predictions of maximum usable frequencies for radio-sky-wave transmission, so that the user of the predictions service may calculate best sky-wave operating frequencies over any path, at any time of day, for average conditions for the month of prediction. An additional objective is the development of methods for improving the accuracy of the predictions, of simplifying and increasing their usefulness; and the application of operational information, ionospheric data and theory to the preparation of practical predictions.

The selection of the best sky-wave frequencies for communication purposes over a given transmission path depends upon the time of day, season of the year, phase of the sunspot cycle, length of the path, and location of the path, as well as the conditions prevailing in the ionosphere over the path. This predictions work is a direct continuation of the effort made during the war to provide the Armed Services with the latest available radio propagation information in usable form. These predictions are widely used in planning frequency assignments and utilization in short wave radio communication by many organizations, including the Armed Services and other U. S. Government agencies, numerous scientific and commercial organizations, and foreign governments. As the predictions become more accurate, more and more efficient use can be made of the radio spectrum, where the needs of services exceed the available frequencies. The predictions are important for efficient frequency allocation, efficient use of allocated frequencies, and in the preparation of specifications for communications equipment.

During the past year, prediction charts were prepared as usual for the CRPL-D Series, "Basic Radio Propagation Predictions." Twelve monthly issues were prepared, Nos. 191-202, July 1960 through June 1961. Twenty-four issues appeared of the CRPL-Ja Series, "Semimonthly Frequency Revision Factors for CRPL Basic Radio Propagation Prediction Reports," between July 1960 and June 1961; Nos. 369-392. At the end of the year, 912 copies of the D Series were being furnished each month to the Department of Defense, while about 1700 were printed each month for civilian use. The distribution of the Ja Series, at the end of the year, was 270 copies per issue.

Over the past year solar activity as measured by sunspot number, continued to decline. The provisional smoothed 12-month running average Zurich sunspot number for July 1960 was 108, and the provisional number centered on December 1, 1960 is 83. There was a sudden drop in sunspot number in the autumn of 1960. The average of the eight monthly Zurich numbers from Oct. 1960 through May 1961 was 65, whereas the average for the eight previous months was 118. This unexpected result led to predictions that, for the year as a whole, have been somewhat on the high side, especially for the last quarter of fiscal 1961.

In an attempt to assess the importance to predictions of such sudden changes in level, the Section Chief developed equations relating critical frequency at Washington to solar activity. It is expected that the resulting paper, entitled "A Quick Method for Estimating the Stage of the Mean Sunspot Cycle," will be published shortly.

Among the more important and interesting of the special analyses performed during the year are the following: Contacts with various representatives of the Navy, or holders of Navy contracts, at NRL, Bureau of Ships, CNO, University of Chicago, University of Michigan, involved discussion of sunspot cycle variations, usable frequencies at sunspot minimum, time of next minimum, sporadic-E variations, availability of data, antenna design requirements for varying modes of propagation.

Close telephone contact was maintained with RCA Tucson for several months. They were given information concerning propagation for November 1949, and were furnished copies of predictions for November 1960 and March 1961 several weeks in advance of the regular publication date. Various sets of predicted sunspot numbers, for January through May 1961, were also reported by telephone. Information concerning the effect of sporadic-E over North Atlantic paths, during the summer of 1960, was given to RCA Communications. An analysis of possible reasons for lack of radio communication between Cape Canaveral and Grand Bahama Island on the morning of Monday, May 1, 1961 (the week of CDR Shephard's flight) was telephoned to RCA Palm Beach.

Help was given to a communications engineer for the FAA in Honolulu with regard to the use of predictions of regular E and sporadic E for Pacific paths, and the possible modes of F2-layer propagation.

High-frequency communication problems were discussed with personnel of the U. S. Geological Survey, Denver, in connection with a seismic survey of crust thickness in the western United States. Four frequencies between 2 and 8 Mc/s, for use from 0-300 miles, to cover the entire sunspot cycle, were suggested.

Information and literature were supplied to a communications engineer of the Dept. of the Interior in Washington to help him with the problem of avoiding F2 transmitted interference to land-mobile services in the 30-42 Mc/s band.

A paper by W. B. Chadwick, "Improvements in Radio Propagation Prediction Service," appeared in the September 1960 issue of Electrical Engineering. He prepared a chapter of a monograph on sporadic-E, entitled "Variations in Frequency of Occurrence of Sporadic-E, 1949 - 1959," to be published by Pergamon Press. He presented a paper on the same general subject at the AGU meeting in Washington, April 1961.

This project will continue to: (1) Prepare contour charts for inclusion in the CRPL-D Series, "Basic Radio Propagation Predictions," (monthly) and analyze results. (2) Prepare "Semimonthly Frequency Revision Factors for CRPL Basic Radio Propagation Predictions Reports," and analyze results. (3) Scale ionospheric records (special analyses as needed). (4) Prepare predictions for special problems as required. (5) Study statistical variations of ionospheric characteristics. (6) Study possibility of applying machine methods to the preparation and application of the predictions. In this connection it is planned to compile parallel predictions (by hand and by machine) with a view to using machine methods entirely, beginning sometime in FY 1962. The present estimate is that this will be accomplished by January 1, 1962. (7) Study relationship between critical frequency and various indices of solar activity.

Personnel contributing to work on this project were: M. PoKempner (project leader), S. M. Ostrow, E. D. Powell, F. L. Downes, N. H. Farley, A. Oldfather, G. Waggoner, and J. C. Harman.

# SUN-EARTH RELATIONSHIPS SECTION

## Solar Influences

82141

The purpose of this project is to gain fuller understanding of the sun and its influence on the earth by the study of the emission and propagation of solar wave and particle radiation. Prediction of periods of enhanced solar emission forms the basis for advanced warning of disturbance of radio communications. Increased emission at short wave-lengths at the time of some solar flares is responsible for sudden short-wave fadeouts; while low-energy solar particle emission causes geomagnetic and ionospheric storms that disturb communications for longer periods. An understanding of solar emission of energetic particles is of particular interest in connection with direct measurement of these particles by means of rockets or balloons, and also for the avoidance of such solar radiation events by a manned space vehicle.

A study of ionospheric effects of solar flares clarified some of the relations between short-wave fadeouts and flares, and among various manifestations of the sudden disturbance in the ionosphere. A report of this study has been submitted as a letter to the editor of the Journal of Geophysical Research.

Close cooperation with the warning services continues, and is exemplified by participation in weekly forecasts of disturbance, evaluation of forecast success, and suggestions for improved forecasting methods.

Contracts with High Altitude Observatory, funds for which are partially provided from this project, support the routine observation and reporting from HAO's Climax station of intensities of coronal emission lines and the occurrence of solar flares. These contracts have also provided for the development of a 15-inch coronagraph-spectrograph, improvement of the main coronagraph dome, renovation of a smaller coronagraph, and improvement of a 75-mm, fast time-resolution flare patrol instrument. These funds also partially support the work and travel of Dr. Chapman, and of Richard Hansen's work in the IGY solar data center.

A study of the relation of various types of solar activity to solar emission of particles in the 10 to 100 Mev energy range showed which type of solar flare event is most likely to be associated with particle emission, and also led to a model of the interplanetary field. Characteristics of the propagation from sun to earth of these, and other solar particles, show that the field must be comparatively intense and irregular at times of high solar activity. Near minimum of the solar cycle, the interplanetary field may be identified with the galactic arm field, with intensity less than $10^{-6}$ gauss, and with its main component normal to the ecliptic plane. Emission of low-energy solar particles leads to compression of this weak, regular field, and formation of regions where the magnetic field strength is $10^{-5}$ or $10^{-4}$ gauss. Regions of enhanced magnetic field such as these, moving outward from the sun, impart a small systematic velocity to the distribution of cosmic-ray particles. This velocity, and the resulting decrease in density in the vicinity of the sun, provide an explanation of the eleven-year variation, the Forbush decrease, and the diurnal variation which is in rough quantitative agreement with observed measures of these three main effects of the solar modulation of cosmic rays. Reports of this study have been submitted to the Journal of Geophysical Research.

Work continues on a program designed to combine and correct solar flare reports from various observatories. Grouping of reports of the same flare has been successfully programmed for the computer.

Completion of the flare project involves determination and elimination from flare area and importance, values of systematic errors dependent on solar and terrestrial longitude. Importance, or area, of the H-alpha flare is the basic solar index in the majority of studies of solar-terrestrial relations, and of relations between different solar events. Availability of these values, freed from systematic errors, will permit studies of the significance of flare position to terrestrial effects, and of the directivity of associated short-wave, radio and particle emission. A general statistical study of solar activity and geomagnetic disturbance during IGY is planned, and preliminary studies have already been completed. The problem of the relation of recurrent geomagnetic disturbance to solar activity remains unsolved, and should be attacked. More precise calculations should be carried out of the effect of solar magnetic clouds on the flux of cosmic radiation.

Personnel who contributed to this project were: C. S. Warwick (project leader), M. B. Haurwitz, and L. W. Acton.

## Ionogram Scaling Specialists

82143

This project provides a group of ionospheric soundings experts for specialized ionogram reductions and analysis; supervises training of station personnel in the reduction of ionograms; makes partial or complete reductions of ionograms when the data have not been reduced at the field stations; provides consultative service to individuals and organizations interested in particular aspects of ionospheric data; and performs research on ionospheric problems.

A group within or outside of the Bureau may not have personnel qualified to make systematic reductions of ionograms, yet such information may be necessary to the completion of other work performed by the group. The availability of such assistance from competent persons within the Bureau will materially improve the work of such groups.

Personnel assigned to vertical sounding field stations must have a thorough understanding of the techniques of ionogram reduction. Data obtained from such field stations are used in the radio propagation services predictions and in basic research, and it is essential that the quality of the station data be high.

Research studies carried on within the project lead directly to NBS reports or published research notes. Therefore, great care must be taken to insure the maximum accuracy and reliability of the research.

During this past fiscal year, 5 scaling requests were completed. Since the start of the project in June 1958, a total of 45 scaling requests have been completed.

Seven months of ionograms from Byrd Base were completely reduced, including the preparation of daily f-plots.

During the past year, 9 trainees were given instruction in the reduction of ionograms; of these, 2 were associated with the training program at the ionosphere school at and near Fort Monmouth, New Jersey, under the auspices of the U. S. Army Signal Radio Propagation Agency. Seven persons were personnel attached to NBS field stations, with four of these assigned to Antarctic vertical-incidence ionosphere stations.

Seven persons visited the project during the year for consultations with the project leader.

Research started on the screening height of the F-region of the ionosphere has progressed satisfactorily. Results obtained thus far suggest a definite seasonal variation in the screening height. Typical winter values are about 290 km, and typical summer values, 350 km. In this research, much use has been made of the true-height data produced under Project 82145.

A paper, "A Note on the Heights of the Different IGY Types of Es," was completed. This paper will form part of the monograph on sporadic-E, edited by Dr. E. K. Smith and Dr. Sadami Matsushita.

Training of field station personnel in the reduction of ionograms will continue. The project will continue to be at the service of groups or individuals inside or outside of NBS as the opportunity presents itself. Work will continue on the study of the screening height of the F region of the ionosphere. Additional stations will be included in the study, and an attempt will be made to determine where the seasonal reversal with hemisphere occurs, as well as whether any dependence upon latitude or longitude is present.

This work was carried out by S. C. Gladden (project leader).

## Ionospheric Responses

82144

The purpose of this project is to study the physics of the F region and the nighttime E region, and the neutral atmosphere in the same regions. These studies have the importance of any research directed towards understanding a phenomenon of nature. Moreover, this project stimulates the data gathering and processing facilities of CRPL by using their data.

Studies during the past year can be divided into three categories:

1. Contributions to a New Model of the F Layer. Two eclipses during 1952, a year of low solar activity, have yielded rates of photoionization and recombination considerably smaller than during high solar activity in 1958, but still considerably larger than the rates of Ratcliffe, *et al.*

The success of our analyses of equatorial eclipses without transport of any kind has led us to apply the same "photochemical" model to the daytime equatorial F layer in the absence of eclipses. It was apparent during the previous fiscal year that such a model would have considerable success, provided the atmospheric temperature increased in a certain way during the day. However, the complexity of the model has forced us to program it for the electronic computer. The results are expected to explain much of the behavior of the daytime equatorial F layer, the daytime E layer at all latitudes, and to provide a basis for comparison with the nighttime equatorial F layer.

The logical counterpart in middle latitudes of this "photochemical model" at the equator is a photochemical model plus plasma diffusion. We have shown that, indeed, the daytime F layer in middle latitudes is described by a steady-state continuity equation involving only photoionization, recombination, and diffusion. The parallel success of the photochemical model at the equator, and the "diffusion model" in middle latitudes, strengthens credence in both models. Comparison of the diffusion model with F layer data leads to determinations of the atmospheric scale height, and the variations of the number densities of atomic oxygen and molecular nitrogen.

These ionospheric model studies are complemented by a study of the course of the ionizing radiation, undertaken by J. S. Denison for her master's thesis in the Physics Department of the University of Colorado. This work, which is not yet complete, has lead to the following identification of the ionospheric layers with solar radiations: the Ly $\beta$ ionizes the E1 layer, the CIII line at 977Å ionizes the E2 layer, and the Ly continuum ionizes the F1 layer. Further work will aid in understanding the formation of the ionized layers, and in determining precisely the absorption cross, sections and model atmospheres which must be used in the calculations.

2. The Heat Balance of the Thermosphere. Early results of this research have been published by D. C. Hunt and T. E. Van Zandt. They show that the structure of the F region of the thermosphere can be accounted for by a heat flux from photoionization of about 1 erg/cm$^2$sec.

The analysis is being generalized to investigate the effect of varying the atmospheric compositions, the solar spectrum, and the solar zenith angle.

3. Low Frequency Ionogram Research and Magnetic Station. Research on the nighttime E layer has continued. A paper was presented at the spring meeting of URSI, and a written paper is in preparation. It has been shown that the E layer decays slowly during the night, and that its density is lower during sunspot minimum.

A magnetograph was installed at the Boulder Laboratories and began regular operation during the third quarter of calendar 1960.

All of the lines of research described in 1. and 2. will be continued and amplified. It is expected that the photochemical and diffusion model studies probably will be completed during 1962. It is obvious that many anomalies will still remain to be explained. This will involve the investigation of transport processes. Likewise, the study of the course of radiation and of the heat balance will be carried as far as possible during the year. Further progress will then depend on better data on atomic cross sections and model atmospheres. Such data appears to be forthcoming soon.

These studies were carried out by: T. E. Van Zandt (project leader), D. C. Hunt, W. S. Hough, R. B. Norton, R. Murphy, G. H. Stonehocker, G. Goe, J. Denison, J. DeLine, and S. A. Wingfield.

## Synoptic Studies

82147

The purpose of this project is to investigate those features of ionospheric behavior that benefit from synoptic study, making use of the very considerable amount of ionospheric data available from the world-wide soundings network.

The immediate objectives of this project pertain to the improvement of our understanding of the physics of the ionosphere. Unless ionospheric behavior is well understood, we cannot hope to be able to use it to full advantage for practical communications purposes. For example, phenomena such as sporadic-E and spread-F have a very real and direct effect on the propagation of radio waves, especially in the equatorial, auroral and polar regions.

During the past fiscal year, three research studies have been carried on under this project. The results of these studies are summarized below:

1. Width of the equatorial Es belt. This analysis involved the study of the occurrence of equatorial type sporadic-E (Es-q) at seven closely-spaced sounding stations in Peru and Bolivia. The results, submitted for publication in the Sporadic-E Monograph, suggest that Es-q tends to occur in a belt centered on the dip equator, having a width of about 600-700 km. Independent studies of the equatorial current system (the electro-jet), using geomagnetic data, indicate that the current flows in a belt of about the same width.

2. Equatorial spread-F. The geographical and temporal variations in spread-F occurrence over four closely-spaced low latitude stations in Peru were studied. In addition to delineation of the nocturnal, seasonal, magnetic activity, and solar cycle variations in spread-F occurrence, an important drift phenomenon was discovered. The patches of ionization irregularities responsible for producing the spread-F or, alternatively, the mechanism producing the irregularities, was found to have a strong tendency for movement, toward the east, at velocities of the order of 150 m/s. Between about 2200 and 0600 local time, particularly during the June solstice and September equinox seasons, this drift phenomenon was the dominant factor in the occurrence of spread-F at the stations studied. The early results of this work were published in Nature 187, 927 (1960); a more complete paper is now in the final stages of preparation.

3. Solar flare effects in the F region. By-and-large, solar flare effects are restricted to the D and E region of the ionosphere. On rare occasions pronounced effects are observed in the F region. Of the six large flares since 1949 that were accompanied by sea level increases, four have also shown F region effects. The F region effect during the two most recent cosmic ray flares (November 12 and November 15, 1960) was found to be equivalent to a lowering of the 6 Mc/s vertical incidence reflection height by about 15 km. The selective nature of the F region effects is also being investigated. Preliminary results suggest that the pre-flare height of the F layer is the principal factor in determining whether or not a significant effect will occur. The initial findings of this study were published in Nature 190, 797 (1961).

Early in the next fiscal year, a more complete paper on the solar flare effects study will be published. On completion of this work, attention will be directed to the area of Universal Time correlations in F-region phenomena. An unresolved question, for example, involves the extent to which short-term variations in solar output effect the sunlit F-region. Also, the possibility of correlated F-region effects at magnetically conjugate locations will be investigated.

These studies were carried out by: R. W. Knecht (project leader), R. E. McDuffie, and S. Matsushita.

## Ionospheric Topside Sounder

82444

The objective of this project is to investigate the topside of the ionosphere from above by means of rocket and satellite-borne radio pulse sounders (ionosondes). The project is sponsored by the National Aeronautics and Space Administration.

That portion of the ionosphere above the level of maximum electron density has been designated the "topside". Because it is inaccessible to the usual method of ionospheric sounding, it has been observed only sporadically by rockets, satellites, moon echoes, and scatter radar. Enough is known about the topside to say that it contains the great majority of electrons in the ionosphere, and that it acts as a reservoir of electrons; the ionized gas diffuses up into it during the day and down out of it at night. As yet little is known about its detailed shape or variations. The topside sounder is intended to fill this gap in our knowledge by putting a simplified ionospheric sounder in a satellite above the topside.

The highlight of the year's activities occurred at Wallops Island, Virginia, on June 24, 1961, when a two-frequency version of the proposed satellite sounder was carried to an altitude of over 1000 km in a rocket test of the system. On the 6 Mc/s sounding frequency, topside echoes were obtained for 13 of the 14 minutes that the sounder was above the maximum of the ionosphere. On the 4 Mc/s frequency, at least 7 minutes of echoes were obtained. The results clearly confirmed the feasibility of obtaining soundings from the topside with a relatively low power system (3 to 5 watts of peak pulse power). Preliminary analysis of the data suggest an electron-ion scale height between 400-600 km of about 100 km;

indicating a temperature of only about 800°K, assuming an $O^+$ atmosphere. Also, there were effects present on the 4 Mc/s frequency that could be explained by ionization irregularities at about the 800 km level. A second rocket firing to evaluate the operation of the system during disturbed nighttime conditions is set for August.

Planning for the satellite phase of the program continued during the last year with final selection of the sounding frequencies to be used and designation of the ground telemetry stations to be employed. By means of a near-polar orbit, primary emphasis will be placed on obtaining meridional cross sections through the ionosphere along the 70° - 80°W meridian. Telemetry stations will be so located as to assure continuous coverage from the southern tip of South America to the north geographic pole on at least four satellite passes per day. Present schedules call for the launching of the satellite (S-48) during the second or third quarter of calendar year 1962.

The equipment design and fabrication aspects of the program are being handled by the Airborne Instruments Laboratory under a separate contract with the National Aeronautics and Space Administration.

Final analysis and publication of the results obtained from the rocket tests will take place in early FY 1962. As the time for the satellite launching approaches, technical liaison visits will be made to both the bottomside sounding stations and the telemetry stations in the primary observing area. Also, final satellite data acquisition schedules will be formulated and the necessary command instructions provided to the telemetry stations. Techniques for reducing the satellite topside sounding data to electron density profiles will be developed and tested.

Also, during the coming fiscal year, plans for extensions to the present satellite program will necessarily have to become firm. In addition to investigating still higher portions of the terrestrial ionosphere and protonosphere, the possibility of using the topside soundings technique for studying the ionospheres of other planets from great distances (about 10,000 km), is being considered.

The personnel who worked on this project were: R. W. Knecht (project leader), T. E. Van Zandt, R. G. Green, J. Watts, A. H. Shapley, J. W. Wright, G. Goe, and L. Banks.

# FIELD ENGINEERING SECTION

## Ionospheric Field Station Technical Control and Development

82154

The objectives of this project are essentially unchanged from last year. These objectives are to assist and equip the vertical incidence sounding stations in order that they obtain the best possible data, to provide equipment modifications and improvements to meet new data requirements, and to operate the Boulder sounding station.

This project provides the essential liaison between the data user and field stations on matters concerning the equipment operation and performance. This project strives to standardize the operating procedures of all the NBS-sponsored and affiliated stations which is quite necessary when comparing data from stations located in many different parts of the world.

An evaluation of the present NBS-type vertical incidence sounders, types C-2, C-3 and C-4, was made to determine where their performance falls short in data recording ability. This evaluation involved primarily the Sun-Earth Relationships Section, which is most active in regular and special application of the vertical incidence data. This evaluation took form in performance specifications prepared for the possible purchase of a new ionosonde which has been named Model 5 Ionospheric Recorder.

With the Model 5 specifications as a goal, considerable effort has been given the up-dating of the Type C sounders to these standards. One of the larger projects, as a result of this, has been the extension of the low frequency end of the frequency sweep. With solar activity declining, more of the important vertical incidence information appears below the 1 Mc/s lower limit of the conventional ionosonde. A frequency of 0.25 Mc/s was selected as being a practical and useful lower limit.

To determine if it would be possible to obtain adequate performance down to 0.25 Mc/s with the Type C sounders, a C-3 unit was set up to transmit and receive at the lowest desired frequency. With minor circuit changes, the transmitter and receiver were made to perform from 0.25 to 20 Mc/s, as well as at the original 1 to 25 Mc/s range. An operational test of the low frequency performance was completed using the Sunset LF antenna. Even though the characteristics of this antenna were not well suited to the C-3, these tests provide sufficient encouragement to warrant further work toward a complete low frequency modification. Since these tests, most of the major electrical and mechanical changes have been completed and tested to the point where there now exists a field operational LF sounder. By the fall of 1961, the equipment phase of the low-frequency modification should be ready for installation at several key locations.

One of the more difficult problems in making soundings at one-fourth the lowest frequency previously used is developing a practical antenna system for field station installation. It must be of relatively low cost, simple in construction and require a minimum of real estate. These restrictions severely limit possible antenna configurations, since the wave length at the lowest frequency used is approximately three-quarters of a mile. Two types of antennas, properly combined, seem to show promise in meeting the requirements: an electrically switched horizontal dipole for less than 2 Mc/s (because of the simplicity of the structures), and a log-periodic configuration for above 2 Mc/s, due to its exceptional bandwidth. Comparative gain and pattern measurements were obtained, using scaled models of these types of antennas, at the Division 85 antenna test site on Green Mountain. The log-periodic tests were to study the effect of changes in typical parameters to increase the low frequency response at a fixed tower height. With the horizontal dipoles, comparative gain and bandwidth measurements were made at heights much less than 1/4 wavelength above ground. Also, mutual coupling effects between antenna systems were noted. These tests indicated that an antenna system of these types would provide a gain of at least 2 db over a 1/2 wave dipole in free space with a single lobe always vertically directed. It is anticipated that this antenna performance will be adequate for good quality data throughout the frequency range of the sounder.

The switching of proper length of the dipole antenna as the frequency varies was successfully accomplished by using solenoid-actuated knife switches, especially insulated to handle the high R-F voltages.

Good progress has been made in solving the problem of transforming the impedance to match the dipole antenna to the transmitter by using a transformer of ferrox-cube core material. The log-periodic antenna will probably be matched with a tapered transmission line.

On two separate occasions, a C-4 installation at Eglin AFB was reactivated and operated to obtain data to be used in conjunction with rocket probes. These occurred in November for a one-week period, during a Stanford Research Institute VLF experiment, and again in February, for a duration of three weeks in connection with an Air Force Cambridge ionospheric probe. During the latter period, the C-4 was modified for low frequency soundings (.25-20 Mc/s) with good success, considering a poor performance antenna was used in the low frequency region.

Two field-worn C-3 sounders were given a complete overhaul and up-dating. One of these was shipped to the Manila Observatory in the Philippines to replace the C-2 sounder there. The other C-3 will remain temporarily at the Boulder Field Station.

All modifications involving new assemblies were constructed, and all regular field stations were furnished with installation instructions. Nearly all sub-assembly repair work, and construction of replacement components used in the Type C sounders are done by this group, as is much of the field station test equipment repair and calibration.

Regular operation of a C-3 or C-4 sounder continued at Boulder on a program of 00, 01, 15, 30, 45, and 59 minutes past the hour. Hourly tracings are made and turned in to the Soundings Review Group each month.

Plans for Fiscal Year 1962 include the continuation of the program involving field station assistance and control, and the completion of much of the up-dating on the Type C equipment to meet Model 5 performance specifications. It is hoped that more time will become available, by the addition of personnel to this group, to investigate and develop some of the basically new and more efficient techniques for ionospheric data recording.

Personnel working on the project were: E. J. Violette (project leader), J. J. Pitts, R. M. Schumaker, R. N. Lyons (since January), D. M. Marks (since April).

## Barrow Ionospheric Station

82155

The objective of this project was the operation of the Radio Propagation Field Station located at Barrow, Alaska. This station's prime mission was the operation of automatic ionospheric sounding equipment, and data reduction, to obtain synoptic vertical incidence ionospheric data over the frequency range of 1-25 Mc/s. Another important mission was the technical assistance to other projects and special telegraphic data to the North Pacific Radio Warning Service, Anchorage, Alaska.

The vertical incidence data are used by CRPL's Regular Predictions Service Section in the preparation of the CRPL-D and F Series publications, which are used by Department of Defense establishments, other Government agencies, as well as commercial communications concerns. These data are also increasingly being used by the Laboratory in studies of the physics of the upper atmosphere.

The Barrow station, in addition to executing the work mentioned, is responsible for carrying on special assignments for other groups in the Laboratory due to the combination of geomagnetic location, competent personnel and facilities. It furnished special ionospheric data directly to the North Pacific Radio Warning Service, Anchorage, Alaska. Finally, the Barrow station maintains close liaison with the nearby Arctic Research Laboratory, thus benefiting both organizations in carrying out high latitude research.

At the beginning of the reporting period, the NBS Barrow staff completed the operation and calibration of four transmitters for the Arctic Meteor Burst Propagation Project, and shipped the gear to Lima, Peru for the use of Dr. Bowles' group. Technical assistance to the Auroral Ionospheric Communication project was completed. Special ionospheric data continued to be furnished the NPRWS, Anchorage. The precision of vertical incidence soundings data was improved in line with research requirements. The difficulties normally encountered with complex electronic gear were cleared up by station personnel, thus eliminating the need for exchange.

Arrangements were completed for the installation and operation of field intensity recordings of transmissions originating in Greenland for the NPRWS, previously done at the Arctic Research Laboratory. Similar arrangements were made for installing and operating electronic gear in connection with a proposed VOA project.

The Engineer-in-Charge furnished valuable communication between the Arctic Research Laboratory, Barrow; T-3 Ice Island, the ship BURTON ISLAND, and the Under Water Sound Laboratory, New London, Connecticut.

A valuable coordination visit was paid the station by a member of the NPRWS Anchorage staff.

The very old auxiliary buildings, housing the diesel power plant and the heavy equipment, will be replaced with an insulated 24' x 52' metal building. Equipment and antennae will be installed in conjunction with field intensity recordings for the NPRWS and the Voice of America.

The following personnel worked on this project: A. O. Crawley, Engineer-in-Charge and Project Leader; A. Simmonds; G. Leavitt (who replaced Mr. Simmonds); M. M. Crawley; and H. G. Sellery.

## Maui Ionospheric and WWVH Station

82157

This project had as its prime missions the operation of Standard Frequency and Time Station WWVH, and the operation and data reduction of ionospheric soundings obtained from type C-4 automatic equipment. Objectives also included the engineering of new equipment at the station to improve the accuracy of WWVH transmissions.

The data obtained from vertical incidence soundings are incorporated into the CRPL-D and F series publications which are used by Department of Defense establishments, other government agencies, and private communication concerns. Due to Maui's location, a large area in the Pacific is properly covered. Of equal importance is the skilled operation of the very precise Standard Frequency and Time Station WWVH, which serves the vast reaches of the Pacific area with around-the-clock transmissions on 5, 10, and 15 Mc/s. In addition to the above, the competent Maui staff carries out VLF and other measurements for other Boulder Laboratory projects.

In order to avoid duplicating a necessarily rather cumbersome transmitting antenna system for receiving, a vacuum tube transmit-receive (T-R) switch was developed. The final design actually surpassed expectations, with an insertion loss of less than 1 db at all frequencies between 0.25 and 20 Mc/s, and producing no increase in the noise figure of the receiver. This switch will handle at least 25 kilowatts of peak pulse power. It has been completely field tested and a report entitled, "A T-R Switch for C2/C3/C4 Type Ionospheric Recorders," by J. J. Pitts was written for field station distribution.

Approximately 20 acres of land, located about 12 miles south-east of Boulder, have been leased to test the complete 0.25 to 20 Mc/s vertical incidence sounding system. Construction should be completed by mid-summer, and all performance tests made by early Fall.

Other programs completed or nearing completion in up-dating Type C sounders to the specifications of the Model 5 are as follows:

C-2 and C-3. Increased transmitter peak pulse power; reduction of distortion and spurious oscillations in transmitter output signal; crystal-controlled height markers.

C-2, C-3 and C-4. Improved frequency marker accuracy; phase locking of PRF and power line frequency; several minor circuit and component changes to improve both stability and reliability.

During the months of July and August 1960, most of the members on this project were involved in the ionized cloud detection project at Eglin Air Force Base. This stimulated some changes and additions to the C-4 sounder for use during cloud detection tests and ionospheric rocket probes. These consisted of some refinement to an echo amplitude measuring system, a technique for more precise range measurements (to within plus or minus 1 km), and some special observing techniques. A Technical Note covering this work is forthcoming.

Activity has again increased towards improving the quality of the data from the vertical incidence stations to meet minimum standards now necessary to obtain accurate electron density data and, of course, to produce more useful data for various research programs. About one-third of the 27 stations now operating on a complete soundings schedule receive weekly discussions on equipment performance and methods for improvement, as well as instructions on equipment operating procedures. The remaining stations receive the same type of information monthly. Periodic technical assistance is also given several stations in foreign countries who operate sounders on a semi-cooperative basis.

This past year has been an especially busy period for the small but very capable Maui staff. A sampling of the station's many activities follows. The phase recording of station WWVL, 20 kc/s, Sunset, Colorado, was transferred to the Kealia Pond site to reduce interference from the station's own transmissions. Due to the proximity and frequency of the U.S.N. station, NPM, 19.8 kc/s, continuing difficulty was experienced in obtaining good phase recordings.

The phase recording of NBA, 18.0 kc/s, was also transferred to the Pond site with worthwhile improvement. Sudden phase anomalies due to solar flares were recorded. Equipment was designed and constructed by the Maui staff to automatically record the 100-cps time code transmitted by Station WWV, Beltsville, Maryland. The standby C-2 sounder was prepared for shipment to India as part of the CRPL's loan program. It has been a useful back-up to the C-4.

Hourly values of foF2, h'F2, and h'F for May and June 1961 were forwarded to Dr. Walter Steiger, Hawaii Geophysical Institute, University of Hawaii. This will be continued in future months. The Institute furnished the Maui station solar flare patrol data for use in conjunction with the phase recording program.

The North Pacific Radio Warning Service short-term forecasts, and the Geophysical Alerts and Special World Intervals have continued to be broadcast on WWVH from NPRWS via the FAA communications circuits. The staff receives the data to be transmitted and sees that the proper symbols are broadcast.

Plans are to continue the basic functions of transmitting highly precise Standard Frequency and Time Signals, WWVH, and to further refine the quality of vertical incidence soundings of the upper atmosphere. Additionally, it is planned to further perfect the reception of WWVL, 20 kc/s, for "steering" purposes, which, in fact, presents very difficult problems due to NPM, 19.8 kc/s. The automatic recording of time coded signals from WWV will be perfected, it is planned.

The other major planning area concerns a new structure for the auxiliary equipment and the C-4, and the erection of a sea wall, and related measures, to control the serious erosion and drifting sand. Cooperation with and technical support of other sections, particularly 82.0, will be continued.

Personnel who worked on the project were: Sadami Katahara, Engineer-in-Charge and Project Leader; W. J. Christian, G. Tam, R. S. Yoshida, and H. G. Sellery.

## Puerto Rico Ionospheric Station

82158

The project objective was the operation of the CRPL field station located at Ramey Air Force Base, Puerto Rico. The prime mission of this radio propagation field station has been the operation of automatic sweep frequency ionosphere sounding gear. From this operation, synoptic vertical incidence ionosphere and derived true height data over the frequency range 1-25 Mc/s are obtained.

The scaled vertical incidence data obtained through this project are fed into the Regular Prediction Service Section as part of the world-wide data from which the CRPL-D and F Series publications are derived. These are utilized by government and private agencies. The accurate ionospheric data consistently furnished by this station are regularly drawn upon by Laboratory projects concerned with furthering our knowledge of the physics of the upper atmosphere. As an important link in the chain of 75° West longitude stations, the station has and is playing a significant role in the increasingly important true height program. Finally, the station supports other programs, including field intensity recordings for the Radio Warning Service.

This CRPL field activity maintained its output of precise vertical incidence data and large quantities of true height tracings, which are finally fed into the computer as part of the 75° West true height program. Field intensity data were supplied to the CRPL short wave fadeout data program. The station Engineer-in-Charge paid a visit to the University College of the West Indies, Kingston, Jamaica, for the purpose of evaluating the staff and facilities before making a loan of a C-3 sounder. An excellent report was written by the station chief.

As a key and pioneer station in the 75° West chain of stations, further refinements in equipment, antennas, etc. will be carried out at this station.

Personnel who worked on the project were: T. R. Gilliland, Engineer-in-Charge and Project Leader, J. W. Pritting, and H. G. Sellery.

## Technical Assistance to Associated Laboratories

82159

The objectives of this project are to assist the Associated Laboratory stations on problems encountered in ionospheric recorder operation, to furnish labor and material for major improvements and repairs on the sounders, and to provide training to station personnel.

This project provides the Associated Laboratory Stations with the same information and modifications as the other sounding stations. This provides for uniform soundings data.

All field station assistance work on this project was accomplished in the first two quarters since the funds were depleted at that time. After this time, the continuation of this work was carried by Project 82154. Some of the funds were used for electronic parts in the overhaul and modification of the C-3 recorder shipped to the Manila Observatory in the Philippines.

Father Frank Glover, now a regular member of the staff at the Manila Observatory, received a week of intensive training on the operation and maintenance of a C-3 sounder. He was also assisted in the planning of their new ionospheric station to be located near Manila.

Programming will continue for the stations as in the past, except there will be increased activity at those stations receiving the low frequency modification.

Personnel who worked on the project were: E. J. Violette (project leader), J. J. Pitts, and R. M. Schumaker.

## Antarctic Soundings

82452

The objectives of this project, sponsored by the National Science Foundation, are to operate, maintain and supply two ionosphere stations, located at Byrd Base and the South Pole in the Antarctic, and to supply three other ionosphere stations, located at Ellsworth, Wilkes and Hallett.

These latter stations are operated by personnel from Argentina, Australia, and New Zealand, respectively.

This project is part of the U. S. Antarctic Research Program. The ionospheric data collected by each of the stations are transmitted to the IGY-World Data Center A for Ionosphere and Airglow at the National Bureau of Standards Boulder Laboratories. They are used for the preparation of maximum usable frequency prediction charts and for basic ionospheric physics research.

During this fiscal year, the project followed the same plan of operation as in previous years. New personnel were hired and trained during the first quarter. They replaced the previous year's personnel during November. Resupply shipments to the five stations were completed during January with a shipment of late order items sent via air mail. In September, the personnel in training and the project leader attended the yearly Antarctic orientation meeting held by USARP at Skyland, Virginia. This week-long meeting enables personnel destined for the various Antarctic stations to meet one another, attend lectures about the Antarctic, and to be fitted with cold weather clothing. During October and November, the project leader made an inspection trip to the Byrd and Amundsen-Scott Pole stations, thus obtaining first-hand knowledge of station operation problems and difficulties encountered during travel to and from the Antarctic. Recruitment of personnel for the coming season was completed during June 1961 with the selection of three men.

Ionospheric data coverage at all the Antarctic stations has been satisfactory, with the possible exception of Ellsworth. Although it is known that data are being taken, none have been received from this station since it was turned over to Argentine operation at the end of the IGY in December 1958.

The Radio Noise program, operated as part of this project at Byrd Station, was satisfactory throughout the year. A much needed new building for this operation will be constructed at the new Byrd Station during the coming Antarctic "Summer." The VLF monitoring program, performed by NBS personnel for Stanford University as an extracurricular activity, at both Byrd and the Pole stations was successfully carried out.

Due to the accumulation of snow above the station buildings at Byrd Station, the buildings have been under increasing pressure. Shoring of the buildings and tunnels has not been very effective; therefore, an entirely new base to replace the old one is being constructed some nine miles east of the old site. Work on this new station can only proceed during the Antarctic "Summer." October through February. Construction was begun last November and will be completed by February 1963. However, construction will be complete enough to start moving in during December 1961. A new construction method, similar to that used at Camp Century on the Greenland Ice Cap, is being used. By this method, open trenches of varying width (9 to 40 feet) and depth (up to 20 feet) are cut in the snow surface with Swiss snow miller machines. These machines cut a trench with a rectangular cross-section, throwing the removed snow up on the surface on either side of the trench. These trenches are then covered over with corrugated metal arches positioned several feet below the surface. The space above the arches is filled with the previously removed snow, leaving a long mound over each covered trench (which has now become a tunnel) which will not catch drifting snow. Standard insulated buildings are then assembled within the tunnels. Access to the tunnels is by ramps at either end and by vertical shafts at intervals along the sides of the tunnels. When completed, the station will consist of several of these tunnels intersecting at $90^{\circ}$. The total length of these tunnels will be approximately 3500 feet. Since there will be no snow load on the buildings, and little accumulation above the tunnels due to drifting, the new station is expected to remain in good condition for at least ten years. After many years, it is expected that the cross-section of each tunnel will change from rectangular to elliptical due to the pressures involved.

The new Radio Noise Recording Building will be more isolated from the station at the new site than at the old. It will be located two miles north, and will have to be reached by walking on the snow surface. This isolation is necessary to eliminate as much as possible the local radio interference from the station itself.

The project will continue through the next fiscal year as a part of the U. S. Antarctic Research Program with a plan of operation similar to the past year.

The following personnel worked on the project: E. E. Ferguson (Project Leader), H. G. Sellery, D. Sands, O. C. Morse, F. Iversen, D. R. Reed, G. W. Angus, K. E. Marks, and J. B. Burnham.

## Puerto Rico Ionograms

82453

The objective of this project was to furnish the General Electric Company with ionospheric recording tracings for use in true height data required by the company. The N(h) data were required by General Electric in connection with work they were carrying out for the Department of Defense.

Data, as required, were delivered to the General Electric Company.

T. R. Gilliland (Project Leader) provided the requested data.

## C-4 Modification AFCCDD

82551

The objective of this project was to renovate a C-4 ionosonde in order to provide the Air Force Cambridge Research Center with a C-4 ionospheric research instrument for performing their mission. This project was originated on a request from Richard Miner of Air Force Cambridge for the purpose of installing all current modifications in their C-4 ionosonde and putting it into good operating condition.

The equipment was first restored to the original state by removing all non-standard modifications, and replacing all broken and worn parts. All appropriate modifications were then installed and tested for proper operation. The operating adjustments and calibrations were completed, and the equipment received a two-week field test at the Boulder site.

The personnel who worked on this project were: E. J. Violette, J. J. Pitts, and R. M. Schumaker.

## VERTICAL SOUNDINGS RESEARCH SECTION

### Soundings Review

82172

As its primary objective, this project strives to maintain high scientific quality in the ionospheric data produced by a number of vertical sounding ionospheric stations located throughout the world. These stations are associated with, or in some cases operated by the National Bureau of Standards. In addition, personnel of this project coordinate the observational and data-scaling activities of U. S. soundings programs with those of other countries. The data resulting from routine and special soundings programs are reviewed in order to: (1) achieve the greatest possible consistency in methods of observation, data reduction and reporting; (2) develop and institute improved data-reduction practices; and, (3) note and classify new natural phenomena for research problems in ionospheric physics.

Sweep-frequency radio-echo sounding is one of the most important methods of observing the ionosphere, and, in turn, of obtaining quantitative physical data concerning the upper atmosphere. The observations are used directly in communication predictions; the derived physical data are essential to the geophysical and space science programs of this and many other countries. The quality-control activity bears the primary responsibility of assuring that the reliability and accuracy of the data, resulting from the U. S. Vertical Sounding Program, meet or exceed the requirements that may be placed upon them by current or anticipated applications.

During fiscal year 1961, the U. S. - associated network consisted of twenty-seven stations. Of this number, eight stations are NBS-operated, eight are operated by the U. S. Army Signal Corps, and eleven are operated by associated or cooperating laboratories. During the year, twenty-one stations were operating on full schedules, three stations on patrol basis, and three stations on special projects. In addition, data from the Mexico City station have been submitted for reviewing, and the stations being established in Formosa and Israel have received advisory assistance.

Three hundred and forty-two station-months of soundings, after review and clearance, were sent to World Data Center A, and shortly thereafter became available to research workers on a world-wide basis. The Review Group also scaled the sounding data for the Boulder station, and assisted in the reduction of special research soundings. Nine station engineers have been instructed in scaling procedures, and assistance has been given to a number of visiting scientists during the year.

The Review Group operates a system of bi-monthly detailed critiques of data reduction and ionosonde operation, also providing to the station weekly or monthly copies of ionogram prints which have been circulated among members of the review and equipment development groups for comment. Telegraphic replies to station inquiries have proven effective and efficient in maintaining data quality.

Field assistance visits by members of the review and equipment development groups are a final means of maintaining the quality of soundings data. During the current year, visits were made to stations in South America, Bogota, Columbia; Huancayo, Peru; La Paz, Bolivia; Concepcion, Chile; and Natal, Brazil; (A. H. Shapley), to stations in Greenland, Thule, Godhavn; (J. W. Wright), in the continental U. S., Ft. Monmouth, White Sands, Grand Bahama Island, Puerto Rico, (J. W. Wright); Austin, Texas; Puerto Rico, (G. H. Stonehocker).

It is evident from the rapidly expanding scientific (e.g., space research) and practical (e.g., military) applications of ionospheric data, that a correspondingly rapid and effective means must be found to improve the reliability and accuracy of these data. Relatively more of the basic ionograms are needed for electron density profile analysis, and this places considerably more stringent requirements on these observations. The review activity plans first of all to integrate its efforts more closely with those of the electron density profile group. Coordinated quality control over the "conventional" and electron-density programs will accompany the development of coordinated, simplified, and improved scaling methods for both programs. The extension of the frequency range of many ionosondes (to 0.25 Mc/s) will necessitate many changes in scaling methods.

At the international level, the quality-control group provides the focus of experience upon which U. S. recommendations for improvements to international data procedures are made through the URSI World-wide Soundings Committee. The group is presently charged, by the way, with the task of assembling a revised and improved international "Atlas of Ionograms".

Personnel who have worked on this project are: J. W. Wright, (project leader), V. E. Miller, L. S. Hayden, I. Brophy and A. E. Burns.

## True Height Calculations
## Ionospheric Structure

82175

This project provides electron density data for specific NBS upper atmosphere physics investigations and sponsors part of the development of facilities for electron density profile analysis.

A great amount of the basic investigative work on the ionosphere done at NBS is relying more and more on the availability of accurate electron density profiles computed from vertical soundings. As examples, the research conducted upon photochemical rates, and the studies of long distance propagation paths (via ray-tracing) at NBS, utilize these data. This project assures that N(h) data produced for the research activities of NBS and other scientists are obtained by the most reliable and accurate methods available. By undertaking or sponsoring the development of new techniques for this analysis, the project helps to keep the available methods abreast of the needs imposed by local research projects.

During the past year data, have been provided by this project to the following NBS scientists for the studies indicated: K. Davies -Oblique Propagation ; R. S. Lawrence- Satellite Faraday-rotation Studies ; T. E. VanZandt -Solar Eclipse Analyses, F -Region Analysis ; R. W. Knecht - Topside Sounder Design Analysis ; S. C. Gladden -F Region Screening Height Study.

Within the Electron Density Profile Group itself, several investigations have been carried out under this project. Investigation of incoherent scatter from the ionosphere over the Trinidad, T. W. I. station, has been a joint project with MIT and the G. E. Company. A study of the southern polar region is under way. The correlation of certain air glow emissions with F-region parameters is being studied.

The initial work done by this project in a search for a satisfactory model for the "topside" of the F-region is being extended to deal with more general conditions. The model is compared with the results of some 25 rocket and satellite observations of this region.

The search for satisfactory N(h) parameters with which to replace older and less basic ionogram parameters is continuing, especially in those parameters linked with propagation prediction service such as M(3000)F2. A program to consider the proper extrapolation of the electron density profile near h maximum has been done.

Development work on the N(h) method itself is continuing for improvement in accuracy of our computations.

Emphasis will be given to three primary areas of improvement in the electron density profile system: (1) The project is undertaking the development of a new scaling system for the use of field stations, integrated with that for conventional ionospheric data. It will permit any necessary increase in frequency accuracy up to a limit imposed by bandwidth consideration in the ionosonde and the ionosphere itself. Data from both magneto-ionic components will be recorded. (2) Parallel with the development of a new N(h) method by a guest worker, the project is designing the new parameters to be derived under this system. New parameters defining the shape and position of the F region peak are expected; together with other parameters more directly usable in certain physical theories of the ionosphere. For example, the method will provide accurate values of $dN/dh$ and $d^2N/dh^2$, of interest in diffusion theory. (3) The project will encourage and guide the modification of ionosondes, particularly to extend their frequency range downwards to permit observation of lower electron densities than at present. The establishment and study of a North-South chain of such stations is an objective of this project shared with Project 82446.

Personnel working on this project were: J. W. Wright (project leader), G. H. Stonehocker, L. Wescott, S. Opitz, D. J. Brown, R. A. Duncan, and S. Matsushita.

## Associated Laboratories-Support

82176

This project, through supply support, provides for the operation of sounding stations at College, Alaska (Geophysical Institute); Huancayo and Talara, Peru (Instituto Geofisico); Reykjavik, Iceland (Post and Telegraph); Narssersauq and Godhavn, Greenland (Danish URSI Committee); and Baguio, Philippines (Manila Observatory). NBS has continued to support partially the sounding stations established at the beginning of IGY at Bogota, Colombia (Instituto Geofisico de Los Andes Colombia); La Paz, Bolivia (Cosmic Ray Institute of Chacaltaya); Concepcion, Chile (University of Concepcion); and Natal, Brazil (Brazilian Navy). The principal activity is the operation of these stations by local personnel. At NBS, the soundings work at these Associated Laboratories is reviewed to ensure that the data produced meets currently acceptable standards.

The U. S. - Vertical Soundings Program is indeed fortunate in these arrangements with other institutions. Much valuable data from remote locations are obtained thereby, which would not otherwise be available.

The station operation at the Associated Laboratories is, in most respects, similar to that of our NBS ionosphere stations, and compares to the standards set internationally. The NBS quality-control efforts under the project are identical with those used for U. S. - operated stations; these are discussed in Project 82172.

As a rule, the "associated laboratories" assisted under this project have a larger research potential than is often exercised, especially in the application of vertical soundings data to local or outstanding geophysical problems. An increasing effort will be made to encourage analysis programs at associated laboratories. Electron density profile data, returned to these laboratories in exchange for their cooperation in providing the necessary scaled input data, is an important example of the newly available raw-material for such analyses.

Personnel who worked on this project were: J. W. Wright (project leader), G. H. Stonehocker, L. S. Hayden, V. Miller, I. Brophy, A. E. Burns, and B. A. Benway of Section 80.40.

## Magnetic Observations

82179

For use in its numerous scientific and engineering applications of ionospheric and solar data in the Boulder area, NBS requires local observations of geomagnetic activity. Under this project, conventional magnetographs are operated to produce continuous recordings of horizontal and vertical intensity, and declination of the earth's magnetic field. The project also studies its geomagnetic observations for correlation with locally-observed ionosphere conditions.

NBS accomplishes many of its objectives in both scientific and engineering missions through the use of observations in the Boulder area. Thus, a number of local research activities are concerned with movements and variations of the ionosphere which are known to correlate with variations in geomagnetism. The NBS Radio Warning Services are examples of local activities which also have need for comprehensive local geophysical observations. The Boulder magnetic observatory serves these needs and, at the same time, performs important studies in the relation of other observations to geomagnetic data; it also seeks to play an active role in the improvement of methods of magnetic observation.

Several site locations on NBS property were considered and magnetically surveyed, resulting in the selection of the present site, south of the radio building. A non-magnetic building was constructed on the site, and the instruments, on loan from the U. S. Coast and Geodetic Survey, were placed in operation. Since January, copies of the daily magnetograms have been provided several other projects for use in studies of low frequency propagation, airglow, magnetic micropulsations, and the disturbance forecasting services.

Plans and specifications for a rapid-run magnetograph to be established at NBS-BL will be completed. This installation will provide greater time resolution of changes of the magnetic field not now available here. It is hoped this more complete installation will be in operation at least one year before the beginning of I.Q.S.Y. The building will be expanded to two rooms to permit the installation of the necessary additional instrumentation. Studies are contemplated concerning the recording of magnetic variations directly onto magnetic tape for more complete analyses on analogue or digital computers.

Personnel who worked on the project were: W. S. Hough (project leader), J. R. DeLine, and R. G. Green.

## Detection of Artificial Ionization Using Ionosondes

82441

The United States Air Force has for some years pursued the study of the chemistry and physics of the high atmosphere with artificially introduced chemical species at Eglin Air Force Base, Florida (Project "Firefly"). NBS participates under this project by performing vertical soundings of the ionosphere near the launching point, and by coordinating similar observations made by the U. S. Army Signal Corps at several nearby locations. NBS analyzes these data for a variety of research and comparative studies, and acts in the design of certain of the experiments.

Observations of ionized clouds, produced either in explosive bursts, or in trails over considerable height ranges (70-120 km) provide useful information on the photo-chemical processes of the atmosphere, motions, winds and wind shear, and on the possibilities of generating ionized clouds for point-to-point communications. Vertical soundings data are an essential method of observation, capable of providing valuable information on the quantity and behavior of the ionization produced. Radio observations are capable of observing the ionized clouds long after any optical or visible effects have disappeared.

The NBS provided a completely equipped mobile van with ionosonde, test equipment, and film and data processing equipment at Eglin Air Force Base, Florida, during the experimental program, August-September 1960. Personnel were provided from 82.70 and 82.50 to operate this equipment, advise in operation of similar equipment by the U. S. Army Signal Corps, and advise in certain research aspects of the program with project personnel of the Air Force Cambridge Research Center.

The ionosonde data resulting from Project Firefly (in both the 1959 and 1960 test series) have been analyzed at NBS, providing data on the electron density variations of the clouds, their movements, and their lifetimes. In addition to publication, these results have been presented at the Project "Firefly" Symposia.

A program of increased NBS activity is proposed for the next series of "Firefly" tests, together with more detailed analysis of present and future data. Utilization of a standard radio technique for measuring ionospheric winds is suggested as a supplement to the observations of cloud drift motions by ionosondes.

Personnel who worked on this project were: J. W. Wright (project leader), G. H. Stonehocker, L. Wescott, D. J. Brown, S. Optiz, L. S. Hayden, I. Ford, and E. J. Violette, J. J. Pitts, R. M. Schumaker of Section 82.50, and B. A. Benway of Section 80.40.

## Electron Density Distribution for AFCRL

82475

This project was originally organized at the request of the Air Force Cambridge Research Laboratories to prepare and study N(h) profile distributions across the geomagnetic equator along the 75°W meridian. In the current year, the project's objectives have been broadened to cover the installation and operation of an ionosphere sounding station at the Air Force rocket research range at Eglin Air Force Base, Florida. Under this new requirement, NBS will provide vertical soundings data, N(h) profiles, and consultative guidance in cooperation with Air Force upper atmosphere research rocket programs.

The concentration of vertical sounding stations in the immediate vicinity of the geomagnetic equator during the IGY, and the favorable distribution of stations along the 75°W meridian permit the preparation of detailed graphical representations of the equatorial ionospheric anomalies. These cross sections provide a basis for a more detailed explanation of the unique structure of the equatorial ionosphere.

A wide variety of upper atmosphere research rocket programs are conducted by AFCRL and its colleagues at Eglin Air Force Base. These include rocket measurements of electron density, positive ion density, solar radiation, and radio propagation experiments, and the study of artificial electron clouds. For these and other experiments conducted at Eglin Air Force Base, an ionosonde capable of producing ionograms of the highest scientific quality is essential. The data resulting from the planned Eglin Air Force Base installation will be an essential adjunct to these experiments.

The IGY electron density profiles for this project have been completed. The data have been checked and averaged, and are now being used to prepare vertical cross-sections along the 75°W meridian for each month of the IGY. Several months have been prepared for publication, and the others will follow shortly.

As an interim measure for the requirements of the Eglin Air Force Base rocket experiments, an NBS trailer with C-4 ionosonde has been operated by NBS personnel. A site survey and considerable initial planning have been initiated, following a visit to Eglin Air Force Base by the project leader, in preparation for a permanent ionosonde installation there. An AFCRL C-4 ionosonde is being placed on loan to NBS for modernization and installation in the new facilities.

The $75^{\circ}W$ cross-sections will be studied to prepare a seasonal and diurnal summary of the equatorial ionospheric anomalies.

The responsibilities of NBS at the Eglin Air Force Base rocket research range will broaden to include increased participation in the experiments conducted there. Following completion of the ionosonde installation, NBS will assist through real-time consultation, covering ionospheric conditions during the rocket experiments, and through N(h) or other analyses of ionograms for comparison with the rocket results.

Personnel who worked on this project were: G. H. Stonehocker (project leader), L. S. Hayden, and J. W. Wright.

## Ionospheric Electron Density Studies

82476

The provision of ionospheric electron density data to Government agencies and their contractors, concerned with many aspects of the U. S. Space Program, is the primary objective of this project. Supporting objectives are the development of accurate methods for determining N(h) profiles, and the accumulation and interpretation of a sufficient body of N(h) data to permit generalizations regarding the structure of the complete ionosphere for space-research purposes.

N(h) data have an essential practical importance in permitting corrections for radio refraction errors in the launching, guidance, or tracking of missiles and space vehicles. Such data are also of unique value in nearly all of the studies undertaken on the physics of the high atmosphere. In fact, these data represent virtually the only source of upper atmosphere data available on a world-wide, continuous basis.

During the year, electron density profile data have been provided to ten Government and private institutions for the following purposes:

| | |
|---|---|
| Air Force Cambridge Research Center | Rocket Probes (Ft. Churchill, White Sands, Eglin AFB) |
| Raytheon Company | Missile Detection |
| Space Technology Laboratory | Rocket Flight Analysis |

| | |
|---|---|
| Applied Physics Laboratory Johns Hopkins University | Analysis of Data for Project Transit (Navigation Satellite) |
| Ballistic Research Labs. (U. S. Army) | Rocket Probes |
| Stanford University | Satellite Ionosphere Studies |
| Marshall Space Flight Center (NASA) | Missile Ballistics |
| Goddard Space Flight Center (NASA) | Electron Density and Magnetic Fields from Rocket Probes |
| Pennsylvania State University | Satellite Doppler Measurements |
| Lockheed Aircraft Company | Rocket Electron Density Probe Studies |
| University of Illinois | Faraday Rotation Studies |

A still further increase in the economy of large-scale N(h) reduction has been accomplished in the past year through the use of the computer at NBS, Boulder. A more efficient scaling method at field stations has greatly increased the accuracy of the N(h) reductions. Employing the method of obtaining representative N(h) curves from median virtual height curves, the station at Boulder, Colorado was added to the systematic N(h) (hourly) reduction program. The current program receives hourly virtual height data for N(h) analysis from the following field stations (the systematic computations are supported jointly with Project 82175):

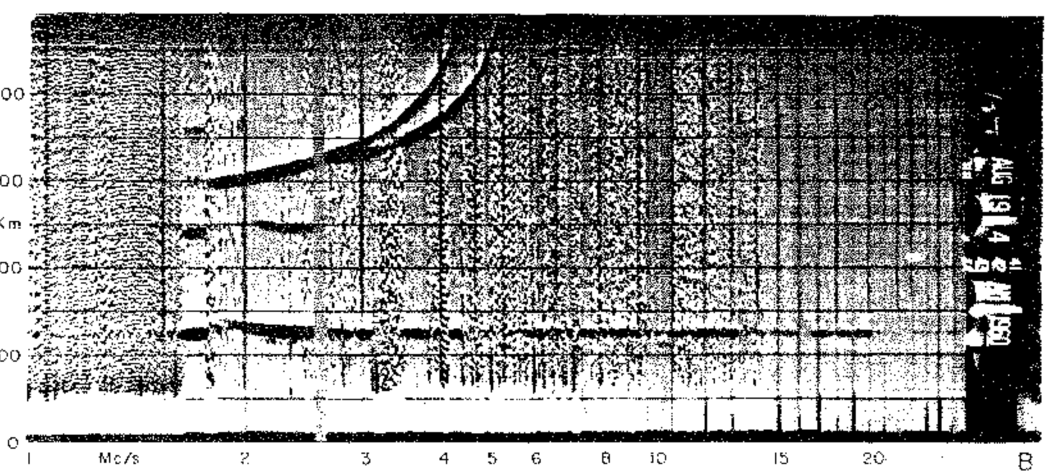
| | |
|---|---|
| Puerto Rico - since Jan. 1959 | Grand Bahama Is. - since Feb. 1959 |
| Ft. Monmouth - since Feb. 1959 | St. Johns, Nfd. - since Mar. 1959 |
| White Sands - since Mar. 1959 | Adak, Alaska - since June 1959 |
| Okinawa - since June 1959 | Thule, Greenland - since June 1959 |
| Huancayo, Peru - since Jan. 1960 | Talara, Peru - since Jan. 1960 |
| Baguio, Phil. - since Feb. 1960 | Bogota, Colombia - since Jan. 1960 |

Publications of NBS N(h) data designed for application to space studies include the hourly electron density profiles and derived parameters, including monthly averages, for the NBS Puerto Rico station in each issue of the CRPL-F series; a series of NBS Technical Notes (40-3, 40-4) by J. W. Wright, L. R. Wescott and D. J. Brown which portray the mean quiet ionosphere in several ways, using data from stations between latitudes of 15 and 15°N along the 75°W meridian. Activities of this project have been described in NBS Report 6725, "The NBS Electron Density Profile Program 1959-1960," and 6726, "Vertical Cross Sections of the Ionosphere Across the Geomagnetic Equator," by J. W. Wright.

The primary activities of the coming year will center around the development of a radically new and more accurate method for deriving N(h) profiles from vertical soundings. Devised by A. Paul (Breisach, Germany), the new method will utilize the ordinary and extraordinary reflections from the ionosphere to obtain information regarding the ionization at low densities and heights, and within valley minima; it will permit an improved accuracy in the determination of the layer peaks, and an improved ionogram scaling method, as well as making use of ionosonde observations at low radio frequencies.

A more detailed and extended survey of ionospheric variations along the 75°W meridian will be inaugurated with the assistance of stations in Greenland and South America.

Personnel who worked on this project were: J. W. Wright (project leader), G. H. Stonehocker, L. Wescott, M. Durham, F. Burmont, L. Fine, D. J. Brown, S. Opitz, G. Lira, G. A. M. King, I. Ford, and L. S. Hayden.




Ionospheric sounding showing reflections obtained from an artificially created electron cloud. The ionosonde is located about 70 km away from cloud ground-zero at an altitude of 106 km.

## Make Ionospheric Observations and True Height Profiles

82447

The project was organized through the Applied Physics Laboratory (John Hopkins University, Silver Spring, Maryland), to provide vertical soundings from which electron density profile data may be obtained at Austin, Texas, for the "transit" navigation satellite program of the U. S. Navy.

Electron density profiles of the ionosphere are essential to the calibration and testing phases of the Navy's "transit" navigation satellite program. Of the several transit tracking stations, only one, at Austin, Texas, is comparatively remote from an existing ionosphere station. For this reason, NBS has established at Austin a temporary and portable ionosonde with which to obtain ionograms during special periods of tracking.

Personnel of the University of Texas operate the Cossor portable ionosonde during the short intervals the data are needed. The personnel of NBS have acted as consultants to the operation of the ionosonde since its initial installation. The station has been relocated and operated several times this year. NBS also obtains for APL the electron density profiles required by that agency from the ionosphere observatories near their other "transit" tracking station .

The funds allocated have been nearly expended, and those remaining are reserved for the return of the equipment to NBS. If a continuing program of observations becomes desirable, it is hoped that more automatic and powerful equipment might be provided, so that the ionograms will be suitable for the modern methods of analysis now available.

Personnel who worked on this project were: J. W. Wright (project leader) and G. H. Stonehocker.

## NASA - Wallops Island Ionosonde and Installation Procurement

82478

Under the sponsorship of the National Aeronautics and Space Administration, the NBS is undertaking the procurement of a research ionosonde for use at NASA's research rocket range at Wallops Island. NBS also operates this installation, and provides consultative guidance to range-users of the data and data reduction, especially to electron density profiles.

Wallops Island is the location of a large number of important experiments conducted by NASA and others in the fields of upper atmosphere, solar, geomagnetic, and space research by high altitude rockets. The ionosonde is an essential adjunct to a wide variety of specific experiments within each of these fields. NBS seeks to provide NASA with ionospheric soundings, N(h) profiles, other ionospheric data, and consultative guidance within its fields of competence; all of the highest possible reliability.

In the original concept of this project, NBS would begin by procuring an ionosonde for Wallops Island, only then being able to provide data and other services under the project. Considering the long delivery time, and the special requirements for this ionosonde, NBS has instead made available to NASA an NBS model C-3 ionosonde for interim use, and has thus, from the beginning, been able to serve NASA in all the above-noted capacities.

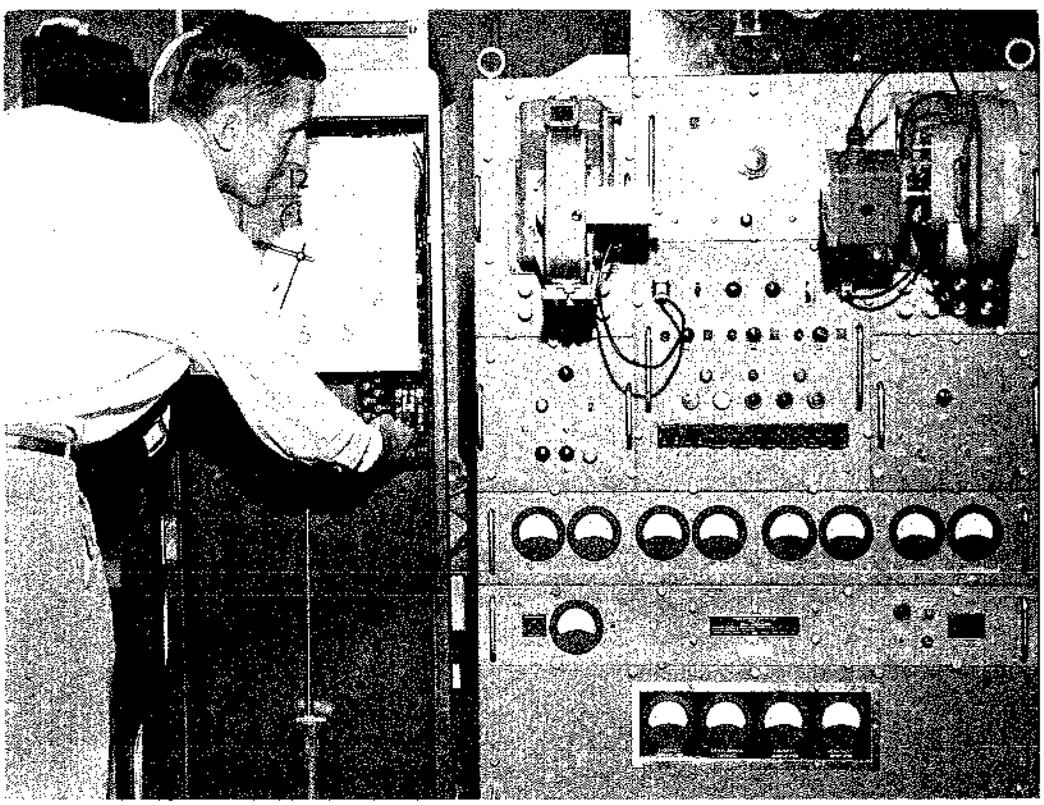
NBS personnel have, on a number of occasions, operated this ionosonde at the specific request of NASA, and have supplied the appropriate scientific groups with the data requested. Rocket experiments measuring upper atmosphere electron and positive ion densities, and rocket-borne versions of the planned "topside-sounder satellite" are typical examples.

NBS personnel have visited Wallops Island for site-selection and facilities-planning purposes on two occasions. Specifications for the new ionosonde, for the antenna, and final site exist now in nearly final form.

It is expected that final procurement action for the new ionosonde can be initiated within the next few months, and that the new instrument will be deliverable approximately 15 months thereafter. In the meantime, NBS will complete its antenna design studies, and on the basis of the resulting site requirements select a final permanent location for the ionosonde installation. Antenna installation can then proceed immediately, with direct benefit to the present interim ionosonde. The interim ionosonde will be improved and modernized in several ways to make it more suited to its present mission. This will include an extension (down to 0.25 Mc/s) of its frequency range together with circuits for improved height and frequency marker accuracies.

An NBS Technical Note is in preparation for the guidance of agencies anticipating a need for ionospheric data from the ionosonde.

Personnel who worked on this project were: J. W. Wright (project leader), L. R. Bauhs, R. W. Knecht, T. E. Van Zandt.



The ionosonde, principal tool for measuring electron density and height in vertical soundings of the ionosphere.

# RADIO WARNING SERVICES SECTION

## Forecast Research

82161

This project initiates research activities on radio propagation forecasting techniques and semantics. It also provides supervision, coordination and services for the North Atlantic Radio Warning Service (NARWS) at Fort Belvoir, Virginia, and the North Pacific Radio Warning Service (NPRWS) at Anchorage, Alaska. In addition, the Boulder group issues a series of general forecasts of geomagnetic activity, and answers many inquiries on disturbance forecasting and on the availability of solar-geophysical data as received from government agencies and from the public.

High frequency radio communications may at times be impaired by prevailing ionospheric conditions. These variations in conditions are usually associated with geomagnetic storminess. By proper interpretation of the variations in solar electromagnetic radiation, geomagnetic storms may be predicted. Thus, disturbances in the ionosphere can be anticipated and, by suitable changes of schedules or operating frequencies, communications operators can usually maintain usable circuit performance throughout all but the most severe phases of the disturbances.

The demand for the radio quality forecast services by both government and public communication organizations, as well as private citizens remains at many hundreds. In addition to the routine services, many have requested special forecasts, and more and more research groups, especially those concerned with space science, are requesting various current solar-geophysical data summaries.

This project provides the general supervision, coordination, and services for the two field sites of the Radio Warning Service Section: North Atlantic Radio Warning Service at Fort Belvoir, Virginia, and North Pacific Radio Warning Service at Anchorage, Alaska. Research on forecasting techniques continues at Boulder with results transmitted to the field sites for application in practical forecasting.

The CRPL-Jb and Jb' forecasts of geomagnetic activity continue to be issued each Wednesday at Boulder. Special disturbance warnings are issued whenever a significant change in solar activity has been observed which is thought likely to produce disturbance for a period which had been expected to be quiet in the regular weekly forecast. In the hopes of making these geomagnetic forecasts more specific a plan was developed whereby each forecasting center (NARWS, NPRWS and Boulder) would forecast a range in which the Ak index for each day would fall. These forecasts were made at each forecast conference. Thus, the forecasts were in advance by 1 to 7 days. A statistical analysis comparing the forecasts with the actual A-indices was not very encouraging. The plan was then modified slightly by expanding each Ak range. Preliminary analysis of the results from the modified plan indicates forecasts are now more accurate. Although this is due primarily to the expanded Ak range, the forecasters also are not as conservative as they were earlier.

A very great magnetic storm October 6-7, 1960 was not anticipated by the CRPL Radio Warning Services. Post-analysis by CRPL did not indicate any likely explanation for a storm of its magnitude. A series of letters were exchanged with the other forecast centers throughout the world without reaching a satisfactory answer. They, too, had not forecast the storm. The solar event coverage was complete enough that the possibility of having missed an outstanding solar event because of weather was unlikely. The period is still under study.

On the other hand the series of outstanding geomagnetic storms during November 1960 were anticipated from the many events occurring in a large region on the sun November 9-20. Special studies of the data were made and presented at a conference at the AF Cambridge Research Center in February 1961.

A joint conference of personnel from the High Altitude Observatory, Sacramento Peak Observatory, Los Alamos Scientific Laboratory, and National Bureau of Standards was held at Los Alamos. This was another in an annual series of conferences designed to keep each other current on particular observing and research programs so that future programs remain coordinated.

During the year, the distribution lists for the CRPL-Jb' report series grew to such proportion (nearly 1500 recipients), that the funds allocated for this service were insufficient to cover the costs involved. A plan was therefore developed to charge the recipients of the Jb' reports to reimburse the government partially for this service to the public.

Members of this group participated in drafting a work agreement between the National Aeronautics and Space Administration and the National Bureau of Standards for the Project Mercury Radio Warning Service (see Project 82464). This service is operated by the North Atlantic Radio Warning Service with most of the research involved in preparing radio propagation forecasts for middle and low latitudes being done by the Boulder group.

A small geophysical observatory is maintained in the section at Boulder with a horizontal component visually recording magnetometer, a short-wave fadeout recorder, a sudden phase anomaly recorder, and the 108 Mc/s solar radio emission recorder working side by side. NBS Boulder research workers can and do receive immediate advice concerning these phenomena.

The section chief travelled to Japan during the year to visit the facilities of the Japanese radio warning service at Hiraiso, as well as other radio research laboratories and solar observatories. At Hiraiso, it was possible to compare forecasting methods and techniques to benefit future CRPL operational planning.

The project leader visited the University of Hawaii in connection with the latter's solar flare patrol program. While on this trip, it was possible to resolve with the Federal Aviation Agency most of the problems encountered in transmitting the short-term radio forecasts from NPRWS in Anchorage, to WWVH on the island of Maui, in time for the first scheduled broadcast.

The staff is responsible for the coordinated planning, with the University of Washington at Seattle and the Department of the Navy at Adak, for the operation of the beacon transmitters at those locations for the NPRWS program. Also for the NPRWS program, arrangements were completed with USAF-NORLANTAACS Region for continued operation of HF transmissions from Thule, Greenland, directed toward Barrow, Alaska.

The shortwave radio fadeout program is directed by the Boulder group. The data provided by this program are used for research on solar flare effects on radio propagation. All Signal Corps trainees, enroute to field stations operated by the Signal Corps Radio Propagation Agency, pass through Boulder for indoctrination in the shortwave fadeout program.

The various information leaflets -- eleven of them, which describe the services of the Radio Warning Services section, were reviewed, rewritten where necessary, and reissued. The one entitled, Sun-Earth Relationships and Radio Propagation Forecasting, now re-emphasizes 27-day recurrence phenomena, as well as solar event associated forecasts, since the sunspot maximum phase is now over in this cycle.

A review of the degree of success that was achieved in declaring Special World Intervals (SWI) during the IGY was made. In the most pessimistic case considered, a SWI was considered a success only if a magnetic disturbance began in the day covered by the SWI. To allow for persistence in this case, it seemed likely that only about 274 independent observations were possible during the IGY. Using a 2 x 2 contingency table, and the Chi-square test, the probability of obtaining by chance a distribution as good or better than that of the table was about $5 \times 10^{-7}$. From this, it seems clear that the forecasting techniques used by the IGY World Warning Agency were certainly valid, and the objectives of the Special World Interval programs were achieved.

A study was made of the frequency of occurrence and the duration of radio disturbances on the North Atlantic path, 1953-1960. The six-hour quality figures calculated for the path by NARWS were used in this work on a monthly, seasonal and yearly basis. Results of the study showed that more disturbances occur during equinox with the month of March showing more disturbed periods than September. At sunspot maximum, radio disturbances occur frequently, are relatively severe, but persist for only a few hours. During the minimum years of the solar cycle, radio disturbances occur less frequently, are moderate in severity, but the average duration is about five days. This work was presented at the May 1961 AGARD meetings in Naples, Italy.

Development of techniques for specific path forecasts and semantics for transmitting the forecasts to communications agencies will continue. The possibility of utilizing electronic computer techniques for forecasts is under study.

In the coming years, approaching minimum solar activity, emphasis in forecasting will be placed on the tendency for geomagnetic activity to recur at 27-day intervals. Basic research leading to development of new methods of forecasting at solar minimum must be undertaken. The programs planned for the International Year of the Quiet Sun should help to evaluate these researches.

An effort will be made to predict both the onset and ending times of disturbances as far in advance as possible. An estimate of the degree and severity will be made for each predicted disturbance. Very preliminary trial forecasts along these lines are available.

As the space research programs dictate, special services will be initiated to answer their specific needs. Cooperation with NBS groups working on disturbance effects on electron density profiles and ray-tracing techniques will be expanded and applied to short-term disturbance forecasts.

Personnel assigned to this project were: M. E. Nason (project leader), J. V. Lincoln, O. E. Youngdahl, R. E. Sodergren, and G. Otto, with forecasting assistance by C. S. Warwick, and M. B. Haurwitz, as well as D. E. Trotter of the High Altitude Observatory.

## North Atlantic Radio Warning Service

82162

This project, in connection with Projects 82161 and 82163, forms the NBS-CRPL Radio Warning Services. Under this project, the radio disturbance warning and forecast services for the North Atlantic area are continued. Various radio propagation and geomagnetic forecasts are prepared and distributed by telephone, teletype, and mail with two of the forecasts being available over NBS standard frequency station (WWV) on a twice per hour schedule. Users of these services include the many governmental communication facilities, universities, and commercial companies engaged in radio physics or allied scientific fields, and private communications systems.

Activities associated with the primary function of these services include various other geophysical experiments, such as regular vertical incidence ionosphere soundings, geomagnetic, and radio field strength measurements. Also associated with these services are the preparation, distribution, and interchange of geophysical data summaries on a rapid schedule. The resulting regular interchange of these observations with the other forecasting centers throughout the world, as the World Warning Agency of the International World Day Service (IWDS), permits a complete daily representation of the various solar-geophysical occurrences; from this can be derived more reliable forecasts. The North Atlantic Radio Warning Service has become the principal distributor of geophysical data in the Washington area, and undertakes to satisfy all bonafide requests for the various scientific data needed by many governmental and commercial scientific organizations.

High frequency radio propagation is dependent upon the prevailing state of the ionosphere. As certain changes in the ionosphere occur, communications using high frequencies may be adversely affected or, at times, become impossible. These changes are usually associated with geomagnetic storms. By proper interpretation of solar, geophysical, and geomagnetic tendencies, these storms, together with their severity and duration, can be accurately predicted well in advance. Communications users then may reduce the affects of the ionospheric disturbances by proper frequency and scheduling changes. Of equal importance are the scientific users who may want to accelerate certain observations, or measurements, during an ionospheric and geomagnetic storm. The importance of the NARWS services is reflected by the continual demand for information from almost every scientific agency concerned with geophysical work, as well as the communication agencies concerned with long distance radio propagation. With the accelerated work being done in the space sciences, the need and use of solar and geophysical data has greatly increased with NARWS being in the U. S. the principal source of these data on a rapid daily exchange basis.

During the year, the regular project functions were accomplished as scheduled. The NARWS is manned on a 24-hour schedule every day of the year. The services were as follows: 1) NARWS - forecasting radio propagation conditions for the North Atlantic path; 2) IWDS - continuation of the plan adopted for the IGY-IGC to coordinate periods of intensified observation of solar and geophysical phenomena; 3) Special Services and Projects - providing current ionospheric, solar, and geophysical data to those having an immediate use for these data.

The distribution of NARWS forecasts by mail, telephone and teletype is as follows:

<u>Advance Forecast</u>: CRPL-J Series, 1-7 days ahead (issued every Wednesday) 106 regular mail; 110 air mail; 75 teletype; 12 telephone to local centers.

<u>Special Disturbance Warning and Supplementary Advance Forecast</u>: CRPL-J Series, 1-3 days ahead (issued irregularly when changes in propagation conditions, not included in Advance Forecast, are expected); distribution same as Advance Forecast.

Medium Term Forecast: 24 hours ahead (issued daily at 1600 local time); 10 telephone to local centers; 6 teletype.

Short Wave Fade-out Probability Forecast: 24 hours ahead (Issued daily); 10 telephone to local centers (given with medium term forecast).

Geomagnetic Forecast: 24 hours ahead (issued daily); 2 teletype to Antarctic centers.

Short-term Forecast: 1-7 hours ahead (issued 4 times daily); broadcast on WWV twice hourly; 8 telephone to local centers; 3 teletype.

A record of these forecasts and their evaluation is published monthly in the CRPL-F, Part B "Solar-Geophysical Data" reports.

In addition to the above forecasts, a daily summary of important current solar and geophysical events, collected from observations in this country and abroad, is prepared and distributed by teletype and mail; these include 32 telegraphic addressees and 5 mail addressees. The distribution of IWDS Geophysical Alerts and Special World Intervals is world-wide, and is accomplished by broadcast on WWV on a twice per hour schedule, and by teletype (53 telegraphic addressees) throughout the extent of the AGIWARN and the World Meteorological Communications Network.

Forecasting techniques during the past few years of high sunspot activity have been based primarily on statistical relationships between solar event-type activity and geomagnetic storminess. Now that we are in the period of sunspot decline, however, more dependence is being placed on the tendency of geomagnetic activity to recur at 27-day intervals. To this end, many of the statistical aids, such as daily recurrence numbers and 27-day recurrence charts of geomagnetic activity and radio propagation conditions, which proved so essential during the minimum phase of the last solar cycle, were re-established. The format used for the weekly CRPL-J reports was changed to incorporate a prediction of disturbed days up to 25 days ahead, taking into account 27-day recurrence tendency, and the inclusion of a chart showing the history of radio and geomagnetic storminess in the past five 27-day recurrence cycles. Literature pertaining to the various services of NARWS was rewritten, and distributed to subscribers.

Special activities during the year included a finalized report on the study of a least-squares method of short-term forecasting. It was decided that, especially in view of the nature of current requirements for NARWS/AGIWARN services, the least squares method is not sufficiently effective to replace our present techniques. All work on equation forecasting, therefore, has been discontinued.

Another special activity which might prove valuable to the forecasting service is the computation of daily storm indices through a method developed by Mr. Hallock S. Marsh of AFCRC. NARWS has undertaken the task of computing the storm indices, beginning January 1961, using information concerning usable high frequency ranges for radio propagation over North Atlantic paths, as derived from data provided by the German Post Office. Preliminary work has begun on computing indices for the last three months of 1960 to determine procedures to be followed in the future. Indices have been determined for October 1960, but these results are not conclusive.

In a long-range look toward the future, it is anticipated that mutual benefits will result from a close cooperation between NARWS and the newly formed Defense Communications Agency. Several briefing conferences have been held between personnel of these two agencies, both at NARWS and at DCA. Of course it is expected that NARWS prediction services will help DCA in meeting its communication problems. It is also hoped some of the circuit performance information available to DCA from its many circuits may be made available to NARWS. This would provide the warning service with much more data than is now available, and should lead to a more meaningful and valid measure of radio quality, and to more extensive research toward improving forecasting techniques.

It is expected that the installation of sweep frequency receiving equipment, which should be delivered in the near future, will lead to a better means of determining current propagation conditions -- it should at least supplement present direction finder observations. Of greater value, however, should be the information gained relative to the variation of usable frequencies, both diurnally and in association with other geophysical and solar phenomena.

Since July 1, 1960, five major geomagnetic disturbances have been recorded: July 14-17, September 4-6, October 5-10, November 12-17 and November 30-December 2, 1960. Disturbed radio propagation conditions, associated with the October storm and the two November storms, were predicted by forecasts, issued one day in advance. Short-term forecasts successfully anticipated the beginning of the other disturbances. The two most important storms began October 5 and November 12. The latter was the most severe disturbance recorded in the history of CRPL and was associated with solar activity as outstanding as any observed in the current sunspot cycle. Research at CRPL, as well as other forecast centers throughout the world, has not yet revealed the cause of the October disturbance.

During the past year, most members of the NARWS forecasting staff participated in visits to other forecasting centers to exchange information concerning radio propagation prediction procedures. Discussions were held with forecasting groups at CRPL, Boulder; Darmstadt, Germany; Bagneaux, France; and Nederhorstdenberg, Netherlands. The accent in these discussions was on changing methods of propagation forecasting, as the post-maximum phase of the sunspot develops. Various members of the NARWS staff also attended the technical sessions of the meetings of a number of scientific unions and organizations, including URSI, AGU, IRE, COSPAR, and AGARD, actively participating in the latter two. Of note was the interest expressed in the coming International Year of the Quiet Sun, and how valuable this type of concentrated effort is expected to be in the development of more effective radio propagation forecasting service for the critical sunspot minimum years.

A new area of activity has resulted from the contract with the National Aeronautics and Space Administration to provide a radio propagation prediction service for the Project Mercury ground communication network. (See Project 82464). In recent months, enough radio circuit data has been made available to NARWS so that a number of statistical studies could be initiated. These studies form the ground-work research involved in the organization of a systematic prediction plan for the particular radio paths within the Mercury communication network. The NARWS forecasting staff has increased from four to six members to implement the Mercury forecast operation. The forecasts supplied to NASA in connection with this project are currently of a general nature. The predictions will be more specifically applicable to the Mercury circuits as more complete and systematic circuit reports become available.

During the past year, NARWS has operated the World Warning Agency (AGIWARN) in accordance with their obligations in the International World Day Service. The IWDS plan for the issuance of Geophysical Alerts and Special World Intervals was continued last year, along the general lines of the program initiated for the International Geophysical Cooperation

1959, but with several important changes, effected to keep pace with the ever-growing interest in solar and geophysical research. Geophysical Alerts are issued as notification that certain solar or geophysical events have taken place. Special World Intervals (SWI) are declared after observation indicates that a magnetic storm is going to reach major proportions. Recently, however, the Special World Interval plan has been supplemented to allow issuance before the onset of a major storm. This is a re-introduction of the plan in effect during the IGY in recognition of the new interest expressed in the study of pre-storm conditions. Special World Intervals, declared before the onset of a geomagnetic storm, are differentiated from those issued after a major storm begins, by prefixing the announcement with the word "predicted". The distribution of Geophysical Alerts and Special World Intervals is still accomplished by the methods initiated during the IGY.

In the period July 1960 - May 1961, AGIWARN issued 47 World-wide Geophysical Alerts, 32 of which announced the beginning of a geomagnetic disturbance of a specified level of activity. During these disturbances, 12 days were designated as Special World Intervals. SWI covered the greater portion of the three most severe disturbances of the year. Two Alerts announced the occurrence of unusual cosmic ray increase (November 13 and November 15, 1960). One additional Alert declared a Predicted Special World Interval. During this same interval, 30 Advance Geophysical Alerts were distributed to interested western hemisphere groups, and to regional and associate warning centers throughout the world. The Advance Alerts were issued within a few hours after the observation of certain unusual solar or geophysical phenomena, as reported by western hemisphere observing stations.

AGIWARN continues, within its function as the World Warning Agency and the Regional Warning Center for the Western Hemisphere, to participate in world-wide solar and geophysical data interchange program as initiated for the IGY. Messages include daily interchange of solar-geophysical observations with the other Regional Warning Centers, daily current data summaries distributed to many Western Hemisphere agencies, and collection of observations from Western Hemisphere stations. Several circular memoranda were prepared for the IWDS. "The Plan for Geophysical Alerts and Special World Intervals, 1961-62" was sent to the National Warning Contacts and Regional Warning Centers. It has also been submitted for publication to see that it gets wide distribution to geophysicists throughout the world. Other memoranda have been concerned with priorities for data interchange, updating station indicators, and describing present operations in the Western Hemisphere.

Other aspects of AGIWARN's operation include, cooperation with many programs associated with the U. S. space effort by fulfilling many special requests for predictions, measurements, and interpretation of geomagnetic and ionospheric activity.

With support from NASA, AGIWARN also has cooperated in the international aspects of the earth-satellite program through the systematic distribution of U. S. satellite launching announcements and orbital elements of all satellites (see Project 82462).

NARWS has cooperated with NPRWS and the forecasting center at Boulder throughout the year in an experiment designed to compare the forecasting philosophies of the different centers. Periodic analysis of the data, comprising advance predictions of geomagnetic activity in conjunction with probability factors, should result in more objective and systematic forecast techniques, and has already suggested areas wherein certain practice change could be expected to result in more effective predictions.

Ionospheric soundings, and the use of these data in the Washington area, continued to be one of the more important functions of the field station throughout the year. In addition to furnishing ionospheric data to CRPL for part of its prediction services, the staff at NARWS is frequently asked to assist in special studies and communications problems by making available its current ionospheric data. For instance, complete copies of the daily Washington ionospheric values were mailed to six government and private scientific users during the year, and the local ionosonde was operated specifically for 8 rocket launchings that took place from NASA's Wallops Island. In addition, NARWS furnished personnel to install and operate the Wallops Island Ionosphere Station (see Project 82465). A total of six trips to Wallops Island, Virginia, was made for this purpose during the year. A member of the NARWS staff also was on temporary duty at the Puerto Rico Station for three weeks as vacation relief for the Engineer-in-Charge of that station.

Pending further progress on a new permanent building for the NARWS operation, several changes were made in the station's plant facilities to accommodate the staff's added responsibilities during the year in the operation of the Mercury Forecasting Project. Included was the installation of a separate teletype circuit between the station and the Mercury Communications Center at NASA. The addition of this teletype machine resulted in excessively cramped quarters. It also interfered with the operation of the station's magnetic variometers, making it necessary to relocate the teletype room and the NARWS observing facilities elsewhere in the building.

Aside from making a more efficient operation, these changes effectively isolated the geomagnetic recording heads, thus eliminating the frequent recording of spurious signals which, in the past, could have misled the duty forecaster at a critical time.

The North Atlantic Radio Warning Service will continue its activities in the many areas discussed above. Greater effort towards specific path forecasts, and more accurate forecasting of beginning and ending times of disturbances will be made.

The NARWS staff consists of: E. J. Wiewara (station Chief), J. M. Weldon (head World Warning Agency), K. D. Boggs (chief forecaster), J. W. Pritting (to June 1961), W. A. Daniels (from January 1961), J. M. Kennedy (from January 1961), J. J. Sullivan, C. G. Smith, J. Cio, C. E. Akers, J. A. Spindle (from June 1961), H. L. Hedrick, W. E. Higgins (to October 1960), C. E. Enfield, P. Ruark, and L. A. Jones.

## North Pacific Radio Warning Service

82163

This project in connection with Projects 82161 and 82162, forms the NBS-CRPL Radio Warning Services. Under this project, located at Anchorage, Alaska the radio disturbance warning and forecast services for the North Pacific area are continued. The radio propagation condition forecasts are based upon reports of current solar and geophysical phenomena. The forecasts are distributed by telephone, teletype, and mail with the short-term forecasts also broadcast over NBS standard frequency station (WWVH) twice an hour. The users include many government communication facilities, commercial companies, universities engaged in radio physics or allied scientific fields, and some private citizens.

Other geophysical experiments are conducted at the station, such as routine vertical incidence ionosphere soundings, geomagnetic, and field strength measurements. Advice is given on specific radio propagation problems. Research is under way constantly to improve forecasting techniques and to evaluate observed conditions.

Prevailing conditions in the ionosphere affect the performance of high frequency radio propagation circuits. These variations in the ionosphere can adversely affect communications, at times making them impossible. These changes are normally associated with geomagnetic storms. By proper interpretation of solar-terrestrial relationships, such storms can be predicted in advance, both in degree of severity and expected duration. By proper frequency and scheduling changes, communication users can minimize the effects of such disturbances, maintaining usable circuit performance throughout all but the most severe phases of the disturbances. Scientific users frequently accelerate certain observations or measurements during ionospheric and geomagnetic storms, or have need for identification of disturbance to interpret their results.

During the year, the regular project functions were accomplished as scheduled by manning the station on a 15-hour basis every day of the year. The distribution of NPRWS forecasts by mail, telephone, and teletype is as follows:

Advance Forecast: CRPL-Jp series, 1-7 days ahead (issued every Wednesday); 59 regular mail; 152 air mail; 47 teletype.

Special Disturbance Warning: CRPL-Jp series, 1-3 days ahead (issued irregularly when changes in propagation conditions, not included in Advance Forecast, are expected); 46 regular mail; 125 air mail; 54 teletype; 19 telephone to local centers.

Supplemental Forecasts: CRPL-Jp series, 1-3 days ahead (revision of Advance Forecast following Special Disturbance Warning or unexpected disturbance); 59 regular mail; 152 air mail, 54 teletype.

Short-term Forecast: 1-13 hours ahead (issued 2 times daily); broadcast on WWVH twice hourly; 23 teletype; 19 telephone to local centers.

Probability of Short-wave Fadeouts: 24-hours ahead (once daily); 23 teletype, 19 telephone to local users.

A record of these forecasts and their evaluation is published monthly in the CRPL-F Part B "Solar-Geophysical Data" reports.

The daily summary of important current solar and geophysical events is forwarded to the Geophysical Institute at College, Alaska.

During the past year, the major disturbances in the North Pacific area occurred July 15-17, September 3-6, October 5-9, November 13-16, and December 1-2, 1960. Though for only one of these storms was first-day of disturbance forecast more than a day in advance, the severity and duration of the storms were correctly covered by special forecasts in all but one case. For all the storms, the short term forecasts were well handled.

The fade rate meters, with accompanying field strength recordings, were put into full operation. Two of them monitor transmission from installations at the University of Washington, Seattle, Washington (4894 and 12080 kc/s), and two, transmissions from the Navy transmitting site, Adak, Alaska (5782 and 10217 kc/s). These frequency choices usually provide at least one usable frequency throughout the 24-hours. All of the transmitters are operated continuously with identifying "off tags". These recordings have proved immediately valuable for forecasting reductions of these data are being used in the preparation of the North Pacific radio propagation quality figures used to evaluate observed conditions. Trial forecasts of LUHF-MUF for the hours immediately ahead have been made for Anchorage to Seattle and Anchorage to Adak based on these recordings.

Another new program commenced in the past year. That is field strength monitoring of two transmissions furnished by the USAF from Thule, Greenland (9195 and 12036 kc/s). These are recorded at both Anchorage and Barrow, Alaska. These paths are of special interest: the former involves the auroral zone; the latter is limited to the polar cap zone. Comparisons on the two circuits are being studied with intent to prepare trial predictions for conditions on them.

During the year, NPRWS received from Koden Electronics Co. Ltd., Japan, the automatic visual-recording high frequency direction finder for which procurement began a year ago. Difficulties were encountered in making final adjustments so that this equipment was placed in full-time operation only in June. Preliminary assessment of its performance indicates that it will be useful in the development of a program for predicting LUHF-MUF for twelve hours in advance over selected radio paths. It is hoped that eventually this equipment can be programmed to sample a selection of path-frequency combinations per hour, in order to provide an accurate, as well as continuous, representation of path conditions at a variety of frequencies.

The change in solar cycle conditions during the year to the declining phase of the present cycle has led to modifications in the advance forecasting methods. The 27-day recurrence tendency is becoming increasingly important. The Advance Forecasts now include a general forecast for 25 days ahead, as well as a 27-day chart of past observed conditions. The descriptive literature concerning the services was appropriately revised and distributed.

Through close liaison with the groups reporting their circuit performance to the NPRWS, the reliability of these outside reports has been improved. Since there are many reasons why outside organizations cannot report their observations in forms easily interpreted as quality figures, NPRWS is turning more and more to its own controlled observations in preparation of radio propagation quality figures for the North Pacific area. The liaison with communication centers in the area permits the operating personnel to understand the significance of the NPRWS forecasts and to suggest other services that would assist its operations.

Many times during the year NPRWS received visitors from various communication agencies and scientific groups, both military and civilian. The close liaison with these people is an important aspect of the NPRWS function. Assistance is given on many propagation problems, in addition to those associated with the regular forecasting of disturbances.

Station improvements have consisted of installation of cement sidewalks, and filling and grading of the roadway leading to the station. The overall appearance of the area was greatly improved by the removal of the old building from the premises. A new jeep, equipped with snow blade, permits the staff to keep the area open during the winter season. The quarters have also been improved with the addition of front sidewalks and safety railings. Two sets had a closed-in entrance hall added. Other improvements were limited to replacement of furnishings as needed.

Through the efforts of the Signal Corps Radio Propagation Agency, at Ft. Monmouth, New Jersey, more modern teletype equipment was obtained to replace obsolete equipment. The system is now full duplex operation, thus making use of both the send and receive equipment simultaneously.

The C-3 ionosonde which has been in use continuously for ten years created some problems during the year. The requirements on the staff did not permit thorough overhaul until assistance could be given by a visiting engineer from Boulder headquarters. At the close of the year, the equipment was again giving good results.

With the anticipated use of the recently installed equipment, specific path forecasts, rather than general area forecasts, should become possible and more reliable than the trial ones now made. The changes in solar-terrestrial relationships, as the cycle progresses towards sunspot minimum, will be followed in preparing forecasts. An improved antenna field is planned for the several recordings now being made. The feasibility of installing a riometer in the station area will be investigated.

Personnel engaged on this project were: L. W. Honea (station chief), D. B. Bucknam (chief forecaster), R. S. Gray, W. O. Wheeler, F. L. Heffentrager, and M. P. Prescott.

## Solar Geophysical Data

82164

NBS research groups, as well as scientific workers throughout the world, especially those involved in space science programs, have need for summaries of solar and geophysical data that are available on a reasonably rapid publication schedule. These data summaries permit relatively prompt evaluation of a wide variety of solar, geophysical and radio propagation experiments. Definitive publication of some of these data appears years, rather than months, after the NBS publication. This project is responsible for this needed prompt data collection and publication. Data are also collected and edited for final publication in the Journal of Geophysical Research. Selected data are also prepared for publication under the international auspices of the International World Day Service of ICSU.

The needs of the large number of scientific and technical organizations that look to CRPL for centralization of the collection, compilation, and distribution of solar and geophysical observations on a prompt schedule are met in several ways. First, brief telegraphic summaries are distributed within a few hours of observation by the CRPL Radio Warning Services (see Projects 82162 and 82163). Second, data are furnished to the High Altitude Observatory, Boulder, Colorado, which prepares a preliminary report, mailed weekly, based largely on the telegraphic information. Third, there is the monthly intermediate publication, the CRPL-F, Part B "Solar-Geophysical Data" report, based largely on prompt, though at times unverified, written reports. Fourth and finally, final publications are issued monthly, or as directed, including definitely reduced observations, syntheses, and interpretive discussions. Almost all of the data on which these publications are based are first used in the CRPL radio propagation disturbance forecasting activities and associated research.

The monthly CRPL-F Part B "Solar-Geophysical Data" report is a unique data source because of its coverage and timeliness. Usually within the first to second month after observation, detailed basic data are given from sources throughout the world. Practically all of the organizations and research workers in the U. S. active in this field, as well as many cooperating institutions abroad, not only request these data but also ask of the possibility of incorporating additional data. This prompt report allows many types of research studies to be completed quickly. In turn, the results can then influence the design of, or changes in, analytical programs, both at CRPL and elsewhere.

At Boulder a vast amount of solar activity data is processed on day-by-day records. CRPL-Boulder research personnel use these for immediate interpretation and/or planning of geophysical and radio propagation experiments. These data are also used for the weekly forecasts of geomagnetic activity discussed under Project 82161. The availability of much of the solar data depends on NBS support to solar observatories (see Project 82165).

CRPL edits the Geomagnetic and Solar Data portion of the Journal of Geophysical Research. This responsibility was delegated to CRPL by the American Geophysical Union. This monthly definitive publication presents data some of which are only available in this journal or otherwise only available after considerable delay in International Scientific Union publications.

For the International World Day Service (IWDS), certain selected data are prepared for publication by various international organizations.

The format of the CRPL-F, Part B monthly report, "Solar-Geophysical Data," has continued to expand to meet the needs expressed above. Information on cosmic ray data and from more solar radio emission observatories are now included. The contents of these reports cover: (1) daily solar indices, (2) solar centers of activity, (3) solar flares,

(4) ionospheric effects of solar flares, (5) solar radio emission, (6) geomagnetic activity indices, (7) radio propagation quality indices, and (8) alert periods and special world intervals. As of June 1961, about 500 copies of this monthly report are distributed under data exchange arrangements. The tables and charts, available at cost like other IGY data through the IGY World Data Center A for Ionosphere and Airglow at CRPL, now go to 50 addresses under the title "Compilations of Solar-Geophysical Data." To facilitate use of the tables, the descriptive text was issued as a separate booklet, including an index to data included since the beginning of the IGY. The formats of tables conform, whenever possible, to international recommendations. Punch card methods permit the monthly handling of this large quantity of data. Techniques to prepare still more of the contents by such methods are always under study. The radio propagation quality figures are now machine listed. The ionospheric effects of solar flares are also being entered on cards with the intent to change publication format; including in addition to the short-wave fadeouts (SWF), sudden enhancement of atmospherics (SEA), sudden cosmic noise absorptions (SCNA), also the sudden phase anomalies (SPA), and sudden enhancements of signal at low frequencies (SES) in one master table. The 9.1 cm spectroheliograms observed by Stanford University, Calif., and the 500-1000 Mc/s spectrum observations by Convair at Owens Valley, Calif., have been added. The cosmic ray data consist of daily indices from the neutron monitor at Climax, Colorado, and a chart of pressure-corrected hourly totals from the standard neutrons monitor at Deep River, Ontario, Canada. The musical note magnetic activity diagram for three-hour-range indices, Kp, for 1960, and the final Zurich daily sunspot numbers for 1960 were included in appropriate issues. The flare data are available through close cooperation with the IGY World Data Center A for Solar Activity at the High Altitude Observatory.

The monthly editing of the selected geomagnetic and solar data for Journal of Geophysical Research consists of a table of selected data -- Kp, Ci, Cp, Ap, $K_{Fr}$, $R_Z$, and Geomagnetically Selected Days. Quarterly principal magnetic storm data, sudden commencements, and solar-flare effects are published. Annually, the Zurich final relative sunspot numbers and the musical note diagram of three-hour-range indices, Kp, are included.

The IGY Calendar Record was completed and submitted for publication in the Annals of the IGY, Pergamon Press. This Calendar consists of matching pages for each ten days of the IGY: on the left, fundamental indices from several of the IGY disciplines; and on the right, brief narrative remarks highlighting the outstanding events or observations made each day. The Calendar is intended as a convenient reference for research workers, not as a basic data source. A similar Calendar Record for 1959 data has been started. All of the necessary material has not yet been received from members of the International Committee for Geophysics which is sponsoring its preparation.

The Geophysical Calendar for 1961 was prepared for the International World Day Service. This lists Regular World Days, days of unusual meteoric activity, days of solar eclipse, World Meteorological Intervals, Regular World Intervals and International Rocket Weeks. These guide research programs in several geophysical disciplines.

The punch card decks, listing flare information from July 1957 onwards, have been made as correct as possible through incorporation of revisions to original data sent by many observatories. These cards are now available for high speed computation of a statistical combination of multiple flare reports into a single weighted report of the solar event. A somewhat similar list of events has been processed for publication by the IGY World Data Center A for Solar Activity. This is the McMath-Hulbert Observatory Working List of Flares for 1959, by Helen W. Dodson and E. Ruth Hedeman, furnished through cooperation with McMath-Hulbert Observatory.

Preparation of 6-hourly sunspot numbers throughout the Greenwich day for each day of the IGY is near completion. Computations for July 1957 through March 1958 are finished. A research note is anticipated, presenting these numbers as indicative of gross changes in solar activity during a day. The American Association of Variable Star Observers Solar Division, prepared revised coefficients and weighting factors for all their standard observers. Similar coefficients for other data available through IGY auspices were prepared at NBS.

The status of the completeness of the solar radio emission files for the IGY to date in IGY World Data Center A for Solar Activity was made for Dr. M. A. Ellison for the International Committee on Geophysics. Appropriate followups are in progress to determine reasons for any apparent gaps in the data files.

The CRPL will continue to process solar geophysical data at about the same general level as at present. An increasing number of requests from U. S. scientific groups, especially those concerned with space research, is anticipated for these rapid publication services. New data will be added to the CRPL-F, Part B reports if possible. Present plans include data on sudden phase anomalies, on ionospheric blackouts, and from riometers.

Personnel contributing to this project included: J. Virginia Lincoln (project leader), O. E. Youngdahl, G. Otto, R. E. Sodergren, and M. E. Adams.

## Associated Solar Observatories

82165

Research groups throughout the world need solar and geophysical data collected and published on a fast schedule for prompt evaluation of their programs. These data are basically those of a patrol rather than research nature. Thus, many of the solar observatories need outside support to make these observations in addition to conducting their research programs. Under this project the National Bureau of Standards makes both contractual and informal arrangements to guarantee continued receipt of the needed data.

Many of the geophysical programs, especially those in space science, depend upon 24-hour coverage of outstanding solar and geophysical events. To insure availability of these data, the CRPL has acted as a centralizing agency. Not only has CRPL collected and published these data, but CRPL has also maintained contracts with several observatories to guarantee that few, if any, gaps in western hemisphere coverage occur. This is logical since much of the data are also vital to the CRPL radio propagation disturbance forecasting services.

The High Altitude Observatory provided daily reports of the intensity of the coronal emission lines, observations of solar flares, occurrence of SCNA, SEA and 18 Mc/s solar radio emission bursts, and outstanding events on the 8-41 Mc/s solar radio spectrograph. HAO also collected similar reports from the Sacramento Peak Observatory with exception of those of the solar radio spectrograph. Frequent liaison was possible with both HAO and Sacramento Peak Observatory staff. A joint conference on scientific programs is described under Project 82161.

McMath-Hulbert Observatory reported both daily and by monthly summaries their observations of calcium plages, solar flares, SWF, SCNA, and SEA. Liaison was mostly by correspondence. Mutual problems were discussed by telephone and at conferences where NBS and McMath-Hulbert staff were in attendance.

Small contracts with the American Association of Variable Star Observers, Solar Division, provided the American relative sunspot numbers and sudden enhancement of atmospherics reports of this group on a monthly basis. Under contractual arrangements to insure prompt receipt of the data, Y. Ohman furnished the solar flare observations made by Sweden at Anacapri, Italy.

As for many years, informal arrangements continued with many observatories and laboratories. The U. S. Naval Observatory supplied daily sunspot positions and areas. 2800 Mc/s solar radio emission data were available daily and monthly through the cooperation of A. E. Covington of the National Research Council of Canada. Wendelstein Observatory of Germany furnished daily summary reports by airmail of many forms of solar activity. Solar radio emission monthly reports were received from the spectrograph of the Harvard Radio Astronomy Station at Ft. Davis, Texas, from the spectrograph of Convair at Owens Valley, Calif., from the interferometer at Nancy, France, and in the form of 9.1 cm spectroheliograms by Stanford University, Calif. The Research Institute of Atmospherics, Toyokawa, Japan, furnished prompt reports of sudden enhancements of atmospherics, as well as did Dr. M. A. Ellison of Dunsink, Ireland. J. A. Simpson and G. Lentz of the Enrico Fermi Institute of Nuclear Studies, University of Chicago, provided the cosmic ray neutron indices from Climax, Colo., and H. Carmichael and J. Steljes, of Atomic Energy of Canada, Limited, gave similar information in chart form from Deep River, Ontario, Canada. Dr. J. Bartels and Dr. J. Veldkamp made the geomagnetic indices promptly available. Dr. B. Beckmann of the Fernmeldetechnischen Zentralantes, Darmstadt, G. F. R., furnished special radio propagation indices.

Much of the monthly solar flare data was obtained through the IGY World Data Center A for Solar Activity at HAO. However, close contact was maintained with the observatories in the western hemisphere. On field trips visits were possible with Dr. Walter Steiger of the University of Hawaii. He and Gail E. Moreton of Lockheed, Los Angeles, Calif., have cooperated in the daily solar data interchange program, providing much needed data, as well as in the monthly reporting. Dr. Steiger also reported SCNA, SEA, and 18 Mc/s solar radio emission bursts. The Dominion Observatory at Ottawa has again made monthly reports on flare observations. The Geophysical Institute at Huancayo, Peru, has been encouraged to increase their participation in the daily data interchange.

Manila Observatory at Baguio, Philippine Islands, was visited and the staff encouraged to participate in the fast interchange of solar and geophysical data as a valuable addition in their longitude of the world.

Thus solar and geophysical data flowed into CRPL for use in many ways. First these data were used daily for the NBS-CRPL radio forecasting centers at Ft. Belvoir, Anchorage, and Boulder. Then they were processed for monthly publication (see Project 82164). Archives of the data are maintained for special research use and for answering specific inquiries.

Both formal and informal arrangements with many solar and geophysical observatories will continue in order to collect, disseminate, publish and archive needed data. Despite the coverage indicated above, there are still gaps in optimum coverage of solar flare and solar radio emission observations. Plans are under way for a major increase in this area of service since CRPL is recognized as the logical centralizing agency for collection and processing of the solar and geophysical data needed by the many U. S. scientific groups concerned with use of such information for evaluation of their experimental findings. Work of this type was supported for several years by special IGY funds, but now should be under NBS financing to provide centralization. Such funding would establish a CRPL Solar Geophysical Activity Service that would guarantee continuation of observation programs needed for both short-term forecasting of ionospheric and communication disturbances, as well as research in cosmic rays, ionospheric physics, auroral physics and other aspects of solar-terrestrial relationships, both at CRPL and at several score other U. S. laboratories. For example, a serious gap exists on the east coast of the U. S. for solar flare observations that are available on a daily basis. A flare patrol in that area would have top priority in such a program. There is a group willing to operate such a patrol if instruments could be made available. NBS would thus support such solar patrol programs through contractual arrangements.

Personnel active on this project were: J. Virginia Lincoln (project leader), and M. E. Nason.

## NASA Satellite Communications

82462

CRPL was selected by the Comite Special de l' Annee Geophysique Internationale (CSAGI) in 1954 to operate the IGY World Warning Agency which now continues under the auspices of the International World Day Service, IWDS, of ICSU. The North Atlantic Radio Warning Service at Ft. Belvoir, Va., (see Project 82162) furnishes staff and facilities for this service. This service has entailed participation in a network of daily solar and geophysical data interchange with other centers throughout the world. As the earth satellite program developed, the World Warning Agency (AGIWARN) was naturally utilized for the international aspects of the program through the systematic distribution of U. S. satellite launching announcements, orbital elements, and observations of all satellites to other regional centers of the world. The World Warning Agency also relays to U. S. computing centers observations of U. S. satellites made by foreign governments. A SPACEWARN network has been established by the Committee on Space Research (COSPAR), and AGIWARN has been designated as a Satellite Regional Warning Center for the Western Hemisphere in this network. Thus, information of U. S. satellites, released by the National Academy of Science or through the National Aeronautics and Space Administration, is made available to cooperating nations throughout the world. This project has been sponsored by the National Aeronautics and Space Administration.

Use of a system such as SPACEWARN is necessary to provide successful coordination among the countries involved in the earth-satellite program. The experience of the World Warning Agency is valuable in many aspects in addition to the actual handling of the communication interchange. For example, advice is given on message content and on the formulation of synoptic codes presenting the data.

During the past year, AGIWARN continued its responsibilities as the Satellite Regional Warning Center for the Western Hemisphere in the SPACEWARN network of COSPAR. In this role, through both telegraphic and mail distribution, AGIWARN served as an international center for U. S. satellite launching announcements originating at the National Academy of Science, and for orbital elements of U. S. satellites prepared by U. S. computing centers. It also served the Western Hemisphere by relaying observations of U. S. and U. S. S. R. satellites from observers abroad to U. S. computing centers.

Broadcasts of satellite information are made in Europe and the Far East. First steps have been taken investigating the possibility of extending similar broadcast coverage of satellite information to the Western Hemisphere.

As an example of the message handling involved, the record for one recent month follows: 26 messages concerning observations from the USSR, Germany, and U.S.A. were forwarded to the computing centers involving reports on 15 satellites; 25 messages containing modified orbital elements for 17 satellites were distributed; and one launching announcement was disseminated. Many messages are received that are not adaptable for systematic redistribution. In the month reported above, approximately 350 messages were received with information on 43 of 51 bodies of known regular Earth orbit.

The request by COSPAR to unify the codes in use for satellite information data interchange was under active study. Proposed changes are being considered by the various U. S. groups concerned, and upon collection of the replies, a single set of codes will be recommended to the COSPAR Working Group.

Under guidance from NASA, the World Warning Agency at NARWS, Ft. Belvoir, Va., will continue to serve as a Satellite Regional Warning Center in the SPACEWARN network of COSPAR, offering services such as are outlined above.

Personnel who contributed to the project were: J. M. Weldon (project leader), J. V. Lincoln, J. W. Cio, H. Hedrick and P. Ruark.

## Project Mercury Radio Warning Service

82464

Systematic forecasts of short time variations in the ionosphere will be made specifically for the Project Mercury ground communications network. This work is sponsored by the National Aeronautics and Space Administration. Prior to a launch, the communications officer in charge of the network will be given special forecasts and interpretations of the forecasts as may be required. Advice regarding the more likely periods for undisturbed conditions will be made available to NASA officials charged with setting dates for launchings.

Short time variations in the ionosphere often adversely affect the reliability of high frequency radio communications. Disruption of communications within the Project Mercury network at the time of launching would interfere with transmission of acquisition data from satellite tracking stations to the master control center. This could result in the satellite and passenger being lost for a critical period of time. Fortunately, short time ionospheric variations can be predicted with a measure of confidence. CRPL has been engaged in this type of work since 1942 and, utilizing its experience, can contribute to the success of the Project Mercury program.

This project became active on September 17, 1960, after a statement of work to be done was agreed upon by NASA and NBS. Upon acceptance of the work agreement, a chief forecaster and a deputy chief forecaster for the Project Mercury Radio Warning Service were appointed from the team of experienced forecasters of radio propagation conditions at the North Atlantic Radio Warning Service (see Project 82162).

A sweep-frequency receiver was ordered for use in this project. The receiver will sweep from 3 to 30 megacycles in 30 seconds, and its output will be recorded on facsimile paper. By using a suitable antenna beamed down-range, this receiver and recorder will permit forecasters to observe the band of frequencies in use, and thus to ascertain the most appropriate operating frequency for some of the Project Mercury stations.

A plan for Project Mercury stations to follow in reporting observed conditions on their various circuits to the Project Mercury Radio Warning Service was finalized, and Western Electric Company undertook its distribution to the field stations. A simplex landline teletype circuit from the Project Mercury communications center at Greenbelt, Maryland, to the radio warning service at Fort Belvoir, Virginia, was installed to facilitate receipt of the circuit performance reports.

Several Project Mercury circuit performance reports are received currently at the radio warning center. They are being correlated with the preliminary quality figures for the North Atlantic area and solar and geomagnetic activity.

Efforts have been made to correlate the available circuit performance reports with the North Atlantic radio quality figures and with flare activity on the sun. Because of the small number of reports that have been accumulated since this project was begun, the results of these efforts are, as yet, inconclusive. There is a suggestion that perhaps, except for severe disturbances, the night-to-day transition period is the time most likely to be disturbed on the middle and low latitude circuits involved.

The project leader visited the administration offices and receiver sites of operating companies and agencies operating Project Mercury circuits in the Pacific area. These visits were in regard to the plan for each station in the network to furnish circuit performance reports to the forecasting center. The project leader was able to convince both administrators and operators that the reliability of the radio forecasts for the Project Mercury network depended greatly on the regular receipt of the requested circuit performance reports. The visits allowed the project leader an opportunity to discuss with circuit operators their various methods used to compile the reports. This is very useful information when deciding weighting factors to each station's reports.

The chief forecaster, on a European trip, was able to visit some of the European solar observatories and make arrangements for the possibility of special reports from them. The need for such reports will depend upon the scheduled hour of launch.

Card-punching of the homogeneous and comprehensive set of sudden ionospheric disturbance data was begun. This is preparatory to updating the empirical formulae used to predict the likelihood of shortwave fadeouts. They will be used for other research projects as well.

A preliminary study on the occurrence of shortwave fadeouts was completed. This work revealed that the number of severe fadeouts occurring in January 1962 would be about one-half of the number which occurred in January 1961. The total number of shortwave fadeouts per month expected in early 1962 is less than ten.

Efforts will continue to correlate the Project Mercury circuit performance reports with solar and geomagnetic activity, with ionospheric data, and with reports of radio quality observed on similar circuits. To assist in this work, as well as the other work at the North Atlantic Radio Warning Service, some thought has been given to the advisability of using an electronic computer. Since the geomagnetic indices, and much ionospheric data, and most event-type solar activity data are already on punch cards, they are readily available for machine computations.

Some time will be spent in developing forecast formats which are useful to the communication officer of the Project Mercury network. Semantics of the forecasts must be carefully worked out to preclude any chance of a misunderstanding or misinterpretation of forecast on the part of the communication officer.

The project leader will visit the Project Mercury receiving stations in Europe and Africa in FY62. He will make personal contacts there,as he did in the Pacific area in FY61. This contact serves to make the radio warning service function clear to the operators of Project Mercury circuits, to explain the circuit reporting plan to the operators,and to acquaint the project leader with station procedures and personalities. While making these visits,the project leader will call at various solar observatories to make arrangement for receipt of unscheduled solar observations. It is conceivable that critical data could be made available by these observatories to the Project Mercury forecasters just prior to a launch.

Plans are underway for the installation of a riometer at the Project Mercury radio warning service (Fort Belvoir, Virginia),and possibly at other locations, e.g.,Anchorage or Puerto Rico. These would enable forecasters to fix quantitatively the amount of absorption. Riometers, also, are a more reliable shortwave fadeout detector than are field strength records since they do not depend on radio transmitters being on air.

Personnel assigned to this project include: M. E. Nason (project leader), J. M. Weldon, K. D. Boggs, E. J. Wiewara, J. W. Pritting, J. M. Kennedy, and W. H. Daniels plus assistance by other members of the NARWS staff.

## Operation of an Ionosphere Sounding Station Near Wallops Island

82465

NBS was requested by the National Aeronautics and Space Administration to furnish ionosonde data from a site near Wallops Island for correlation with data obtained from NASA rocket experiments launched from that site. This meant the installation of a suitable ionosonde and its operation for specifically requested periods.

Ground based observations of ionospheric parameters are often necessary to provide check points for observations made by rocket experiments and for proper interpretation of the rocket results. The ionosonde data should be from as near to the rocket location as possible to minimize the possible differences in the ground based vs. rocket observations. Thus, it was necessary to obtain and install an ionosonde in the Wallops Island area.

Members of the staff of the North Atlantic Radio Warning Service (NARWS) at Ft. Belvoir, Virginia, with special help from NBS-Boulder groups, installed a C-3 ionosonde at Wallops Island. The equipment had been returned to CRPL by the U. S. Army Signal Corps. While there, the staff made recommendations for necessary building improvements, and kept in touch with personnel at Wallops Island during the process of completing these changes. Field site surveys for possible relocation of the ionosonde were made. The C-3 ionosonde was overhauled, put into operational condition, and operated throughout the year, upon request by NASA research groups, during eight rocket launchings. Data were forwarded to the NBS Boulder Laboratories for analysis and transmission to NASA. On-the-spot data evaluations were also made.

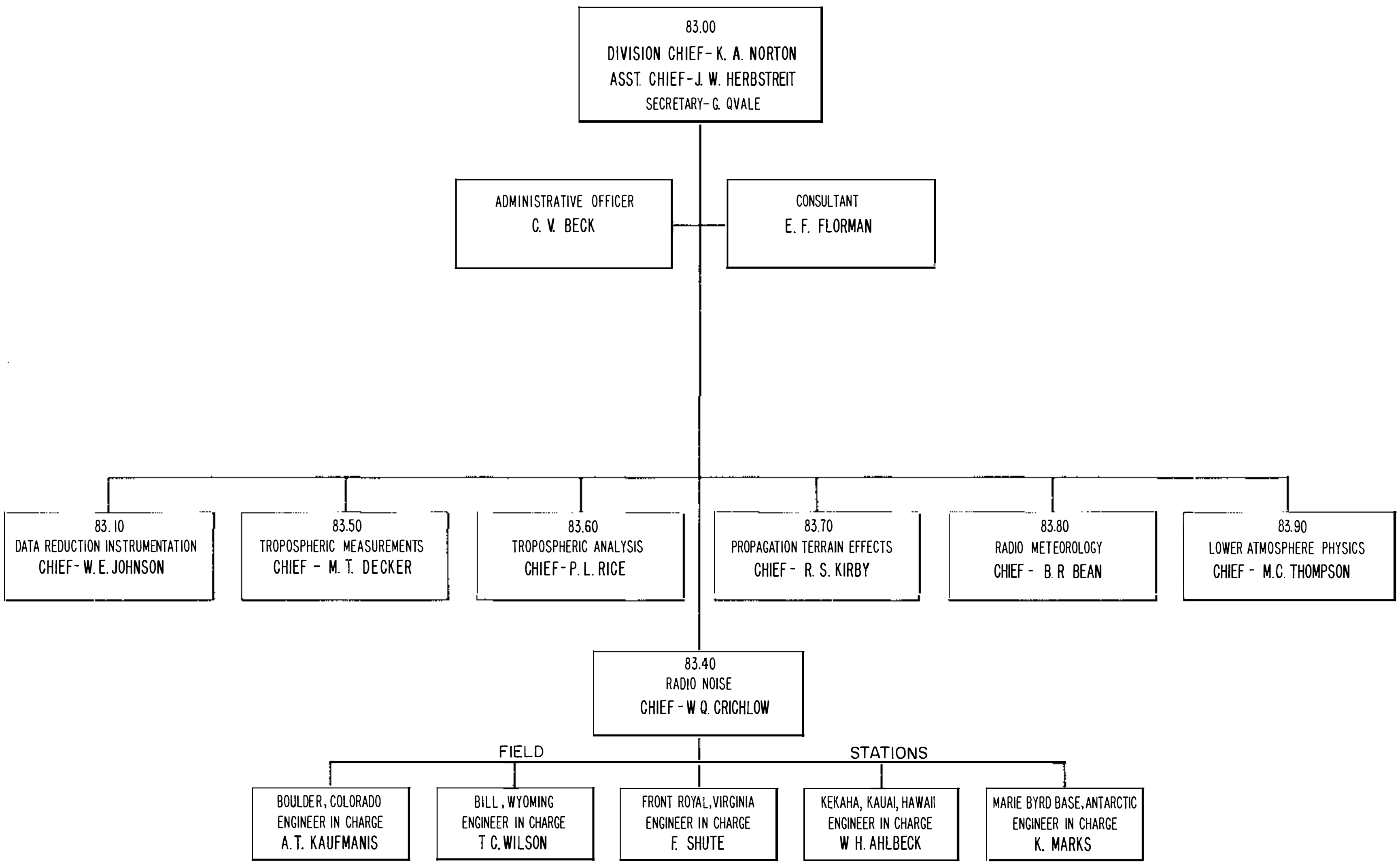
The ionosonde will be periodically inspected to insure it remains in standby condition. More NARWS personnel will be trained to provide the services needed at Wallops Island. The ionosonde will be operated as requested by NASA for rocket launchings and on the desired technical programs.

Personnel who contributed to this project were: E. J. Wiewara, K. D. Boggs, J. W. Pritting, and L. Bauhs.

# RADIO PROPAGATION ENGINEERING

DIVISION 83

RADIO PROPAGATION ENGINEERING



# RADIO PROPAGATION ENGINEERING

## Consultative and Advisory Services

83101

The objective is to provide short term consultative and advisory services to other government agencies, industry, and national and international technical organizations.

This project is an administratively convenient method of accounting for necessary charges occurring when staff members participate in national and international scientific committee meetings and for the time spent discussing general and/or specific technical problems with other agencies and industry.

Members of the staff participated actively on committees for the Institute of Radio Engineers, Consultative Committee International Radio, International Scientific Radio Union, Interdepartment Radio Advisory Committee, and Joint Technical Advisory Committee. Assistance has been given to the Federal Communications Commission on Analysis Industry Advisory Committee studying systems for processing data from the New York City UHF television experiment.

The following is a partial list of other government agencies and industrial companies that were assisted or supplied specific technical information at no charge; sponsoring agencies are not included in this list.

Industry:

Aero Geo Astro Corporation, Alexandria, Va.
Lockheed Aircraft Co., Metuchen, New Jersey
ICS (480L), Paramus, New Jersey
Westinghouse Corporation, Baltimore, Md.
Electronic Communication, Inc., St. Petersburg, Fla.
Hughes Aircraft Co., Fullerton, Calif.
Radio Corporation of America, Camden, New Jersey and New York, N. Y.

AVCO Corporation, Cincinnati, Ohio and Wilmington, Delaware
Collins Radio Company, Burbank, California and Dallas, Texas
Filtron Co., Inc., Flushing, New York
Convair, San Diego, California
Sperry Gyroscope Co., Great Neck, L. I., New York
Sylvania Electronics Systems, Buffalo, New York
Pickard & Burns, Needham, Mass.
McDonnel Aircraft Co., St. Louis, Missouri
Bay State Electronics Corporation, Boston, Mass.
General Electric Co., Lynchburg, Va., and Syracuse, N. Y.
HRB Singer, Inc., State College, Pa.
Space Electronics Corporation, Glendale, Calif.
Rand Corporation, Santa Monica, Calif.
Precision Instrument Co., Washington, D. C.
Collins Radio Co., Dallas, Texas and Burbank, Calif.
Page Communications Engineers, Washington, D. C.
ITT Communication Systems, Inc., Paramus, New Jersey
A. E. Cullum Consulting Engineers, Dallas, Texas
Zenith Corporation, Chicago, Ill.
General Precision Laboratory, Pleasantville, N. Y.
Texas Instruments, Dallas, Texas
Space Technology Laboratory, Los Angeles, Calif.
General Communication Co., Boston, Mass.
National Scientific Foundation, Washington, D. C.
Aeronutronics, Santa Ana, California
American Machine and Foundry Co., Chicago, Ill.
Budd Electronics, Inc., Washington, D. C.
Burroughs Corporation, Paoli, Pa.
Dumont Laboratories, New Jersey
Jet Propulsion Laboratory, Pasadena, California
Martin Company, Orlando, Florida and Littleton, Colorado
Mitre Corporation, Boston, Mass.
Motorola, Inc., Phoenix, Arizona
Cubic Corporation, San Diego, California
Nortronics, Norwood, Mass.
Stanford Research Institute, Menlo Park, California
Hughes Research Institute, Malibu, California
Midwest Research Institute, Kansas City, Mo.
Institute of Defense Analyses, Princeton, New Jersey

Foreign Nations

Institut fur Rundfunktechnik, G mb H, Hamburg, West Germany
Department of Scientific and Industrial Research, Ditton Park, Slough, Bucks, England
Atomic Weapon Research Establishment, United Kingdom
Tohuku University, Sendai, Japan
International Frequency Registration Board, Geneva, Switzerland
University of Birmingham, Edgbaston, Birmingham, England
Geophysikalisches Institut der Universitat Hamburg, Radiometeorologische Abteilung, Hamburg, West Germany

Universities

University of Tennessee, Knoxville, Tennessee
University of Maryland, College Park, Maryland
University of Michigan, Ann Arbor, Michigan
George Washington University, Washington, D. C.
Pennsylvania State University, University Park, Pa.
Duke University, Durham, North Carolina
University of California, Berkeley and Los Angeles, California

Other Government Agencies

U S Naval Research Laboratory, Washington, D. C.
Federal Communications Commission, Washington, D. C.
GEEIA, Attn: AMMXM, Brookley AFB, Alabama
National Security Agency, Ft. G. Meade, Maryland
U S Naval Ordnance Laboratory, Corona, California
Air Proving Ground Center, Eglin AFB, Florida
Geodetics Intelligence & Mapping Research and Development Agency, Ft. Belvoir, Va.
McClellan Air Force Base, California
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Analysis and Measurements of the Performance of Tropospheric Radio Communications Equipment

83103

Modulation Studies
Tropospheric Terminal Equipment

83402

The objectives of these projects are to determine the quality of performance of radio communication equipment versus the carrier-to-noise ratios, when using radio frequency carriers with tropospheric type of fading characteristics. Consultation and advice will be given on measurements to be made so as to take into account both the carrier-to-noise ratio and also the distributions of the carrier and the noise.

The overall objective of these projects was to assist in the determination of how tropospheric radio wave communication can be improved or perhaps optimized through a study of modulation and demodulation techniques, particularly as applied to the equipment.

There is a very urgent need for improvement in radio wave communications as regards to increasing the reliability, message rate and the economy of operations.

Theoretical and experimental studies were carried out to determine the fundamental relationships between message transfer reliability or quality of performance and such factors as signal-to-noise ratios, spectrum bandwidth, available power, intermodulation distortion, frequency stability, radio carrier characteristics, diversity gains, etc.

The results of this work were used as a guide to develop a set of engineering standards suitable for the design of that portion of tropospheric systems covered by the above work. These standards specified the required characteristics of radio transmitting and receiving equipment to be used with various types of modulation and also involved the effect of various combinations of transmission path parameters.

Fiscal Year 1961 tasks will be continued in FY 1962.

Personnel contributing to these projects were: E. F. Florman, J. J. Tary and B. F. Quereau.

## Facility Maintenance

83151

The objective of this program is to maintain and extend present facilities used in the investigation of tropospheric propagation, meteorological and radio noise phenomena.

The field site facilities of the division are used in many projects investigating radio propagation and radio noise.

In addition to rent, utilities, and normal operating costs, a new roof was put on the radio noise building at Gun Barrel Hill.

It is proposed to continue routine maintenance for all field sites. The project number for FY 1962 has been changed to 8300-40-83105.

Personnel contributing to this project were C. V. Beck, M. T. Decker, A. F. Barghausen, R. W. Wilber, R. T. Disney and W. L. Robinson.

## Study of Interference Patterns

83403

To study the interference aspects of space telecommunications systems including: (a) a review of various proposals which have been made for spectrum sharing of space and terrestrial services, (b) an application of the latest available radio propagation knowledge and techniques to the frequency allocation problem for space telecommunication systems, and (c) the presentation of sample calculations to show the results for selected examples. A technical report and a program of future study and experiments deemed essential for obtaining adequate answers to the technical problems which have been presented by the Federal Communications Commission and the JTAC Ad Hoc Subcommittee 60.2 will be prepared in cooperation with the Stanford Research Institute.

The advent of man-made satellites has made possible a tremendous expansion of radio frequency spectrum space technically useable for world-wide radio communications. All radio frequencies up to 40,000 Mc/s have already been allocated internationally for mainly earth-bound telecommunications purposes and one of the greatest problems facing us today is that of providing radio spectrum space for this important new development. The objectives of this project are to provide a sound technical basis to proceed with the solution of this problem.

Predictions of the mutual interference between the ground terminals of satellite communications systems and existing point-to-point services were prepared. These appeared as a chapter of the report of the JTAC to the FCC.

Contingent on additional financing, more extensive work along same lines as in 1961 will be conducted.

## Radio Launch Control System Consultative and Advisory Services

83404

To provide supervision, coordination, liaison, consulting and advisory services by senior technical staff, in the development and confidence test program for a Radio Launch Command System being developed by Boeing Airplane Company.

The Radio Launch Control System is to be used in the Minuteman Program. Extremely high reliability is required to prevent erroneous firing of the missile. Installation of a radio system in lieu of a wired system in the hardened sites will effect a very great savings.

Members of NBS staff attended several Steering Committee meetings in Seattle, Washington and Warrensburg, Mo. Purpose of these meetings was to participate in the evaluation of the Minuteman Radio Launch Control System. A preliminary evaluation was prepared and presented on June 6, 1961. This preliminary report indicates that the system as now installed will not meet established performance requirements. Successful operation of the system may be possible with the Sylvania system, provided that an increase in antenna radiation efficiency is achieved and satisfactory noise suppressing circuitry is employed.

## Tropo Link Tests

83405

The objectives of this project are the measurement of the performance of a tropospheric radio link between La Plata, Md. and Ft. Detrich, Md. in terms of message-load, message error rate, radio receiver output signal-to-noise ratio, and received radio-frequency carrier-signal level. Measurements will also be made of the statistical characteristics of the received radio-frequency carrier signal.

The Signal Corps is experiencing difficulties in obtaining optimum efficiency from the tropospheric radio link mentioned above. Performance tests will be conducted on the system and the results will be compared with previously estimated optimum performance, in order to determine possible modifications necessary to obtain maximum efficiency.

Complete performance-test plans have been made, including the gathering of the necessary special test equipment.

Performance tests will begin July 5. Necessary modifications to the system will be made and they will then be tested. A final report will be prepared outlining the test results.

Personnel contributing to this project were: E. F. Florman, J. J. Tary, B. F. Quereau and P. I. Wells.

## U. S. Air Force Tropospheric Performance Standards

83408

The objective of this project is to prepare for publication a handbook of Tropospheric Performance Standards for the U. S. Air Force.

This publication will provide the Air Force with a comprehensive set of Tropospheric Performance Standards which will be used by all Air Force facilities using Tropospheric Communication systems.

Data have been gathered for preparation of material for the above publication.

GEEIA Handbook Publication

83409

The objective of this project is to complete the publication of a handbook of tropospheric performance standards for the Air Force.

This handbook will provide the Air Force with a comprehensive manual of performance standards for USAF Ground Communication Systems employing tropospheric propagation.

The handbook was completed and published.

Automatic Data Reduction Research

83111

The objective of this project is to improve current methods of data handling and processing by the development of automatic data reduction and computation systems.

A theoretical and experimental radio research program, such as is being conducted by the Radio Propagation Engineering Division, requires the taking and analyzing of a vast amount of radio propagation data. Where such large volumes of data must be processed, there is a constant need for better, more efficient methods of data reduction. It is the responsibility of this project to be thoroughly acquainted with the data recording and reduction problems of all the projects in the division and to provide the assistance required to reduce the data to the desired level. This "assistance" varies from consultive service to projects planning field recording programs to the development of special computation systems designed to meet the reduction need of a particular project.

With the above objectives in mind a variety of data recording and reduction problems were considered. The majority of these problems originated during consultation with other groups within the division and in general were concerned with the recording and reduction of a large volume of field data. In most cases recording requirements were satisfied by recommending the use of multi-channel, FM magnetic tape recorders operating at sufficient speed to accommodate the bandwidth of the desired data. Consideration was also given to keeping the recorded data compatible with the automatic reduction equipment available in the section's Data Reduction Facility. Advanced calibration and editing techniques were developed and introduced into several field recording programs. Special low frequency active filters were developed for use in a multifilter spectral analysis system. Technical Note No. 111, "Data Reduction Instrumentation for Radio Propagation Research", was completed.

The project will continue to keep abreast of the division's needs in the field of automatic data reduction. Advice will be given to groups planning new recording programs and where indicated development will be started on new reduction equipment. Work will continue on the development of the spectrum analyzer mentioned above. Modifications to Projects 83113 and 83114 will also be considered in order to satisfy the particular data reduction requirements of the various research projects in the Radio Propagation Engineering Division.

Personnel contributing to this work were: W. E. Johnson, L. E. Gatterer, and B. C. Willmarth.

## Data Reduction Facility

83112

The objective of this project is to provide support for the Data Reduction Facility. This support provides for the engineering maintenance and modifications which can not be properly charged to individual projects using the facility.

Included in the Data Reduction Facility is a large array of data reduction and analysis equipment which must be calibrated and maintained. As new equipments are added to the facility it generally requires varying degrees of modification to the equipment and to the existing system. The required modifications are generally accomplished during periods when the facility is not being fully utilized. Charges for this work are more appropriately charged to a separate project.

This project was set up primarily for the support of the Data Reduction Facility which is maintained and operated by the Data Reduction Instrumentation Section. This support was in the form of general maintenance of equipment, evaluation and improvement of data handling techniques, and installation of new equipment for the Data Reduction Facility. During the year, further improvements were made in the prewhitening and calibrating techniques. A reduction in the noise level of the playback system at .6 inches per second playback was achieved.

Much of the equipment which is located within the Data Reduction Facility is unique. This presents a maintenance problem when there is insufficient service information contained in the instruction manuals for the equipment. A considerable amount of time was devoted to measuring and recording the waveforms that exists throughout the equipment under normal operation.

A signal analyzer was added to the Data Reduction Facility. This Analyzer will perform four different types of analysis upon a signal as given below.

(1) Cumulative amplitude distribution
(2) Fading rate distribution
(3) Fade duration distribution at several signal levels
(4) Distribution of the percentage of time specific time durations are exceeded.

In addition to the routine engineering maintenance which will be required, certain new equipment will be added to the Data Reduction Facility. A Correlation Computer which is in the final stages of design and development will be added in the very near future. A continued effort is made to improve the accuracy and efficiency of the Data Reduction Facility.

Personnel contributing to this work were: J. A. Sykes, M. S. Johnson and D. R. Stribling.

## Chart Reduction Aids

83113

The objectives of this project are (1) to develop special devices to assist in the reduction of data recorded on strip chart recorders and (2) to develop devices to translate field data into a form suitable for computer entry.

Although the majority of the field data now being recorded in connection with the division's research programs are being recorded on magnetic tape, some of the data are still recorded on E. A. and Sanborn type chart recorders. In addition the division has a need for aids of this type to assist in the analysis of charts now on file as well as for charts received from other agencies. Devices now in use have demonstrated savings of 10 to 1 over previously used methods.

The most efficient media and format for recording experimental data is many times not the most efficient media and format for entry into a general purpose digital computer. Data translation is a very important phase of the data reduction process as it permits editing out unwanted portions of the experimental data and also puts the data in the most efficient form for computer entry.

The major portion of the effort during the past year was expended in developing a Punched Tape Data Translation System. The system includes the following major components: tape reader, removable patchboard type code conversion matrices, electrical input-output typewriter, and tape punch. The system is capable of the following modes of operation: (1) direct copying of data tapes, (2) preparation of data or programming tapes from tabulated data, (3) tabulation in typewriter output format the data punched on paper tape, and (4) simultaneous read, print out, code conversion, and preparation of a new tape.

A special keyboard and tape punch system was also developed for the preparation of tapes for the Bendix G-15 Computer.

Instruction manuals and circuit diagrams will be prepared for the translation system. Modifications will be made to certain existing chart reduction aids. New devices will be designed as required to meet the needs of the various experimental projects within the division.

Personnel contributing to this work were: W. E. Johnson and R. A. Blumenhein.

## Special Signal Analyzers

83114

The objective of this project is to develop special analysis and control circuitry to aid the general program of the section. Typical of the equipment developed are: (a) a special computer to analyze time varying data for their amplitude characteristics, (b) special control circuitry for analysis control applications, and (c) modifications to an electronic digital voltmeter to meet special requirements.

At present large quantities of data are being recorded in an analog form on magnetic tape by other sections of this division. By recording on magnetic tape the data are stored in an electrical form and are readily available for automatic analysis in the laboratory. With analyzers of this type it is possible to play the data back from the magnetic tape at a speed exceeding that at which it was recorded and reduce directly from it the desired signal characteristics. This relieves the need for much time consuming manual analysis and costly computer time.

Development has been completed on a comprehensive system which will compute four desired data amplitude characteristics, i.e., the cumulative amplitude distribution, the fading rate distribution, the fade duration distribution for the various data levels, and the distribution of the percent of time specific time durations are exceeded. The system is based on a pulse counting technique where the incoming data are sampled 20,000 times per second and each sample is then compared against a reference. The output of the comparator is in the form of two pulse trains, one pulse train representing periods when the data exceeded the reference level and the second pulse train representing periods when the data are in a fade (or are below the reference level). The two pulse trains contain the necessary information for obtaining the four data characteristics mentioned above. When the analysis about a reference level is completed the accumulated data are printed out on a digital recorder, and the instrument is reset and the reference is stepped to the next preset level. Thus the data being analyzed can be automatically compared to up to ten preset reference levels. Modular techniques were employed to increase the flexibility of the system so that it can be more readily adapted to other analysis problems as they might arise. Where practicable the system has been transistorized to reduce space and power requirements.

An automatic sampling digital voltmeter with readout onto punch paper tape was modified for special data sampling applications. The voltmeter has a basic sampling rate of sixty samples per second and punches a seven bit binary code onto the paper tape. For one application it was modified to sample once per second with the sampling controlled from an external source. For a second application the voltmeter was modified to sample each of two data sources once per second. Through the use of static pulse logic the data sources were sampled one sixtieth of a second apart, thus approaching simultaneous sampling.

During the coming year some work will be done to increase the versatility and broaden the scope of application of the amplitude analysis system described above. Some peripheral instruments will be added to improve the automatic and editing capabilities of the system.

The basic design has been completed to directly measure the median level of time variant data. The plans are to construct a pilot model of such a system. Some time will be devoted to the design of special circuits to support the general program of the section.

Personnel contributing to this work were: P. I. Wells, D. V. Glen, B. C. Willmarth and R. D. Moodv.

## Correlation Computer

83115

The purpose of this project is to design and develop a specialized Automatic Correlation Computer for use in studying tropospheric effects on radio propagation in VHF, UHF, and SHF regions of the radio spectrum. This type of analysis is of prime importance in carrying out the basic research responsibilities of the Radio Propagation Engineering Division, National Bureau of Standards, Boulder Laboratories.

In the research program conducted within the above division, vast quantities of data are collected in fields of both radio propagation and associated meteorology of the lower atmosphere or troposphere. It is the responsibility of the Data Reduction Instrumentation Section to provide economical, rapid, and accurate instrumentation to reduce these data to useful forms for both theoretical and practical analyses. It is to this responsibility that the computer under development is directed.

A completely analog system has been designed to provide an automatic correlation analysis of data recorded on magnetic tape. A speed-up factor as high as 100 may be employed in analyzing magnetic tape data. The system is being developed to provide the analog solution of the following parameters: auto and cross correlation functions, covariance functions, and normalized correlation coefficient.

The technique developed in computing these values operates around a modified quarter square multiplying system. In order to facilitate the 10 kc bandwidth, it was necessary to develop the multiplier system within the scope of the project since the wideband system could not be procurred from industry. In the technique, computation is made of the variance of both the sum and the difference of the two data input signals. These computed analogs are further added and subtracted by standard computing techniques to yield terms proportional to the correlation function or the covariance function depending on the treatment of the mean values of the signals at the input to the computer. The sum of the variances of the individual signals are also computed. This quantity is used in a unique manner to normalize the covariance term, and thus compute the correlation coefficient when desired.

A complete mock-up of the above system has been constructed and successfully demonstrated, using for the most part available laboratory instruments and equipment. The final computer package is presently under development, in which some specialized and standard analog computer components are being employed.

A dynamic delay time feature as outlined in the project summary for Fiscal Year 1961 is to be used in the system. This feature will eliminate the necessity for discrete computation and will provide instead a continuous solution for all parameters. A dual-capstan tape transport mechanism is being negotiated for, to provide this important feature.

The computer as described above is presently nearing completion, and the final instrument will become an integral part of the Data Reduction Facility of the Radio Propagation Engineering Division during Fiscal Year 1962. It is planned to procure the special transport system as early as possible during the year.

Personnel contributing to this work were: R. W. Hubbard, J. V. Cateora and R. D. Moody.

## RLCS Radio Noise Data Reduction

83414

The objective of the project is to obtain by machine methods, amplitude probability distributions and probability density functions of tape recorded radio noise data taken in conjunction with the Radio Launch Control System confidence tests and at various stations in the NBS radio noise network.

The effects of external radio noise in general and atmospheric radio noise in particular will be one of the largest factors in determining the reliability of a radio launch control system such as is being planned for use in the Minuteman program. Therefore, this program in the over-all confidence tests will, to a large extent, determine the feasibility of using a radio launch control system in place of a wired system. Since the complete installation must be a hardened system, the savings in using a radio system would be very large on each installation.

Details of the machine methods of obtaining the amplitude probability distributions and probability density functions have been worked out. As soon as samples of the radio noise recorded at the various field sites are available, the APD's and PDF's of the samples will be completed.

Data reduction to obtain the APD's and PDF's of the noise samples will continue through the end of the recording period (approximately April 1962).

Personnel contributing to this work were: W. E. Johnson and P. I. Wells.

## Tropospheric Measurements

83152

A basic understanding of the physical characteristics of the lower atmosphere and their relation to radio propagation phenomena is the principle objective of this tropospheric research program.

The efficient utilization of the radio spectrum for communication systems may be considered first, in terms of the service fields, which depend largely on the median and weaker field strengths observed for high percentages of the time; and second, interference fields, which occur for small percentages of the time at very high field strengths.

To meet the above objective and provide a long term study of the variations in service fields and interference fields by comparison with meteorological observations near the earth's surface at each end of the Boulder-to-Haswell path, transmitting and receiving equipment operating at 100, 400, 1000 and 10, 000 Mc has been constructed and is being installed.

A triplex feed system has been designed and constructed to allow simultaneous transmission and reception of 400, 1000 and 10, 000 Mc from a common 60 foot parabolic antenna located at each end of the path.

In addition, an extensive long range measurement program was initiated to experimentally verify the predictions of estimated interference expected to occur between ground terminals of space communication systems and surface point-to-point systems. The principle objectives of this study are to determine the minimum separation distances and antenna elevation angles for the space communication systems such that the interfering signal power appearing at the receiver input terminals is equal to or less than the receiver noise power for a given percentage of time.

The 60 foot diameter, elevation-azimuth antennas located at each end of the Boulder-to-Haswell propagation path are used to measure the transmission loss for various elevation angles at a frequency of 409.9 Mc. From this experiment, conducted over long periods of time, reliable estimates of the amount of transmission loss which may occur for small percentages of the time can be determined when narrow beams of earth-satellite systems are directed well above the horizon. Present theories give conflicting results and on this basis it is important that measurements be made which will provide the data necessary for selecting an appropriate prediction formula and proving its validity.

Preliminary measurements involving elevation angular beam swinging obtained over the Boulder-Haswell test path at 409.9 Mc in February, 1961, were used in a report supplied to the Joint Technical Advisory Committee of the E.I.A. and I.R.E. entitled "Mutual Interference Between Surface and Satellite Communication Systems" by W. J. Hartman and M. T. Decker.

Personnel contributing to this work were M. T. Decker (Section Chief), A. F. Barghausen (Project Leader), S. Murahata, F. O. Guiraud, R. W. Wilber, R. M. Ray, C. E. Fuqua, J. M. Harman and L. Kulhanek.

## 9100 Mc Propagation Studies

83153

This project was established as a continuing program leading toward an examination of the physical characteristics of the lower atmosphere and their relation to radio propagation phenomena.

To accomplish this general objective, work is now in progress to completely instrument, for both meteorological and radio measurements, the Boulder-Haswell test path utilizing radio frequencies of 400, 1000 and 9100 Mc.

During the past year, work was completed on a 2-kw, 9100-Mc transmitter driven by a low noise reflex klystron which, in turn, is phase locked to a stable oscillator with a frequency stability of 2 parts in $10^{10}$ per day. Four narrow band (50 cycle), 9100-Mc receivers have been completed and are available for the radio propagation studies over this path. Work has been started on a triplex feed system which will be used in the 60-foot elevation-azimuth parabolic antennas available at each end of the path to allow simultaneous transmission and reception of 400, 1000 and 9100-Mc signals.

During Fiscal Year 1962, work will continue on this program with the goal of beginning continuous recordings by FY 1963.

Personnel contributing to this work were A. F. Barghausen, S. Murahata (Project Leaders), R. W. Wilber, F. O. Guiraud, R. M. Ray, and C. J. Bowen.

## Wideband Data Transmission Link Measurements

83454

The objectives of this project are to determine the optimum frequency, power requirements, performance estimates, and, in particular, bandwidth limitations imposed by the medium for data transmission circuits over line-of-sight paths up to 500 miles.

During January, February, and March of 1961, an experimental program was initiated between Cheyenne Mountain and Karval, Colorado, to determine the limitations imposed by the medium for wideband data transmissions at 9300 Mc. The experiment was conducted using two transmitters and receivers with a frequency separation of 100 Mc. The received signal envelopes were recorded on magnetic tape and analyzed by obtaining the serial and cross-correlation values which in turn are used to estimate the maximum usable bandwidth. Thus, this means of analysis will include an estimate of the effects of the atmosphere on the received signals. These atmospheric effects are primarily the reflections from elevated layers and trapping of the signal in elevated ducts, both causing signal enhancements as well as defocusing with resultant fadeouts.

Concurrently with the above, a 1040-Mc carrier was transmitted over the same path to observe the radio frequency effects of prolonged space wave fadeouts with respect to time duration of fade, depth of fade, frequency of occurrence, and other signal amplitude characteristics.

A report entitled "Fading Characteristics and Bandwidth Capability for Within-the-Horizon Propagation at 1000 and 9000 Mc/s", by A. F. Barghausen, A. P. Barsis, and R. S. Kirby is now in progress. This investigation was performed in conjunction with Project 83470.

Plans for Fiscal Year 1962 are to complete the analysis and issue the above report on Project 83470. Additional support will not be available to continue the experimental investigation.

Personnel contributing to this work were: A. F. Barghausen (Project Leader), J. B. Snider, F. O. Guiraud, R. M. Ray, J. M. Harman, and C. E. Fuqua.

## Angular Diversity Measurements

83455

This project was established to provide consultative services to the Westinghouse Corporation for field experiments in a feasibility study of angular diversity as a technique of improving the reliability of tropospheric scatter communications systems.

During December, 1960, a two-week measurement program was conducted over a beyond the line-of-sight propagation path extending from Shaw Air Force Base to Myrtle Beach, S. C., a distance of 130 kilometers.

The equipment used for these experiments was the AN/TRC-66 operating in the 4400-5000 Mc frequency range, which was undergoing complete field tests before acceptance for operational use by the U. S. Air Force.

Continuous records of the amplitude variations were made on magnetic tape for various configurations of the dual horn feed systems in the 14-foot parabolic antennas. Each horn output was fed to a separate receiver and recorded on magnetic tape for simultaneous analysis by automatic data reduction techniques developed at Boulder Laboratories, NBS.

Various horn configurations and separations for both horizontal and vertical polarizations were used, as well as dual configurations at both the transmitter and receiver terminals. Preliminary antenna patterns were obtained for each configuration to determine the amount of beamwidth separation obtained for the various physical separations.

The magnetic tape records will be analyzed under another project and a report written in conjunction with Westinghouse personnel.

This particular project is completed. Additional support is not comtemplated during FY 1962.

Personnel contributing to this project were A. F. Barghausen (Project Leader).

## Remote Microwave Probing of the Atmosphere

83456

This project seeks to determine the possible use of microwave frequencies for the determination of temperature and/or water vapor content of the atmosphere, directly or indirectly, by active or passive means, at space coordinates remote from the location of the measuring apparatus. The final result of this study will be a proposal for the design of an experiment to meet this objective.

A specific Army requirement exists for remote sounding of the atmosphere to the extent that basic parameters of the atmosphere such as temperature and water vapor content, etc., should be determined within an atmospheric volume as big as possible without the need of probes located in situ or traversing the region of the atmosphere to be probed.

Some work has been done in a literature search to determine the kind and amount of research in this field which might serve as a basis for the design proposal of a field experiment to meet the above objective.

It is proposed to continue this literature search, and theoretical studies being conducted under Project 83489 and to submit a design proposal of a field experiment to the sponsoring agency.

Personnel contributing to this work were M. T. Decker (Project Leader).

## Bandwidth Capability of Tropospheric Scatter Communications Circuits

83457

The primary objective of this project is to determine the limiting effective bandwidth of the atmospheric medium for multiple communications channels on long distance tropospheric forward scatter circuits.

During the latter part of Fiscal Year 1961, an experimental program was initiated which will provide bandwidth limitation information to serve as a basis for predicting the quality of service, or message error rate, in tropospheric telecommunications circuits. The bandwidth capability will be determined as a function of such parameters as the antenna beamwidth and path length.

To accomplish the above objectives, an experimental path has been established between a receiving terminal at Boulder, Colorado, and a transmitting terminal near Altus, Oklahoma, a distance of 800 kilometers. An intermediate receiving site will be used at Haswell, Colorado, 500 kilometers from the Altus transmitting terminal. Thus, from simultaneous records at both distances a measure of the path length dependence versus bandwidth limitations will be obtained.

The determination of the bandwidth capability will be made by simultaneous transmissions on two r-f carriers spaced 0.5, 1, 2, 4, and 6 Mc apart, and obtaining the cross-correlation coefficients for various sample lengths. The correlation coefficient of the two received signals will be a function of the frequency separation, $\Delta f$, and other propagation variables. A high correlation coefficient means that the signal components at either end of the frequency band are essentially in unison and little or no distortion exists. Conversely, a low correlation coefficient means distortion is present, and the frequency separation must be reduced to maintain coherence over the band.

Theoretical studies have shown that distortion in the received carrier envelope over a wide bandwidth may be related to multipath delays caused by atmospheric irregularities within the scatter volume. Since the size of the scatter volume is determined by the antenna beamwidths at each end of the path, antenna sizes ranging from 4.3 meters to 18.3 meters in diameter will be utilized on the test path to ascertain the beamwidth effect on the useful bandwidth.

The transmitting location near Altus, Oklahoma, has been established and a 10-kw transmitter, operating at 410 Mc, is now being constructed. Cavity loading and stagger tuning of the final amplifier tube will be employed to obtain the 6-Mc bandwidth required for the tests. Two narrow band, high gain receivers will be used at each receiving location having separate crystal oscillators and multipliers for each pair of frequencies transmitted.

This is a continuing program. Measurements will be obtained during the first part of Fiscal Year 1962, and a detailed analysis and report issued.

Personnel contributing to this work were A. F. Barghausen (Project Leader), S. Murahata, F. O. Guiraud, J. B. Snider, R. W. Wilber, R. M. Ray, C. E. Fuqua, J. M. Harman, L. S. Kulhanek, W. J. Hurst and R. B. Gearhart.

## Manufacture of 2-kw, 400-Mc Transmitter

83814

This project was established for the construction of a 400-Mc transmitter with a power output of 2 kw. It is intended to be used with another 400-Mc, 2-kw transmitter of similar design for long term studies of the medium bandwidth obtained over the Boulder-to-Haswell test path.

Several new features have been incorporated in the design of this second unit. These are: (1) the design of a roll-out carriage for easier installation and removal of the final amplifier tube, (2) front panel cavity tuning by a series of gears and linkages to control the resonant frequency of the final tube, and (3) exciter redesign to allow easier maintenance and adjustment.

The transmitter has been completed. Final testing is now in progress.

Personnel contributing to this work were R. W. Wilber (Project Leader), J. M. Harman and C. E. Fuqua.

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## Radio Noise Field Operations

83141

The objectives are to gather and disseminate data pertaining to external radio noise levels in relation to location, time of day, season, and sunspot cycle.

Radio noise is the basic limitation to any radio communication system. In general, interference from unwanted signals and internal or "set" noise can be controlled by the design and construction of the equipment to be used. Conversely, external radio noise is not under the control of the design or operating personnel. A knowledge of the external radio noise both as to level and character, is necessary to determine the efficiency and reliability of the communications system involved.

The measurement of external radio noise involves the study of radio noise arising from three principal sources - man-made, atmospheric, and galactic. The predominant type of noise will be determined by the frequency used, the existing propagation conditions, time of day, and location of the receiving equipment. Since radio noise of varying character will not affect different types of communication systems in the same manner, it is necessary to have a knowledge of both the character and level of the external radio noise for a complete evaluation of any given communication system. The importance of the radio noise work has been recognized at the international level by CCIR and URSI. Various agencies under the Department of Defence as well as commercial users of radio communication systems have used and shown great interest in the predictions of world-wide radio noise.

The radio noise program is a cooperative project under the general direction of CRPL but also involving the Signal Corps Radio Propagation Agency, Bureau of Ships, Air Force, National Science Foundation, and agencies of eight foreign governments.

During FY 1961, data were collected from seventeen fixed-location field sites throughout the world - one new location, Warrensburg, Missouri, having been added to the network this year. Measurements of the received radio-noise power were recorded at all stations. The necessary equipment for measuring the average voltage and average logarithm of the voltage envelope was installed at the Bill, Wyoming and Singapore field stations. The total number of stations recording the three moments is now twelve. The data recorded at these stations were published in Technical Notes, Nos. 18-4, 18-5, 18-6, 18-7, and 18-8.

The central repair depot at Boulder operated through the year taking care of normal maintenance, repair, and supply activities for all field stations. In addition to this routine work, updating of the units as required by the results of the sustaining engineering work performed was carried on throughout the year. The program of changing the recording frequencies of the older equipment to the new equipment frequencies continued.

In conjunction with the work done by another division, the mobile radio noise recorder was taken to the Cape Canaveral area. Measurements of man-made noise were made at several preselected sites to furnish data for the evaluation of the various sites as transmitting or receiving locations for the Atlantic Missile Range Communications Network.

An inspection and consultation trip was made to thirteen of the seventeen field stations to insure proper operation of the stations.

The seventeen stations in the present network will continue the routine recording program. New equipment for sweeping the spectrum from 40 c/s through 550 kc/s will be installed at three locations so that measurements of the frequency law of the noise can be extended to this lower frequency. This same recording equipment, operating on a time sharing program with the ARN-2, will provide spectrum occupancy of stations in this frequency range and by recording the received power from the stations on an absolute basis, will provide a means of determining the transmission loss over a large number of propagation paths. If additional equipment for mobile recordings is available, studies of man-made radio noise will be made at several locations. A vehicle suitable for this work has been acquired, but recording equipment compatible with the equipment at the field stations is needed.

Personnel associated with this project were: W. Q. Crichlow (Section Chief), R. T. Disney (Project Leader), W. H. Ahlbeck, M. A. Jenkins, A. T. Kaufmanis, K. E. Marks, D. R. Reed, E. H. Rogers, W. L. Robinson, F. Shute, T. C. Wilson.

Radio Noise Measurement Techniques

83142

The objectives of this project are the development of instrumentation for making precise measurements of radio noise, and the subsequent research into the detailed characteristics of radio noise based upon these measurements.

Some of the instruments developed by this project are incorporated into the program of the Field Operations Project for use in the world-wide recording network. The research into the detailed characteristics of radio noise is of importance in the determination of the equipment and methods to be used in the field recording program. The results of this research also provide information for the evaluation of specific communication systems in the presence of extraneous noise, allowing more efficient systems to be designed.

Service tests and analysis of the Energy Spectrum Recorder continued. The mixer and filtering circuits were redesigned in order to allow operation of the equipment in the ELF range. Design work was started on control circuitry for the recorder to allow preprograming of the frequency steps and change of the frequency increment and bandwidth used in various portions of the spectrum during a complete sweep. This circuitry will also provide positive frequency identification for each step. The local oscillator drive was redesigned and built. This drive system had to meet very stringent requirements in order to be used with the control system. For instance, the main tuning shaft had to be rotated by $0.036 \pm 0.006$ degrees for each small frequency increment step, yet had to be capable of moving through 1800 degrees per minute on the fastest drive in the same system.

The design of a new antenna coupling unit and associated preamplifiers for the mobile recording unit was started. This new unit will extend the frequency recording range of the present modified commercial equipment up to 50 Mc/s and down to 13 kc/s.

Final design and packaging of the Energy Spectrum Recorder will continue through the first part of the year. Upon completion of the construction of this unit, it will be placed in operation at one of the field sites.

Equipment will be constructed to use in conjunction with an F.M. tape recorder so that samples of noise can be recorded in bandwidths up to 2 kc/s and over the complete dynamic range of the noise. These recordings will then be used for various forms of analysis such as determining the amplitude-probability distribution, pulse crossing rates, pulse durations, and correlation functions of a stationary sample of the noise.

Development of a portable noise measuring recorder will begin. This will be a transistorized, battery-powered, radio-noise meter with absolute calibration means to be used in site selection work or special localized man-made noise measurements.

Personnel associated with this project were: W. Q. Crichlow (Section Chief), C. J. Roubique (Project Leader), R. J. Bosworth, L. J. Edlin, C. M. Minister, R. J. Matheson, R. E. Ridgeway, and J. A. Tonkinson.

## Radio Noise Analysis and Predictions

83143

The objective of this project is the development of an improved world-wide radio noise prediction service, covering an extended frequency range.

Since the results of the research in Projects 83141 and 83142 are analyzed in this project, it has the responsibility for achieving the ultimate objectives of the whole section.

Contour maps of the world showing expected thunderstorm activity were drawn. The maps give information for each hour of the day for each of the four seasons - ninety-six maps in all. These maps are now ready for final drafting and publication. It was originally planned that only working drawings of these maps would be made for use in the development of a method for determining the received atmospheric radio noise based on the meteorological data portrayed on the maps. However, since widespread interest in the maps was shown as a result of a paper presented at the Fall URSI meetings, it was decided to publish the maps themselves for use in fields other than the prediction of radio noise.

A first approximation of the expected radio noise at Boulder, Colorado was calculated using a simplified propagation law. The results of this calculation appeared to give approximately the correct diurnal and seasonal variation noted in the measurements at Gunbarrel Hill.

A preliminary study of the noise records from the sixteen field stations was made to determine the reliability of the CCIR Report 65 predictions and to find the expected value of the amplitude-probability distribution for the two summer nighttime time blocks. A best estimate of the noise for all time blocks for Boulder (Gunbarrel Hill), Colorado was worked out and compared with the CCIR Report 65 predictions. In order to obtain a best estimate from the data, a four-dimensional fit is required. Since the mathematical fit is quite involved, work was started on the writing of a computer program to give a simultaneous least squares fit in all four dimensions.

The computer program for obtaining the best estimate of the noise for each location from which data are available will be completed. As soon as results from this program are available, either new predictions to replace CCIR Report 65 will be prepared or the reliability of the present predictions will be determined and published.

A prediction of the other two moments of the noise in addition to the power moment as predicted in CCIR Report 65 will be made. This will allow a prediction of the amplitude-probability distribution for any location to be made based on the method developed by this section for determining the distribution from the three moments.

Work will continue on the method of predicting atmospheric radio noise based on propagation characteristics and world-wide meteorological data.

Personnel associated with this project were: W. Q. Crichlow (Section Chief), R. C. Davis (Project Leader), M. W. Clark, and A. D. Spaulding.

## ELF-VLF Radio Noise Recorder Design

83442

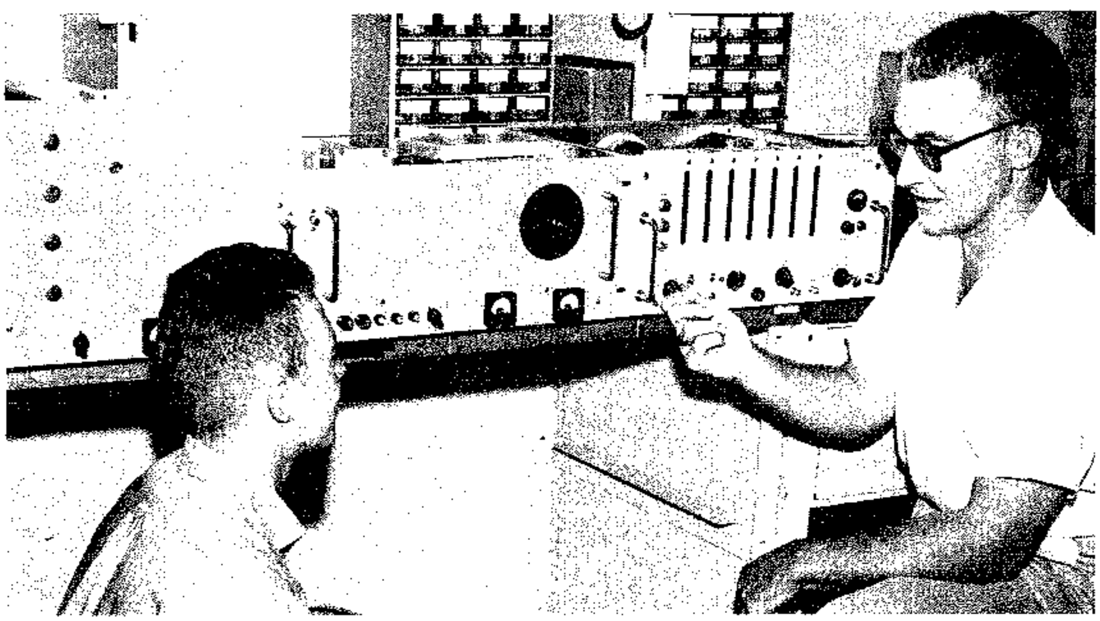
The objective is to develop equipment for recording noise levels below 14 kc/s and construct two sets of equipment for field use.

Radio noise measurements in this frequency range have been extremely scanty up to the present time, practically no data being available in quantative form such that the interference to communications could be evaluated under typical environmental conditions.

It was found that with modifications, the Energy Spectrum Recorder could be used to obtain the information required from the stepping recorder. Therefore, the bulk of the design work performed on this project was to increase the versatility of the Energy Spectrum Recorder so that it could be used for this work. This portion of the program has been completed, and the two units have been essentially completed.

The phase of the program covered by this project has been completed. The design of the programing control circuitry for the Energy Spectrum Recorder will be completed under Project 83142 and incorporated in the two units constructed under this project at that time.

Personnel associated with this project were: W. Q. Crichlow (Section Chief), C. J. Roubique (Project Leader), R. J. Bosworth, L. J. Edlin, C. M. Minister, R. J. Matheson, R. E. Ridgeway, and J. A. Tonkinson.



Project members discuss the operation of the programmed automatic frequency step and bandwidth control system developed for the energy spectrum recorder.

Spectrum Recording and Analysis

83443

The objectives of this project are to record the radio energy at a large number of discrete frequencies in the radio frequency spectrum below 600 kc/s. Two or more spectrum recorders will be operated for one year in conjunction with the ARN-2 Radio Noise Recorders. The records will be analyzed to determine radio noise characteristics in the ELF, VLF, and LF ranges.

Noise measurements in the lower portion of this frequency range have been very meager in a quantitative form such that interference to communications could be evaluated. This project is the first phase of a more extensive program planned to alleviate this lack of information at these lower frequencies and also to provide information on station density in the frequency range extending through the HF portion of the radio spectrum.

The prototype equipment was checked at the Gunbarrel Hill, Colorado field station. Operational procedures were studied. Actual operation will start with the completion of the two units being constructed.

The recording program will be continued through a period of twelve months. Analysis of the data for the year will be made and a final report giving radio noise information obtained from the analysis will be prepared for the sponsor, U. S. Navy, BuShips.

Personnel associated with this project were: W. Q. Crichlow (Section Chief), R. T. Disney (Project Leader), and W. L. Robinson.

RLCS Reliability Noise Measurement and Analysis

83444

The objectives of this program are to gather radio noise at the RLCS confidence test site and evaluate the reliability of the system in terms of the measured parameters of the noise. The reliability of the system can then be determined for other geographical areas based on measurements of radio noise recorded by the National Bureau of Standards world-wide network of stations.

The effects of external radio noise in general and atmospheric radio noise in particular will be one of the largest factors in determining the reliability of a radio launch control system such as is being planned for use in the Minuteman program. Therefore, this program in the over-all confidence tests will, to a large extent, determine the feasibility of using a radio launch control system in place of a wired system. Since the complete installation must be a hardened system, the savings in using a radio system would be very large on each installation.

Assistance was given to Boeing Airplane Company in manufacturing an ARN-2 radio noise recorder for use at the confidence test site in Missouri. The equipment was tested and installed at the test site and Boeing Airplane Company personnel were trained in the operation of the equipment.

Predictions of the noise to be expected at the test site both as to level and character were prepared. Based on these noise predictions, a preliminary evaluation of the reliability of the system was prepared.

Measurements of the noise and signal were made on the above ground (ARN-2) antenna and the hardened underground antenna. The underground antenna losses were obtained, and a comparison of the losses of the two antennas with a change in the character of the noise was investigated.

The writing of computer programs for the analysis of the noise data was started.

Measurements of the noise at Warrensburg will continue including special short-term measurements of various characteristics of the noise. These short-term measurements will be correlated with error-rate measurements made by Boeing or Sylvania at the same time. From these data, signal to noise ratios to give the required grade of service will be determined. Based on the results of the analysis of these data, reliability curves for the system will be prepared.

Personnel associated with this project were: W. Q. Crichlow (Section Chief), R. T. Disney (Project Leader), R. C. Davis, and C. J. Roubique.

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## Shipboard Noise Measurements

83445

This project seeks to measure the level of the radio noise aboard the ship to be used as a Floating Antarctic Research Station. The radio noise of concern to this project is that noise generated by and in connection with operation of the vessel. The level of the noise that is acceptable or tolerable in the conducting of the various experiments to be aboard the ship will be determined. Recommendations for the reduction of the noise as measured to that which is determined to be acceptable will be made. After installation of the recommended noise suppression equipment, the noise level will again be measured to make sure the reduction to the acceptable level has been met or exceeded.

This ship will be used in an extended voyage in the area 40$^{\circ}$ south and below. In order to insure the success of the experiments aboard, the radio noise caused by the ship must be at or below the level of the noise that would disrupt the conducting of the experiment.

A general inspection of a sister ship to the actual ship to be used was made. This inspection was for the purpose of determining possible sources of radio noise associated with the operation of the ship and to plan the measurements that are to be made. No measurements can be made until the ship is available.

The measurements will be made, and recommendations for suppression of all objectionable noise will be made. After the installation of the recommended radio noise suppression equipment, the ship will again be checked to insure that the required degree of quieting has been achieved.

Personnel associated with this project were: W. Q. Crichlow (Section Chief) and R. T. Disney (Project Leader).

## T. V. Coverage

83161

The primary objective of this program is to study the potential coverage of television broadcasting stations as a function of distances between stations, radio frequencies, antenna heights, etc. This study will be similar to an investigation made in 1949 for the Federal Communications Commission Ad Hoc Committee, but will be based on extensive additional propagation information obtained since that time, largely by CRPL, plus information on cochannel and adjacent channel protection ratios recently published by the Television Allocations Study Organization.

This study should provide an objective basis for resolving some of the critical technical problems encountered in properly dividing that portion of the spectrum from 54 to 890 megacycles per second between TV and FM broadcasting and other services.

During the past year calculations of the performance of television systems in the presence of interference from other stations were begun. These calculations show the effects of various techniques which may be used to reduce interference and increase the area covered by a single channel. These techniques include precision off-set, directional receiving antennas, and cross-polarization of interfering stations. Optimum separation of stations for efficient use of channels is the principal result of the calculations. Application of these results to a realistic geographical arrangement of stations was begun.

The calculations will be continued in Fiscal Year 1962 to cover the required range of parameters. Their application to area coverage problems will be completed. The results will be examined to determine if experiments should be undertaken to confirm or modify the important bases for the study.

Personnel contributing to this work were: M. T. Decker (Project Leader and Section Chief, 83.50), R. S. Kirby (Section Chief, 83.70), F. M. Capps, M. E. Johnson, J. H. Clark, H. R. Dahms, K. A. McElfresh, R. C. Scott, and S. L. Snelling.

## Earth Diffraction Studies

83102

The primary objective is to evaluate earth-diffracted radio fields for various (non-stochastic) propagation models. The goal is to publish tabulations of these fields, in which the values of the parametric quantities involved will be so spaced that simple interpolation formulas will give an accuracy of at least 0.1 db.

The earth-diffracted field is the predominant field over a range of distance which is a function of frequency, for essentially all radio frequency communications. Accurate evaluation of such fields is necessary, for example, in the estimation of potential service and interference ranges of communication links. Calculations can be based on a residue series, stated in terms of a modified Hankel function of order one-third. The individual poles at which the residues must be evaluated are, in the second order approximation being used, the roots of a transcendental equation in the same modified Hankel function having the earth's dielectric constant and conductivity as its principal parameters.

During the year this project was transferred to the Tropospheric Analysis Section. Complex arithmetic subroutines were written and given to the central computing facility for inclusion in the computer library. Studies were begun to determine the feasibility of programming an integral form of the diffracted fields rather than using the residue series. A numerical integration approach would appear to be especially advantageous in the region just within line-of-sight. Research into the literature concerning the numerical evaluation of smooth-earth diffracted fields will continue during Fiscal Year 1962.

Personnel contributing to this work were: L. E. Vogler (Project Leader), W. V. Mansfield, J. A. Payne, R. C. Rios, and D. A. Williamson.

Project number has been changed for Fiscal Year 1962 to 83162.

## Standard Theory

83163

This project involves the further development of standard theories of reflection, refraction, diffraction, and scattering and the constant examination of their implications and practical application.

Besides applying standard theories to the solution of specific problems of service, interference and frequency allocations, this project provides charts, graphs, tables, and reports of information useful to propagation engineers in other organizations.

During the past year graphs and calculations were made of the phase and magnitude of the Fresnel plane wave reflection coefficient used in interference theory for various values of frequency, electromagnetic ground constants and horizontal and vertical polarization. This work was included in NBS Memorandum Report PM-83-33. A simple graphical method to determine diffraction calculations in the far diffraction region for horizontally polarized waves was developed and a paper written describing this method. The rigorous smooth-earth diffraction theory was re-examined and asymptotic expansions of the height gain functions valid for satellite heights and beyond were developed. Also a more exact criterion to determine when the second term of the diffraction residue series can be neglected was formulated.

A final draft of a report discussing and describing defocusing effects of various model atmospheres was completed.

Work was done on mathematical expressions designed to fit certain empirical curves used in prediction methods of (a) tropospheric transmission loss, and (b) radio noise. Mathematical formulas for these curves will allow the prediction methods to be programmed for electronic computers.

During Fiscal Year 1962 we plan to do the following:

Task 1: Continue the preparation of an atlas of interference and diffraction curves for varying polarization, effective earth's radius, surface dielectric constant and conductivity, distance, frequency, and antenna heights. This includes preparation of a Technical Note showing theoretical attenuation relative to free space at $\theta = 0$ for several values of frequency, ground constants, and effective earth's radius.

Task 2: Publication of results of the investigations into satellite height gain functions and defocusing effects of atmosphere.

Task 3: Evaluating numerically through computations and graphs Bremmer's theory of wave propagation through a concentrically stratified troposphere with a smooth profile.

Task 4: Development and extension of a simple graphical method to calculate diffracted fields in the far diffraction region for vertical polarization.

Task 5. Special studies and consulting. This project covers: (a) Intensive study of propagation over each path, (b) comparison of relevant data with the theory concerning special phases of propagation such as height gain, antenna gain, short-term fading, dominance of particular mechanisms, and attenuation of fields with frequency, distance, angular distance, and earth roughness, (c) application of standard theory to the solution of specific problems of service, interference, and frequency allocations.

Personnel contributing to this work were L. E. Vogler (Project Leader), P. L. Rice (Section Chief), C. P. Allen, J. L. Noble, J. A. Payne, and R. E. Wilkerson.

## Advanced Theory

83164

Basic research into the physics of the atmosphere and of electromagnetic wave theory is here concentrated in specific areas where special needs have arisen or where unusual opportunities exist for the formulation or development of theory.

Studies of models of atmospheric turbulence as well as layers and ducts, statistical descriptions of the atmosphere and of irregular terrain, and solutions of line-of-sight propagation problems over arbitrary terrain will all contribute to the more precise and reliable application of propagation theory where present-day engineering is inadequate.

During the past year a thorough investigation of the radio star and relay link problems was completed, and a paper describing the results of this work is being written. An attempt to explain atmospheric scattering of electromagnetic waves through a quantum mechanical approach was suggested and a preliminary analysis begun.

Considerable work was done on the mathematical formulation and methods of solution of the problem of defocusing of radio rays in model atmospheres. Some of the results of this work can possibly be used in the problem of calculating ray bending in various atmospheres.

Investigation of Bremmer's theory of wave propagation through a concentrically stratified troposphere was initiated and studies of the limitations and applicability of this theory to actual conditions will be continued. Some work was done on the problem of predicting the effect of atmospheric irregularities on the polarization of a transmitted radio wave, and also work is being carried out on the problem of predicting the field from a large parabolic antenna when only part of the antenna is visible to the receiver.

An investigation of the problem of predicting the mutual interference expected between the ground terminals of space communication systems and surface point-to-point systems was carried out and a paper describing the results published in collaboration with personnel of 83.50. The re-examination of the mathematical and physical aspects of forward scatter theory is continuing and the results being applied to problems outlined for the coming Fiscal Year.

During Fiscal Year 1962 we plan to do the following:

Task 1: Continue the re-examination of the mathematical and physical aspects of forward scatter theory.

Task 2: Study of anisotropic turbulence and its implications for forward scatter, path antenna gain, space and frequency diversity, and phase and refractivity spectra.

Task 3: Investigation of H. Bremmer's recent theory for diffraction over a spherical earth in an atmosphere which has a non-linear and almost arbitrary refractive index variation with height.

Task 4: Solution of line-of-sight propagation problem over an arbitrary rough terrain profile in an airless atmosphere.

Task 5: Investigation of theoretical wave propagation by diffraction over an arbitrary rough terrain profile in an airless atmosphere.

Personnel contributing to this work were P. L. Rice (Project Leader and Section Chief), K. A. Norton (Division Chief), C. P. Allen, E. C. Barrows, H. Bresinsky, J. D. Droppleman, A. E. Goertz, W. J. Hartman, J. L. Noble, L. E. Vogler, and R. E. Wilkerson.

Data Center

83165

In this project is concentrated most of the centralized organization and routine descriptive analysis of long-term radio transmission loss, verification and cross-referencing of information about data, continual search of the literature and correspondence with other agencies, and the maintenance of comprehensive files of topographic map information. Because the Bureau has conducted an extensive program of data recording and reduction for the past nine years, it has a unique opportunity to study the dependence of system performance on the many variables involved, such as frequency, distance, antenna heights, topography, and meteorological conditions.

Accurate and comprehensive files of basic data and information about the data are essential to the development of propagation theory and engineering prediction methods.

During the past year we have checked all basic information about some three hundred and fifty radio propagation paths and prepared card files of this information. Cross-reference files have been prepared so that information about particular parameters, such as frequency, may be readily available. A reference file of literature has been organized and cross-referenced by author, and recording agency. A continuing search of the literature is made for additional data and new sources and methods of analysis.

Computer programs have been written to compute a great circle path given the latitude and longitude of both transmitter and receiver; given the latitude of any point on the path the corresponding longitude may be computed and vice versa. This increases the efficiency and accuracy of the work with terrain contour maps in obtaining detailed path profiles, essential to point-to-point predictions.

Sorting, organizing and listing of hourly median values of radio transmission loss has been continued, and a study has been made of the effect of sample size on observed variability.

During Fiscal Year 1962 we plan to do the following:

Task 1: Map work. Terrain contour maps are obtained as they become available, and terrain parameters are tabulated for all great circle propagation path profiles, including detailed profiles from each antenna to its radio horizon. Special parameters are required for intensive study of propagation over individual paths, for study of the statistics of

terrain variation, and for the development of definitions of effective antenna height. Occasionally it may be necessary to go into the field or to write subcontracts for aerial photographs of regions where adequate maps are not available and are urgently needed.

Task 2: Organization and routine analysis of data. The organization of long-term data on IBM punch cards, listings obtained from them, and the verification of information about the data are essential to the reliability and comprehensiveness of present and future work. There is a punched card for each of almost a million hourly medians, and listings include cumulative distributions for each time-block, period of record, summer and winter, "monthly-hourly medians," and simultaneously recorded data for which correlations are sought. This project works closely with the meteorological analysis section.

Task 3: Literature search for data. A bibliography of data sources is kept up to date, summaries of general information obtained from each technical report are filed, tabulations of information required for each propagation path are maintained, and cross-references of information are compiled. Special studies are undertaken to compare data from various sources, and a list of proposed investigations is constantly added to, with remarks as to possible sources of pertinent data and suggestions as to experiments which ought to be undertaken to provide needed data.

Personnel contributing to this work were A. G. Longley (Project Leader), P. L. Rice (Section Chief), K. A. Norton (Division Chief), M. M. Coyle, P. H. Elder, V. L. Fuller, F. I. Harrington, and P. G. Ratcliffe.

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## Prediction Methods

83166

The Tropospheric Analysis Section combines theoretical research with data analysis in order to improve our understanding of the physics of radio wave propagation in a turbulent atmosphere and over irregular terrain. There is an acute need for a reliable method of predicting the performance of radio systems employing propagation through the troposphere. Estimates of transmission loss and of long-term and short-term variability (fading ranges, fading rates, and signal continuity) are essential to the proper design and allocation of military and commercial broadcasting, communication, and navigation facilities.

Transmission loss prediction methods are worked out in detail, applied to all available data, and written up for publication. Although much information concerning the propagation of UHF and VHF radio waves has been obtained in measurements carried out over the past several years by both government and private laboratories, there is still an acute need for a reliable method of predicting the performance of radio systems employing propagation through the troposphere at these frequencies.

Work on this project during the past year has consisted for the most part of improving and simplifying the prediction method described in NBS Technical Note No. 15, of developing a new prediction method which depends on standard atmospheres with exponential gradients, and of consultation and guidance given people from other organizations in the use of CRPL prediction methods.

An improved and simplified version of the prediction method described in NBS Technical Note No. 15 was prepared for Memorandum Report PM-83-33, sponsored by the Air Force Ground Electronics Engineering and Installation Agency, and was later rewritten as NBS Report 6767.

This report includes a new method of estimating long-term variability as a function of path distance, effective antenna heights, frequency, and "take-off" angles. This new method has the advantage of being applicable to short, line-of-sight paths as well as to longer tropospheric paths.

Improved methods of tracing radio rays have been programmed for an electronic computer and incorporated into a computer program for calculating the geometrical parameters needed for predicting diffraction or forward scatter transmission losses between two antennas.

A great deal of work has been done in developing a new prediction method which depends on standard atmospheres with exponential gradients. This method has the advantages of greater simplicity and better agreement with meteorological data than previous methods. The theoretical basis of the method has been developed in detail and included as notes for Lecture 9 of the 1961 Course on Radio Propagation. Analytic functions have been developed in order to permit greater mechanization and programming for digital computers in addition to the more approximate graphical methods.

Long-term variability as a function of period of time, effective distance, frequency, and terrain has been expressed in terms of analytic functions, which have been programmed for a digital computer. Thus it is possible to predict the field strength exceeded for any desired percentage of time over a given path. A description of this method is included in the notes for Lecture 10 of the 1961 Course in Radio Propagation.

Certain suggested modifications and techniques in the use of CRPL prediction methods have been examined and evaluated.

During Fiscal Year 1962 we plan to do the following:

Task 1: Complete the development and description of the new prediction process, apply it to all available data, and write the method up for publication, including formulation of theory, ray tracing methods, specific application to data, and mechanization of the prediction process.

Task 2: Continuation of long-term variability study considering possible effects of irregular terrain, surface refractivity, unusually high antennas, and angular distance. A continued emphasis on expressing variability in terms of analytic functions and the development of computer methods for predicting the transmission loss to be expected for any desired percent of time for any given time block. The results of this study will be written up for publication.

Task 3: Consulting work to assist other agencies in the use of our data and prediction methods.

Personnel contributing to this work were A. G. Longley (Project Leader), P. L. Rice (Section Chief), K. A. Norton (Division Chief), C. P. Allen, W. R. Burns, M. M. Coyle, and V. L. Fuller.

## Prediction of Values for System Parameters Important to IRAC Radio Frequency Allocation

83463

This project is sponsored by the Office of Civil Defense and Mobilization and the Federal Communications Commission. It is proposed to prepare a comprehensive study of technical factors pertinent to the allocation of radio frequencies. Special attention will be given to system parameters in the range 50 Mc/s to 1000 Mc/s.

The furnishing of such technical information to radio regulatory agencies in a form suited to their specific needs is a CRPL mission of national importance and is a matter of some urgency for long-range planning now underway.

Particular emphasis during this past year was placed on the study of satellite communications, including estimates of the interference to be expected between line-of-sight telecommunication relay and satellite or space systems. Also under investigation was the matter of radio frequency spectrum requirements, and a great deal of work has been done in assembling information which bears on this problem. A comparison was made of the service areas of a network of airborne and ground-based television transmitters.

Personnel contributing to the work of the project were R. S. Kirby (Project Leader and Section Chief, 83.70), L. J. Maloney, A. P. Barsis, M. T. Decker (Section Chief, 83.50), W. J. Hartman, L. G. Hause, G. D. Gierhart, and P. L. Rice (Section Chief, 83.60).

## ATIC Radar Propagation Analysis

83465

This project assists the Aerospace Technical Intelligence Center in the analysis of certain radar data, providing procedures which should enable Air Force personnel to interpret their observations.

It is essential to understand the effects of changing atmospheric conditions in order to interpret radar data. Meteorological conditions affect the average bending of radio rays, as well as focusing and defocusing radio energy, and this changes apparent positions and produces image broadening. The effects of both ordinary and unusual meteorological conditions on the apparent position of cultural, terrain, and atmospheric features normally detected by radar may be seen from the data analysis.

During the past year, data supplied by ATIC has been studied by comparing apparent positions with the known position of a target. These variations were correlated with meteorological data, and results of the analysis were provided to the sponsor in informal letter reports.

Additional data will be provided by ATIC for analysis during Fiscal Year 1962.

Personnel contributing to this project were H. T. Dougherty (Project Leader), M. E. Johnson, J. S. Miller, J. H. Clark, H. R. Dahms, K. A. McElfresh, P. H. Elder, F. I. Harrington, and P. G. Ratcliffe.

## Global Range Real Time Communications

83466

This project is sponsored by the Aeronautical Systems Division, Air Force Systems Command, Wright Air Development Division. The objective of this program is to extend the range and increase the reliability of aerospace communication links through exploitation of forward scatter modes of propagation. The program shall consist of a theoretical study and analysis to determine the feasibility of beyond-horizon scatter transmission to and from satellites. The program shall also serve to define experimental instrumentation parameters which will be required to gather data on the signal characteristics and directional properties of scatter transmission as the instrument carrier traverses the area above the scattering regions of test transmissions.

Phase I of the project is divided into two parts: (1) the study of effects of the mode of propagation, free space, diffraction or scattering through the atmosphere, and (2) a study of the effects of system parameters such as satellite orbits, external noise sources, antenna size, available power, etc.

Phase II is devoted to the design of experiments for the acquisition of whatever data is needed to supplement or verify the studies undertaken in Phase I.

Global range, real time communications between earth stations and orbiting vehicles is a requirement. Possible vehicles participating in such links include early-warning satellites, manned reconnaissance satellites, and Boost-Glide vehicles. Present techniques for global communications include LF, HF, and multiple point-to-point relay with attended difficulties in propagation outages, and/or system complexity. Passive or active relay satellites are in development for future application to the general communication relay problem. Devices of both categories have finite performance limitations, and are expensive in terms of development and launching into orbit or on station.

During the past several months, the following accomplishments have been made:

The existing tropospheric scatter prediction method has been programmed for a 1604 computer to give transmission loss values for propagation to and from satellites.

A theoretical study has been started to try to determine the applicability of these methods to the present problem. Data taken from high flying aircraft, although not available in quantity, will be used as a further check.

Smooth earth diffraction curves are being extended by computer methods to account for antenna heights corresponding to satellite orbits.

A machine program is being prepared to give as a function of the angle below the horizon, (a) the percent of time a satellite is visible in a given orbit and (b) the area seen by a single satellite at one position of the orbit.

A literature search on the problem of the bandwidth capabilities of tropospheric scatter revealed discrepancies between different theoretical treatments. At least one paper was found to have an error. A small amount of data is available at present from which an estimate of the medium bandwidth can be made. It is expected that additional data will be available in time to incorporate it into the final report.

A comprehensive literature search into all aspects of the present problem is in progress.

The work already initiated will be continued into Fiscal Year 1962. It will be necessary to have preliminary results from the above studies before defining new areas for investigation.

Personnel contributing to the work of this project were W. J. Hartman (Project Leader), C. P. Allen, E. C. Barrows, H. Bresinsky, J. D. Droppleman, J. L. Noble, P. G. Ratcliffe, R. R. Ridge, and L. E. Vogler.

## Point-to-Point Communication on the Moon

83467

The objective of this program is a study of the system loss expected in point-to-point communication between arbitrary geographical locations on the moon. Using standard propagation theories together with the best available estimates of lunar physical conditions, the requirements necessary for practical communication systems will be investigated. Most of the work will describe the known possibilities of point-to-point communication using surface waves. Consideration will be given to antenna types, power requirements, noise limitations, and the influence of the earth and sun on the communications system.

In anticipation of the time when manned flights to the moon become practical, the results of this project will serve as a guide to the planning of communication procedures to be used between exploring groups and base installations on the surface of the moon.

The objectives outlined above will be carried out in Fiscal Year 1962.

Personnel contributing to this project will be L. E. Vogler (Project Leader), J. L. Noble, J. A. Payne, and R. R. Ridge.

## Terrain Effects on Propagation

83171

The objective is to determine by experimental and theoretical studies the effect that an irregular, finitely-conducting, ground boundary has on radio propagation, and to provide methods for predicting these effects in terms of radio propagation theory.

Terrain affects radio propagation in a variety of ways. At the lower end of the frequency spectrum it is primarily a conductor of surface waves. At higher frequencies it acts as a boundary causing random reflections and diffraction. A more complete knowledge of the behavior of radio waves in the presence of irregular terrain increases the effectiveness and efficiency of systems operating at all radio frequencies.

A series of measurements was completed in a study of VHF and UHF signal characteristics observed on a long knife-edge path. Long-term transmission loss measurements were performed over a 223 km path in Eastern Colorado using frequencies of 100 and 751 Mc. This path intersects Pikes Peak which forms a knife-edge type obstacle visible from both terminals. The transmission loss measurements were analyzed in terms of diurnal and seasonal variations in hourly medians and in instantaneous levels. As expected, results show that the long-term fading range is substantially less than expected for tropospheric scatter paths of comparable length. A technique was developed for estimating long-term fading, the results of which are in good agreement with the measurements.

The results of this study were made the subject of NBS Report 6751, "VHF and UHF Signal Characteristics Observed on a Long Knife-Edge Diffraction Path," by A. P. Barsis and R. S. Kirby, dated March 1, 1961. This report will be published in the Journal of Research NBS, 65D, September-October, 1961.

Personnel contributing to the project were R. S. Kirby (Project Leader), A. P. Barsis, P. L. McQuate, B. F. Quereau, M. E. Johnson, H. R. Dahms, J. H. Clark, and K. A. McElfresh.

## Propagation Study Relative to Wideband Data Transmission Links

83470

This project is sponsored by the U. S. Army Signal Research and Development Laboratory. The objectives are to determine optimum frequency, power requirements, performance estimates, and in particular bandwidth limitations imposed by the medium for wideband line-of-sight data transmission links. Applications include air-to-air as well as air-to-ground paths up to 500 miles in length, with frequencies in the 1000 to 10,000 Mc range.

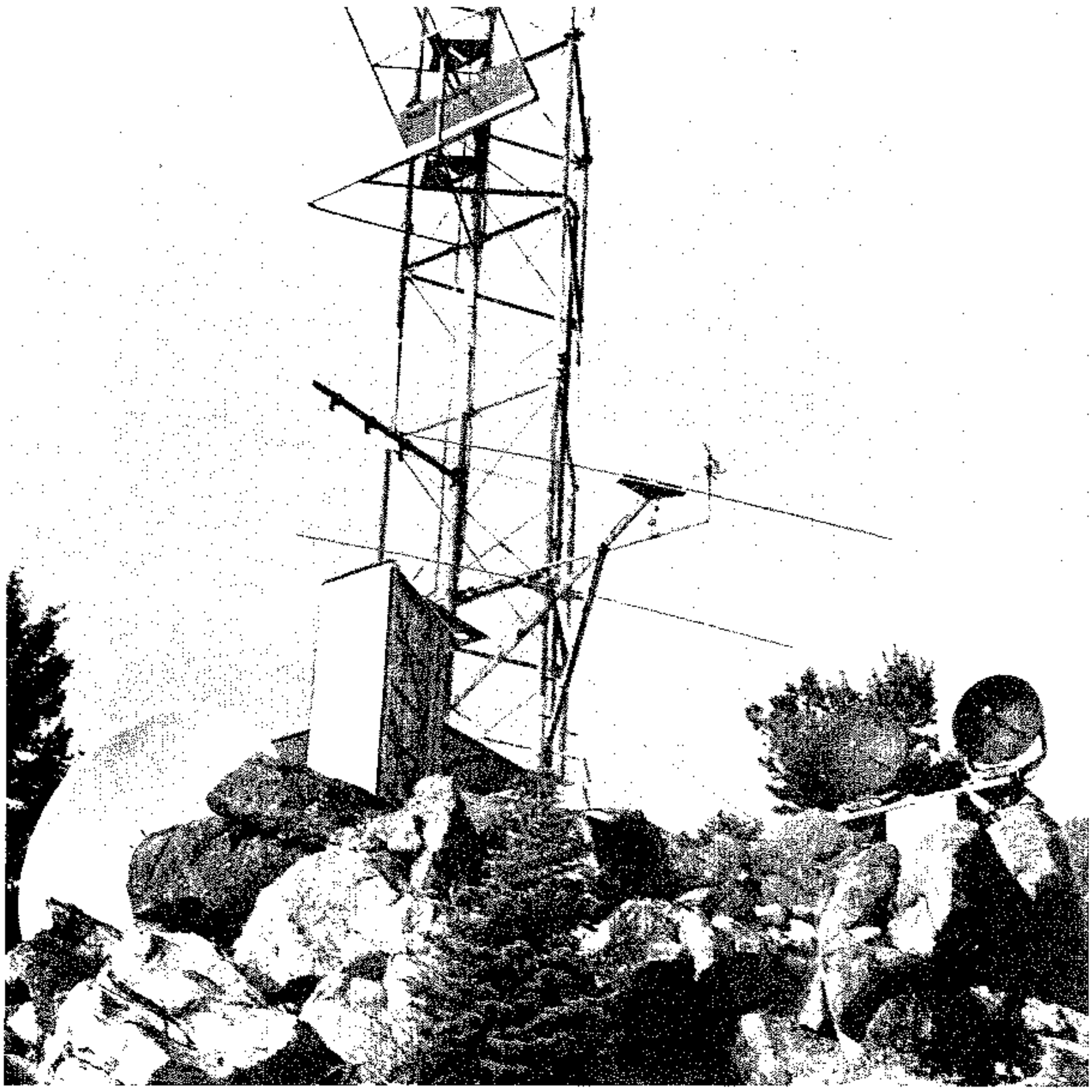
Available results of short-term signal variations over within-the-horizon tropospheric propagation paths were assembled in the form of a NBS Technical Note and supplied to the sponsoring agency. A literature search on available data on bandwidth of the medium was carried out. A program to measure transmission loss variations at two carrier frequencies in the 9000 Mc range separated by 100 Mc was initiated, using equipment made available by the sponsoring agency. These measurements were performed over a 70-mile within-the-horizon path in Eastern Colorado, and are described in detail under Project 83454.

The results of the measurements are being analyzed for the variability of hourly basic transmission loss medians, correlation between the medians obtained on 9250, 9350, and 1040 Mc, statistics on short-term signal variations (space-wave fadeouts) on these frequencies, and correlation between instantaneous values of transmission loss on 9250 and 9350 Mc. The last item, together with an analysis of the instantaneous field strength ratio of the two signals, serves as a basis of estimates for the coherence of signal amplitudes over the 100 Mc bandwidth.

The simultaneous measurements on 1040 Mc serve as a basis for comparing the results with earlier measurement results over the same path.

A report will be prepared describing the measurements, the analysis of the data, and the results obtained. Results will be evaluated in terms of the project objective, namely the bandwidth capability of the medium. It is not anticipated that the project will be extended beyond the analysis and evaluation of the presently available data, and the preparation of the report.

Personnel contributing to this work (analysis and evaluation) were A. P. Barsis (Project Leader), R. S. Kirby (Section Chief), A. F. Barghausen, F. M. Capps, M. E. Johnson, J. H. Clark, H. R. Dahms, and K. A. McElfresh. Personnel of the Data Reduction Instrumentation Section (W. E. Johnson, P. I. Wells, J. A. Sykes, and M. S. Johnson) also contributed to the work.



Mountain-Top transmitting location for studies of fading characteristics in wide-band transmission systems. Receivers are located at a distance of 70 miles on the plains within line-of-sight.

2 12

## Attenuation Measurements "Prince"

83471

This project, sponsored by the Defense Department, is the study of the propagation of radio waves through various typical building materials. Information is desired on the transmission, reflection, and absorption of energy over a wide frequency range. The effects of polarization, angle of incidence, and resonances are to be investigated.

While a large amount of work has been done in the radome field, most of the studies have approached the problems as a search for materials which will aid in providing certain desirable characteristics for a radiating system, or which will provide protection without impairing the system operation. In some cases, however, the presence of other materials in a system propagation path may be unavoidable. Measurements leading to methods for the prediction of system operation under these circumstances are required.

Information from the measurements on a residential type brick veneer wall has been treated to determine the distribution of insertion loss in a volume behind the wall at 500 Mc and 1000 Mc. Similar information obtained at 4.7 kMc, 9.4 kMc and 20 kMc from attenuation measurements on a frame wall is being presented in the form of field mappings of insertion loss.

The work done at the above five frequencies will be formally reported and additional attenuation experiments will be performed.

Personnel contributing to this work were M. T. Decker (Project Leader), L. G. Hause, G. D. Gierhart, and J. E. Farrow.

## FAA Siting and Inspection

83473

The objective of this project is to assist the Federal Aviation Agency by increasing its knowledge in the areas of siting of electronics equipment with effects caused by local and distant terrain, and the propagation anomalies resulting from the condition of the atmosphere so that this knowledge may be applied to increasing the accuracy of predictions involved with siting and operating facilities and to equipment design.

This project was undertaken during the final quarter of the year. Studies were initiated on the Very High Frequency Omnirange (VOR) and the Instrument Landing System (ILS).

Personnel from NBS attended a conference at the FAA operating base in Oklahoma City to obtain information on the operational aspects of these systems. Studies were made of the influence of antenna siting on bearing errors in the VOR system. Meteorological influences, particularly the conditions which cause abnormal bending of radio waves were also studied. There is an indication that higher ground-based antennas would be desirable in many instances where rough terrain exists, but special techniques frequently must be resorted to in order to minimize the tendency to lobe at higher antenna heights.

Machine computer techniques being developed under Project 83478 are used to develop criteria for judging the effectiveness of proposed modifications.

Personnel contributing to the project were R. S. Kirby (Project Leader), L. G. Hause, and A. P. Barsis.

## Technical Factors Relating to System Spectrum Usage for IRAC Long-Range Planning

83474

The objective of this project is to provide technical information for use in long-range allocation planning for the Interdepartment Radio Advisory Committee. The results of this study will be applied to future planning for use of the radio spectrum.

The radio spectrum is essentially a natural resource, and its effective use depends entirely upon an adequate allocation plan. The Interdepartment Radio Advisory Committee and the Federal Communications Commission have the responsibility in the United States for the maintenance of a national table of allocations, as well as the assignment of frequencies to government and non-government users. It is very important for these agencies to have adequate information about the performance characteristics of all the various systems, both present and future, for which allocations must be made.

Particular emphasis was placed on a study of satellite communications. Studies were made of the interference aspects between line-of-sight telecommunication relay and space systems. Also under investigation was the matter of radio frequency spectrum requirements. A comparison was made of the service areas of a network of airborne television transmitters and transmitters located on the ground. Allocation aspects of many other services were studied for incorporation in a final report, which is expected to be completed near the end of 1961.

Personnel contributing to the work of the project were R. S. Kirby (Project Leader), L. J. Maloney, A. P. Barsis, P. L. Rice, M. T. Decker, L. G. Hause, and G. D. Gierhart.

## Systems Application Consulting

83475

This project is sponsored by the U. S. Army Signal Engineering Agency which has engineering responsibility in certain areas of the world for the installation of tropospheric-scatter communication circuits. The objectives are to provide engineering assistance in the selection of terminals for such circuits, and to provide estimates of terminal equipment requirements for specific paths, based on site surveys, topographic map studies, and tropospheric propagation theory. Such studies are essential for efficient planning of circuits, terminal locations, and choice of equipment.

Systematic methods for predicting the performance of tropospheric communication links and for the evaluation of circuit reliability were assembled in handbook form. This work included an evaluation of the relative importance of path loss measurements as compared to the predictions. These studies are applicable jointly to the work done for the U. S. Army and the U. S. Air Force, and are described more fully in connection with Projects 83409 and 83408.

Performance estimates for specific paths included in a tropospheric communication network between classified locations in Europe were completed based on a previously reported site survey. Classified reports dealing with this network were submitted to the sponsoring agency. Due to changes in the originally specified or recommended terminal locations, several additional reports were prepared, or are under preparation now, which contain a re-evaluation of the various propagation paths, and also new performance methods based on newly available equipment specifications and refined methods of analysis.

A similar, classified, report was also prepared dealing with an overland path in the Western Pacific area.

Additional performance estimates as well as site surveys and, possibly, path loss tests will be undertaken as requested by the sponsoring agency. Theoretical investigations and a program of measurements of transmission loss over obstacle-gain paths will be carried out which will provide for continuous improvement in the methods and techniques applicable to system design and performance predictions.

Personnel contributing to this work were A. P. Barsis (Project Leader), R. S. Kirby (Section Chief), F. M. Capps, M. E. Johnson, B. D. Samsel, J. H. Clark, H. R. Dahms, and K. A. McElfresh.

Radar Propagation
83476

CLASSIFIED

Military Assistance Program Evaluation

83477 - 83479

The objectives of this project are to provide engineering assistance to USASEA and USARJ in the evaluation of an engineering survey for a proposed communication system in Indonesia, to inspect proposed sites, and to assist in the development of requirements and specifications for the system.

The U. S. Army Signal Engineering Agency has engineering responsibility for the planning and installation of this communication system under the Military Assistance Program. It is essential that such circuits even if designed and installed by foreign contractors be planned efficiently and in accordance with accepted engineering standards.

The responsibility for a continuing review of the engineering survey reports required the presence of one NBS engineer assigned to U. S. Army Japan, in Japan.

Performance estimates were made for proposed paths, using the latest available prediction methods, in connection with the evaluation of the engineering survey reports.

At the request of USASEA, an NBS engineer visited Indonesia as a member of a survey team for the purpose of obtaining certain information relevant to contracting for the installation of the communication system.

This project has been broadened to include sending an NBS engineer to Djakarta, Indonesia, to act as technical assistant to the Contracting Officer's Representative. It is planned to recompute performance estimates based on final selection of terminal sites.

Personnel contributing to the work of the project were L. J. Maloney (Project Leader), J. E. Farrow, B. D. Samsel, R. S. Kirby (Section Chief), and A. P. Barsis.

## Studies of Service Volumes for Air Navigation Facilities

83478

This project is sponsored by the Federal Aviation Agency (Bureau of Facilities and Materiel). The objectives are to develop a general program for a large electronic computer for the determination of service volumes of air-ground systems such as VHF Omnirange or TACAN. Radio wave propagation modes, variability of transmission loss, equipment parameters, and the geographical configuration of potential interfering facilities are some of the variables considered in this problem.

The first step in the attack on the problem was the development of an overall flow diagram. Then, individual sub-programs were written and tested for each of the "blocks" in the flow diagram, like transmission loss calculations, long-term and short-term variability of transmission loss, transmitting and receiving antenna patterns, and methods for combining cumulative distribution functions.

The next step will be the integration of the completed "blocks" in the overall program, and a complete calculation run for a specific set of equipment parameters and station configuration. After the overall program is checked out, it is relatively easy to vary individual parameters in order to obtain service volumes for a number of systems under different assumptions of reliability, station spacing, interference, etc.

Personnel contributing to this project were A. P. Barsis (Project Leader), R. S. Kirby (Section Chief), F. M. Capps, M. E. Johnson, G. D. Gierhart, J. S. Miller, B. D. Samsel, and K. A. McElfresh.

Radio Meteorology Research

83181

The work of this project tends toward the examination of basic properties of the atmosphere and their effect upon the transmission of radio waves at VHF frequencies and above. Examples of previous work have included the determination of the constants in the equation for radio refractive index, the magnitude of gaseous atmospheric absorption of radio waves in the frequency range of 100 to 50,000 Mc, the development of a "radio standard atmosphere" and the preparation of world climatology of the surface radio refractive index.

Results of this work are applied immediately within Division 83 for the development of tropospheric radio wave prediction techniques. The results are of further use to industrial, governmental, military engineering groups, as well as those responsible for planning of advanced technical projects that involve basic principles of the atmosphere at radio frequencies.

A synoptic climatology of migratory high and low pressure cells over the central and eastern United States has been initiated. The purpose of this study is to obtain a representative picture of the vertical and horizontal radio refractive index pattern with such systems. A study, co-sponsored with Project 83481, concerned with the degree to which the average n structure in the vertical direction reflects the gross differences in climate over the North American continent. This latter study, including a new analysis of the diurnal and seasonal range of n at the earth's surface, has been completed and is available as an NBS report.

Considerable progress was made in the long-term project of compiling a world-wide atlas of $\Delta N$ (refractivity difference between the earth's surface and one kilometer). The portion of the atlas devoted to the United States climate has been the chief accomplishment to this date. It has been completed and is available as NBS Monograph 22. Data was also assembled from meteorological towers and wiresonde observations for starting a micrometeorological climatology of radio refractivity near the ground. An initial survey report, based on a literature search, concerning the attenuation of microwaves by atmospheric gases and raindrops is essentially complete.

An appreciable amount of the material presented by the Radio Meteorology Section in the NBS course in Radio Propagation was prepared by 83181 sponsorship. Among the topics so prepared were: "The Radio Refractive Index and its Climate," "Anomalous Refractive Index Structure," "Attenuation of Radio Waves," "Refraction of Radio Waves in the Troposphere," and "Measuring the Radio Refractive Index." In addition, a study developing the concept of the bi-exponential atmosphere has been completed and has been accepted for publication.

The National Refractive Index Data Center, consisting in part of about 7,000,000 IBM cards, added at least fifteen foreign land and ship stations during this period. These represent the climates of Japan and the North Pacific, Arabia, Cyprus, South Africa and the Antarctica.

The micrometeorological study of N near the ground and the world-wide survey of $\Delta N$ will be expanded. An extensive study of synoptic meteorological systems and their associated N patterns will be made, with emphasis being placed on the effect of the humidity and temperature fields. As larger amounts of data and improved computer techniques become available, an attempt will be made to program synoptic changes for computer interpretation.

The following people contributed to this project: B. R. Bean (Project Leader), B. A. Cahoon, E. J. Dutton, J. D. Horn, C. M. Miller, G. Richmond, L. P. Riggs, W. B. Sweezy, G. D. Thayer, B. Weddle, and P. Whittaker.

## Synoptic Refraction Studies

83481

The objectives of this project are to develop methods of predicting the synoptic and climatic variation of radio refractive profiles as applicable to Naval Operations.

The results of this work are basic to the prediction of the occurrence of such radio phenomena as ducting and radio holes. The prediction of these radio phenomena enables steps to be taken to maintain radar surveillance and radio communications during unusually low field strength conditions or in the presence of severe interference.

A first attempt has been made to examine vertical seasonal profiles and diurnal-annual changes of radio refractive index climates of the world; previously available data has been predominantly of U.S. origin. Another study, essentially complete, has as its subject the absorption of microwaves by atmospheric gases and raindrops.

The U. S. Navy continues to be the major contributor to the huge refractive index card file consisting of some 7,000,000 cards. This contribution assumes even more important proportions when it is remembered that the majority of the data of foreign regions has been sponsored by the USNWRF.

A study, co-sponsored with Project 83181, concerned with the degree to which the average n structure in the vertical direction reflects the gross differences in climate over the North American continent and including a new analysis of the diurnal and seasonal range of n at the earth's surface, has been completed and is available as an NBS report. This report is also to appear soon in the open literature.

An investigation, just completed, of the time lag constants in the humidity and temperature sensors of the radiosonde instrument shows clearly that corrections for the time lag in the sensors of both parameters is necessary for a climatological comparison for ducting incidence. By ignoring sensor time lag, one tends to underestimate ducting incidence; by correcting only for humidity sensor lag, duct incidence is over-estimated.

As radiosonde and detailed surface data for various stations around the world are accumulated, a climatological program will be tailored specifically for the use of the Navy. Continued support will be given to analyzing vertical seasonal profiles and diurnal-annual changes of radio refractive index climates of the world, especially from those localities and climates not previously available.

Personnel contributing to this project were: B. R. Bean, J. D. Horn (Project Leader), C. M. Miller, L. P. Riggs, and B. Weddle.

## WSMR Refraction Studies

83482

The objective of this project is not only to determine the expected radio ray refraction errors for the semi-arid desert conditions of the White Sands Missile Range, in various configurations of angle and distance measuring equipment, but to develop optimum procedures for correcting these errors.

Range and elevation angle errors must be represented in such a manner as to be readily available to the users of distance- and angle-measuring equipment at the White Sands Missile Range. It is necessary that the representations be prepared and put into general use as soon as possible.

The formulation of the proposed mathematical solution for the AME/AME system has been prepared. The development of exponential atmospheres for February, May, August, and November, and the annual refractivity conditions has been completed.

Plans are to continue to study the errors inherent in an AME/AME system. During this period a complete FORTRAN General Refraction Program for the White Sands Missile Range will be prepared, and the initial contract requirements will be completed.

Personnel contributing to this project were: B. R. Bean, E. J. Dutton, W. B. Sweezy (Project Leader), and B. Weddle.

## Radar Height-Finding Errors

83483

The objective of this project is to determine height-finding errors arising from atmospheric refraction for the major climatic regions of the United States and to develop methods of correcting these errors by use of commonly available weather data such as the standard surface and radiosonde observations.

Correcting of height-finding radars for atmospheric-induced errors is of vital importance in air traffic control and safety.

The preparation of a height-finding error program for the CDC-1604 computer has been completed, and preliminary samples of test data have been checked for general correlation with meteorological parameters.

Plans include completion of the above type calculations for at least 12 United States stations for each of the four seasons, using five years of data.

Personnel contributing to this project were: B. R. Bean, W. B. Sweezy (Project Leader), and B. Weddle.

## Baseline Refraction

83485

The purpose of this project is to examine the effects of the refractive index structure of the atmosphere on the accuracy of baseline radio guidance systems, for baselines from approximately one to a thousand miles, and to develop relations between the refraction errors and easily measured meteorological parameters. The zone of climatic coverage will include all of the United States and, time-wise, will include from one day to seasons and years. Particular emphasis will be made upon a study of the relationships between the degree of refraction error encountered and the type of meteorological air mass present at each end of the path and in the intervening distance.

A knowledge of the size of the refraction error to be expected with a baseline radio tracking system, together with methods for predicting such errors from common meteorological elements, e.g., the air mass present, will be of great value in increasing the accuracy of such baseline systems.

Pilot calculations on the calculation of refraction errors from ray-tracing theory for many United States locations, for varying time intervals and seasons, were completed. Mathematical formulations for the solution of distance-measuring-equipment range errors were derived. A large number of meteorological synoptic situations were collected and analyzed with regard to their possible effect on the performance of baseline systems.

This project terminates at the end of fiscal year 1961.

Personnel contributing to this project were: L. P. Riggs, G. D. Thayer (Project Leader), and B. Weddle.

## Radar Meteorology

83487

To study the influence of meteorological conditions upon the bending of radio waves and the occurrence of meteorological phenomena that give rise to propagation of radar energy are the objectives of this project.

It is important that radar personnel understand the meteorological influences that affect the detector capabilities of their radar equipment in order that measures may be taken to correct, or mitigate, adverse effects of certain meteorological conditions.

Refractive index profiles were constructed from meteorological data gathered from selected geographical locations. The correlation between different meteorological situations and abnormal operating conditions for radar systems (using ray-tracing techniques), were studied.

The activities of this project have been transferred to project 83476.

Personnel contributing to this project were: E. J. Dutton, L. P. Riggs (Project Leader), W. B. Sweezy, G. D. Thayer, and B. Weddle.

## Special Refraction Effects

83488

The primary objective of this project is to examine the effects of the radio refractive index structure of the atmosphere on the accuracy of phase-measuring radio tracking systems of long baselines, particularly for baselines of 10,000 feet. This is to be based on the atmospheric conditions of Cape Canaveral, Florida. This will involve a search through the literature and other sources for the meteorological data for the Canaveral area. Wherever possible, methods will be developed for relating climatological or meteorological parameters with the refracting errors of the baseline system; investigation will be made as to the efficient utilization of airborne refractometer measurements in such methods.

Little is presently known about the atmospheric refraction errors of phase-measuring baseline systems. This knowledge will be invaluable in the utilization of such systems for the accurate tracking of missiles, earth satellites, and outer space vehicles. The program will attempt to determine the effect of such climatic extremes as land-sea breezes and low-level radio ducts on long baseline-phase measurement systems.

Meteorological data for Cape Canaveral, Florida, was gathered and analyzed in the form of vertical profiles of refractivity to make an evaluation of baseline system refraction errors as a function of meteorological variables. Mathematical formulas for the solution of Distance-Measuring-Equipment were derived. Procedures have been developed for the efficient use of meteorological data, including airborne refractometer measurements. Full support was given to the initiation of a land-sea breeze study due to its significance in microwave transmissions in coastal areas.

Future plans include completion of the land-sea breeze study. Some study of the effects of horizontally inhomogeneous refractive index structure upon DME crrors will bc made for the Florida peninsula. Contract requirements will be completed and a final report prepared for the sponsor, General Electric Company.

Persons contributing to this project the past year were: C. Auer, J. D. Horn, C. M. Miller, L. P. Riggs, G. Thayer (Project Leader), and P. Whittaker.

## Sky Temperature Theory

83489

The objective of this project is to study the feasibility of remotely probing the atmosphere to determine its gross temperature and water vapor content profile using gaseous atmospheric absorption of electromagnetic waves and effective sky temperatures at microwave frequencies. The project will have the following specific objectives:

(a) To survey the field and, in so far as possible, to determine the present state of the art as regards the theoretical aspects of gaseous atmospheric absorption of microwaves and effective sky temperatures.

(b) To make an analysis and evaluation of the findings by other workers in the field.

(c) To establish which physical variables would be most applicable to studies of this type and to propose both theoretical and experimental studies which would further the primary objective to the greatest degree.

The effective sky temperature is the lowest limit of noise into a radio receiver and thus constitutes a limit to practical space communications systems whose signals traverse the troposphere. A knowledge of gaseous absorption by the atmosphere is also fundamental to communications between points on earth. This project would also enhance the knowledge of the atmosphere most immediate in its effect on most of mankind's activities. The temperature-water vapor profile is of practical importance, useful not only in predicting weather but in the prediction of probable atmospheric contamination in congested areas around large cities. It would be useful also in other scientific investigations.

A literature search is in progress and a number of papers have been reviewed. Pilot calculations of the expected thermal noise in the microwave region based on the simplified versions of the Van Vleck theories of absorption by oxygen and water molecules, utilizing the best data available, have been completed.

A substantial beginning has been made on computer programming to use the full Van Vleck theory of oxygen in calculations of thermal noise. This program is designed to allow the estimation of errors inherent in the experimental data. A preliminary report incorporating the information obtained to-date is near completion. Progress has been made on other questions relative to the project. Among these is the determination of a method of including non-gaseous components in calculations of thermal noise.

Calculations of thermal noise will be made to allow an estimation of the mean thermal noise in the microwave region to be made as a function of geographical location, time of year, frequency, elevation angle and rainfall rate. It is hoped to include calculations which will allow estimations to be made of the errors inherent in the experimental data used in the calculations, as well as the necessary extrapolations. For a limited number of geographical locations, plans have been made to determine the deviation from the mean thermal noise received, and to relate these by correlations to the departures of the atmosphere from the mean structure for the period considered. A survey of the equipment necessary to accomplish the proposed evaluations will be made. The literature search pertinent to the project will be continued.

Personnel contributing to this project were B. R. Bean, R. L. Abbott (Project Leader), and E. R. Westwater.

## AEPG Refractometer Utilization

83491

The objectives of this project are to determine optimum refractometer techniques for absolute and differential humidity measurements. Expected accuracies are to be investigated in terms of expected costs.

The Army Electronic Proving Ground Facility has a need for a recording hygrometer capable of measuring humidity to a degree not attainable by present conventional methods.

The present study was directed to ascertaining the feasibility of developing an instrument having the above desired capabilities. Techniques and equipment considered were only those which could be utilized in field applications. On the basis of current knowledge and reasonable expected improvement, it would seem that the desired accuracy of the measurement of the absolute ($\pm$ 0.1 $g/m^3$) and the humidity gradient ($\pm$ 0.01 $g/m^3$) cannot be met.

An NBS report "A Microwave Hygrometer Research Study" was issued to the sponsor reflecting the following recommendations. Since there appeared to be a greater probability of approaching the desired results in the case of the absolute hygrometer rather than in the case of the differential hygrometer, it was recommended that present efforts be concentrated on the absolute hygrometer with the hope of utilizing the success achieved with that instrument in determining the expected optimum accuracy for a differential hygrometer.

In the case of the absolute hygrometer, the use of more or less conventional means for temperature and pressure controls yields accuracies of $\pm$ 0.5 $g/m^3$. The use of more exacting techniques embodying the ultimate in temperature and pressure controls should yield accuracies approaching $\pm$ 0.2 $g/m^3$.

This project terminates at the end of fiscal year 1961.

Personnel contributing to this project were: Ralph P. Fitzpatrick, B. R. Bean, and R. E. McGavin (Project Leader).

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Refractive Index Structure

83193

The objectives of this project are: 1) to study the distribution of the specific parameter, refractive index, throughout the lower atmosphere as a function of time, 2) from examination of the correlations between the index and other physical quantities, to arrive at a better understanding of the mechanisms which determine the behavior of this parameter.

In communication systems employing tropospheric scatter, the basic mechanism is described in terms of the small variations in refractive index which are ever present as a result of atmospheric turbulence. This turbulence becomes the limiting factor in the accuracy of radio direction finding systems basic to missile tracking and guidance problems. Larger scale fluctuations in the distribution of index produce bending effects which can result in serious errors in such guidance systems as well as major disturbances in microwave communication systems.

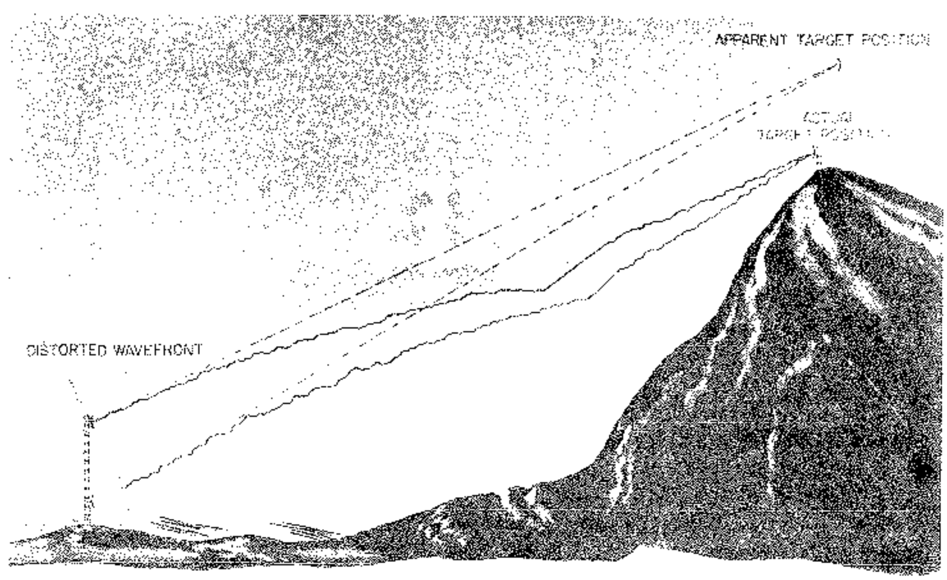
Since the development of microwave refractometers was begun at the National Bureau of Standards about ten years ago, the value of this type of instrument in studying the above effects has been recognized. During that time many improvements have been made over the first instruments. This project is intended to continue the improvements in instrumentation, and also to perform definitive field experiments wherever possible.

The plans for this project for FY 61 had to be postponed because all available personnel were transferred to project No. 83495. Essentially no progress can be reported at this time.

Although this is a continuing project, one new specific experiment is planned to begin during FY 1962. This is the operation of a three-dimensional array of microwave refractometer sampling cavities. Five sampling points will be arranged along each of three orthogonal axes oriented cross-wind, upwind, and vertically. The latter will be provided by the 160 meter meteorological tower at Haswell. Simultaneous recording of temperature, pressure, wind speed and radio refractive index are planned at each of these sampling points. The frequency response of each of these parameters is being pushed as high as is economically feasible; at this time 10 cps appears to be attainable. The data will be recorded on magnetic tape in analog form for economic data reduction and analysis. This approach to the wave number spectra of turbulence is expected to provide a valuable supplement to information gained from the conventional velocity transformation of the frequency spectra of single point measurements.

Within the next two years (FY 62, 63), such spaced cavity studies are expected to be passing from the ground-based tower to the airborne stage. The results of this are expected to be of considerable value in resolving the current apparent discrepancies between experimentally observed tropospheric forward scattering of radio waves and ground-level measurements of atmospheric turbulence.

Personnel assigned to this project were Moody C. Thompson, Jr. (Project Leader), Frank E. Freethey, William B. Grant, Harris B. Janes, Albert W. Kirkpatrick, Dean Smith, Jack D. Tefft, Maurice J. Vetter, and Donald M. Waters.




Atmospheric effects on vertical baseline radio tracking systems.

## Radio Tracking Accuracy

83194

The objective of this project is to study the effects of the troposphere on radio tracking systems.

During the past few years, the ever-increasing precision and accuracy requirements placed on electronic tracking and guidance systems for space research has greatly increased the relative importance of errors introduced by propagation through the lower atmosphere. In fact, the general heteorogeneity of the refractive index structure of the lower atmosphere constitutes a fundamental limitation on the accuracy of radio direction-finding systems. This limitation has been studied by this organization over a period of several years. Although the results of data have proven valuable and appear to be practically the sole source of data in this field, there are still many effects which cannot be confidently resolved. Among these are such questions as the effects of path length, antenna size, polarization, frequency and geography. The main objective of this project is to study these factors, using microwave refractometer and phase measuring techniques.

The plans for this project for FY 61 had to be postponed because all available personnel were transferred to project No. 83495. Certain elements of the plans for this project were included in the latter. The results are summarized in the report of that project.

The basic experiment will combine four types of physical measurements:

(a) Accurate determination of the locations of the terminals of the test path by independent measurements

(b) Observations of time variations in apparent radio path length

(c) Radio and optical observations of the apparent angular position of one path terminal as viewed from the other

(d) Direct measurement of the physical structure of the atmosphere in the vicinity of the path by means of airborne, tower-mounted and ground-based refractometers, and such other techniques as may be available at the time

These measurements will be made first over a 15 kilometer path near Boulder, Colorado, using vertical and horizontal baselines simultaneously. The horizontal baselines will range up to 1 km in length, and the vertical baselines up to 30 meters in height. Concurrent with the recordings of variations in apparent range and angle of arrival, variations in refractive index will be recorded continuously at the path terminals, and periodically along the path by means of the airborne refractometer. The structure of other variables such as temperature and windspeed will also be recorded in the vicinity of the path.

The use of Snell's law to estimate corrections for such atmospheric effects has received considerable attention over a period of many years. The techniques developed differ chiefly in the method used to interpolate and extrapolate discrete measurements of atmospheric index to form a continuum throughout the range required by the practical problem. Unfortunately, little work has been done in evaluating the ability of these methods and procedures to actually correct for the phenomena involved; this is because of the difficulty in the past of devising a sufficiently precise method of measurement. A significant part of this project, therefore, is to design and perform carefully controlled experiments to permit evaluation of such correction processes and subsequently to evaluate the relative efficiency of various assumptions or models concerning the atmospheric structure.

Personnel assigned to this project were M. C. Thompson, Jr. (Project Leader), Frank E. Freethey, William B. Grant, Harris B. Janes, Albert W. Kirkpatrick, Dean Smith, Jack D. Tefft, Maurice J. Vetter, and Donald M. Waters.

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## Geodetic Research

83195

The objectives of this project are to study the effects of atmospheric turbulence and similar phenomena on the accuracy of electronic distance measuring systems.

The spectacular advances in the field of geodetics and particularly land surveying which have been achieved by the use of electronic distance measuring techniques have led naturally to the question of what physical phenomena limit the ultimate accuracy of these methods. Numerous technical problems have been encountered which are amenable to resolution by the use of improved circuitry, components, choice of operating frequency, etc. However, as these factors are improved, the basic problem of the propagation characteristics of the atmosphere itself will become an increasingly important factor in the problem.

Some of the basic questions which arise concern the effects of path length, geographical and climatological environment, polarization, and antenna size and configuration. Additional problems enter in the conversion of such measurements from time measurements to distance. This is done by estimating the average velocity of propagation along the path from spot measurements. Both the interpolation process and the actual correction measurements are subject to serious errors.

The plans for this project for FY 61 had to be postponed because all available personnel were transferred to project No. 83495.

This project would include establishing controlled test paths under various conditions to evaluate systematically the effects of such parameters mentioned above. A variety of geographic locations would be selected to include a range of atmospheric environments. Simultaneous observations would be made using different frequencies and antenna configurations. Some work in this field has already been done by this organization.

Two further aspects would be studied. The first relates to the uses of these general phase measuring techniques to problems in seismology. In this area very small earth motions are involved and the ordinary turbulence encountered in the lower atmosphere appears to be a serious limitation on such measurements using radio techniques. An experiment is planned in which two slightly divergent paths would be observed simultaneously and the degree of correlation between the atmospheric effects on each path would be analyzed carefully in terms of general atmospheric conditions. The paths would be several kilometers in length and have low elevation angles to simulate conditions found after inspection of several known fault zones in the United States. Microwave frequencies, such as have already been introduced in electronic distance measuring equipment would be used. By the end of this initial experiment, it is expected that a clearer picture would be available as to the feasibility of this approach.

The work of the past several years indicates that the instruments and techniques developed for these purposes will permit the detection of changes of the order of 1 micron in the relative length of two lines of several km length. However, path lengths cannot be obtained in field measurements with this accuracy today, largely as a result of our ignorance of how to take account of atmospheric effects in the propagation phenomena. However, the existence of techniques capable of such high precision indicates that considerable attention should be given to the problems of improving the accuracy of path length measurements by properly correcting for the atmospheric structure. The study of such factors is, thus, clearly essential to the improvement and refinement of electronic geodetic techniques.

A third experiment planned for this project is an investigation of the accuracy which can be attained from angle-measuring instruments using the CW phase comparison technique. In this experiment several short baseline systems would be set up on typical path lengths with fixed targets. The apparent angular scintillations would be recorded, analyzed and studied in terms of other direct measurements of atmospheric parameters. These experiments would be repeated over a variety of paths in different geographical areas and weather conditions. It is believed that short baselines (say 2 meters or less) would permit angular resolution of the order of less than one minute of arc which would be useful for many current military applications.

Personnel assigned to this project were M. C. Thompson, Jr. (Project Leader), Frank E. Freethey, William B. Grant, Harris B. Janes, Albert W. Kirkpatrick, Dean Smith, Jack D. Tefft, Maurice J. Vetter, and Donald M. Waters.

## G. E. Tracking Systems

83495

This project is sponsored by the General Electric Company. The objective of this project is to study the refraction of radio waves in a simulated tracking system.

All surface based radio tracking systems are subject to errors resulting from the heterogeneity of the lower atmosphere. These errors range from systematic bias in apparent position of a target which results from the normal variations in atmospheric composition with height above the surface to the rapid fluctuations in apparent position resulting from turbulence. In the interim high precision tracking system being built for Patrick Air Force Base by General Electric Company, it is important that these effects be taken into account. This project is intended to provide accurate and reliable estimates of the extent and nature of these effects and so far as possible to develop methods of correcting for them.

A simulated tracking system operating in the X-band was installed using a fixed beacon mounted on the side of Green Mountain near Boulder, Colo. These roughly orthogonal baselines were established about 16 km east and about 800 meters lower to give an elevation angle of about $3^{o}$. The two horizontal baselines were about 500 meters in length and the "vertical" one making use of a steep cliff was about 30 meters. Simultaneous recordings were made of the range to the central antenna and differences between this range and each of the other baseline terminals. Refractive index was measured at each antenna as well as at five levels on a 30 m. tower near the central antenna.

Several data runs have been made, the longest being a five-day period in May 1961. These data are still being analyzed.

The data already taken will be analyzed more completely and recording will be made during several more periods. If the sponsor desires, the horizontal baselines will be extended to 10,000 feet and similar data runs made. Plans for FY 62 also include making airborne refractometer surveys in the vicinity of the first MISTRAM site near Patrick AFB, Florida. It is anticipated that a report on the Boulder results will be prepared during this period.

Personnel assigned to this project are M. C. Thompson, Jr. (Project Leader), Frank E. Freethey, William B. Grant, Harris B. Janes, Albert W. Kirkpatrick, Dean Smith, Jack D. Tefft, Maurice J. Vetter, and Donald M. Waters.

## Light-Weight Refractometer Tests

83496

This project is sponsored by the U.S. Air Force Cambridge Research Lab. The objective of this project is to evaluate the use of a light-weight refractometer as a tool for making refraction corrections in a radio tracking system.

All surface based radio tracking systems are subject to errors resulting from the heterogeneity of the lower atmosphere. These errors range from systematic bias in apparent position of a target which results from the normal variations in atmospheric composition with height above the surface to the rapid fluctuations in apparent position resulting from turbulence. Current methods of measuring atmospheric index structures have various limitations in accuracy, sampling trajectory, etc. There is reason to believe that data obtained from a relatively new light-weight refractometer may provide much more efficient corrections than previous techniques. This project is intended to check the relative efficiency of corrections based on this new instrument with other methods using surface, tower and airborne measurements.

As soon as the prototype instruments are made available by the sponsor, they will be operated in conjunction with the currently programmed MISTRAM tests. The results will be examined for correlation with the refraction effects observed and compared as correction information with that obtained from other support systems.

During the procurement stage consultation and technical assistance will be made available to the sponsor, Air Force Cambridge Research Laboratory.

## Manufacture of Refractometers

83813

The objective of this project is to manufacture two microwave refractometers suitable for measuring the outputs of six sampling cavities simultaneously.

To study more thoroughly the nature of atmospheric turbulence, it is important to estimate the wave number spectra more directly than the former technique of transforming single point measurements of frequency spectra. This approach is important in connection with radio forward scattering theory in which agreement has not yet been obtained between the various techniques which have been applied.

The first multiple cavity unit was used in the fieldin project 83495. Construction of the second unit has been held up to review the performance of the first.

Following evaluation of the tests on the first unit, the second will be completed.

Personnel assigned to this project was M. J. Vetter.

## Manufacture of MC Tape Recorder

83815

The objective of this project is to manufacture a tape recording system of 26-channel capacity for use with the microwave refractometer of Project 83813.

The study of turbulence by microwave refractometers as proposed requires that signals in various combinations from some 18 transducers be recorded in a say which permits feasible, economic analysis for spectral densities and cross-correlation. These requirements are felt best met by an FM sub-carrier analog tape recording system.

All components and sub-assemblies were obtained.

The two units (14 channel each) have been completed except for interconnecting and final test.

Final tests should be performed and the project completed.

Personnel assigned to this project was Maurice J. Vetter.

## Manufacture of Temperature and Wind-Velocity Measuring System

83816

The objective of this project is to manufacture a system for recording rapid fluctuations of wind speed and temperature.

This equipment is to provide vital supplementary data for the refractometer turbulence measurements program.

Some of the instruments needed for assembly of the hot-wire elements were obtained. Very little work was done as a result of the effort on project 83495.

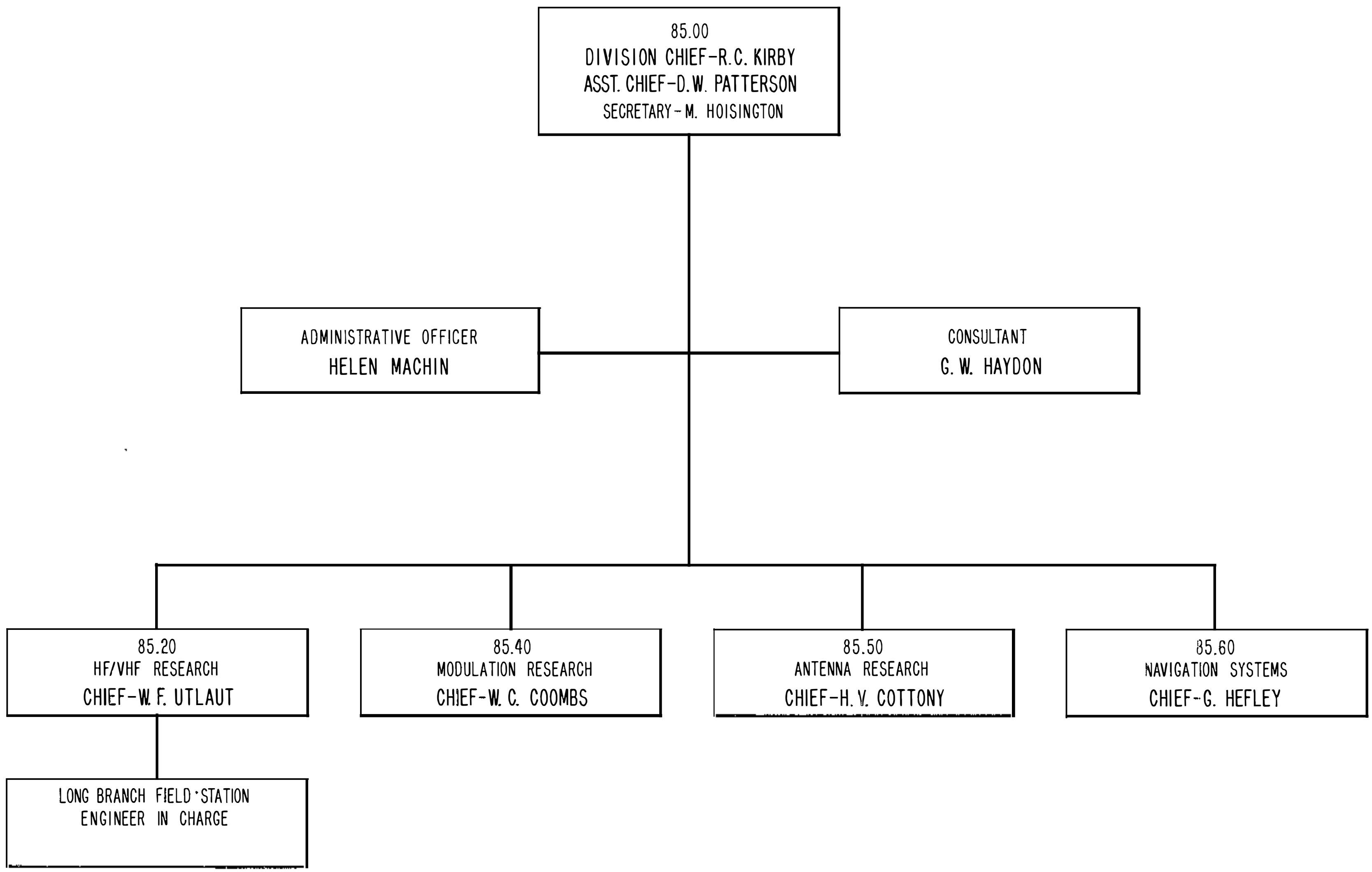
The necessary electronic elements should be received, tested and installed in conjunction with the tape recording equipment which will be used for recording these variables. Present plans are to construct the hot-wire units in this laboratory. Operation of the complete system is expected during 1962.

Personnel assigned to this project was Donald M. Waters.

# RADIO SYSTEMS

DIVISION 85

## RADIO SYSTEMS



# RADIO SYSTEMS

The objective of the Radio Systems Division is to develop and apply knowledge of electromagnetic wave propagation, radiation phenomena, and communication theory to the requirements of systems which depend upon radio wave propagation. The program of research and services is directed toward the development and dissemination of information in the fields of wave propagation, antenna design and radiation, modulation and coding, methods of measurement and instrumentation, and the conservation and efficient utilization of the radio frequency spectrum.

During the past year the Space Telecommunications Section was combined with the Modulation Research Section. The projects and project emphasis were retained without change in this merger. The Division is presently composed of sections in HF-VHF Research, Modulation Research, Antenna Research, and Navigation Systems. In addition a consultative group on radio frequency spectrum requirements and utilization is attached to the Division Office.

Since the formation of the Division in January 1959, the requests for assistance by other agencies in systems problems has greatly increased. To accommodate the many requests for information and assistance, it has been necessary to devote a large effort to our consultative and advisory function. The technical program of the Division is being oriented insofar as possible toward long-term, basic programs in system fundamentals in order that the consultative and advisory services rendered by the Division will be current and of greatest benefit to the largest number of users.

## Consulting and Advisory Services

85101

The objectives of this project are to (1) provide consulting and advisory services within the areas of the mission and special technical competence of the division, (2) to sponsor or assist in conferences, publications, travel and attendance at conferences, and other means of exchanging technical information, with research and development organizations in the United States and abroad, and (3) to investigate in a preliminary way promising avenues for research and development, or to carry out appropriate feasibility tests.

One of the principal responsibilities of the Radio Systems Division is to provide consulting and advisory services to government and non-government agencies engaged in commercial, scientific, regulatory, or operating activities involving the design and operation of radio systems. The work mainly concerns wave propagation and radiation problems in long range communication, radio navigation, timing and positioning systems. This activity is important for effective use of the various radio propagation media for radio systems, for the initiating of new studies in the field, and for the advancement of knowledge in radio systems technology. Information developed is directed toward güidance of engineering practice, frequency allocation and utilization, and evaluation of system capabilities, according to uniform criteria, standard and methods of measurement; information is needed for the efficient development and use of radio systems and increasing efficiency of use of the radio frequency spectrum.

The second report was drafted on national research and development in space telecommunications for Panel II of the Telecommunications Planning Committee, Office of Civil and Defense Mobilization, Executive Office of the President. This report surveyed existing and planned programs in satellite relay communications, and recommended areas for further study. In the process of preparing this report a bibliography on space telecommunications was set up, and more than 100 titles and abstracts were processed.

The division has furnished the National Bureau of Standard member of the Panel of Experts Advisory Committee, to advise the United States member of the Panel of Experts of the International Telecommunication

Union on the reduction of congestion in the high frequency band. A report on wave propagation in the high frequency spectrum was prepared for the advisory committee. This report surveyed United States work in prediction of solar activity for future cycles, acknowledging that opinions are divided as to the sunspot number for maxima of future cycles, the report concluded that the most probable value as estimated by the average of past observations is about 100 on the Zurich sunspot number scale. Probably of greater practical importance was the study of foF2 observations at Washington, D. C. over nearly three solar cycles, which indicated much less variation than did the sunspot numbers. It appeared that a severe reduction in sunspot number at times of maxima would not be accompanied by corresponding reduction in ionospheric critical frequencies. The data also gave no indication that future solar activity minima will be accompanied by any lower ionospheric critical frequencies than have been experienced in previous solar activity minima.

Division representatives participated in the work of the Inter-Range Instrumentation Group (IRIG), on the working groups in Telemetry and Telecommunications. In the latter working group the Bureau contributed to the recommendations for radio timing systems for synchronization of separated clocks within the missile ranges.

A tutorial briefing was conducted on Very Low Frequency and Low Frequency Propagation and Systems at the Rome Air Development Center, during November 1960, at the request of their propagation section.

For the second year the Antenna Section Chief has served as Associate Editor (Antennas) for the Transactions of the Institute of Radio Engineers, Professional Group on Antennas and Propagation. More recently he has begun service as the "government member" of the committee on IRE Standard on Antenna Measurements.

Modulation Research Section participated in discussions and correspondence on difficulties with the microwave relay system at Warren AFB, Cheyenne, Wyoming. A subsequent formal test program was set up.

At the request of the Commander, North Atlantic Air and Airways Communication System, a meeting between NBS, Air Force and the Bureau of Ships personnel was held at the Naval Research Laboratory, Washington, D. C. to discuss some low frequency communication problems of interest to the Air Force. This discussion was followed by further review and discussion of the problems at headquarters Norland AACS at Westover AFB, Massachusetts.

The project provided support for revision, completion of the text of a proposed NBS monograph, "Radiation Patterns in the Lower Ionosphere, and Fresnel Zones for Elevated Antennas over a Spherical Earth", by R. B. Merrill and W. G. Mansfield, covering work done through other project support in previous years.

The project has also provided the initial support of a program of sferic signal studies under Dr. Haruji Ishikawa, visiting consultant from the Research Institute of Atmospherics, Nagoya University, Japan. Four proposed sferic experimental programs were considered and it was decided to pursue two of these. Instrumentation, experimental work, and data collection have been planned to study the sferic source signal. The first of these will be a three dimensional location of the origin of each individual atmospherics involved in the electromagnetic field changes due to a lightning discharge. The second will be short range direction finding of ground strokes from the earth-current direction measurement. The actual program will be separately funded during the next fiscal year.

This project also funded the attendance of professional staff at national and international technical meetings including presentation of papers at the AGARD meeting on navigation in Istanbul, the AGARD meeting on ionospheric disturbances in Naples, the national URSI meetings and the national Global Communications Symposium.

Technical Committees and Societies:

International Radio Consultative Committee (CCIR)
- U.S. National Executive Committee
- Study Group I Committee (Transmitters)
- Study Group II Committee (Receivers)
- Study Group III Committee (Fixed Systems)
- Study Group IV Committee (Space Systems)
- Study Group VI Committee (Ionospheric Propagation)
- Study Group VII Committee (Standard Frequency and Time Signals)

International Scientific Radio Union (URSI)
- Commission 3 (Ionospheric Radio)
- Commission 4 (Radio Noise of Terrestrial Origin)
- Commission 6 (Antennas and Wave Guides)

Institute of Radio Engineers
Professional Group on Antennas and Propagation
Professional Group on Communication Systems

Associate Editor for Antennas, IRE Transactions on Antennas and Propagation
Committee on Standards for Antenna Measurement

Interdepartment Radio Advisory Committee
Subcommittee on Frequency Allocation

Telecommunications Planning Committee
Panel II (R&D)

Radio Technical Commission for Marine Services

Inter-Range Instrumentation Group
Working Group on Telemetry
Working Group on Telecommunications

Personnel from all sections participated in the project. R. C. Kirby was project leader.

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## International Radio Consultative Committee (CCIR) Studies

85102

This project is intended to provide studies for and staff participation in, the work of the International Radio Consultative Committee (CCIR).

The CCIR is the organ of the International Telecommunication Union having as its purpose the study of technical and operating radio problems of international interest and to recommend solutions for those problems. With the rapid advancement of the electronics and telecommunications art, the scope of studies of the CCIR has necessarily become very broad, and the countries that are members of the ITU have become increasingly dependent on CCIR Recommendations or other results of CCIR work in their decisions on international telecommunication regulations, standards, and operating procedures. The Ninth Plenary Assembly was held in Los Angeles in April 1959. Preparatory work began in most of the U.S. committees in early 1960 for the Tenth Plenary Assembly to be held in New Delhi in 1963. One of the most important activities has been the organization of a new international study group (IV) on space systems.

Members of the division staff have participated in the work of Study Group I on transmitters, Study Group II on receivers, Study Group III on fixed service systems, Study Group IV on space systems, and Study Group VI on ionospheric propagation. Regular members are provided for each of the United States preparatory committees for these groups, and the national chairmanship of Study Group III is provided by the division. The division has been especially active in Study Group IV on space systems and a division representative has been chairman of the sub-committee dealing with propagation and noise problems in space telecommunication systems. During the past year in addition to drafting the revision of CCIR report No. 115 on "Technical Factors Influencing the Selection of Frequencies for Space Communications", CCIR questions have been drafted dealing with frequency sharing, natural noise limitations, and space antenna problems. An NBS report was prepared as a draft CCIR report entitled "Practical Trends in Coding Theory" in response to CCIR Study Program No. 86. The study program is concerned with improving the efficiency of radio communication through reducing the bandwidth, transmission time of a quantity of information, and the transmitter power. The draft report reviewed information and coding theory, presented the status of codes in use and those likely to find use, and briefly compared the efficiency of error correcting codes with more conventional radio error detection automatic repetition techniques such as the ARQ. It was shown that there exists error correcting codes of the Bose-Chaudhuri type which indicates more efficient performance than the ARQ.

Expansion of division participation in the CCIR activities has been initiated by naming members to twelve of the fourteen study group committees. During the next year interim international study group meetings will be held in preparation for the Plenary Assembly, and it is expected that several division members will participate in this work especially Study Group III (fixed systems), Study Group IV (space systems), Study Group VI (ionospheric propagation), and Study Group X (broadcasting).

Personnel contributing to the project were: R. C. Kirby (Project Leader), G. W. Haydon, W. C. Coombs and M. Nesenbergs.

## Spectrum Allocation Studies

85104

The objectives of this project are to summarize the propagation factors important in frequency allocations and assignments into a concise format suitable for use by those responsible for frequency management, such as, the Interdepartment Radio Advisory Committee, and the Federal Communications Commission. Project 85104 is NBS supported to supplement spectrum allocation studies supported by FCC-OCDM.

The explosive growth of conventional radio services coupled with the development of new radio communication techniques, such as, satellite relay systems and new radio applications, such as, radio and radar astronomy, require a continuous examination of pertinent technical factors to assure efficient spectrum utilization.

Various modes of propagation have been studied and data compiled in a format applicable to FCC-OCDM in the estimation of circuit performance or interference potential, e.g., the classical field intensity methods used in the analysis of high frequency circuits has been translated into the more flexible system loss format, and factors determining the optimum frequencies for meteor burst communication systems have been summarized.

The project will be continued with emphasis on space communications systems.

Personnel contributing to this project were: G. W. Haydon (Project Leader); E. L. Crow; and D. L. Lucas.

## DASA Assistance

85404

The object of this project is to provide consulting and advisory services to the Defense Atomic Support Agency in the general field of atomic effects on systems which employ radiated electro-magnetic waves in their operation. Work conducted under this project is classified.

## NSA Transmitter Loan

85405

The objective of this project is to prepare two NBS 3 kw transmitters and loan to the National Security Agency for a period of one year.

The National Security Agency requested the loan of two 3 kw VHF transmitters for use in the Western Pacific for a period of one year.

NBS prepared and loaned the two transmitters to NSA for a period of one year beginning September 1, 1960. These transmitters were modified, calibrated and tested by NBS in accordance with specifications and instructions furnished by NSA cognizant technical personnel. The transmitters and spare parts required to maintain and operate them for a period of one year were shipped from the Long Branch, Illinois Field Station.

The plans for fiscal year 1962 are unknown.

Personnel contributing to the project were: R. H. Sublett (Project Leader), D. H. Layton, W. B. Harding, G. E. Wasson, K. V. Ballard, P. W. Fry, E. F. Snider.

## Page Transmission Services

85406

The objective of this project is to furnish facilities for providing High Frequency transmissions from the NBS Long Branch field station.

The Long Branch field station is uniquely located and NBS has the facilities available to supply radio transmissions. The U.S. Air Force has requested Page Communications Engineers to provide the necessary HF transmission in an investigative program.

NBS provided facilities at the Long Branch field station for a six week period during October 1 to December 20, 1960. One technician was also provided to assist in the maintenance and operation of the transmitters. (Transmitters were furnished by Page).

There are no plans for fiscal year 1962.

Personnel contributing to the project were: R. H. Sublett (Project Leader), D. H. Layton and E. F. Snider.

IRAC Frequency Allocation Study

85407

The objectives of this project are (1) to prepare a report or series of reports of propagation data and associated technical considerations having a bearing on the use of frequencies by the various radio services, emphasizing trends in radio frequency usage so the data will be applicable to long range planning in frequency allocation and (2) to prepare specific studies emphasizing selected radio services or portions of the radio spectrum as may be under special consideration by the Interdepartment Radio Advisory Committee or the Federal Communications Commission.

The Interdepartment Radio Advisory Committee and the Federal Communications Commission allocate radio frequencies for use within the United States and are major participants in the formulation of the U.S. position in International Radio conferences. It is essential that concise, authoritative technical data be readily available, to these organizations for the development of frequency allocation plans nationally and their defense or modification internationally.

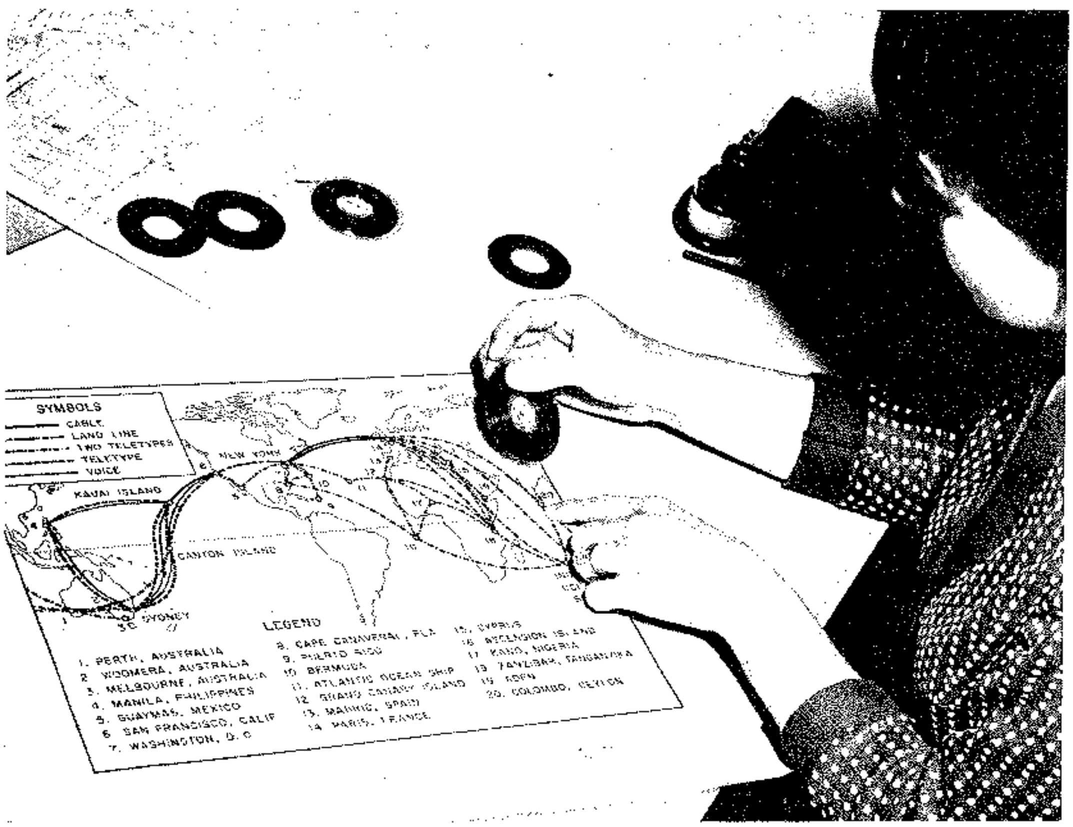
Fiscal year 1961 was devoted primarily to the application of propagation data to the problem of frequency allocations in space communications.

A series of graphs, nomograms and maps were prepared to illustrate the more important propagation considerations in selecting frequency for space to earth communications systems. These charts with associated descriptive material have been adopted by the IRAC and the FCC as a technical appendix to the proposed U.S. position in the allocation of frequencies for the space services.

In addition to the space frequency allocation problem, some effort was devoted to high frequency propagation, especially as to the transformation into the more flexible system loss format and an analysis of Arctic communication statistics.

The remainder of the project objectives will be completed. High frequency propagation, radio noise, ionospheric scatter and meteor burst communications with special emphasis on the space frequency propagation problem will represent the major effort. An electronic computer program will be used to compile high frequency data to bracket many high frequency allocation problems. Emphasis will be maintained on the evaluation factors influencing suitable frequencies and whenever necessary special charts illustrating the frequency dependence in a particular frequency allocation problem will be prepared as requested by FCC or IRAC.

Personnel contributing to this project were: G. W. Haydon (Project Leader); and Peter G. Ratcliffe.




Plotting high frequency radio paths for use in manned satellite communication system (Project Mercury).

## High Frequency Communication Studies

85408

The objective of this program is to develop information on natural geophysical phenomena and to apply this information to the problem of automatic frequency selection and prediction of circuit performance for long distance HF circuits. New information obtained will be used to upgrade the prediction of ionospheric characteristics produced by automatic computer methods which have been developed in project 85473.

Long distance HF radio circuits, which utilize ionospheric reflections, carry a large load of vital communication traffic. Characteristics of the ionosphere important to radio communications are variable and related, in a complex manner, to other geophysical phenomena. A better understanding of the various phenomena and their effects upon radio propagation conditions is required to provide automatic frequency selection and prediction of circuit performance.

Work on the project began in January 1960. In view of the breadth of the field under consideration, a number of consultations were held in an effort to define the most promising areas of attack. The project was broken down into three principal lines of investigation:

1. Improvement in regular predictions
2. Modification of predictions to take account of disturbed or unusual conditions
3. Selection of instrumentation for identifying ionospheric conditions and determining optimum frequencies.

A major part of the project is to carry out a search of the literature in order to gather information from other research of value to the project. In the case of regular prediction improvement six papers have been selected and summarized, and the pertinent data abstracted. Twelve papers related to short-term modification of predictions have been similarly studied. Of these, seven treated some phase of auroral absorption. A considerable list of references has been compiled, to be examined in detail as time allows.

A preliminary examination has been made of all the CCIR data having a possible bearing on the project. The documents submitted by the various governments to the Los Angeles, Geneva, Warsaw, and London conferences have been summarized. Those of particular interest will be studied in detail later. The success achieved by the North Atlantic Radio Warning Service is now being analyzed statistically to discover what degree of predictions improvement might be possible through use of its forecasts.

In the future, we will continue to seek answers to these major questions, among others:

How can the effects of moding, non-great circle propagation, sporadic-E propagation, and the high ray, be taken into account in such a way as to improve the reliability of basic predictions?

What solar-terrestrial relations can be employed in order to forecast with optimum probability of success the radio disturbances typical of the current phase of the solar cycle?

What experimental technique can best be employed to detect imminent disturbances and possibly prescribed the frequency re-assignments most appropriate for the ensuing conditions?

Personnel who have contributed to the work of this project are R. M. Davis, Jr. (project leader), Garney Hardy, and O. D. Remmler.

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## Mercury MUF/LUF Curves

85409

The objectives of this project are (1) to update previous CRPL predictions of the performance of the ground communications networks required to relay information concerning the Mercury capsule to Mercury headquarters near Washington, D. C., and (2) to advise the National Aeronautics and Space Administration as to adequacy of frequency complements, circuit routings, terminal locations, and other equipment or operational aspects to optimize the ground communications network reliability.

Hundreds of millions of dollars are being spent to achieve manned space flight. The ground communication system serves two general purposes (1) provides continuous information on the condition of the space capsule to a central headquarters to provide for the safety and well being of the astronaut, and (2) provides a means for the rapid transmission of data to a central analysis point. The ground communications system is of such importance the failure of any link can serve as sufficient cause to cancel a launching.

The useful range of high frequencies on 10 of the more crucial ground communications links were calculated for March, June and September 1961. The June 1961 computations included an estimate of circuit reliability, i.e., the percentage of days within the month that satisfactory operation could be expected. Frequency complements on these links were analyzed and modifications recommended when necessary. A special analysis was made to select a U.S. terminal location for high frequency circuits into South America.

Work on this project will be continued if requested by the National Aeronautics and Space Administration.

Personnel contributing to this project were: G. W. Haydon (Project Leader); A. V. Brackett; and D. C. Hyovalti.

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## Studies for More Efficient Use of Radio Spectrum

85446

The objectives of this project are to perform research and studies to identify possible techniques, operational procedures, management procedures and equipment developments, which can contribute to more efficient use of the radio spectrum and to develop the application of such factors to spectrum use.

Effective long range planning is necessary to insure maximum use of radio communication capability of the nation during a Civil Defense emergency, and for warning the civilian population of enemy attack. Careful positioning of the various radio services in the radio spectrum, and effective operational and management procedures will contribute to communication during an emergency.

Activity during fiscal year 1961 was limited to preliminary library research.

The project will be completed in accordance with the objectives including a study of (1) operational procedures to improve time sharing (2) receiver sensitivities, modulation methods, antenna directivity, etc., to improve frequency sharing and (3) receiver selectivity, transmitter tolerances, harmonic emissions, equipment noise levels, minimum transmitter powers, etc., to assure maximum spectrum occupancy.

George W. Haydon was project leader on this project.

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## Ground Telecommunication Performance Standards

85472

(Note: See also Project 83409)

The objective of this project is to develop standards of performance for ground telecommunications systems for the Air Force Ground Electronics Engineering Installation Agency (GEEIA). Considerable emphasis is placed on radio propagation characteristics. The initial purpose of these standards is to provide information to Air Force personnel upon which system performance specifications can be developed and operational performance determined and measured. The ultimate purpose is to provide a guide for continued improvement of Air Force communication systems, by establishing standards of performance by which communication systems will be judged.

Military communicators are continually faced with substandard operation of communication systems and incompatibility between equipments and between systems. GEEIA has responsibility for the engineering and installation of Air Force ground communication systems and has been delegated the task within the Air Force for developing System Application Standards "to provide qualitative and quantitative values and measures for obtaining uniformity of controls governing performance, engineering, and supply of equipment and systems for ground communications." This project covers those aspects of System Application Standards related to performance.

There are a large number of standards now in existence covering various aspects of radio communications. In many cases, however, standards are contradictory or incomplete. For many areas standards do not exist. This has resulted in confusion in specifying and interpreting performance standards for new equipment or for operating circuits. In many cases the lack of standards for performance, and for methods for measuring performance, has resulted in the acceptance of substandard equipment and systems. This project is an attempt to arrive at a single standard and method of measurement which can be used throughout the Air Force for classifying and specifying the performance of Air Force ground radio equipment and systems. The effort under this project is the initial step of sorting and assessing existing standards and developing preliminary standards where standards do not exist or are considered to be inadequate. The continual revision of these standards will be required if they are to maintain effectiveness in fulfilling the requirement for which they are being developed.

Standards of performance and measurements have been developed for ground radio and wire and cable circuits. These standards cover, in five parts, VLF-LF systems, MF-HF systems, VHF Ionospheric scatter systems, UHF tropospheric scatter systems (reported under Project 8300-40-83409) and wire and cable systems. Standards have been developed in the general areas of the transmission medium, antennas and siting, message signals, modulation, equipment, and system performance.

Recently developed information has been used to improve the accuracy for predicting the transmission properties of radio waves. Standard procedures are given for computing the expected performance of radio links based upon signal-to-noise requirements. Performance criteria have been established for measuring expected circuit performance.

Standards for antennas and antenna siting have been developed for representative Air Force operational antennas. Standards are also provided for antenna matching networks, couplers and transmission lines.

Basic message signals have been standardized for both analog and digital signals. Bandwidth and channeling standards are presented as well as teletypewriter codes and transmission rates.

Signal-to-noise requirements have been developed for various types of modulation for establishing signal quality or grade-of-service. Data have been prepared and are presented for circuit degradation caused by signal fading, data rate, and multichannel operation. Improvement of received signals through diversity reception is presented. Information has been developed and is presented on the degradation of circuit performance by multipath propagated signals.

Standards have been developed for specifying the performance of transmitters, receivers, and auxiliary equipment. Input-output signal levels and impedance levels have been standardized to permit interchangeability. Standards for signal generating equipment are given to provide for standard message signals.

Procedures are given for computing the performance of radio links and circuits of tandem links. Information has been developed for relating expected monthly median signal-to-noise to the required hourly median signal-to-noise to determine the expected performance or time availability of high frequency circuits. A standard wire and cable circuit has been defined and a method for comparing the performance with the standard is presented. Standards for wire and cable terminal equipment have been established, including standard signals and signal channels. Standards are given for multiplexing and channeling.

All work on this project is scheduled for completion by the end of FY 1961. The material is being furnished to the Air Force in the form of a working draft of an Air Force Technical Order. The material will be reviewed and revised by the Air Force and issued as Air Force Technical Orders as part of the System Application Standards. Preliminary discussions have been held with the sponsor regarding NBS work revising and updating the working draft. No definite plans have been made.

Personnel from all sections participated in the project. D. W. Patterson was project leader.

## Develop MUF / LUF Program

85473

To predict the Maximum Usable Frequency (MUF), Optimum Frequency (FOT) and the Lowest Useful High Frequency (LUF) by high speed computers.

The range of useful frequencies is important in the planning and operation of high frequency circuits. The manual methods commonly used to predict these frequency limits are very laborious and time consuming. In addition to predicting efficiently the performance of high frequency radio circuits, a computer program will readily allow the comparison of observed data against the predictions. The ease of comparison of predicted and observed circuit use permits a revision of prediction parameters and leads to more accurate and efficient predictions.

The goal of the project is to produce an efficient and completely general high speed computer program for the prediction of upper and lower useful frequency limits. The use of recent improvements in the mapping of F2 layer of the ionosphere through its representation by numerical coefficients permit the first fully automated MUF / FOT prediction technique emphasizing data from the current sunspot cycle. Full automation is essential to meet the fast changing extensive communication requirements of the military.

The numerical mapping technique recently developed by CRPL is the basis of the F2 layer upper frequency limit predictions. The project requires a general computer language compatible with large high-speed computers. Predictions of the world wide critical frequencies by this method are made as continuous functions in time, geographic latitude, and longitude. Grid point machine storage of constant time function maps are not necessary input parameters in this method.

The work began 20 January 1961. A machine program based on this mapping technique has been completed for the prediction of upper limiting frequencies of point to point circuits. The input coefficients that represent the world wide distribution of critical frequencies were stored on binary tape, edited and thoroughly checked in the prediction program. The limiting frequencies for the regular E layer are represented by a semi-empirical equation involving the angle of the sun and sunspot number.

The geographic variation of the F2 layer gyro-frequency is represented by orthogonal polynomials. Polynomials representing other needed parameters were generated on the computer at CRPL.

The monthly median predictions of MUF and FOT are general, i.e., applicable between any geographic locations for any time of day, any month of year, and any degree of solar activity. The Sporadic E, F1 layer, or high angle (Pederson) ray are not considered in the initial program.

The program has been satisfactorily checked on the computer at CRPL and the large computer at David Taylor Model Basin, Washington, D. C. The time required to calculate 24 hourly values of MUF's and FOT's for a given month is approximately 5 seconds on either machine. Automatic tape searching for all needed parameters is included within the program and searching takes place during machine calculation of prior circuit month. Two auxiliary magnetic tapes are required for input storage. The internal storage used by the program is approximately 10,000 locations.

The project is currently authorized to 1 September 1961. During this time further effort will be devoted to developing machine programs to predict the lower frequency limits of high frequency point to point circuits. Emphasis will remain in flexibility, and a major effort will be devoted to an orthogonal polynomial representation of the numerous contour maps required in the LUF and circuit reliability predictions.

The initial program will be designed to use readily available data. After the initial program is completed, improvement of input parameter formats such as noise grades, antenna patterns, and interpolation factors will be the major concern.

Personnel contributing to this project were: D. L. Lucas (Project Leader); G. W. Haydon, J. D. Harper, Jr.; B. A. Kingsbury, R. G. Merrill; and W. C. Coombs.

## MF/HF Experimental Phase Path Studies

85442

The objective of this project is to conduct experimental measurements on phase path length changes and group path time delays of medium and high frequency signals reflected from the ionosphere. Data from this experiment will be used in defining special ionospheric behavior during nuclear detonations.

The problem of the detection of nuclear explosions is an essential aspect of control in any internationally agreed nuclear test ban and thus one of extremely great importance to the nation and the world at the present time. Simple, reliable detection methods are scarce and new ones are needed badly. Any special behavior of the ionosphere that is caused by nuclear detonations can only be identified after sufficient data is available on the normal short-time ionospheric variations.

Techniques of instrumentation have been devised and units of equipment are being built and procured.

One special problem involved in this instrumentation is that of recording very rapid phase changes. It is planned to do this by using special circuits that will sense rapid changes and by using short duration magnetic tape storage. Such a technique will make possible expanded scale recording during the selected time segments of interest.

Studies of estimated critical frequencies and expected ionospheric behavior during solar disturbances indicated that frequencies around 2 and 4 Mc/s would be best for the experiment. Frequency assignments have been obtained at 2.1 and 4.055 Mc/s.

The types of antennas to be used have been decided on and their design and construction is in progress.

The receiving site will be at Table Mesa (north of Boulder) and the transmitting site has been selected at Erie, Colorado, about 11 miles away.

Two 40-kilowatt transmitters have been obtained for use in the experiment.

A low power transmitter operating at 4.055 Mc/s has been installed in order that experience in the technique developed for phase recording can be obtained during the period required for installation of the high power transmitters.

It is planned to develop additional equipment needed and to obtain experimental data on phase path and group path changes at frequencies of 2 and 4 Mc/s. Both long duration and short durations of phase changes will be measured as well as rates of change. Besides obtaining data on diurnal and seasonal variations of phase, special events such as SID's, magnetic storms and sporadic-E occurrence will be monitored for phase changes. The rate of phase change during these special events is considered important to the objectives of the project because nuclear detonations are believed to cause very rapid phase changes in HF signals that are reflected from the ionosphere.

Personnel contributing to the work of the project are J. C. Blair (project leader), G. E. Wasson, and C. H. Johnson.

## D-Region Scatter Propagation
## VHF Scatter Engineering

85123 - 85144

The objectives of the project (which will continue as project 85123) are to study VHF signals scattered from the D-region to obtain information on the long term variation of field intensity, the short term variation of fading envelopes, the statistical distribution of angles of arrival and the effects of field-aligned ionospheric irregularities.

The program will provide information on the effect of solar activity on scatter signal intensity, and on the reliability of scatter systems during solar disturbances and nuclear detonations. The data obtained will contribute to the basic understanding of the scatter mechanism and will aid in the design of optimum scatter communications systems.

Signal intensities were recorded on five frequencies up to September 30, 1960 and on 30 and 50 Mc/s for the remainder of the year. This recording program serves as a continuous monitoring method for special events such as sudden ionospheric and magnetic disturbances. Moreover, continuous recording of average received scattered power is needed to determine the variations of signal during the sunspot cycle. Four years of this data have already been obtained.

Ten-minute samples of short term variations of the fading envelope were recorded on magnetic tape at six-hour intervals one day per month. Some of these data were analyzed for duration of fade at various signal levels and sample fading spectrums were obtained. Such data are vitally important in making estimations of scatter-circuit reliability and information handling capacity. This short-term data is also needed to acquire a better understanding of the basic scattering mechanisms. It furnishes information on the relative contributions of turbulence, meteoric reflections and sporadic-E to the composite signal.

Average fading rates of the signal envelope were recorded continuously and simultaneously on five VHF scatter frequencies during the period July 1 to September 30, 1960 and on 2 frequencies (30 and 50 Mc/s) since September 30. The fading rate recordings furnish a continuous monitoring system for short-term signal conditions.

A series of high-speed tape recordings of signal envelope was made during the Orianides meteor shower in October. This was done in cooperation with Division 82 to provide information on meteor counts during the shower in order to test for correlation between meteor activity and phase perturbations at VLF. These runs have been analyzed by counting the number of bursts at different signal levels, and the percentage of the total times taken up by the bursts (at different levels) has been determined.

During September, signals were recorded on magnetic tape for antenna comparison purposes. Signals that were transmitted and received on Yagi antennas (65° beamwidth) were recorded as well as signals transmitted and received on rhombic antennas (6° beamwidth). A comparison of power spectrum and depth of fade for the different antenna systems will be made from these tapes.

Some results of this study are:

1. Scatter signals at lower frequencies in the VHF band display longer durations of fades than signals at higher frequencies.

2. Depth of fade is deeper under weak signal conditions than it is under strong signal conditions.

3. Pilot runs show that the power spectrum bandwidth of the received signal increases with frequency and antenna beamwidth. Wider spectrum bandwidths are observed during weaker signal conditions.

4. Average fading rate of the signal envelope is greatest around midnight and lowest around noon on all carrier frequencies.

5. The meteor bursts that were received during the peak of the Orianides shower were of shorter average duration than bursts received during the early and late days of the shower.

Recording of 30 and 50 Mc/s scatter signals on the Long Branch-Boulder path will be continued. Further measurements of the short term fading envelope will include spectrum analysis and fade duration at different signal levels at all seasons and times of day. The scanning antenna described in project 85152 will be used to study the statistical distribution of directions of arrival of scatter signals transmitted from different types of antennas at Long Branch. The data obtained on these distributions at different times of day and for different seasons will be valuable in the design of optimum antennas for scatter communications systems. By transmitting pulsed signals from Long Branch, the range of the various signal components can be determined simultaneously with their directions of arrival. Since meteor trail and sporadic-E reflections usually occur at greater ranges than the scatter component of the signal it becomes possible to separate the contributions of each mode of propagation.

Personnel contributing to the work of the project were J. C. Blair, O. D. Remmler, V. H. Goerke, M. W. Woodward, A. E. Smith, R. L. Sudduth III, J. L. Workman, Garney Hardy, E. F. Snider, and G. E. Wasson.

## Meteor Radiants

85103

The objective of the project is to observe rates of occurrence and direction of arrival (radiants) for meteor influx into the earth's atmosphere.

This project has been designed to provide supplementary data to NBS meteoric propagation programs. Meteoric propagation circuits can effectively utilize only meteors having certain directional characteristics and hence, meteor radiant information is necessary in relating observed circuit performance on a given path or paths to circuits having different orientation or different latitude. The rate of occurrence of meteors is a determining factor in the transmission capacity of a communication system.

Observations at three stations of meteor reflected signals on a regular basis have been made since September utilizing a 27 Kw transmitter and a trough antenna for transmission. Film reduction and data analysis through the aid of a computer program which provides meteor rate and radiant information has been carried on by Harvard under NBS contract.

A high power transmitter formerly installed in two large vans has been relocated in a building constructed for this purpose and is capable of delivering 2.5 megawatts of peak pulse power at 40 Mc for use in the radiant program.

It is planned to complete the construction of the high power transmitter so as to provide 5 to 6 megawatts of pulse power for use in a continuing program of determining meteor radiants and orbits. The observational program will be carried on by Harvard University under National Science Foundation sponsorship and will no longer be funded by NBS.

Personnel contributing to the work of this project are W. F. Utlaut (project leader), J. C. Carroll, and D. H. Layton.

## High Frequency Guided Exospheric Propagation

85105

The objective of this project is to determine experimentally as many characteristics as possible of the HF ducted propagation mode along the magnetic field lines through the exosphere.

In the light of the present-day interest in expanding and improving communication techniques, the addition of a new propagation mode is of considerable interest both as a possible communication path, as well as a source of interference to other communications. Of perhaps more importance, however, is the potential which this mode possesses for the investigation by ground based radio observation of various properties and parameters of the earth's exosphere normally accessible only by earth satellites.

During FY 1961 plans were made and steps were taken to facilitate an expanded experimental program for the investigation of HF ducting along the magnetic field lines through the exosphere.

Because of the extremely large attenuation suffered by this propagation mode it was necessary to increase the sensitivity of the system. It was decided to use longer transmitter pulses and narrower receiver bandwidths. Two photographic recording systems designed especially for use with long pulses were assembled. An electronic integrating system was constructed and made ready for testing.

A Collins 205J 50 kw transmitter with its exciter unit was obtained on loan from the Signal Corps for transmitting pulses with an unlimited duty cycle. The fast frequency change feature of this transmitter will permit its use to determine the frequency dependence characteristics of the exospheric propagation mode. This transmitter was installed in a trailer and was being tested at the end of the year.

It is planned to use the Collins 205J transmitter with long pulses to search for exospherically propagated backscatter echoes. The integrator unit should be available for increasing the effective sensitivity to echoes. The frequency shift facility of the transmitter will be utilized to determine frequency dependence characteristics of this mode. If this part of the experiment proves successful, experiments to determine geographical dependence will also be performed. In its simplest form this will involve moving the transmitter and receiver to other locations. In this way it is hoped to obtain statistics on the occurrence of this ducted mode.

Personnel who contributed to the work of this project are L. H. Tveten (project leader), W. F. Utlaut, A. R. Mitz, A. H. Dove, H. E. Petrie, V. H. Goerke, G. J. Morzinski, and J. L. Spindle.

<u>Investigation of High Frequency Arctic Propagation over Various Paths - Phase I</u>

85421

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# High Frequency Transmission Loss Studies for Auroral Regions

85422

In order to improve understanding of the part played by absorption in the transmission loss observed on Arctic HF paths, measurements were made to determine the dynamic range and frequency dependence of such losses over three representative paths at frequencies in the range 5-20 Mc/s. In addition measurements of ionospheric absorption, using the cosmic-noise technique, to investigate the relationship between vertical-incidence absorption as measured by a riometer and oblique-incidence absorption measured in the same manner were made.

During and since the IGY, a considerable amount of high-latitude ionospheric absorption data has been obtained using riometers. These data, taken at about 30 Mc/s cannot be used directly for HF transmission loss predictions until experiments have been conducted to investigate the relationships between riometer and HF field-intensity data taken simultaneously at various frequencies. This project was designed to provide information on these relationships, particularly on the frequency dependence of the absorption, and to study the effects of absorption disturbances on HF signals propagated through the Arctic.

Continuous HF transmissions were made on paths Barrow to Kenai, Barrow to Boulder, and Thule to Barrow. These paths and the 50 Mc/s riometer at Kenai, Alaska, and the 30 and 50 Mc/s riometers at Skwentna, Alaska, were operated through August 31, 1960, at which time the observational phase of the project terminated. The riometer records have been scaled and the data processed to give absorption values. Particular attention has been given to the relationships between the HF transmission losses observed at 5, 10, and 15 Mc/s over the Barrow-Kenai path, and the sum of the 50 Mc/s absorptions observed on the oblique-incidence riometers at Barrow and Kenai. (These riometers were aimed along the great-circle path connecting the two sites, at an elevation angle corresponding to the 1-hop F2 mode). The observed absorption on the different frequencies showed less frequency dependence than predicted by the simple $1/f^2$ law; the deviation from $1/f^2$ was greatest at the lowest frequency. This failure of the $1/f^2$ law was found both in the 30 and 50 Mc/s Skwentna riometer data, and in the Barrow-Kenai 5, 10, and 15 Mc/s field-intensity data, and also in the comparison of the

Barrow-Kenai riometer and field-intensity data. The failure of the $1/f^2$ law is interpreted in terms of a significant fraction of the absorption occurring in a region where the electron collision frequency is comparable with the operating angular frequency; in this way it is deduced that the majority of the daytime absorption occurs in the height range 55-75 kms.

The basic analysis of the HF transmission data was done by automatic computer methods. After the hourly medians of signal intensity were scaled by hand, the diurnal distribution of the signal levels exceeded 10%, 50%, and 90% of the time for all three paths and for frequencies near 5, 10, 15, and 20 Mc on Barrow to Kenai and Barrow to Boulder (near 9 and 12 Mc on Thule to Barrow) were computed and plotted by machine. Cumulative distributions of the transmission loss for all paths and all frequencies were similarly prepared.

The effects of disturbance were compared among the three paths to determine the differences between auroral absorption and proton events as these differences varied with geographical position. The polar cap path was found to be less susceptible to disturbance than the auroral zone paths. It was concluded that on the whole during disturbances higher frequencies have a greater probability of successful transmission than lower frequencies on high-latitude paths.

A study was made of the absorption observed on the arctic paths with that which would have been expected from the use of available calculation methods. It was found that except in June and July the absorption calculated by present methods is too small. In June and July the discrepancy is much smaller, and calculated absorption may even be greater than that observed.

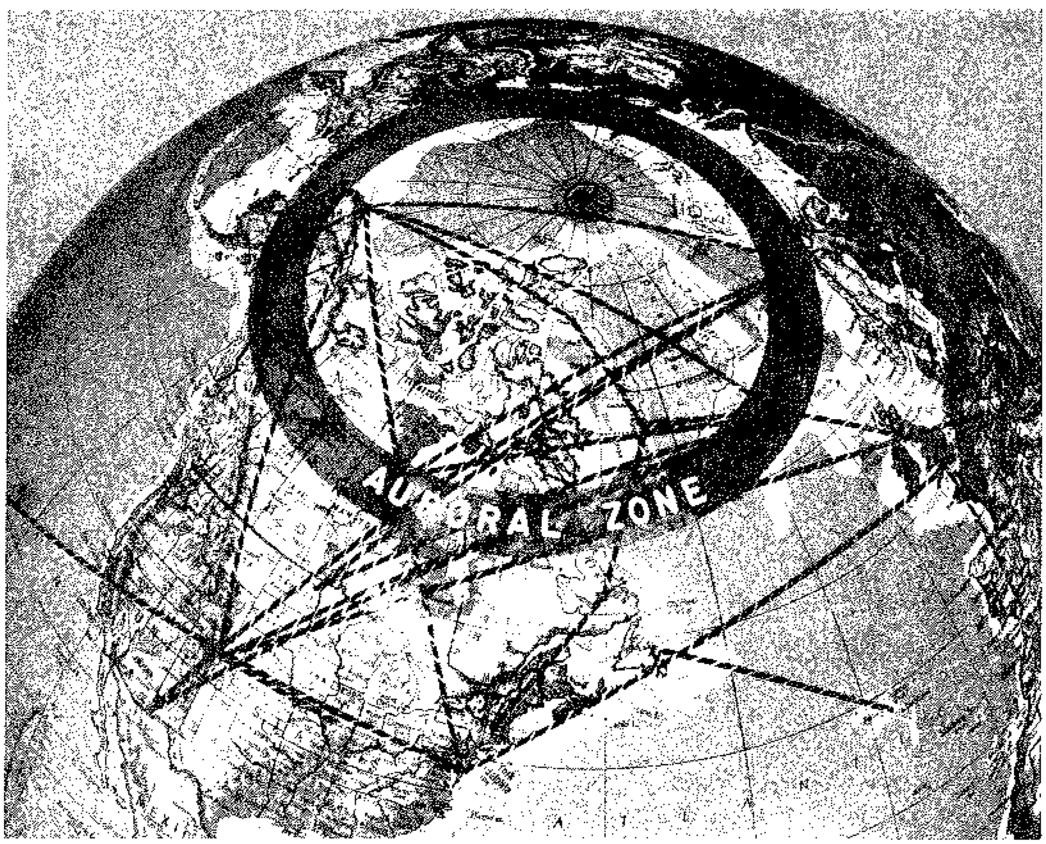
It was hoped to use the sweep-frequency records made in the previous fiscal year on the Barrow to Boulder path to identify those days when the 1-hop F mode was in effect and thus to find the absorption applying unambiguously to this mode. The value of absorption obtained in this way did not differ significantly from that obtained on days when the 1-hop F mode was not in effect.

A number of additional analyses were made and are described in the final reports (NBS Report 6742, Final Report on Evaluation of Auroral Propagation Factors: Transmission Loss Phase - Part I, System Loss Behavior and Prediction on Some High-Frequency Arctic

Paths, and NBS Report 6743, Part II, A Comparison of Arctic HF Transmission Loss & VHF Riometer Data). Among them are studies of noise levels, relative usefulness of disturbance indicators, and fading rates.

This project was terminated furing FY 1961.

Personnel contributing to the work of this project were R. Silberstein, C. G. Little, S. S. Barnes, H. E. Petrie, J. L. Workman, L. H. Tveten, R. M. Davis, Jr., Garney Hardy, and R. L. Sudduth III.




Radio propagation paths used in auroral region experiment to measure high frequency transmission loss.

MF/HF Theoretical
Phase Path Studies

85425

The objectives of this project are:

1. To search the literature for the results of previous workers investigating phase path perturbations of ionospherically reflected MF and HF radio waves to obtain information useful to both the experimental and theoretical parts of the phase path perturbations study.

2. To make calculations of phase path perturbations resulting from hypothetical detonations of nuclear devices in outer space and by using variable parameters to determine the most sensitive detection technique and conditions.

3. To aid in the interpretation of results from the experimental study.

The problem of the detection of nuclear explosions is an essential aspect of control in any internationally agreed nuclear test ban and thus one of extremely great importance to the nation and the world at the present time. Simple, reliable detection methods are scarce and new ones are needed badly. Any special behavior of the ionosphere that is caused by nuclear detonations can only be identified after sufficient data are available on the normal short-time ionospheric variations.

This study was begun about mid-year. It has so far consisted of a literature search of previous works on phase measurements of ionospherically reflected waves. This has been done to build up a fund of information on natural phase perturbations to be used in the interpretation of data obtained by the experimental program as well as to point to possible new directions the experimental program may take.

Another direction the theoretical program has taken is the calculation of phase path perturbations on MF and HF waves imposed by various ionization profiles thought to be generated by the explosions of nuclear weapons of various sizes in outer space. These ionization perturbations would occur in the D region and result in added attenuation as well as a reduction in phase path. Calculations have been made for both undisturbed noon and midnight conditions with parameters suitable for the Boulder area where the experimental program is to begin. Calculations have shown phase path changes to be rather small with the ionization profiles used.

It is planned to continue the work along similar lines. The calculations of theoretical phase path perturbations will continue using different geographic and ionospheric parameters in an effort to discover the most sensitive detection conditions. In addition the output of the related experimental program will undoubtedly present problems of interpretation which require solution.

Personnel contributing to the work of the project are L. H. Tveten (project leader), Garney Hardy, and F. W. Lott III.

## Investigation of Forward Scatter Communication Techniques - Aerospace Vehicle Links

85427

The objective of this project is to conduct a theoretical investigation of the possibility of extending the range and increasing the reliability of aerospace communication links through exploitation of ionospheric forward scatter modes of propagation. A second but equally important objective is to define instrumentation parameters required for the gathering of pertinent scatter data if such a system proves feasible.

Real time, global range, communications between earth stations and orbital vehicles is of paramount importance. This investigation is designed to conduct research into methods and reliability of these communications.

A study consisting of literature review, a theoretical investigation, and a preliminary mathematical analysis has begun. This study covers ionospheric scatter transmission and other propagation phenomena which may be applicable to this problem.

A survey of the literature has shown that signals have been detected from satellites many minutes before the satellite has appeared over the horizon. The signal strength of these "precursors" is often within a few db of free space levels. Investigation is continuing to determine if these "precursor" signals are the result of ionospheric scatter, tropospheric scatter, or if they result from some undetermined phenomenon.

Activities of FY 61 will be continued and mathematical models will be constructed where desired. Major emphasis will be placed on the characteristics of a signal after passing through a scattering medium. This shall have reference to bilateral transmissions, i.e., earth/vehicle and vehicle/earth Doppler, radiation angle and directivity of scattered signals will be analyzed.

Personnel contributing to the work are D. R. Macken (project leader) and J. T. McKinney.

### Evaluation of High-Frequency Communication Techniques Under Conditions of Disturbed Ionospheric Propagation in Auroral Regions

85441

The objective of this project is to obtain experimental information on high-frequency auroral propagation factors which affect the performance of modulation techniques for continuous wave and pulse communication for air/ground systems.

Communication at high frequencies via ionospheric propagation in auroral regions is severely disturbed at times in a manner characteristic to these regions. These disturbances take the form of intense absorption of the propagated waves or severe distortion of the transmitted signal. The extent and characteristics of the imposed distortion must be known in order to predict the performance and limitations of systems and to assist in the design of optimum modulation methods.

Experimental observations of pulse-to-pulse phase stability were carried out on a path from Barrow, Alaska, to Boulder, Colorado. One-millisecond pulses at a 250 c/s repetition rate were transmitted at frequencies of approximately 15 and 19 Mc/s. The phase of corresponding parts of successive pulses was compared continuously, and then the integrated values of phase differences during one-millisecond periods were determined. An NBS report, No. 6764, entitled "Observations of pulse-to-pulse phase stability on a high-frequency auroral path" , by J. W. Koch, reporting on the results of the observations was published.

Observations to determine the fading correlation bandwidth of pulse transmission and pulse fading rates were made on a path between Sterling, Virginia and Barrow, Alaska, using pulses of 100 microsecond and 1 millisecond duration having a peak power on the order of 100 kw. In this, groups of pulses closely spaced in frequency were transmitted in rapid sequence at various frequencies in the HF band. The pulses received after propagation over the path were recorded photographically and have been analyzed in terms of the normalized covariance of pulse amplitude as a function of frequency separation between pulses. This analysis has shown that 1 millisecond pulses separated in frequency by more than about 3 kc/s and 100 microsecond pulses separated by more than 5 or 6 kc/s fade in an uncorrelated manner for this path over which single-hop propagation is not normally expected. By comparison, measurements made earlier on a short path of 2300 km, between Sterling, Virginia and Boulder, Colorado, indicated that there was correlation in the fading of 100 microsecond pulses separated in frequency by 40 to 50 kc/s.

Early in the first quarter, analysis and reporting of the pulse fading correlation study will be completed and thus conclude this project. No further observations are planned.

Personnel contributing to this work were J. W. Koch, W. F. Utlaut, L. H. Tveten, A. R. Mitz, A. E. Smith, R. C. Peck, J. L. Spindle, G. E. Wasson.

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## Meteor Count Recording at 50 Mc/s for United States Air Force Program to Determine Extremely Low Frequency Perturbations

85426

The objective of this project is to aid in determining whether or not low frequency oscillations of the earth's magnetic field are associated with meteor activity.

In recent years research workers have reached conflicting conclusions regarding the correlation of ELF perturbations of the earth's magnetic field with the incidence of meteors on the earth's ionosphere. This project attempts to resolve the question by comparing meteoric activity in a restricted volume of the ionosphere with magnetic field perturbations observed on the ground below.

NBS participation in this project began in early April 1961. Continuous records of the ionospheric scatter signal at 50 Mc/s on the Long Branch-Boulder path were furnished to Denver Reseach Institute (DRI). They are comparing meteor activity on these records with oscillations of the magnetic field observed at the path midpoint near Schickley, Nebraska.

The 50 Mc/s scatter records will be furnished to DRI to September 30, 1961, the end of the contract period.

Personnel contributing to the work of the project are O. D. Remmler (project leader) and A. E. Smith.

RADC Propagation Studies
Task I & Task III

85522, 85523

The objective of this project is to study the fine structure and irregularities of the ionosphere by means of observations of signal amplitude, phase and polarization of backscattered and forward propagated signals.

In the design or improvement of any communication system it is of great importance that as much as possible be known about the normal perturbations existing in the ionosphere which affect the phase or amplitude of a radio signal as well as its direction of arrival.

Since this is a new project slated to really begin with FY 62, activity in FY 61 was limited to a study of the equipment needs of the project and their acquisition.

Early in the year very narrow beamwidth antennas, one of which will be capable of scanning a sector in the horizontal plane and another which will scan a sector in the vertical plane, should be ready for use by the project. These antennas will be capable of operating over the frequency range 12-25 Mc/s and will be used to receive and effectively determine angle of arrival of backscattered signals or forward propagated signals over the sector of the antenna. By the use of suitable displays, and being able to separate the signals reflected from relatively small areas of the ionosphere, one should be capable of making many deductions concerning irregularities and fine structure in the ionosphere.

A 400 kw peak pulse power transmitter operative at fixed frequencies over the range 5-28 Mc/s will be available for backscatter work as well as a sweep frequency 100 kw peak pulse power transmitter capable of sweeping from 1-25 Mc/s now in the final testing stage.

Personnel contributing to the work of the project are W. F. Utlaut, L. H. Tveten, D. R. Macken, and P. P. Viezbicke.

Modulation Studies

85141

The objectives of this project have been to investigate the source communication function, its encoding, the affect of the media on the communication system, spectrum conservation, the performance of radio communication systems, and methods of measurement applicable thereto.

The efficient communication of intelligence over a channel necessitates a knowledge of the information to be derived from the information function, generation of a communication function (including signal design, and encoding), the effect of the media on the transmitted function, and effective demodulation techniques. If the radio frequency spectrum is to accommodate the increasing traffic load, it is imperative that these factors be investigated and the results integrated to afford the design of new communication systems which close the gap between the present theoretically efficient and practically inefficient systems.

Work on the source communication function has been concentrated upon the determination of speech statistics, although a literature search on the video function has been initiated.

Long term speech statistics, primarily amplitude distributions have been studied for the effect of high frequency pre-emphasis and also the effect that clipping and filtering would have on SSB signal.

Most of the long term speech statistics available in the literature have been gathered for comparison, including several foreign languages. Separate reports will be published in fiscal year 1962 on the experimental measurements of speech statistics and on the literature survey.

An investigation of the HF medium was continued from the fiscal year 1960, Project 85549. A paper on, "Signal Strength at Frequencies Lower than and at the MUF", has been prepared for publication.

A "Historical Survey of MF and HF Fading" with emphasis on oblique incidence propagation has been prepared for a report. It is noted that sufficient short term information concerning fading as a function of distance and frequency is not available to determine a realistic estimate of communication systems or signal design.

A report " Propagation and Modulation Studies" has been prepared. A new*MRF including reflection from a parabolic layer, and experimental oblique incidence data has been derived. For small time delays, the new MRF indicated operation up to 20% closer to the MUF than previously considered.

A crossed dipole experiment on F2 layer propagation indicated the contribution of the magneto-ionic components in the fading signal. The effectiveness of polarization diversity was implied. A similar crossed dipole experiment was performed for $E_s$ propagation. The fading characteristics indicated the possibility of a "Classical MUF" for the E layer. However, at frequencies below the MUF, only one magneto-ionic component appears to have been present.

The results of an arctic direction of wave arrival experiment are also presented and compared with temperate latitude results. It was concluded that arctic signals exhibit greater short term and long term deviations. Although the long term deviations may be at least 5 degrees from the median value, they appear to be diurnally consistent.

The video communication function will be investigated as a high communication rate signal. The information content and redundancy will be studied.

Communication function encoding will be studied with emphasis on efficient use of the communication channel.

A study of FM systems will be conducted. Work on the short term statistics of the HF media will continue. These results will be interpreted as they affect the modulated signal. A VHF ionoscatter link will be investigated as an operational system.

Personnel contributing to this project were R. K. Salaman (project leader), J. L. Auterman, J. W. Koch, H. Akima, E. L. Komarek, W. B. Harding, and G. E. Wasson.

*Multipath Reduction Factor.

Information Theory and Coding for Radio Channels

85143

The prime objectives of this investigation are to study channel capacity for time-varying radio propagation media and indicate practical application of information theory to radio systems. This project initially is directed to promoting in the modulation research program, competence in the field of information theory and coding. Experimental studies will be carried out over an ionospheric link.

It is well-known that ionospheric transmission suffers from numerous random distortions. It is our task to establish a suitable mathematical model for this channel and to estimate its capacity.

A typical description of a radio channel performance has often been given via sets of empirical tables and graphs. Unfortunately, sometimes an analytical treatment is desirable. Then the construction of the necessary equation calls for a representative mathematical model.

Another objective is the channel capacity. It is probably the most basic parameter of the channel. Knowledge of it may not help in the design or operation of a system. The channel capacity does, however, provide us with a standard, though unreached, upper bound for information transfer.

To promote interest and understanding of information theory an informal seminar was conducted for Division 85 personnel from October 1, 1960 to January 31, 1961.

A talk on "Nonlinear Transducers" was given by Dr. D. F. Drenick of Bell Telephone Laboratories, (March 9, 1961).

From June 12 until June 30, 1961, the Information Theory Project was in part host to Professor W. W. Peterson of Florida University. Professor Peterson gave two lectures on information theory. A subsequent seminar on coding had some ten meetings.

The research activities regarding the ionospheric channel can be summarized as follows: There has been conjectured a rather common input-output representation for the ionospheric model. This includes the degree of diversity, selective fading, phase variation, additive noise, and burst interference. All these are stochastic variables. Their statistical distributions are known, if not completely, nevertheless to a considerable degree.

There are special cases, when one or two of these random disturbances are predominant, and all others can be neglected. It is an unfortunate fact, that only for such simplified models the channel capacity is known in any explicit form.

For example, for no diversity and the sole disturbance - an additive noise, the capacity is known. A special case of this is Shannon's result for Gaussian noise.

It is practical to include, in addition to noise, a few types of non-selective fades and then solve the capacity problem. Similarly, under suitable assumptions, it has been possible to show the effects of diversity. However, for the general model, there is still a great need for concrete significant results.

It is planned to continue to study the capacity problem for the above model. Effort will be concentrated on the joint effects of noise, fading and burst phenomena.

The realization of higher transmission rates will undergo a close scrutiny. It is apparent that error statistics provide a practical justification for use of coding schemes. Such statistics will be studies, and attempts will be made to implement a suitable coding system.

Personnel. Martin Nesenbergs was the only person committed to this project.

## Space Communications

85171

The objectives of this program are to analyze problems of wave propagation and modulation pertinent to space radio telecommunications and measurements; and to determine more efficient arrangements of the signal information function for providing reliability of transmission under the limited levels of power and bandwidth available.

Both the military and civilian common carrier systems are freely estimating 10-fold increases in channel capacity requirements in the next decade, and corresponding later increases as a natural consequence of new developments in data systems technology.

The use of satellite relays opens the way for availing entirely new bands of the frequency spectrum for global communications. High altitude satellite relays make this possible by avoiding the common anomalies which characterize atmospheric horizons in ground station communication links, the more nearly vertical propagation path to satellites allowing more direct penetration of otherwise refracting, reflecting and attenuating atmosphere.

This space communications study program is accoringly needed, to provide fundamental propagation and modulation information needed to exploit new bandwidths of channel space, in new regions of the frequency spectrum made feasible by space vehicle and relay systems.

Under the broad terms of this project, many facets of space communications have progressed. An extensive survey of literature and national effort was conducted, to establish the existing state-of-the-art concerning such factors as: Attenuation or loss factors setting apparent limitations on atmospheric penetration by radio waves; apparent capability of extremely high frequencies for space applications, modulation systems appropriate to the greater bandwidths available for satellite systems, or narrow bandwidths pertinent to interplanetary systems; encoding principles that might be used to conserve power through bandwidth exchange; apparent bandwidth required to satisfy various space communication functions; and problems for general telecommunication systems development, such as pin-pointing needed system developments for venturing into new frequency regions.

This literature research provided much of the background information used by Panel II of the Telecommunication Planning Committee in its survey of national space telecommunications. Further reporting has been prepared for Chapter 42 of the Summer Lecture Series and revision of Circular 462 on Ionospheric Radio Propagation.

More general telecommunications systems analysis, applicable to the problem of operating multiple links in tandem -- such as would characterize the relay operation of space systems -- was additionally conducted under this project and has been adapted to the ionospheric propagation systems performance estimation procedures recommended by the Bureau under Project 85472.

In a separate facet of this project, modulation and spectrum conservation objectives have been considered in the practical problem of television transmission. A two-fold significance is attached to this problem investigation: (1) Since television bandwidth requirements dominate the total spectrum required for transmission of common messages, it study is pertinent to all communications spectrum conservation; and (2) there is a requirement for better correlation between standards of human perception and standards of television. Advancement in this area is directed toward achievement of real time television for power-and-bandwidth-limited space communication systems. In this phase of project research, Mr. R. G. Merrill of the Boulder Laboratories, is joining in cooperative studies with Dr. David Metcalf of the University of Colorado Medical Center, on the application of computer techniques for evaluating human visual response data acquired from subjective observations.

Depending on available funding, information gathered from propagation studies and experiments, particularly those dealing with pulse transmissions, will be analyzed to determine desirable parameters for encoding, modulating and demodulating the various information functions required for space communications considering the ultimate limitation of line-of-sight channels. These studies will be directed toward: (1) Pulse and waveform distortion effects imposed by space propagation media; (2) performance of broadband modulation techniques under the influence of perturbation effects of space media; (3) investigation of multiplexing methods for relaying multiple information functions such as television, voice, and data via satellites; and (4) determination of improvements to be realized for diversity reception in time, space, and polarization of satellite signals, for various modulation methods and carrier frequencies. In general, the effort in this program will be to apply knowledge already existing in terrestrial communications to space application problems, and to develop new knowledge where present deficiencies of information exist.

Tests will give special attention to the broadband systems required for transmission of video information applying the results of present studies of standards information. Additional effort will be directed toward identifying and providng encoding bases for separating essential from non-essential information in repetitively scanned images, taking advantage of the recently discovered buffer storage of the human visual system, and applying more advantageous standards appropriate for binary information changes.

Personnel contributing to this project have been W. C. Coombs, (project leader), B. A. Kingsbury, D. A. Ellerbruch, W. D. Bensema, R. G. Merrill, C. C. Watterson, Dorothy Werden and Freda L'Manian.

## VLF Automatic Communication Study

85443

This project investigates VLF system parameters including antenna characteristics, transmission loss expected, atmospheric noise levels, and carrier-to-noise requirements for various types of communications systems in a manner which will permit calculation of required transmitter powers to provide reliable service over various radio paths. System design improvements are indicated.

VLF radio signals provide one of the most reliable means of long-range communication, and determination of the extent of reliable coverage, along with improvements in range and reliability, is extremely desirable.

Much of the work of this project is classified. Valuable progress in this area has been realized. Communication equipment based upon a system developed by the project is now in production by commercial manufacturers for Navy installation and some of the units are now in operational use in the fleet.

A system utilizing bandwidth reduction techniques has been developed and nearly completed. Preliminary testing on a radio teleprinter modulation system indicated that the technique will offer a 4 or 5 db improvement in system performance factor. An unclassified NBS Report 6719 " Performance of a Multi-Frequency-Shift Teletype System", by E. L. Maxwell, F. S. Mathews, and A. D. Watt was published October 3, 1960. NBS Report 4BB103 (confidential) " Application and Performance of Multi-Frequency-Shift Teletype in Naval Communications", by E. L. Maxwell and E. H. Whelan, was published December 15, 1960.

Development work will continue on the project in order to make eventual field tests during the year.

Personnel contributing to this work were: R. M. Coon (project leader), E. H. Whelan, W. D. Bensema and E. C. Bolton.

## RLCS Noise Reduction

85444

This project consists of evaluating known impulse-noise reduction techniques and/or developing new ones that might prove useful in connection with communications problems related to the Minuteman missile program.

One proposed method of maintaining reliable communications between command centers and launch centers in the event of an atomic attack, is that of utilizing underground radio transmitting and receiving systems. One of the difficulties of implementing such a system, however, is that rather low radio frequencies are necessary, and in this frequency region atmospheric noise is an extremely serious problem. Accordingly, noise reduction devices or means are needed to provide a satisfactory system.

Since the earliest days of radio experimenting, efforts have been devoted to devise circuits with which to remove the ill effects of atmospheric noise. Many devices have been invented, some simple and others complex. While some have been found to be more or less effective, other schemes have been found by this project to be entirely useless when evaluated from the standpoint of effectiveness and reliability.

An impulse noise reduction circuit developed earlier by NBS for another sponsor was adapted to the Radio Launch Control System for evaluation at the Confidence Test Program test site at Warrensburg, Missouri. Evaluation results to date appear promising.

The technical aspects of this work is classified. Development and evaluation work will continue until January, 1962 when the project terminates.

Personnel contributing to this work were: R. M. Coon (project leader), E. C. Bolton and G. G. Ax.

## Information/Communication Theory Studies for Radio Frequency Spectrum Allocation

85445

Objective - broadly stated, to investigate factors of information theory which hold promise to long range spectrum conservation. A more immediate objective - to study the utility of modern coding techniques in radio communications. Ultimately more sharing of spectrum is hoped for by enabling power reduction, reducing multiplicity of frequencies used, and reducing bandwidth and transmission time.

Increased demands for communication services have led to a congestion of the available media. Consequently, the allocation of radio spectrum has become a national as well as an international problem. This project is sponsored by OCDM (Office of Civil and Defense Mobilization) to study the effectiveness of recent theoretical measures, such as coding, to achieve spectral savings. It is well-known that certain codes can reduce error rates. If these codes are efficient enough, a given amount of information can be transmitted in a shorter time. Or, to put in other words, the power and bandwidth can be reduced to some degree. Whereas the reduction of bandwidth is tantamount to spectral economy, power savings also have to be considered. Clearly, low power levels reduce interference and cross-talk between adjacent channels. This can lead to more compact spectrum utilization.

The project was initiated in January, 1961. Since then one-half of one man power has been devoted to this project. It has been a theoretical study concerning digital communication systems.

As is well-known, practical systems such as radio-teletype rely heavily on ARQ (Automatic Repeat Request) to exercise error control. In this study a search has been made for multiple error-correcting codes, which would out-perform the ARQ.

A new family of codes, the Bose-Chaudhuri codes, appear to be promising. These Bose-Chaudhuri codes and the customary ARQ have been compared under the assumption of independent errors. The comparison involves two performance criteria: the transmission rate and the error rate. Both these rates are functions of the element error probability in the channel.

To show the differences of the two systems, graphs have been prepared covering some 76 Bose-Chaudhuri codes. These codes vary in length from 7 to 255, and the emphasis was placed on an element error probability range from $10^{-1}$ to $10^{-4}$. On the other hand, of course, one chart suffices to show the performance of an ARQ system.

A multitude of relationships has been summarized by outlining regions of error probability in which some Bose-Chaudhuri codes out-perform the ARQ by both criteria.

The study so far indicates that: (a) There may be a definite performance and economy advantage in using multiple error-correcting codes instead of ARQ for relatively "bad" channels. As a "bad" channel we define one possessing an element error probability of not less than $10^{-3}$. (b) The burst correcting ability of short Bose-Chaudhuri codes is limited. However, to this problem there are a few alternative solutions. For example, in the case of erasure bursts ("erasure" - neither a 1 or a 0 is received), burst correction is effective. In the definite case of error bursts, the Bose-Chaudhuri codes are superior in error detecting. Hence, they can still replace ARQ 3/7 code, assuming the presence of a return channel. (c) The Bose-Chaudhuri codes possess a cyclic property. Therefore, they are relatively easy to implement. We have studied the implementation of such codes up to length of 63. The circuits are quite simple, of digital feedback prototype. They can perform the functions of both the encoder and the <u>error-detecting decoder</u>.

It is expected to complete present code implementation studies for the Bose-Chaudhuri codes. The hardest remaining problem here is the <u>error-correcting decoder</u>.

Consideration is being given to a promising alternative - a partial error-correcting scheme. In this scheme, the decoder will be implemented to correct but a small number of independent errors. The remaining redundancy of the code will be used to detect the presence of long error-burst. It is planned to evaluate and outline possible alternatives of such a system.

Two more practical, but maybe not too distant studies, which we plan to undertake, are: (a) Simulate the coding model over a given practical radio channel, possibly an ionospheric radio link. (b) Implement and test the performance of a coding scheme of best promise over such radio channel.

These studies, if sufficiently pursued, will identify significant factors of both the practical channel and the coding scheme, which hold promise for future communication systems.

This project is being conducted by Martin Nesenbergs.

## High Communication Rate Microwave Study

85447

The objective of the project is to determine the bandwidth or maximum information rate of a long-range line-of-sight microwave link at various elevation angles, as limited by multipath propagation caused by atmospheric effects.

In the near future there will be a need for wide-band transmission of information between space vehicles and earth. The limitation on the bandwidth in the 10 Gc/s region will probably be due to atmospheric effects on the propagation, about which very little information is available at present, particularly for non-horizontal paths. This project will make experimental studies of the atmospheric effects on bandwidth for propagation paths from a mountain top to a lower elevation so as to obtain information for non-horizontal paths. While this will not provide data for all elevation angles, it should materially add to present knowledge of the bandwidth capabilities of space vehicle-to-earth links.

The project has just been undertaken and during fiscal year 1961 only a very limited amount of study and planning was undertaken.

A microwave link will be designed, constructed and operated during fiscal year 1962, that will transmit and receive pulses of approximately $2 \times 10^{-9}$ seconds duration which will allow time separation of the pulses received via two or more paths under the more severe multipath propagation conditions. Angle-of-arrival measurements of the received short pulses are planned and c. w. bandwidth measurements will be made and compared with pulse bandwidth measurements.

The program will be conducted in three phases: (1) A literature review and theoretical study will be made and the design and construction of the microwave link will be undertaken. (2) The experimental link will be installed, probably from Cheyenne Mountain, Colorado, to a lower elevation and preliminary experiments conducted to obtain information which will be used for improving the instrumentation and experimental procedures to be used in phase (3). (3) A period of operation will be started to collect and analyze statistical data under a variety of atmospheric conditions over several paths if possible. Operation from Pike's Peak to a lower elevation may be undertaken during the summer months of 1962 when road conditions permit.

C. C. Watterson has performed preliminary efforts in this project.

## 358L-3 Microwave Carrier Terminal Unit Evaluation

85448

The objective of this project was to test and evaluate some trouble that had been reported to exist in the microwave terminal units used in the telephone system at Warren AFB, Cheyenne, Wyoming.

Two very frequently recurring troubles were associated with the telephone system. One trouble was dialing errors, either a wrong number would be connected or no connection could be made. The other difficulty was that of certain voice frequencies causing relay actuation resulting in disconnection.

The sensitivity of the terminal unit to certain voice frequencies to cause disconnection was shown and measured, and recommendations were submitted to alleviate the problem. No evidence was located to prove that the dialing difficulty could be attributed to the terminal units.

Plans for Fiscal Year 1962 have been completed.

The primary efforts of this project were performed by R. Marshall Coon.

## High Speed Digital Television Study

85547

Classified

## High Frequency Propagation Factors Affecting Modulation Techniques

85549

The objective of this project has been to evaluate modulation performance standards for high frequency communications through auroral regions. This includes investigation of multipath and fading, modulation techniques for signals at frequencies higher than the classical MUF, and modulation performance factor.

In order to predict the performance of an HF auroral communications channel one must have quantitative information about the frequency stability of the received signal, the correlated bandwidth, modulation performance factor, and the channel capacity dependence on signal-to-noise ratio.

Experimental measurements were made on the 4470 km path from Barrow, Alaska to Boulder, Colorado. Transmissions were made on closely spaced frequencies near 15 or 20 Mc/s from Barrow. Correlation coefficients were obtained for the fading envelopes of pairs of frequencies for spacings of 0.2 to 6.0 kc/s. The correlated bandwidth can be as much as 4 kc/s but less than 6 kc/s for low fade rates (less than 2 c/s) dropping to 2 or 3 kc/s for fade rates above about 6 c/s. Measurements are presently being made of the short term perturbations of the received signal's frequency.

Measurements of the received frequency will be completed and the data analyzed. A more complete analysis of the correlated bandwidth data will be made and, if possible, the frequency and bandwidth data will be related to other factors known about the path.

Personnel contributing to this project were: J. L. Auterman, J. W. Koch, G. E. Wasson, J. L. Workman and W. B. Harding.

## Antenna Instrumentation

85151

The objectives of this project are to plan and prepare instrumentation and to develop improved techniques for antenna measurement work.

Measurements of antenna performance, particularly those of radiation patterns and gains can be carried out in a number of different ways. Some methods are superior to others depending on circumstances. To obtain comparable results at different times by different workers, it is important to know the limitations of the various techniques for antenna measurements. This project also serves to equip the antenna ranges with instrumentation required for a variety of projects. Instruments peculiar to specific projects continue to be procured and charged to these projects.

A new Vee frame for the Green Mountain Mesa antenna range was completed and installed. Work is partially completed to install a turntable under the Vee frames. This will permit azimuthal pattern measurements in addition to the vertical plane measurements.

The proposed paper "Techniques for Measurement of Performance of Operational Antennas" is being revised.

The work of devising techniques for antenna measurements will continue in the present direction.

Personnel contributing to the project are: E. L. Kilpatrick, (Project Leader), D. Reed, and G. W. Angus.

## High Resolution Antenna

85152

The objective of this project is to develop an antenna having a narrow main beam capable of being scanned rapidly over a predetermined sector in azimuth.

The primary importance of this project lies in its possible application to investigation of propagation phenomena. Very many projects are concerned with determining the direction of arrival of a signal, its dispersion, and changes with time. The successful completion of this development makes it possible to observe and record the amplitude of the signal against the direction of arrival.

The antenna is a broadside receiving array of twenty-five Yagi antennas. The principal tasks of this fiscal year were to increase the number of Yagi antennas from the seven which were placed in operation during the previous fiscal year, to the total of twenty-five Yagi antennas and to complete the electronic instrumentation for utilization of all twenty-five Yagi antennas.

The frequency of operation is at 41 Mc/s. The antenna is oriented to receive signals propagated by ionospheric scatter, ionized meteor trail reflection, and sporadic-E layer reflection, from a transmitter at the Long Branch, Illinois Field Station, 1295 Km away.

Since the direction of arrival is restricted by path geometry to a formal sector of approximately 40 degrees, the Yagi antennas in the array are spaced 1.4 wavelengths apart. This reduces the beamwidth to 1.5 degrees and the sector of scan to -20.9° - 0 - +20.9°. The points of ambiguity introduced by wide spacing lie outside the sector. The beam is scanned unidirectionally at the rate of 20 scans per second. Electronic scanning techniques originated for this project were employed to obtain the rapid scan.

Personnel contributing to the project were: A. C. Wilson, (Project Leader), H. V. Cottony, J. E. Adams, A. C. Stewart, R. J. Richardson, C. G. Smith and W. L. Martin.

## Antenna Prince

85451

Classified

Communication Site Consulting

85453

Classified

Wullenweber Antennas

85454

The objectives of this project were to measure the performance of three antennas of Wullenweber type, and to verify the suitability of a site by making pattern measurements of a simple dipole.

Four elaborate and expensive antenna arrays were erected near Rome, New York. It was highly desirable to verify the effectiveness of these antennas by carrying out measurements of their performance.

Terminal impedance of three antennas was measured over the operating frequency range. Radiation patterns and gains were measured at three frequencies within the operating band. The results were analyzed and a report was prepared and reviewed.

Additional measurements of radiation patterns of a dipole at Stony Point, New York were carried out. The relationship between the angle of departure and the height of antenna was plotted in a report describing the results. "Survey of Stony Point and Ava Test Sites" by P. P. Viezbicke was prepared and distributed.

The work is completed. The printing and the distribution of the report "Measured Performance of Three HF Wullenweber Antennas" by P. P. Viezbicke should finish the project.

Personnel contributing to the project were: P. P. Viezbicke, (Project Leader), W. B. Goodwin, R. Harsh, J McKinney, J. J. Chukoski, and R. Fitzpatrick.

Steerable Antenna

85456

The objectives of the project are to study the existing schemes for antennas capable of steering the main beam in any direction in azimuth, and to consider variants which would accomplish the same purpose. The goal is to find an antenna which is more efficient in its utilization of elements.

The present communication requirements demand increasingly higher performance antennas in terms of gain and directivity. This is obtained at a cost, both in money and size; the antenna, nevertheless, remains usually a single-function structure, i. e., it is directed in one direction and is used for one channel or group of communication channels. It is very desirable from the standpoint of economy and efficiency to investigate possibilities for employing a single antenna for communication on several channels in different directions simultaneously.

A study of concentric ring arrays has been carried out and a report "Theoretical Performance of Antenna Arrays of Concentric Circles" by C. O. Stearns has been prepared in draft form. One of the arrays considered, consisting of a central element, an inner ring of ten elements and an outer ring of twenty elements was constructed for 90 Mc operation. No provisions were made for electronic scanning. The array was erected on a turntable. After adjustments, a radiation pattern closely approximating the theoretical was obtained. Construction of a 20 Mc model is under way.

It is proposed to construct and put in operation the 20 Mc model of the antenna.

Personnel contributing to the project are: A. C. Stewart, (Project Leader), C. O. Stearns, W. L. Martin.

## AMR Site Engineering Study

85457

The objective of this project was to assist the personnel of Eastern Division GEEIA, U. S. Air Force in relocation of communication facilities of the Atlantic Missile Range.

The present communication facilities of the AMR located at Cape Canaveral were established when the missile activities were very limited. The two communication sites were located fairly remotely from launching sites. Since then the launching activities multiplied manifold, completely engulfed the transmitting site and are crowding the receiving site. As a result, it is necessary to reduce the transmitter power in order to avoid the possibility of activating the destruction charge on the missile unintentionally.

The present communication facilities at Cape Canaveral were inspected. A map study of various possible alternate locations was carried out and a number of sites considered. Some were ruled out for various reasons such as inaccessibility, proximity to inhabited areas, etc. The remainder of the sites were inspected from a light plane or by personal visits in an automobile and some both ways. An abandoned Navy air base at Malibar, Florida was selected as the first choice with several others as alternates.

Personnel contributing to this project were: H. V. Cottony and E. L. Kilpatrick.

## High Frequency Broadcast Antenna Study

85458

The objectives of this project are to compile and analyze published data concerning research in antenna configuration and design with emphasis on broadcast antennas and antenna arrays, and to make computations and extensions of theory for suitable new antenna designs. In addition, some experimental antenna tests and measurements may be undertaken.

This study is of importance because of the bearing on possible development of more effective VOA broadcasting and adoption of more economical methods.

A literature search and the accumulation of material has been started. The work will be intensified shortly after the conclusion of the Radio Propagation course.

It is anticipated that the preliminary study will be completed about the second quarter FY 1962. A plan for detailed studies and experimental measurements will then be submitted to the sponsor for approval.

Personnel contributing to the project: H. V. Cottony.

## Rhombic Antenna Computation Program

85459

The object of this project is to write a program in Fortran language for the 1604 electronic computer. This program will compute the far field radiation pattern and maximum gain of rhombic antennas for general ground constants.

This project will furnish the Voice of America with the results of the desired computations with the necessary accuracy in a minimum time.

A program has been written and checked for the ground reflection coefficients for both vertical and horizontal polarization. Programs for the radiation patterns for both vertical and horizontal polarization have been written. These have been checked for perfect ground.

The programs that have been written will be combined to form one program. This program will compute the radiation patterns in the vertical plane and the horizontal plane for a desired angle of elevation, leg length, height above ground, and angle that the short diagonal makes with the leg of a rhombic antenna, and for conductivity and dielectric constant of the ground. Also it will locate the elevation and direction of maximum gain and compute it.

If sufficient funds remain, a study of the possibility of programming the effects of rough terrain will be made.

Personnel contributing to the project: C. O. Stearns, (Project Leader), K. Phillips, H. Davies.

## RADC Field Strength Measurements

85551

The objectives of the project are (a) to investigate methods or techniques of making measurements of complex fields which allow for non-planar waves, polarization characteristics, direction of propagation and multipath reception so that a calculation of the response of an arbitrary antenna to the field can be made, and (b) to examine and evaluate several commercial field-strength meters to determine their adequacy for both c.w. and pulse measurements. Emphasis is being placed on measurements in the 300 to 10,000 Mc/s portion of the spectrum.

Prior to installation of proposed receiving systems at a site it is often desirable to be able to accurately predict the interference from various undesired ambient signals. In general, it is not possible to do this by a simple measurement of the total interfering-signal field because it can be composed of components arriving over several paths, each with non-linear polarization. If the amplitude, direction of arrival, polarization and relative time phase of each multipath component can be measured, an accurate prediction of the response of an arbitrary antenna with a known pattern can be made.

Two techniques were analytically devised for determining from measurements the amplitude, direction of arrival, polarization and relative time phase of several multipath components of a complex field. The first method requires the field-strength-meter antenna to move continuously along a track while the varying meter reading is recorded. In the second technique consecutive measurements are made with the antenna in a number of fixed locations. In both techniques the measurements effectively synthesize an antenna whose aperture is equal to the distance of movement of the measuring antenna. It should be possible to separately measure the values of two or more multipath components whose angular path separations are equal to or greater than the beamwidth of the synthesized antenna. A track of fiber-glass-tubing construction has been designed and is being constructed to experimentally check the techniques.

Laboratory measurements on a TRM-7, an FIM and an NF-105 field-strength meter have been started.

Measurements in the field are planned to experimentally investigate the two field-strength-measuring techniques which have been devised. Additional different techniques will be considered. Laboratory measurements of the TRM-7, FIM and NF-105 in addition to one or two other meters will be conducted to determine their accuracy, sensitivity, dynamic range, shielding, stability, detector responses and other characteristics which determine their adequacy for both c.w. and pulse measurements. Individual and comparative measurements of the equipments will be made in the field.

Personnel contributing to the project are: C. C. Watterson, (Project Leader), E. L. Kilpatrick, G. T. Blake, A. H. Dove and W. B. Goodwin.

## RADC Field Strength Measurements

85501
85521
85561
85471

The above projects, shortly after initiation, were combined with project 85551.

## RADC Propagation Studies Task 2

8552

To develop and implement an antenna capable of high resolution in elevation and capable of being scanned electronically at a rapid rate.

The antenna will be used as a receiving antenna system to determine the angle of arrival of long range HF signals, direct and backscatter. This will provide information on the variability of the angle of arrival of long distance backscatter signals.

The results of these experiments will provide information on the range and propagation mode of HF signals propagating over long distances in the ionosphere.

The plans for Fiscal Year 1962 are to design and place in operation an antenna array having a high resolution and capable of being electronically scanned at a rapid rate in elevation, and to demonstrate its use for determining the angle of arrival of HF signals.

Personnel contributing to the project are: A. C. Wilson, (Project Leader), and J. E. Adams.

## Design of Radio Antenna Complex for Floating Antarctic Research Station

85553

The objective of this project is to reconcile the requirements for antennas for various geophysical research projects on board the Antarctic Research Ship, U. S N. S. Eltanin.

This is an ice-reinforced vessel designed for geophysical research in the Antarctic Ocean. A number of research projects are to be carried out aboard the ship. It is important to measure the performance of antennas for various research projects each in its own location on board the ship and in proximity to other antennas.

The project is barely begun. The vessel was visited and inspected. A complete set of plans was obtained, negotiations are underway for construction of a 50:1 scaled version of the ship. The antenna range is being readied for the project.

Antennas requested by scientists in charge of various projects will be constructed in the form of 50:1 scaled down versions, placed in appropriate positions on the deck of the ship. Measurements of performance will be carried out and various adjustments to obtain optimum performance will be tried.

Personnel contributing to the project are: D. R. Reed (Project Leader) and O. D. Fogg.

## Radio Launch Control System Ground Conductivity

85557

The objectives of this project have been to provide consulting and advisory assistance to the Boeing Aircraft Company (as USAF contractor) on the tests of radiation from "hardened" antennas for the Minuteman missile program. This is part of the Confidence Test Program.

One of the objectives of the Minuteman missile installation is to insure that a near hit by a nuclear weapon does not incapacitate the retaliatory capability of the Minuteman installation. "Hardened" antennas, i. e., antennas buried several feet below the surface of the ground are a part of the reliability program. Such antennas are quite inefficient and it is important to verify the efficiency of their radiation, their radiation patterns, the relation of these factors to ground conductivity, and to measure ground conductivity by a convenient method which gives results significant and accurate for the purpose.

Several consultative meetings were held and suggestions were made on the techniques of ground conductivity measurements. An examination was made of work on the measurement of the radiation pattern and suggestions offered towards improving these measurements.

The work of the Boeing Aircraft Company will be followed and suggestions and criticisms offered as necessary.

Personnel contributing to the project are: A. C. Stewart (Project Leader), and H. V. Cottony.

## Wullenweber Antenna Evaluation

85558

The purpose of this project was to carry out measurements on a modified Wullenweber antenna located at RADC Stockbridge test site, near Rome, New York. Its performance, in terms of gain, radiation pattern, and side-lobe levels, was evaluated and compared with the modified antenna.

Although the modification to the antenna, permitting multibeam operation, was intended to improve its versatility as an air-to-ground communications antenna, measurements were necessary to determine whether the modification improved or abated its performance. An evaluation of its performance, based on the results of measurements, served as a guide to justify extending or limiting modifications on this and other antennas.

The performance of the modified antenna was measured, in terms of gain, radiation pattern and side-lobe levels, and compared with the unmodified antenna. The results of these measurements were compiled and its performance was presented in NBS Report No. 6748, "Performance of a Modified HF Wullenweber Antenna".

Personnel contributing to this project were: P. P. Viezbicke, (Project Leader), W. B. Goodwin, R. Harsh, J. McKinney, J. E. Chukoski and R. P. Fitzpatrick.

## Ground Communication Antenna Studies

85559

The objective of this project is to carry out measurements required to determine the suitability of basic antenna designs, obtain performance data, and to provide other information made necessary to answer questions arising from operational requirements of the U.S. Air Force. The studies and measurements are sufficiently restricted in scope so that the establishment of a special project for each is not desirable.

The importance of the project varies with the particular problem involved. In general, all involve decisions on selection, procurement, or installation of costly antenna equipment.

The work on scaled model measurement of radiation patterns of U.S. Air Force discone antenna interrupted by equipment failure were completed. A report on this study is in preparation.

Computations of performance of moderate size super-gain antennas were completed. A report "Performance of Moderate-Size Super-Gain Antennas" by C.O. Stearns was written and is undergoing an editorial review. The values of mutual impedances of parallel dipoles made necessary for these computations have been tabulated and are also to be issued as an NBS report.

Measurements were carried out to determine the effect of interactions between two nested rhombic antennas on the performance of each. A report, "Interactions between Nested Rhombic Antennas" by P.P. Viezbicke was prepared, reviewed and is now being typed in the final form for reproduction.

Personnel contributing to this project are: H. V. Cottony, (Project Leader), P. P. Viezbicke, W. G. Goodwin, E. L. Kilpatrick and C. O. Stearns.

Navigation Systems Analysis

85161

The objectives of this project were to design and participate in experiments to test and evaluate radio navigation systems and relevant radio propagation theory. To process, analyze, and interpret data obtained from these experiments. To provide consultative services to other agencies as regards navigation and timing systems or problems associated with such systems.

Radio navigation systems and time synchronization systems are fundamentally related; knowledge of position is essential to evaluate radio time synchronization, and time synchronization is an extension of a radio positioning system. Navigation and timing systems have both recently acquired increased importance, with the requirement for accuracy in connection with space tracking and guidance problems.

Much of the work carried on in this project was of a consultative nature. One example oriented toward system design is the report "Timing and Space Navigation with Existing Ground Based Systems", by G. Hefley, R. F. Linfield, and R. H. Doherty, presented at the AGARD Symposium in Istanbul, Turkey in October, 1960. This paper is presently being prepared for Journal publication. The paper describes a possible means of extending the Loran-C timing system to include space navigation.

Work has also been carried out on this project to provide facilities and auxiliary equipment necessary to utilize the Loran-C timing receivers for a sky wave monitoring program. Data from Loran-C experiments involving sky wave reception have been studied in an attempt to better describe the propagation medium. For example, ionospheric conditions that can explain an observed latitude effect on signal amplitude or an observed phase stability accompanied by amplitude instabilities are being investigated. The results of these experiments and the associated theories will be submitted for publication.

The measurements of Loran-C sky waves and the analysis of the data will be continued with the ultimate objective of improving predictions of the lower ionosphere. This work will be carried on in close co-ordination with the theoretical group which is studying the lower iono-sphere. Correlation of the measured data with predictions of the theoretical group will be carried on wherever possible. Consulting services will be provided for the U. S. Coast Guard on a Loran-C sky wave monitoring program which is planned. Sky wave signal measure-ments will be carried on at Table Mesa Field Site and other locations. The work directed toward a space navigation system will be continued. This work would include a rather complete analysis of the problem and a program outlined for the use of other agencies.

Data obtained during the Loran-C (originally Cytac) feasibility tests will be prepared for publication, since it has now been declassified. It is of considerable importance today because of the interest in Loran-C for timing purposes, and expansion of the coverage areas.

Personnel contributing to this project were: R. H. Doherty (project leader), G. Hefley (section chief), T. L. Davis, A. H. Dove, C. A. Samson, G. F. Schreiber, Jr., and M. W. Schroeder.

## Transient Propagation

85162

This project is a continuing program for the development of advanced theoretical concepts and techniques to analyze transients in LF radio wave propagation and systems.

The technical problems of LF radio navigation-timing systems require the most advanced knowledge of transient propagation for the correct interpretation of the physical phenomena involved and the correct interpretation of the physical phenomena involved and the correct system implementation. The extensive interest in sferics at LF also requires efficient theoretical treatment of the problem of sferic propagation.

The techniques for the analysis of sferics via the ground wave mode were developed to the extent that a ground conductivity determination could be made by an analysis of sferic signatures recorded at different geographic localities. The general problem of performing the transformation from the frequency domain to the time doamin for the case of linear systems was further developed so that advanced instrumentation of the Loran-C clock or the Loran-C navigation-timing systems for tagging a point-in-time on the pulse could be analyzed in detail. In particular, the amplitude minus the derivative of the amplitude point-in-time concept was reduced to a large scale computer code (IBM-704, CDC-1604).

The application of the transient techniques to project 85472 resulted in an experiment to test a new technique for conductivity determinations reported as follows: J. R. Johler and C. M. Lilley, "Ground Conductivity Determinations at Low Radiofrequencies by an Analysis of the Sferic Signatures of Thunderstorms", (to be published).

The project will begin the analysis of ionospheric transients or transients propagated by reflection, transmission in an electron-ion plasma, and transmission through an electron-ion plasma. An attempt will be made to analyze certain non-linear transient phenomena under study in projects 85563, 85564.

Personnel contributing to this project were: J. R. Johler (project leader), J. D. Harper, Jr., L. C. Walters, C. M. Lilley, and D. C. Hyovalti.

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## Navigation Systems Instrumentation

85163

The objectives of this project were to develop new techniques for the measurement of propagation parameters and signal characteristics which are pertinent to radio navigation. This includes the design of specific circuits for data processing. To compare and evaluate existing methods of measurement with respect to their adequacy and efficiency.

Radio navigation systems are concerned with accurate measurement of time and direction of arrival of radio signals. These systems often require the ultimate in instrumentation techniques. It is of paramount importance that instrumentation techniques be continually improved to meet the challenge of new system concepts such as those in Mistram.

Project work during the past year included: (1) The conversion of EPHI to use microwave rather than coaxial cable from the antennas to the midpoint. (2) The design of a transistorized amplifier circuit to be used in conjunction with the measurement of atmospheric or impulsive noise, as well as pulse navigational signals. (3) The design of a highly stable transistorized electronic ramp circuit to provide variable delays. (4) The design of a transistorized low noise amplifier circuit.

The low noise amplifier circuit has applications as the input circuit to either navigation systems or atmospheric noise measuring systems. The highly stable ramp circuit has applications in the EPHI system, in pulse position modulation circuits, and other circuits requiring a stable electronic delay.

Data recording instruments including a digital voltmeter and an associated printer have been ordered. These instruments will be used in connection with the Loran-C timing receivers to make sky wave propagation measurements at the Table Mesa Field Site.

After completion of the instrumentation of the data recording system, Loran-C propagation measurements will be initiated. A transistorized UHF transmitter and receiver will be developed for use with the EPHI DF system. The objective of this work is to make the EPHI system portable, in that the instrumentation at the peripheral antennas might be completely battery operated. The use of punch paper tape for the Loran-C data and for investigating characteristics of atmospherics will be tested.

Logic circuits are now utilized in the Loran-C clock, its associated code generator, and in the Atomic Time Accumulator system. It is envisioned that improved logic circuits would be of considerable value in much of the instrumentation carried on within this section, and an effort will be made to develop such circuits.

A generally recognized limitation of VLF systems for timing is the uncertainty in cycle identification. The dispersive characteristics of the VLF transmission medium over long paths has not been adequately evaluated. A further objective is therefore to measure the dispersion of VLF signals (WWVL and/or NBA) in order to define their limitations for timing purposes.

Personnel contributing to this project were: R. F. Linfield and R. H. Doherty (project leaders), E. E. Johnson, C. A. Samson, C. J. England, T. L. Davis, and M. W. Schroeder.

## LF-VLF Ground Conductivity

85164

Refer to project No. 85466.

Personnel contributing to this project were: G. Hefley (project leader), C. J. England, E. L. Berger, E. E. Johnson, C. M. Lilley, J. D. Harper, Jr., J. R. Johler, L. C. Walters, D. C. Hyovalti, and C. A. Samson.

302

## Atomic Time Accumulator

85165

The objective of this project is to design and construct instrumentation which will operate as a fail-safe clock. This instrumentation will be used by the Radio Standards Laboratory in conjunction with a fail-safe frequency source.

Historically, our time has been derived from astronomical sources. This source of time is subject to errors of the order of 1 millisecond for any given observation. Present day requirements often demand that time intervals be measured more precisely. A clock operating from the best available frequency source is capable of measuring time intervals to better than 1 microsecond as related to that frequency source. This program will provide a means for the National Bureau of Standards to maintain a time scale based on the period of an atomic transition. Several such time scales are being maintained internationally, and their comparison is of scientific importance, in view of international consideration of redefining the second in terms of an atomic transition. A means is also provided for the National Bureau of Standards to check various time signals against an atomic source and to publish corrections of these time signals as they relate to the atomic time source.

The basic concept of this instrumentation is first, a number of pulse dividers to provide redundancy and allow for checks against each other; second, battery standby power to provide for uninterrupted service if primary power is interrupted; and third, a means for reading out or checking the dividers one against another. The objective of the entire instrumentation is to provide 1 second and 1 minute pulses derived from the 1 Mc standard frequency on a fail-safe basis.

Design and prototype production have been completed for two different pulse type dividers and for a readout display unit to operate with these dividers. Design of the fail-safe power supplies including battery standby power with automatic recharging techniques has been completed, but the materials for the power supplies have not been ordered. The first divider incorporates the use of binary techniques to divide by 100 in 3 serial stages, thereby giving a division of $10^6$ in time increments from one microsecond to 1 second. These 3 stages are followed by 1 stage of division by 60 to give a 1 minute output. The divider is scaled down from a count of 128 to 100 by a coincidence circuit. The total propagation delay through this divider from the 1 microsecond input to the 1 minute output is 400 nanoseconds. The second divider design incorporates the use of beam-switching tubes to provide division from 1 microsecond to 1 second. An additional divide by 10 stage and a divide by 6 stage give the 1 minute output. This circuit has a total of 150 nanosecond delay.

The clock-readout unit consists of 8 identical decades, each of which contains binary counters to divide by 10 with storage and visual readout circuits that are activated by a read command. The read command will be derived from the 1 second or 1 minute outputs of the various dividers, although any random pulse can be used to display the time. This flexibility allows the clock-readout unit to be used for checking any time signal from which a pulse can be derived. The clock-readout unit will not have fail-safe power but does have means for automatic setting of the clock from any of the other dividers. Each divider also has means for automatic set or reset from any of the other dividers. An order has been placed for construction of three of the beam-switching tube dividers using the Burroughs "Beam-X" tube, and plans are presently being made to place an order for the entire clock readout unit as well as batteries and other component parts for fail-safe power supplies.

Plans for Fiscal Year 1962 are to complete the procurement of components and to integrate all of the various components into a packaged system. Present plans call for 1 clock readout unit and 6 divider units to operate together. The design is such that additional dividers could be added to the system as they are desired. Additional dividers will provide greater reliability against loss of the accumulated time. An additional clock readout unit would provide complete redundancy in this portion of the system. This may be important if the Bureau is monitoring signals and must have a continuous output for this type of work. It may be advantageous to prepare complete specifications, circuit diagrams, working diagrams, etc., for the procurement of any additional equipment to be used with this system.

Personnel contributing to this project were: R. F. Linfield and R. H. Doherty (project leaders), G. Hefley (section chief), E. L. Berger, T. L. Davis, E. E. Johnson, M. W. Schroeder, J. D. Harper, Jr., J. R. Johler, C. M. Lilley, and L. C. Walters.

## 304
## ELF-ULF Propagation Research

85401

This project is a continuing program for the development of theoretical concepts and techniques for the study of ELF-ULF (extra low frequency-ultra low frequency) propagation, i.e., propagation about the earth of radio waves in the frequency range below 30 kc/s.

ELF-ULF waves have stimulated considerable scientific interest in recent years in the field of geophysics, since the waves travel in the ground and in the ionosphere. The possibility of practical applications for such waves has also stimulated further research. The interest in the theoretical problems of ELF-ULF is therefore assuming even greater importance.

A technique was developed to solve the rigorous electromagnetic problem of the propagation of spherical ELF-ULF waves in and about a spherical earth of finite conductivity by a direct use of the scalar wave equation in the Hertz vector in a series of zonal harmonics. Preliminary computations have been successfully carried out on a large scale electronic computer. Basic techniques for the calculation of a variety of Hankel and Bessel functions were worked out in detail. The effect of the ionosphere "shell" was introduced into the analysis and the analysis was extended generally to include multiple shells of both ionosphere and ground (vertical stratification). The effect of the heavy ions in the ionosphere was studied.

The technical objectives of this program will be continued under project 85563.

Personnel contributing to this project were: J. R. Johler (porject leader), L. A. Berry, L. C. Walters, and C. M. Lilley.

305

## Development of a Loran-C Clock and a UHF Timing Distribution System

85464

The objectives of this project were to study and demonstrate the feasibility of a method for time synchronization to the order of 1 microsecond over great distances, and to provide a method for time code distribution by UHF to terminal equipment with an accuracy of the order of 1 microsecond within line-of-sight transmission distances.

Time synchronization accuracies of 1 microsecond are obtainable from Loran-C within the ground wave range of the transmitter. This accuracy is approximately 1, 000 times better than that obtainable by high frequency techniques such as WWV and at least 10-50 times better than obtainable using VLF signals. Since Loran-C incorporates slaved oscillator techniques, this system provides a means for transferring time and frequency standards from one location to another. Loran-C sky wave signals have not been completely evaluated, although it appears that improvement over existing systems may be achieved in time and frequency synchronization. Further study is needed to establish the useful range of these sky wave signals, but at least 5, 000 miles is anticipated during certain portions of the night.

Local time distribution systems have used land lines or radio links in which a separate frequency is used for each format of information to be transmitted. In this project a system has been devised based on pulse position modulation wherein a single UHF frequency is capable of carrying many time codes to the terminal points.

Feasibility tests of the time synchronization were conducted by operating clocks on the Atlantic Missile Range during October, 1960. Time synchronization was checked at various points on the Atlantic Missile Range (Cape Canaveral, Jupiter, Florida, Grand Bahama Island, Grand Turk Island, Puerto Rico, Antigua Island, Ascension Island and Johannesburg, South Africa) and at the Canary Islands and the Azores. Time synchronization of 1 microsecond accuracy was demonstrated within the ground wave range of the signals received; however, the receivers used were not capable of obtaining range that is possible with better receivers. The sky wave synchronization measurements showed at least 10 to 50 microsecond capabilities with the receivers used, but it was felt that the tests were somewhat inconclusive due to the poor receiver performance.

A time code generator was operated directly from the Loran-C clock. This generator was capable of producing the new IRIG code formats as well as the old AMR code formats. The UHF distribution system operating from this generator was demonstrated at the Cape.

Complete specifications for the UHF distribution system, including circuit diagrams for a terminal point decoder and logic diagrams for the encoder to operate from existing time code generators or the Loran-C clock time code generator, were delivered to GEEIA for their use in procurement.

In January of 1961, four Loran-C timing receivers built by Sperry Gyroscope Company to NBS specifications were delivered. These receivers have demonstrated far better performance than the SPN-28 receivers used on the down-range tests. Plans are presently being made to use these receivers in the NBS program for monitoring Loran-C time signals as controlled by the Naval Observatory.

During the past year the Telecommunication Working Group of the Inter-Range Instrumentation Group has reviewed the range time synchronization problem, and is recommending that Loran-C be used by the missile ranges as the primary time synchronization system on a virtually world wide basis. The Loran-C system will be used in conjunction with presently existing VLF systems. VLF and Loran-C can support each other to a mutual advantage. They (TCWG) further recommend that additional Loran-C transmitters be installed to give ground wave coverage of the Continental United States and sky wave coverage on a world wide basis. These recommendations are being made as a direct result of the NBS Loran-C clock development.

A report entitled "Widely Separated Clocks with Microsecond Synchronization and Independent Distribution Systems", by T. L. Davis and R. H. Doherty, was presented at the WESCON Convention in Los Angeles, California. The report was published in the WESCON Convention Record and later in the IRE Transactions on Space Electronics and Telemetry. Another report based on this work entitled "Timing and Space Navigation with Existing Ground Base Systems", by G. Hefley, R. F. Linfield, and R. H. Doherty, was presented at the AGARD Meeting in Istanbul, Turkey by G. Hefley, and this report will appear in the AGARD publication.

The immediate and specific objectives of this project have been completed. The Naval Observatory will undertake the operational time synchronization of the Loran network. There are no plans for NBS continuation of this project in FY-62.

Personnel contributing to this project were: R. H. Doherty (project leader), G. Hefley (section chief), T. L. Davis, E. L. Berger, R. F. Linfield, J. D. Harper, Jr., A. H. Dove, C. J. England, E. E. Johnson, M. W. Schroeder, and G. F. Schreiber, Jr.

## LF-VLF Sferic Measurements

85466

The objective of this project is the determination of effective ground conductivity from sferic observations.

A method of conductivity mapping is urgently needed to predict the performance of VLF and LF systems. Virtually no conductivity maps are in existance which are valid at these frequencies.

Data taken at Brighton, Colorado and Leoti, Kansas were analyzed to test a new theory for the determination of effective conductivity by taking into account the modification of sferic wave forms when propagated over a particular path.

The analysis showed that the theory was valid. The results of this analysis are described under project 85162. (Projects 85164 and 85162 have been combined because the nature of the analytical work in both projects is entirely similar.)

The funding in this project was not adequate to carry out the above work. Additional funding was provided by project 85164 whose basic objectives were identical.

This project is terminated.

Personnel contributing to this project were: G. Hefley (project leader), and C. M. Lilley.

308

Development of Random-Motion High Speed Camera

85467

The objective of this project was to design and construct a random-action camera capable of recycling in 1.8 milliseconds. This work will be related to work on an earlier camera capable of recycling in 7 milliseconds.

The development of a camera of this type, capable of operating at such high speeds, will provide a new and useful tool to record a wide variety of data; and to measure many randomly occurring events such as sferics or rapidly occurring radio signals.

Tests have been conducted to evaluate the feasibility of using an induction disk drive for the camera. A four layer diode circuit has been tested for the drive to the induction disk. The 7 millisecond camera used a voice coil drive and thyratrons in the electronics. The use of an induction disk and the four layer diodes appears promising in reducing recycling time from 7 milliseconds to approximately 1 to 2 milliseconds.

The general assembly drawings have been completed and machine work is progressing.

Plans for Fiscal Year 1962 are to complete the detailed drawings and to complete shop construction of the camera. The electronic drive circuitry will be built and tested separately, and then the entire camera will be tested prior to delivery. Delivery of the completed camera is anticipated to be no later than August 30, 1961.

Personnel contributing to this project were: E. L. Berger (project leader), and G. Hefley (section chief).

309

## Ground Wave Field Intensity Calculations

85468

The purpose of this project is to evaluate height-gain factors for the sea-water case for variable antenna and receiver heights for frequencies from one and a half through three megacycles.

This project is sponsored by Avco Corporation to fulfill certain requirements of Defense Contract No. AF 19-604-4092. The time element is very important to this company, as it would take many months for it to develop the basic methods and computer programs to obtain the values desired.

The calculations have been completed and forwarded for a permittivity lapse of 0.75. A few calculations for a permittivity lapse of 0.85 have been sent for examination and comparison with the values completed.

The remaining calculations which are considered necessary for Avco to complete the project will be undertaken. The parameters necessary for these calculations will be known as soon as the work previously sent is examined.

Personnel contributing to this project were: J. R. Johler (project leader).

# Mercury MUF/LUF Computer Program

85469

The objective of this project is to provide radio propagation prediction in selected high frequency radio links to be used in project Mercury.

The project is of direct importance to the space program of the nation.

A computer program has been devised to compute the MUF for any radio link. Close co-ordination was maintained with project 85473 during its development. The basis for the program was "Ground Telecommunications Performance Standards", Volume 1, Chapter 1, Section 1-5, produced for GEEIA, Rome, New York, with the replacement of Table 1-2, to $F_2$ and M-4000 maps, with coefficients from numerical mapping techniques devised by Jones and Gallet, NBS Report 6755.

Techniques for the development of an advanced LUF program for large scale computers have been investigated, but the final form of the program has been awaiting efficient techniques for obtaining mapped parameters, such as noise, layer height, etc.

It is anticipated that the work of this project will be continued under NBS project 85473.

Personnel contributing to this project were: J. D. Harper, Jr. (project leader).

## Radio Launch Control System, Sky Wave Interference in Modulation System

85548

The objective of this project is to determine the effects of sky waves on the buried antenna system Boeing is evaluating for the Minuteman program.

The communication for this program must be accurate and reliable. Any interference due to sky wave contamination could seriously degrade the accuracy and/or reliability. It is essential that all aspects of this possible contamination be evaluated to assure the best possible system performance.

A trip was made to Warrensburg, Missouri on February 7-9, 1961 while Boeing was conducting confidence tests. Pulse transmissions were observed at a distance of 65 miles to determine the existence or non-existence of sky waves. It was felt that some sky waves were present, but it was impossible to evaluate any effect that might exist. It was determined that the instrumentation should be cleaned up and the measurements should be repeated. Unfortunately the transmitting equipment was destroyed in a fire before this could be done.

Plans for Fiscal Year 1962 are to carry on the measurement program with the new transmitting equipment and to complete the evaluation of sky wave signals interference on the radio launch system.

Personnel contributing to this project were: R. F. Linfield and R. H. Doherty (project leaders).

## ELF Prince

85562

CLASSIFIED

## RADC Propagation Studies
### Task 4

85563

The objective of this project is to develop a flexible mathematical model for the ionosphere for the LF-VLF and the MF-HF wave propagation and use these models to determine the effects of disturbances of various types on the wave propagated through the lower ionosphere.

The availability of a large electronic computer makes it possible to study analytically the effect of disturbed ionospheric models on wave propagation.

The initial work on the project was begun in April, and the flexible theoretical ionosphere model was developed for the CDC-1604 computer. The model comprised a multi-slab electron-ion plasma with superposed magnetic induction of arbitrary direction which could be adjusted to fit most any electron density-altitude collision frequency-altitude measured profile. The analysis system was completely rigorous for the assumed model since only Maxwell's equations and the equation of motion of the electron were assumed. The Boltzmann theory of ionized gases was studied in some detail and the introduction of recent developments in this theory was introduced into the analysis as an extension of the classical magneto-ionic theory. The introduction of Boltzmann's theory was necessary to take account of the interaction of elastic waves with electromagnetic waves and to take account of non-linear amplitude effects as a result of large signals. The model was tested by an application to the study of a disturbance of solar origin in the lower ionosphere: J. R. Johler and J. D. Harper, Jr., On the effect of a solar disturbance on the low frequency ionosphere reflection process, 6th AGARD Ionospheric Research Committee Meeting, 15-18 May 1961, Naples, Italy for Advisory Group for Aeronautical Research and Development, Organisation du Traite de l'Atlantique Nord, 64, rue de Varenne, Paris 7, eme (to be published, Pergamon Press) (1961).

Plans for Fiscal Year 1962 are: (a) The "diffusely bounded" model ionosphere will be developed by a further exploitation of Boltzmann theory of ionized gases, and transmission and reflection coefficients will be evaluated at LF-VLF utilizing the most recent geophysical data. (b) Perform analysis of the disturbance of the ionosphere and attempt to form a model disturbance. (c) Consider the effect of the deformation of the spherical geometry of the ionosphere and the redistribution of the diffuse boundary as sources of field changes in waves propagated point-to-point along the surface of the earth. (d) Develop a description of the lower ionosphere "transmission coefficient", both amplitude and phase for quiescent conditions. (e) Determine the effect of disturbances of various types on the wave propagated through the lower ionosphere.

Personnel contributing to this project were: J. R. Johler, (project leader), C. M. Lilley, L. C. Walters, L. A. Berry, and D. C. Hyovalti.

## RADC Propagation Studies
## Task 5

85564

The objectives of this project were to develop a series of graphs, curves, and charts in a form suitable for practical system studies in the LF-VLF-ELF region.

This project is an important adjunct to project 85563, since it is considered essential to know the normal behavior of the LF-VLF-ELF waves before the effect of a disturbance of the ionosphere can be properly assumed.

This project was initiated in April 1961, and work on the sky wave field has been dependent upon the results of 85563, or the development of a suitable model for the ionosphere. However, a detailed study of the ground wave has been reported as follows: L. C. Walters and J. R. Johler, On the propagation of spherical waves in the vicinity of a sphere, (to be published NBS Journal of Research, Section D).

The work on this project will attempt to construct field intensity curves from available techniques to cover LF-VLF-ELF for various distances employing various models of the ionosphere for day, night, quiescent and disturbed-blackout models of the lower ionosphere.

Personnel contributing to this project were: J. R. Johler (project leader), L. A. Berry, L. C. Walters, J. D. Harper, Jr., D. C. Hyovalti, and C. M. Lilley.

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RADC Propagation Studies

Task 6

85565

The objective of this project was to determine the effect of natural occurring phenomena such as lightning strokes, solar disturbances, etc., on the phase, amplitude, background noise level, etc., of transmission in the LF-VLF region.

A problem exists in the detection of very weak signals with narrow bandwidth in the ELF through LF regions of the radio spectrum. The natural noise is intense and characteristically impulsive to the extent that any linear system will respond to the transient and interfere with the desired signal for a period of time much longer than the impulse. This time is related to the parameters of the particular system.

In designing any system required to measure weak signals at low frequencies, it is extremely important to understand the nature of the interference. Once the interference is understood, the logical next step is to design circuits that will either eliminate the interference or operate best in its presence.

Circuitry has been designed to detect atmospherics and to gate them out. This circuitry is presently being used to count the number of sferics exceeding a given amplitude and to record the percent of time occupied by these sferics. For example, on a typical summer morning the sferic rate exceeding 50 mv/meter was 10/sec and the percent occupancy of these sferics was 0.1 percent. By afternoon the rate may increase to over 100/sec and the occupancy may approach 2 percent.

Work is continuing on the instrumentation of the Brighton Field Site and a mobile unit for directional observations of sferics with the Ephi system.

Plans for Fiscal Year 1962 are to monitor sferic activity at Brighton, Colorado and simultaneously at another location (suggested China Lake, California) measure directional and other characteristics of atmospheric noise. To continue work on the gating and receiving techniques in order to demonstrate means for best operating an extremely sensitive receiving system in the presence of impulsive noise. To investigate the possibility of using directional techniques to reduce interference level and to determine the direction of arrival of the desired signal.

Personnel contributing to this project were: R. H. Doherty (project leader), G. Hefley (section chief), E. L. Berger, T. L. Davis, C. J. England, M. W. Schroeder, E. E. Johnson, and C. M. Lilley.

# UPPER ATMOSPHERE AND SPACE PHYSICS

DIVISION 87

## UPPER ATMOSPHERE AND SPACE PHYSICS

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# UPPER ATMOSPHERE AND SPACE PHYSICS

## Consulting and Advisory Services

87101

An important aspect of the Bureau's responsibilities is to make available to the nation information and advice within the competence of its scientists and engineers. This project supports the consulting and advisory work of the Division's staff in relation to industrial organizations, research institutions, universities, agencies, and scientific and professional societies, and permits the rapid dissemination of the scientific information and experience existing within the Division. An active interchange of scientific information is essential to the progress of science and technology. National and international organizations such as the American Geophysical Union (AGU), the International Scientific Radio Union (URSI), the International Radio Consultative Committee (CCIR), the International Union of Geodesy and Geophysics (IUGG), the (international) Committee on Space Research (COSPAR), and others exist, in part, to fulfil this need. Participation in such organizations both fulfils national and international responsibilities, and also obtains information essential to the successful progress of our work.

Formal committee appointments of staff members include: for the International Radio Consultative Committee, the Chairman of the International Study Group for the Ionosphere, and membership in the International Working Party for an Ionospheric Index; for the International Scientific Radio Union, the Secretary of the U. S. Commission on the Ionosphere, the Coordinator of Ionospheric Absorption, A-2, and membership on the URSI/IGY subcommittee and the U. S. Committee on the Exosphere; for the International Council of Scientific Unions, the deputy reporter for the IGY Airglow program and editor of the relevant volume of the IGY Annals; for the U. S. Telecommunications Planning Committee, the Chairman of the Research and Development Panel; for the National Aeronautical Space Administration, membership of several NASA working groups and other committees; and for the National Academy of Science, member of the Committee on Atmospheric Sciences, Chairman of the Upper Atmosphere Panel of the Committee on Polar Research, and members of the Space Science Board Committees on Astronomy, and on the Atmospheres of the Earth and the Planets. All these committees or groups have been active during the year.

Much of the information that we have obtained through our radio and optical studies of the upper atmosphere, and our laboratory studies of plasma, is extremely pertinent to the present national emphasis on space research. We have therefore frequently been consulted by scientists and engineers with problems in areas of our competence. In addition, four invited papers were given by members of our staff at the XIIIth General Assembly of URSI, held in London in September 1960, and one invited paper each at the International Symposium on Aeronomy, held in Copenhagen in July 1960, the meeting of the Instrument Society of America, held in New York in September 1960, and the meeting of the American Physical Society, held in Mexico City in June 1961. Several other papers have been presented at the two national meetings of URSI, at the spring meeting of the American Geophysical Union, and at the COSPAR meeting in Florence, Italy.

The following personnel worked on this project: C. G. Little (project leader), D. M. Gates, D. K. Bailey, R. M. Gallet, K. L. Bowles, F. E. Roach, and R. S. Lawrence.

## Spectroscopy

87103

### Atmospheric Spectroscopy

87405

The objectives of this program are to study the properties of the middle and upper atmosphere by spectroscopic techniques. The program consists of several parts being worked on concurrently. These are: far infrared spectrograph for high altitude research from balloons; theoretical studies of the atmospheric transmission functions; simplified balloon instrumentation for ozone, water vapor, and carbon dioxide measurements of the earth's atmosphere; high resolution spectroscopic studies of the atmosphere in emission and absorption; high resolution laboratory studies of atmospheric gases under varying conditions of pressure and temperature.

The balloon-borne far infrared spectrograph experiment will give important knowledge concerning the distribution of atmospheric water vapor at high altitudes. It is the only technique available for giving the total water vapor present between the balloon and the photodissociation level around 80 km. In addition, the experiment will give the solar spectrum between 20 and 40 microns wavelength, a wavelength region in which the sun has never been seen from the ground due to the opacity of the atmosphere. One balloon flight in November 1961 has been obtained in addition to the one reported for FY 1960. The pointing control failed and no data were obtained. As a result the task of improving the reliability of the instrument, which was originally obtained commercially, was undertaken. The improvements which are being incorporated into the system are, (1) an automatic gain control to take into account changes of solar intensity, and (2) a new type of sensor for the "eyes" of the seeker. It is hoped that the equipment will be ready for flight early in FY 1962.

Detailed wavelength behavior of transmission functions for the actual atmosphere are much needed by atmospheric physicists. These are not currently available and so the Atmospheric Spectroscopy Group has undertaken a small computational program to obtain these transmission functions. This information is also needed in order to interpret the observations made on the project.

The infrared transmission of the atmosphere to solar radiation in the 4.3 micron absorption band of carbon dioxide has been computed by means of an iterative process. A regular band model is used for this theoretical analysis. The computed transmissions are based on low resolution laboratory data and when applied to slant paths through the atmosphere give results which are in complete agreement with observations made from balloons by another research group. All necessary programs for the calculation of other bands of $CO_2$ are ready. As soon as time is available, hopefully in August of 1961, work will be completed.

In order to obtain good laboratory data to use in the interpretation of atmospheric spectroscopic observations, a high resolution infrared spectrometer is now under construction. This instrument has been planned, and detailed drawings made for its construction. Certain parts, such as the large mirror, have been ordered. When completed, this instrument will give as good a resolution as any instrument available and will permit some very excellent experiments to be done on the transmission properties of atmospheric gases as a function of pressure and temperature.

A thorough analysis and study is being currently carried out of some infrared data from observations made by Dr. Gates several years ago of the earth's atmosphere. It is expected that this analysis will give the detailed behavior of the absorption coefficients, wavelength by wavelength, throughout the infrared spectrum from 1.0 to 12.0 microns in wavelength.

This work is partly supported by the Office of Naval Research.

The following personnel worked on these projects: D. M. Gates L. R. Megill (project leader), Linus S. Drees, Arthur B. Shafer, Walter Harrop, Leann Droppleman.

Spectrometers

87404, 87812

The objective of this project is to design and construct several spectrometers for observation of night sky emissions in the infrared region of the spectrum. These instruments are being designed to achieve the highest resolution possible consistent with the low intensity, diffuse source of radiation presented by the night sky. The important quantity to be considered in the design of any spectrometer is the product of the flux and the resolving power. This quantity has been maximized in these instruments within the limits dictated by the requirement of portability and availability of components. These considerations have resulted in the design of a rather unique instrument with large aperture, long entrance and exit slits, and very large grating. The large exit slit has made rather elaborate output optics necessary along with the use of a large detector. A cooled photoconductor detector is being used for maximum sensitivity. With these instruments, spectra from the OH emission of the night sky should be observable with a spectral resolution of better than .01 microns and possibly as good as .001 microns.

Design of the infrared spectrometers is essentially completed and construction is well along on one of the instruments in the instrument shop. Four instruments arebeing built; two for observing OH emission at 3.0 microns, and two for observing $O_3$ emission at 9.6 microns. Essentially all of the optical components have been ordered and most of them have been received. Many components have been built or ordered for all four instruments simultaneously as the instruments are quite similiar in design.

Some of the associated electronics have been designed and constructed, and the remainderare currently being worked on. It is expected that the construction of one of the instruments will be essentially complete by September, and the instrument can then be assembled and initial testing started. Construction and testing of the other three instruments will continue throughout fiscal year 1962.

The high resolution spectrometer is an Ebert-type, laboratory spectrometer. This instrument will be used to measure molecular absorption and line width of the various constituent gases of the atmosphere and in high resolution infrared molecular spectroscopy.

The high resolution spectrometer has been designed with the exception of the auxiliary components. The vacuum tank and collimating-camera mirror have been manufactured. The grating has been ordered and is in the process of being ruled. Construction of the instrument has not been started due to a shortage of instrument makers within the Bureau.

Work under this project is supported by the AFSC-ESD.

The following personnel worked on these projects: D. M. Gates (project leader), Howard N. Rundle, David Dunkin, and Arthur Shafer.

Manufacture of Infrared Photometer

87775

The purpose of this project is to construct a photometer for detection of radiation from the atmosphere induced by high power density radio beams.

Theoretical predictions carried out under the spectroscopy project indicate that sufficient intensity will be produced in the beam of the large transmitter now being constructed in Peru, to permit significant experiments on the constitution of the atmosphere to be conducted. This instrument will be used to test the predictions. It is now completed and is being checked out.

Personnel working on this project: L. R. Megill and Linus S. Drees.

Manufacture of Interferometer

87776

A Michelson-type interferometer is being constructed to be used to obtain infrared spectra between 1 and 10 microns. This instrument is to be used for observing the night sky, the day sky, and laboratory sources. The immediate range of interest is from 1 to 4.3 microns where the OH emission is present. Experiments which are involved include: (1) study of the OH molecule itself and the ozone-hydrogen reaction in the laboratory, and (2) the study of OH in the upper atmosphere, particularly its density distribution and subsequent role in the hydrogen-oxygen reaction.

If infrared spectroscopy is to be pursued, this type of instrument has several advantages over conventional spectrometers. It has a higher light gathering power, and observes all the spectral elements simultaneously, thereby increasing the sensitivity of resolution available as compared to spectrometers. The design of the optical and mechanical portions of the interferometer has been completed and construction is under way.

Personnel working on this project: Howard N. Rundle.

## Arctic Propagation

87185

The purpose of this project is to engage in such radio studies of the arctic ionosphere as will result in an improved understanding of the disturbances in the upper atmosphere caused by particle-bombardment processes. The normal type of HF communication link is notoriously unreliable when used at high latitudes. This is due to the frequent occurrence of disturbed ionospheric conditions, during which excessive ionospheric absorption or strong multipath-scatter renders the circuit useless. Another possible difficulty lies in the occasional observation of anomalously high noise-levels, apparently due to the generation of radio noise of auroral origin. These disturbances result from the bombardment of the upper atmosphere by energetic particles, guided to high latitudes by the geomagnetic field. Relatively little quantitative information on these phenomena is available; the importance of this project lies in the fact that new techniques (including radio astronomical methods) are used to make quantitative measurements of the ionospheric absorption and radio noise.

The work on this project has been divided into three main areas. The operation of the sensitive receiving system set up to measure the thermal noise temperature of the D-region of the ionosphere was terminated in November 1960 after one year's data had been obtained. During the last six months of this period, the observations were made using a vertically polarized antenna, and two circularly polarized antennas of opposite sense of rotation. The data for the year, with one exception, showed that the electrons in the lower part of the D-region are apparently in thermal equilibrium with the neutral gas, and that their temperatures are not greatly affected by aurora, polar blackouts, or magnetic disturbances. One important exception, still remaining to be interpreted, occurred during the polar cap absorption event of September 3, 1960, when the equivalent antenna temperature in the ordinary mode increased by some 200$^{o}$ Kelvin. This may represent a contribution due to the high-energy-tail in the electron temperature distribution; alternatively, it may represent the radiation of non-thermal noise from the ionosphere. Work is proceeding on the interpretation and publication of these data.

The development of the transistorized riometer, a device designed to measure ionospheric absorption by the cosmic noise method, has continued. The equipment has been designed, built and tested and several copies have now been built commercially.

The cosmic noise absorption technique has been extended by the design and construction of a 10 Mc/s system which records continuously the cosmic-noise strength on both circular polarizations. This represents a major advance in the field, since the use of the lower frequency and both polarizations permits roughly a ten-fold improvement in sensitivity and a greater dynamic range, together with an indication as to the height at which the absorption is occurring.

The interpretation of the D-region temperature data will continue on this project; the riometer development will continue on project 87402, and the 10 Mc/s dual-polarization work on project 87485.

The following personnel worked on this project: C. G. Little (project leader), G. M. Lerfald, D. C. Keifert, and L. D. Matheson.

## Ionospheric Absorption at Mirny

87409

The objectives of this project are to obtain measurements of the ionospheric absorption occurring at Mirny, Antarctica, one of the principal USSR geophysical research centers in Antarctica. It is well known that HF communications via the ionosphere are frequently disrupted in the arctic by the occurrence of excessive absorption associated with aurora and magnetic storms. Quantitative data on absorption (obtained by the cosmic-noise technique) have been available since the IGY for the Arctic, but no such data have been published for the Antarctic. It is the purpose of this project to obtain such data, in order to determine the magnitude of the radio-wave absorption occurring in Antarctica, and the relationship (if any) between absorption events occurring simultaneously in the two polar caps.

With the acceptance by the Russians of the suggestion that America should undertake a cosmic-noise absorption program at their Mirny base (in exchange for a visit by one of their scientists to the American Byrd base), a hurried program of equipment procurement and personnel training was initiated with support furnished by the NSF. This was successfully accomplished in time to board the Russian supply vessel, at Capetown, S. Africa, in late November. The equipment has since been installed at Mirny base and is operating successfully.

The two cosmic-noise absorption equipments, which operate at frequencies of 30 Mc/s and 50 Mc/s, will be operated until about January 1962, at which time the equipment and the operator, Mr. Gillmor, will return with the data to the Boulder Laboratories. The data will then be processed to determine quantitatively the magnitude of the absorption which occurred during the observations, and the correlation of the absorption values with other geophysical phenomena.

The following personnel worked on this project: C. G. Little (project leader), S. Gillmor (Antarctica).

## Absorption Studies at the Auroral Zone

87485

Abnormal increases in the absorption of ionospherically propagated HF radio waves are frequently observed at the auroral zone. These absorption events are associated with corpuscular bombardment of the upper atmosphere. During the IGY, the first quantitative measurements of these phenomena were obtained using the riometer (cosmic-noise absorption) technique. The importance of this project lies in the extension of the riometer technique by the use of riometers at widely spaced frequencies, and on different polarizations. These modifications of the standard single-frequency, single polarization riometer technique permit observations with much greater dynamic range and sensitivity, and also give some information as to the height of the absorbing region.

This project, supported by ARPA, started late in the fiscal year, and made use of equipment originally designed and constructed on NBS project 87185. Three riometers, operating respectively on 10, 30, and 50 Mc/s were installed at College, Alaska, during March 1961, in cooperation with the Geophysical Institute of the University of Alaska. All frequencies use antennas having the same polar diagram, directed into the zenith. At 10 Mc/s, the ordinary-wave and extraordinary-wave absorptions are recorded independently, by means of circularly polarized antennas. Data of good quality are being obtained, and computer programs are being prepared for their processing and interpretation. As expected, the 10 Mc/s data show that the ordinary-wave absorption is less than the extra-ordinary wave absorption; the differential absorption has at times been as much as 10 decibels.

The current three-frequency operation will, if possible, be extended to a total of five frequencies, with the addition of dual-polarization units at about 5 Mc/s and about 20 Mc/s. In the data analysis, particular attention will be given to the rate of onset and disappearance of the absorption, and to the possibility of detecting radio noise of auroral origin. The frequency and polarization dependence of the absorption will be used to determine the height of the absorbing region, and, if possible, to give information on the electron density distribution in the D-region.

Personnel who worked on this project are: C. G. Little (project leader), G. M. Lerfald, D. C. Keifert and S. S. Barnes.

## Instrumentation Research

87104

The objectives of this project are to develop new techniques for experimental upper atmosphere and space physics research, to design and develop new and specialized apparatus for the above research, to conduct exploratory experiments of new and unusual types, and to design, develop, and provide facilities for the handling of the data resulting from such experiments.

Since many of the problems of the upper atmosphere and space involve uncontrolled experiments, i. e. those in which the experimenter cannot manipulate or change the phenomenon of interest, observations in many different ways may well be necessary. In addition, many of the events to be observed are rare, natural phenomena of unpredictable characteristics, so that personal observation is often impracticable. Therefore, the experimental setup must be as completely automatic as possible. The significance of this project may be seen from the fact that new discoveries are usually made by using new and different techniques of observation.

The Instrumentation Research Group has been engaged in several different projects during the year. Examples are Projects 87101, 87104, 87105, 87113, 87114, 87481, 87482, 87171, and 82444; all of which were assisted in varying degrees -- from the simple repairs of equipment to the design, construction, and installation of special-purpose observational apparatus. In addition, this project supported the early development stages of the prototype VLF hiss-recorder, described under project 87113.

Project 87104, for instrumentation research not specifically connected with another project, has been active at times when personnel were not working on problems having higher priority. During the year this project was used to investigate the feasibility of using C-W techniques in ionospheric sounding. The narrow-bandwidth characteristics of such systems, resulting in low power requirements, are expected to be extremely useful in space research where telemetering and/or storage of data is required. The experimental system was completed to the point that all components of the system were constructed and assembled. No clear results were obtained due to the necessary diversion of personnel to other projects within the Division.

The Electronic Instrumentation Group will be considerably augmented by the addition of another group under the direction of G. R. Sugar. This group, consisting of engineers and technicians, has had considerable experience in digital techniques and contrasts with the analogue experience of the present group. Together, the two groups will move into a common laboratory space, where the combination of facilities will provide a greatly increased capability. The principal task to be undertaken under this project during FY 1962 is the further development of the C-W ionosonde.

The following personnel worked on this project: J. M. Watts (project leader), C. L. Wilson, and D. N. Frazer.

## Whistlers

87105

The objective of this project is to investigate the audiofrequency electromagnetic phenomenon known as whistlers, together with the allied phenomenon known as VLF emissions. It is expected that a better understanding of the structure and composition of the exosphere will be gained by this work.

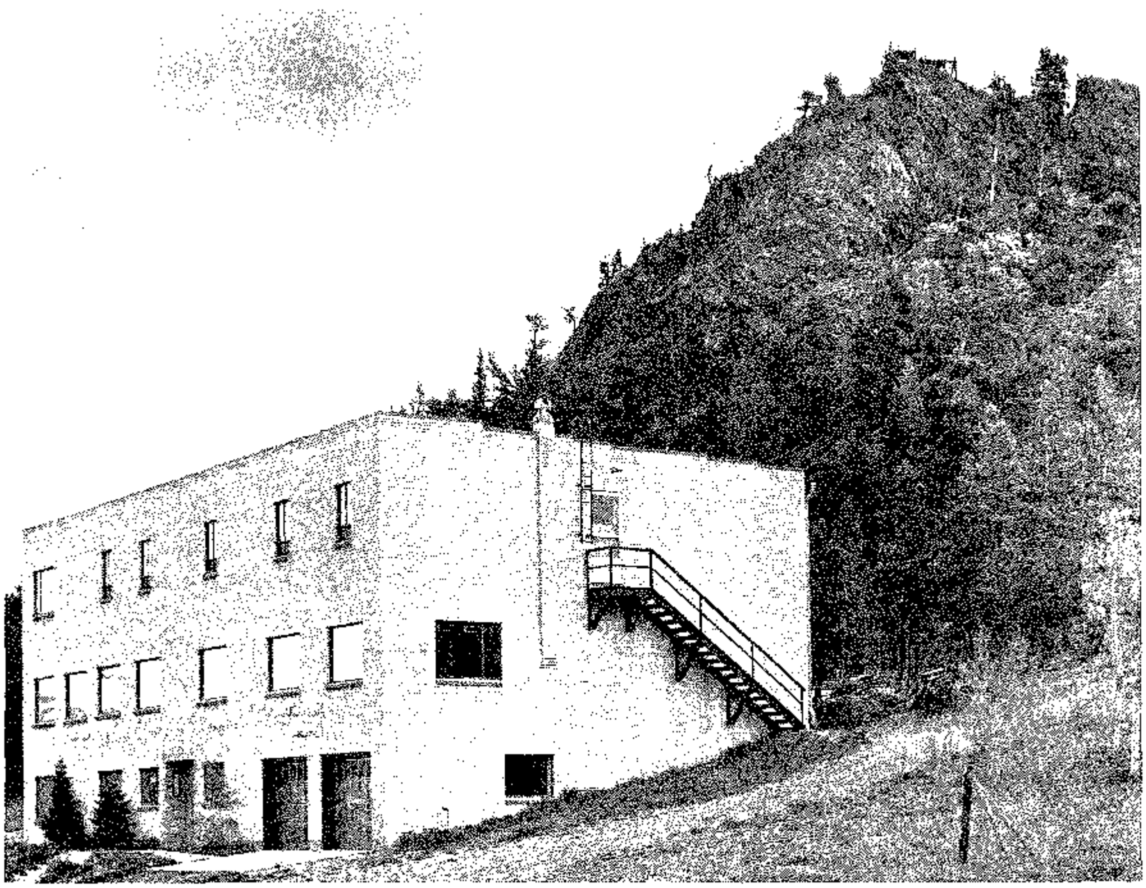
The occurrence of natural events in the exosphere provides one of the cheapest and most widely used means of studying the region. The dispersions of natural signals propagated through the region and the characteristics of natural signals generated in the region give evidence of the structure, composition, and physical processes occurring within it. Therefore, their observation and study are invaluable for a better understanding of the characteristics of the exosphere and its control by solar and geophysical influences.

During the year automatic recording of whistlers and VLF emissions was continued at the international sampling times. Although direction finding information was included, this has not proved very fruitful, and most of the interest lies in trying to correlate observations made at different stations at the same time. It seems from the similarity in received spectra of discrete events observed at separated stations that propagation channels or ducts are present during at least some phases of all geomagnetic storms.

This project will be continued in the same way at least until December 31, 1961. After that, collection of data may be stopped, depending on the scientific results obtained up to that time. The work of monitoring the tapes will, however, be continued through the fiscal year.

The significance of the observations made at Boulder during the period July 1 - December 31, 1961, will be increased because the field station at Minneapolis will record simultaneously, giving a possibility of correlation of the VLF data recorded at the two stations.

The following personnel worked on this project: J. M. Watts (project leader), D. N. Frazer, Vaughn Aandahl, and C. L. Wilson.



Boulder Laboratories Airglow Observatory. Photometer visible at left, on top of Fritz Peak.

UPPER ATMOSPHERE AND PLASMA PHYSICS SECTION

Ionosphere Representation

87111

The objectives of this project are two-fold. The first is to solve the general problem of making world-wide maps of the ionosphere by use of numerical analysis and large-scale, high-speed computers. For this part the main emphasis is on the global representation of ionospheric characteristics and their many variations with time. The second part is to develop satisfactory methods of predicting these ionospheric maps.

The greatest practical achievement of this project is that it provides the first automatic computer method for predicting long-term changes in useful frequencies for radio communication. Thus the regular CRPL public service of furnishing these predictions, which has been made for many years by graphical hand methods and other subjective operations, may now be produced by more rapid, objective, and accurate machine methods. The new computer methods are based upon recent advances in applied mathematics and statistics, and upon the desire to respect as far as possible the empirical knowledge accumulated in ionospheric studies.

The new methods also provide much more flexibility in solving problems of ionospheric radio propagation by treating separately the three basic areas involved: (1) ionospheric mapping, (2) correlation of ionospheric characteristics with various indices of solar activity, and (3) application of the theory of radio wave propagation based on a predicted ionosphere (obtained from the two previous areas). Thus, advances such as improved theories or new ionospheric data may be introduced in any one of these areas without changing the others.

The methods that have been developed are general enough to be applied to any ionospheric characteristics and, with only slight modification, to any geophysical quantities (such as meteorological and geomagnetic) which vary continuously with time on a world-wide basis. As a future application it is planned to analyze the magnetic field in space from satellite measurements.

The development of mathematical methods and computer programs has been completed for part 1 (ionospheric mapping) of the objectives listed above. The basic difficulties in this part of the problem have been satisfactorily overcome. These included the facts that the data are affected by random errors which would produce very rough and physically unacceptable maps if an exact representation were made without a certain amount of space and time smoothing;

that the data are irregularly positioned in the two space dimensions; hence, standard data-fitting methods are not applicable; that the clustering of stations in some regions and absence of stations in other regions tends to produce instability in the function approximations; and finally, the fact that the number of stations available varies from month to month requires considerable flexibility in the numerical methods.

In order to make the new developments usable for practical applications, a great amount of ionospheric data from 1954 through the end of the IGY and IGC (1959) has been prepared on punched cards and analyzed by the mapping program. The numerical maps now available are sufficient for predicting within a computer the ionospheric characteristics, monthly median foF2, and M3000 F2, for any time and place in the future. These maps and their associated computer programs have already been furnished to, and are being used by, two government agencies and one private company to solve radio communication problems.

For producing predicted numerical maps, a satisfactory method has been developed and a computer program is now in operation. To evaluate this method, predicted numerical maps have been made for several past months and the residuals between the actual data and the calculated ones have been computed. Also graphical contour maps obtained from numerical representations of the data and from predicted numerical maps for the same months have been produced and compared. All of the results so far have been satisfactory.

The first computer programs for this project were developed using the computer at Boulder. The capabilities of this machine were far too limited for the problem, and therefore most of the work was done with the system in Washington, D. C. However, now that the Boulder Laboratories has secured its own large computer, some effort was made this year to transfer parts of the mapping program to this machine. A considerable amount of this work still remains for the coming year.

The personnel contributing directly to this work were: W. B. Jones (project leader), M. Hinds, M. Pokempner, V. Rios, J. K. Myers, and W. Van Buskirk.

## Upper Atmosphere Physics

87112

The objectives of this project are to investigate a few selected problems in the physics of the upper atmosphere, chosen either because of their fundamental nature or because of their present importance in relation to new discoveries or theoretical questions. During this fiscal year the work has been concentrated on the following:

1. Ionospheric propagation problems.

2. A long-term study of the theoretical structure of atmospheres of other planets, mainly the giant planets.

3. A study of the effects of expanding shock waves produced by explosions in the upper atmosphere, and the resulting ionization.

The work on ionospheric propagation has for its objective the development of a very large-scale program for a fast electronic computer which will calculate, to the best of our present knowledge, the field strength intensity of the ionospheric wave, as a function of frequency, in a communication link between any two points. It should use a selection of the best theoretical formulas, accurate numerical analysis methods, and efficient programming. Furthermore, this program will be compatible with, and will use the results of, the "numerical maps" of the ionosphere developed in the projects 87111 and 87115. This is a long-range project aiming at modernizing the methods presently employed for the prediction of optimum frequencies for ionospheric communication systems.

A great interest has developed during the last years in the atmospheres of other planets, particularly under the impetus of the Space Science Board of the NASA (One national conference on this subject was held in July 1960). With the technical progress of space probes, it becomes imperative to plan future experiments carefully. The present studies are designed to ensure that the presently available information and theoretical methods are fully utilized to provide as much information as possible on planetary atmospheres.

The ionospheric propagation studies required preliminary programming on the new high-speed, large computer installed at the Boulder Laboratories. Several programs concerning the relations between the phase velocity and direction, and the group velocity and direction of a wave propagating in an anisotropic medium, have been developed. They have been used for investigating the properties of the plasma oscillations branch and of the "whistler" branch of the

Appleton-Hartree equation. Also, a new, completely general program for the Appleton-Hartree equation, including the effects of collisions and of the electric field vector of the wave, has been developed. A program for the calculation of the field strength of a wave of fixed frequency as a function of distance has been developed, and applied to a quantitative study of the "Pedersen ray", propagating in one hop to very large distances (5000 to 6000 km). The computed results appear to be in good agreement with the many observations of this phenomenon.

During this and part of the preceding fiscal year, much work was done on the integration of the system of differential equations giving the density, pressure, and temperature as a function of height in a deep planetary atmosphere, assuming adiabatic equilibrium. However, in order to obtain a physically realistic solution, it is necessary to have an equation of state, and a formulation of the thermal properties (specific heats and their ratio), as a function of density and temperature, sufficiently good for gases under high pressures. This question is a really difficult problem of thermodynamics, which must be fitted and checked against the best experimental data available. Good progress has been achieved but satisfactory results are not, as yet, available. With the installation of the new large-scale electronic computer, it has been necessary to re-program the extensive set of programs previously developed. This has delayed the advance of the study, but should permit, when finished, a much more efficient study of this problem.

The following personnel worked on this project: R. M. Gallet (project leader), Marvin White, D. Obitts, L. Schultz (WAE), Janet Herman (Part-time).

## Exosphere Physics

87113

The objective of this project is to develop the knowledge of the physics of the earth's atmosphere, above the ionosphere and up to six or seven earth's radii, in a realm where until now our knowledge has been slight. Emphasis is placed on plasma properties: wave propagation; production and motions of high speed electrons and ions through the plasma, interaction between the particles and electromagnetic waves, the structure of the magnetic field in this region, and its relation to the plasma properties of the medium. The existence of the program is based primarily on the need for an understanding of the physical phenomena in the exosphere. With the increasing development of satellite and space probe experiments, a theoretical understanding of this region is becoming more and more important. Since the IGY, very rapid progress has been made in this expanding field, and much new experimental information is being produced. As a consequence, new problems are arising at a very high rate.

A joint program has been conducted with W. F. Utlaut and staff from Division 85 to guide high frequency waves along ducts in the exosphere, the ducts being due to the laminar structure of the electron density along certain magnetic lines of force. The observed length of the path differs considerably from the calculated length of the line of force in the absence of external sources of magnetism and also varies from one observation period to another. This is due possibly to the combined effect of diamagnetism and currents from trapped high energy particles in the exosphere.

These observations are believed to have opened an exciting new field for the study of the structure of the exosphere. The resulting data are expected to provide means for studying: the probability of formation of the ducts, their mean life, the diffusion of charged particles across the magnetic field, the speed of deformation of the sheets, and, perhaps more important, the diamagnetism and the currents in the exosphere.

A new field station was installed at Minneapolis and is already furnishing excellent VLF and riometer data. This program represents a joint effort between our group, Dr. Winckler's group at the University of Minnesota, and J. M. Watts (87.00). The purpose is to search for the expected relations between the production of VLF emissions and the high energy electrons or protons measured by Winckler's balloon flights.

A new instrument, the hiss recorder, was suggested by the observations of this project and has been developed by J. M. Watts (87.00). It is now in operation at Minneapolis and furnishes a continuous record of hiss emission between zero and 60 kc/s. This is a very successful instrument, providing a type of record which should prove invaluable for purposes of time correlations of VLF emissions with other geophysical phenomena.

The station is also equipped with the regular VLF monitoring apparatus. A riometer is also in continuous operation, making it possible to search for association between VLF emissions and overhead abnormal ionospheric ionization. The location is proving to be an excellent one in terms of types and amount of VLF activity recorded; the location is also interesting because of the frequent observation in the Minneapolis region of phenomena attributed to the dumping of Van Allen belt electrons.

At least one case has been found of a VLF emission whose echoes were received alternately in opposite hemispheres.

Many calculations of geomagnetic field properties have been performed for the HF Exospheric Ducting and for the Conjugate Point Programs. A theoretical study of the properties of Cerenkov emission in the whistler mode by high speed particles is being carried out.

Theoretical studies will be continued during the coming year, concentrating on the possible mechanisms for the generation of electromagnetic waves in the exosphere.

The relations between high speed particle radiation and discrete and continuous types of VLF emissions will be further pursued in cooperation with the University of Minnesota.

The following personnel worked on this project: R. M. Gallet (project leader), S. Hansen, J. Koch (student trainee), Wm. Waterhouse (summer student); in joint projects: J. M. Watts, D. Frazer, and C. Wilson, Division 87.00

## Shockwave Ionization

87114

The objectives of this project are the production and study of the ionization, temperature, and velocity of high energy blast waves. In particular, it is the aim of this project to obtain and study interactions between electromagnetic waves and the plasma in the blast wave.

The contributions of this project are: (a) an increase in the knowledge of the plasma state by the simultaneous use of microwave and photographic techniques, (b) the development of microwave methods for studying plasmas, and (c) the development of methods for generating high temperature, strongly ionized plasmas. With the increased use of the plasma properties of the ionosphere in the propagation of radio waves, e.g., whistler mode ducting and Faraday rotation of satellite signals, and with the need for a deeper understanding of the ionosphere as applied to missile and satellite performance, it is vitally important that our knowledge of plasmas be extended as far as possible. In addition, information gained from microwave Doppler studies in the laboratory can be directly applied to observing the effects of explosions in the ionosphere.

A systematic study of shockwaves from exploding wires in air has been made using the equipment and methods for generating and measuring strong cylindrical blast waves developed last fiscal year. A wide range of wire sizes, pressures, and energy inputs have been studied. Quite critical optimum conditions were found in which over 40 percent of the capacitor energy supplied went into the shock. When any one of the experimental conditions (wire size, pressure, energy input) was changed slightly, the efficiency of the shock rapidly dropped to below 10 percent.

Simultaneous measurement of the shock velocity on three separate microwave frequencies indicates that all are reflected from the same discontinuity at velocities from Mach number 25 down to Mach number 3. Microwave reflections have been obtained from shocks with velocities below Mach number 3, which indicates an excess of ionization, since from the theoretical standpoint reflections should not occur below Mach number 7. The explanation of the higher ionization is probably the excitation of the medium ahead of the shock front by the ultra violet pulse which occurs when the wire explodes.

The presence of electrons well ahead of weak shockwaves (Mach $\sim 3$) from exploding wires has been detected by microwave absorption in argon, helium, nitrogen, and air at pressures ranging from 5 to 50 centimeters of mercury. Densities of the order of $10^{11}$ electrons per cubic centimeter have been observed 3 centimeters ahead of the shock front. Preliminary measurements show that the distance the electrons are ahead of the shock front is inversely proportional to pressure, but different for each gas.

A program of measurements on strong blast waves in argon is under way. Because of the relatively high ionization potential of argon, it is much more difficult to ionize than air. Consequently, it is harder to obtain adequate electron densities; so the argon gas is "seeded" with cesium vapor which does ionize easily. Preliminary results from shockwaves in cesium-seeded argon indicate a much less efficient energy transfer is obtained than in the comparable case for air.

Theoretical calculations of the energy parameter, "B", in the strong blast wave theory of Taylor, which were started last fiscal year, have been completed. Comparison with previously published values of "B" shows discrepancies as large as 67 percent.

During fiscal 1962 the systematic shockwave measurements completed for air will be extended to argon and possibly other gases. Intercomparisons will be made between theory, results available in air, and the results obtained in argon. Development of the cesium-seeding technique will continue with application to conductivity measurements as well as electron density enhancement. At the same time, working pressures will be extended down to about one millimeter of mercury from the present one centimeter limit.

The preliminary work on shock profile studies by microwave absorption will be continued. It is expected that direct measurements of collision number and electron density will be possible. With lower working pressures, it is anticipated that the profile behind the front can be measured. Photomultiplier measurements of the ultra violet radiation ahead of the shock will be made in an attempt to determine if that is the cause of the ionization.

Equipment development will continue throughout the next year. Several new microwave devices for determination of phase shifts and polarization changes are planned. A new capacitor bank capable of higher energy output and faster discharge speed will be built.

The laboratory study of the whistler mode of propagation of electromagnetic waves in hot dense plasmas has been reactivated. Preliminary development of the necessary experimental equipment and techniques was started.

The following personnel worked on the project during fiscal year 1961: Michael Addison, Robert Hyland, Donald Jones (project leader), John Neary, Louis Phillips and Frederick Yarger.

## Ionosphere Mathematics

87115

The main objective of this project is the application and development of mathematical methods related to Project 87111, Ionosphere Representation. These include methods of function approximation and orthogonal series for representing various types of physical variations, and methods of statistical analysis for studying such things as the effects of random errors on data-fitting problems, optimum separation of noise from true physical variation, and stationary and non-stationary time series analysis.

The primary significance of this project can be seen in the importance and achievements discussed in the report on Project 87111. In addition, however, many other research groups, both within and outside of the National Bureau of Standards, have found useful applications for the methods developed by this project. Also it is planned to make extensive further application of these methods in the work of Project 87118.

The activities of this project have been the development of mathematical methods and computer programs. The most important effort was made on a very general data-fitting method. The program of this method may be applied to obtain a least squares linear regression using any set of real-valued linearly independent functions and weighted data which may be irregularly positioned in a many dimensional space. Thus among the multitudinous applications which can be made are spherical harmonic analysis of irregularly spaced data in three dimensions, Fourier analysis of time series, and analyses using all classical orthogonal systems such as Chebychef and Legendre polynomials. The basic difficulty in this method was the accumulation of rounding error produced in the orthogonalization process. This problem was completely resolved for every application made so far by a reorthogonalization process.

In addition to this general method, a program was written specifically for Fourier analysis of equally spaced data, and another one for fitting polynomials in one variable to irregularly spaced data. All three of these data-fitting methods are in the process of publication.

The personnel contributing directly to this work were: W. B. Jones (project leader), M. Hinds, V. Rios, V. Hunt, and J. K. Myers.

## Electromagnetic Radiation from Shock Waves

87116, 87814

The objective of this project is to produce electromagnetic radiation from a controlled plasma. From these studies, we expect to gain a better understanding of naturally occurring radiations in the ionosphere, solar corona, and stellar atmosphere.

Scientific investigations of radiation from plasmas have been for the most part devoted to the naturally occurring phenomena, such as hook-type whistlers, dawn chorus, solar radio frequency bursts, etc. The sporadic occurrence, and complexity or uncertainty of the conditions under which these phenomena are generated, make it difficult to isolate and study the important parameters contributing to their occurrence and propagation. This program will provide a means for generating and studying the mechanisms responsible for the emission of radiation from plasmas under known conditions. Many improved techniques have been developed and put into operation for producing, observing, and measuring the characteristics of electromagnetically driven shock waves and the associated strongly ionized plasmas during the past year. The preliminary work on this project was devoted to producing strongly ionized plasmas in the form of high velocity shock waves. After some initial difficulties, a shock generator has been developed which produces shock waves in helium at Mach numbers in excess of 100 (10 cm/$\mu$ sec). This generator has been used extensively for studying the distance-versus-time characteristics of plane shock waves generated in a linear shock tube.

Several methods have been employed to investigate the behavior of the shock wave and plasma. Doppler shift measurements using the reflection of several different microwave frequencies simultaneously, make it possible to penetrate to different parts of the shock wave, and thus gain some information about the variation of electron density at different depths in the shock front. This procedure is analogous to the reflection of radio waves to determine the variation of electron densities in the ionosphere. Photomultiplier circuits were designed and used to observe the luminosity front associated with the shock wave. A comparison of the luminosity data and the microwave data indicates a broad structure of the shock front in advance of the luminosity front.

The same shock driver was used in conjunction with a strong electromagnet having a 12" pole face to study the behavior of the plasma traversing a magnetic field. Theoretical calculations were made to determine the conditions necessary to produce a strong hydromagnetic interaction between the flow of ionized helium and a transverse magnetic field. When the proper combination of magnetic field strength, ambient gas pressure, and shock wave velocity can be achieved, a strong deceleration of the plasma shock wave takes place as it enters a transverse magnetic field, i.e., when the magnetic energy density, $H^2/8\pi$, is comparable to the kinetic energy density, $\rho u^2/2$, and when the magnetic Reynold's number, $R_m = 4\pi \mu\sigma uL$, is sufficiently large. Since the dimension, L, in the laboratory system is small, it is necessary to achieve high shock velocities in order that the gas flow velocity, u, and the conductivity, $\sigma$, be large. Magnetic probe techniques, designed to obtain magnetic field measurements at several points along the length of the shock tube, make it possible to observe and record the change in magnetic field strength as the fast, highly-conducting plasma enters and traverses the homogeneous magnetic field. The results of such observations show very definitely the magnetic breaking of the ionized shock wave as the hydromagnetic interaction takes place between the conducting plasma and the magnetic field.

A dual microwave transmitter-receiver was designed and fabricated. Because of shifted emphasis in the work for which it was intended, the equipment is now used as two single beam transmitter-receiver systems.

Although the operating conditions of the plasma-magnetic field system are marginal at the present time in so far as producing radiation is concerned, a search was made in the hope of detecting non-thermal radiation from the shock wave plasma. Radiations have been observed; however, it is too early to make a definite report on these findings. More detailed experiments are needed using a more favorable magnetic field configuration. Provisions must also be made for searching over a much wider range of radio frequencies.

Now that success has been achieved in producing sufficiently fast shock waves and strongly ionized plasmas, a concentrated effort will be made to determine the conditions under which radiations are emitted by a plasma. Further efforts will be directed toward developing and testing theories to explain such radiations.

The work in this project was performed by K. B. Earnshaw (project leader), Wm. Saxton, R. Dickason, and R. Calfee on a consulting basis.

## High Speed Framing Camera

87813

There has been a growing need for photographic studies in the plasma research in the Upper Atmosphere and Space Physics Division of the Boulder Laboratories. Because of the great flexibility inherent in the grid forming type of high speed camera (designed by Sultanoff* of Aberdeen Proving Grounds), it was found desirable to manufacture this type of instrument.

The project was started in January 1961 by the purchase of the necessary high quality lenses and camera accessories, and fabrication work was performed by the Buck Instrument Company of Boulder. Camera fabrication was completed by mid-March, and the necessary synchronizing system was developed and installed by early April.

Since completion of the camera, a strong effort has been made by personnel in the Shockwave Radiation project and in the Boulder Laboratories

* Sultanoff, M., "A 100,000,000 Frame per Second Camera," Rev. Sci. Instr. 21, 653 (1950)

Photographic Laboratory to determine the best films, proper camera speed and F stop, and suitable development techniques for recording images of the luminosity front in a strong shockwave.

Good photographs have been obtained by using the camera in essentially three different ways:

(1) By using a single slit in the focal plane of the camera and rotating the mirror at top speed, streak photographs with a top writing speed of about 3.7 mm per micro-second can be obtained. Streak photographs of the luminous front in a shockwave have been taken for pressures in the range of 50 $\mu$ Hg to 5 mm Hg using a polaroid camera back. These photographs give a rapid distance-versus-time plot of the shock luminosity, and, in addition, give a quick check on the exposure required for producing usable framing photographs on glass plates.

(2) By operating the camera at fairly high speed, multiple exposure photographs are obtained which give the effect of a stroboscope, stopping the action at equal time intervals. Using this technique, a single shockwave can be seen in as many as 300 positions throughout a distance of 60 cm, with an effective shutter speed of $2 \times 10^{-8}$ seconds.

(3) By operating the camera at a relatively low speed, single exposure photographs are obtained. Using this technique, a single shockwave can be photographed at 30 positions throughout a distance of 60 cm, with an effective shutter speed of $2 \times 10^{-7}$ seconds.

The work in this project was performed by K. B. Earnshaw (project leader), R. D. Dickason, and W. R. Saxton of Division 87, with very important help in camera design and photographic techniques from C. M. Benedict, T. L. Theotokatos, and F. H. Dunbar of the Photographic Laboratory.

# IONOSPHERE AND EXOSPHERE SCATTER SECTION

## Scatter Radar Antenna

87027

## Scatter Radar Transmitter

87028

## 50 MC Amplifier

87029

## Scatter Radar Site Preparation

87091

## Scatter Radar Building

87092

## Scatter Radar

87156

## Study of Avalanche Ionization Absorption and High Energy in the E Region

87456

The objectives of these projects are to develop and exploit new experimental methods for studying the ionosphere, the exosphere, the interplanetary medium, and the Sun, using a radar equipment of high sensitivity. One principal method depends upon an extremely weak incoherent scattering of radar waves which is proportional to the electron density under study. Additional information on the kinetic temperature of the heavy ions, on the identity of the ionized chemical constituents, and on the intensity of the earth's magnetic field, is also obtained as a function of the height. Other studies utilize scattering from aggregations of coherent irregularities in the D-region and above. Particular interest is attached to hydromagnetic aspects of irregularities which bear a strong geometric relationship to the lines of force of the earth's magnetic field. Due to the intense beam of radio energy produced by the radar transmitter and antennas, absorption is produced in the lower ionosphere. Project studies concern the physical processes present in this absorption. Radio echoes will be sought from the outer corona of the Sun, and from gas clouds ejected by the Sun.

The outstanding feature of the incoherent scatter technique is that it provides, for the first time, a practical means of measuring the electron density variation with height out to great heights using equipment located entirely on the ground. This electron density variation, or profile, is of great importance to scientists concerned with the dynamic and static structure of the outer atmosphere.

Accurate measurement of the profile is an absolute necessity in all missile and satellite work requiring radio tracking of the vehicle trajectory or orbit. Previous methods available have been of severely limited value. For instance, the so-called True Height calculation from conventional ionograms provides electron density profiles only up to the height of the F-region maximum density. Satellite and rocket measurements are both expensive and limited in that the samples they take are of a "one-shot" nature and are more difficult to apply directly than the incoherent scatter observations. Using incoherent scatter equipment, it is possible to obtain, above any given geographical point, the electron density profile continuously from below the E region to heights of more than 3000 km. The equipment can be operated continuously in time, permitting profiles to be taken every few minutes for days, months, or years, so that the atmospheric and exospheric dynamic variations can be studied. Possible use of incoherent scatter to provide reliable long range communications has been suggested, and an understanding of the ionosphere above F-maximum is essential to this application.

In other observations the project stands to contribute in the following ways: The project has achieved, for the first time, vertical incidence radio echoes from the D region at VHF. By studying the characteristics of the echoes, important contributions to the description of turbulence and meteorology at that level will be made. By using the enormous radar system sensitivity available, echoes from the moon can be obtained at short pulse lengths, thereby aiding in the study of the lunar surface. A study of echoes from the sun should provide a description of disturbances in the outer corona. In fact it is predicted that direct observations of clouds of particles ejected by the sun could be made well in advance of the time their arrival at the earth would cause auroras and magnetic storms. Studies made in connection with IGY equatorial scatter, described in an accompanying report, suggest that small irregularities of electron density may exist at greater heights than had previously been suspected. A search for such irregularities, most likely to occur during periods when the outer atmosphere is disturbed in some manner, may prove successful and provide further powerful means for studying disturbances. Absorption occurring in the lower ionosphere is a serious limitation to large numbers of practical applications of radio propagation through the ionosphere. The project will be exploring absorption phenomena in the region of extremely high radio-frequency flux densities, a region where the physical processes are poorly understood.

This fiscal year has been largely occupied with the work of establishing the new scatter radar observatory facility at the Quebrada de Jicamarca near Lima, Peru. Leveling of the site for the antenna, and earth removal for flash-floods protection were completed. A small test section of the antenna, using the new design, was completed and found to be as efficient (about 85 percent aperture efficiency) as had been hoped. The design was then employed in the construction of most of the first half of the array according to plan. The first one-quarter section of the array has been completed and in operation for several months, while the second quarter should be complete early in July upon delivery of the remaining ground screen.

Through the help of the U.S. Air Force, the transfer was obtained of a large part of the components of a surplus military radar transmitter. These, with the shielded-grid-triode amplifier mentioned a year ago, will complete the six megawatt transmitter planned for the project. Manufacture of the components for the amplifier is complete. Delivery of the military radar components to the site met with shipping difficulties,but is nevertheless largely complete. Assembly of the complete transmitter on site has begun, albeit delayed by contractor difficulties on construction of the laboratory building which forms the transmitter "chassis". Connection to commercial power mains, also plagued by contractor difficulties, is expected to be complete early in August.

Observations of incoherent scatter from the ionosphere have begun at the Lima Observatory, using a modified transmitter of lower power which had earlier been used by NBS during IGY in Peru. Numerous profiles of electron density have been obtained in the height range,150-1200 kms. Early analysis of the records has resulted in the following conclusions: (1) the decay of the electron density with heights above the maximum of the F-region is usually exponential for several kilometers. The electron density decays with height by a factor of 1/e for an increase in height of from 80 to 200 kms. (2) Frequently a second approximately exponentially decaying region can be found above the region mentioned in (1). The electron density in this region decays more slowly than in the first region, and the changeover from the first region to the second is relatively abrupt. (3) At about 2000 hours time, the entire north layer over Lima seems to rise. At heights between 150 and almost 300 kms, the electron density becomes "vanishingly" small.

From the measurements made thus far, it is certain that the electron density in this height range, and this time of day, is no greater than $10^3$ electrons per cubic centimeter. (During the remainder of the day, and at other parts of the world, the corresponding electron densities are usually in the range $10^5$ to $10^6$ per cubic centimeter.)

During the first half of Fiscal Year 1962, the big pulse transmitter should be completed, and the second half of the antenna array will be constructed. It is hoped that by January the entire system will be complete and taking data. The remainder of the fiscal year will employ taking data with the system as planned.

Work on project 87456 was supported by the AFSC-ESD.

Personnel working on this project were: for NBS directly: K. L. Bowles (project leader), R. S. Cohen, G. R. Ochs, B. B. Balsley, J. L. Green, D. C. Whittaker, G. F. Miller, J. L. Valega, C. Y. Matsunaka, C. L. Kimmel, E. G. Clark, and personnel of the Boulder Laboratory Instrument Shop. Under cooperative contractual agreement with the Instituto Geofísico del Perú: A. A. Giesecke, J. A. Ghersi, H. Goller, A. Arévalo, M. Tábara Ferrier, H. Cabada, and a large staff of Peruvian workers.

## Equatorial Ionosphere

87151

This project is an outgrowth of the research on transequatorial ionospheric scattering at VHF begun in South America during the International Geophysical Year. In conjunction with the work in incoherent scatter being conducted at the magnetic equator, this project is aimed at a better understanding of the equatorial ionosphere and, in particular, the effects in that ionosphere due to magnetic field aligned irregularities in electron density.

These studies contribute to the understanding of the equatorial ionosphere, a subject of basic physical interest. Much of this interest stems from the fact that a considerable simplification of physical processes involving charged particles exists in the ionosphere at the magnetic equator due to the unique horizontal orientation there of the magnetic field lines. Thus, if certain ionospheric processes can be understood in the equatorial ionosphere, this knowledge can be applied to better understand ionospheric effects at other magnetic latitudes. Furthermore, there are many unexplained propagation phenomena at the magnetic equator which have been little explored experimentally, and which may be capable of application to communications.

This year has been devoted to the completion of a study of the experimental results to date, and to the publication of the results of the experiments.

The nature of spread-F irregularities near the magnetic equator has been clarified, and in particular, an explanation has been given as to the origin of the spread-F configurations appearing on equatorial ionograms.

The research on the sporadic-E effects encountered near the magnetic equator has provided material for a survey paper describing the general results to date. A more detailed study of various facets of this research is under way in four other papers now in preparation. The first of the remaining papers, regarding VHF oblique scattering, will contain results of various analyses of the IGY signal-strength data, which have now been transcribed to magnetic tape such that any desired study may be accomplished in a matter of minutes. These data are for propagation measurements on six of the experimental paths, and include about 100, 000 signal intensities, one for each five-minute interval during the year of observation. These data have also been reproduced photographically in a readily accessible form so that qualitative studies may be made. The data, both in digital and photographic form, are being transmitted to the IGY World Data Centers. The second paper treats the association between radio wave scattering from equatorial sporadic-E irregularities with the equatorial electrojet. Much of the analysis for its preparation has been completed, and the pertinent equatorial magnetic data for the IGY have been transcribed to punched cards and magnetic tape so that detailed correlations can be made between the magnetic and radio results. The third paper in progress describes the nature of the equatorial sporadic-E irregularities, and is mainly based on experimental results obtained on the magnetic equator (at Huancayo, Peru) subsequent to the IGY. The material for this paper is essentially complete.

It is expected that the remaining papers will be completed during the initial phase of this fiscal year, as well as further analyses now in progress. Experimental activities will then be resumed at Lima, Peru, in conjunction with the new observatory there. Many aspects of the irregularity-associated phenomena remain to be investigated. The new facility, combined with the existing laboratory of the Instituto Geofísico del Perú at Huancayo, will provide a powerful tool for this research.

Personnel contributing to the project included: Robert Cohen (project leader), K. L. Bowles, Wynne Calvert, M. L. V. Pitteway (guest worker), K. W. Sullivan, J. T. Brown, Jr., J. R. Winkelman, G. W. Pickering, N. W. Bivens, H. L. Ericson, C. Y. Matsunaka, and W. Chappelle (HAO guest worker).

## Meteor Burst Signal Distributions

87451

The objective is to study the probability distributions of meteor burst signals, and the relationships of these distributions to time of day and of year, threshold amplitude, occurrence rate, operating frequency, and transmission starting delays, with particular emphasis on signals in temperate regions.

Detailed signal distributions are important in affecting transmissions of information in short bursts. The relationship of the meteor-burst signals to ionospheric scatter signals, absorption, and auroral reflection signals is different in the Arctic than in the temperature zone; these differences need to be delineated to understand the signal characteristics to be expected in such regions.

A set of computer programs has been prepared which analyzes the basic meteor-burst data tapes and measures the waiting times between bursts of arbitrary lengths. Although some results have been obtained from these programs, they are currently being revised so that more specific information about the probability distribution of waiting time may be obtained.

Research under this project was completed during Fiscal Year 1961. The results obtained are being used on the other projects concerned with meteor propagation. Support for this project was furnished by the WADC.

Personnel who worked on the project were: G. R. Sugar (project leader), and V. E. Garcia.

Meteor Burst Propagation

87152

Arctic Wolf

87455

The object of this work is to study the basic principles and the statistics governing the propagation of radio signals scattered by meteoric ionization over oblique paths. The Arctic Wolf part of the work is particularly concerned with meteor-burst communication paths in the Arctic. The approach is to take as complete data as possible on several test paths engineered to be nearly identical in terminal equipment. Use is being made of automatic digital techniques to provide a means of recording and analyzing the necessarily voluminous data.

Results of these projects are required for accurate design of meteor-burst communications systems. They should permit accurate prediction of most of the propagation factors in any proposed system before prototype construction is attempted.

The basic experiment involves measurement of the propagation characteristics of transmissions at 30, 50, and 74 Mc/s , over three paths engineered to be as nearly identical as possible. These paths, all about 1300 kilometers long, are from Havana, Illinois, to Boulder, Colorado; from Norman, Oklahoma, to Fargo, North Dakota; and from Barrow, Alaska, to Kenai, Alaska. The first two are paths crossing at right angles and having the same common volume of ionosphere in which the echoes take place. Because of the geometrical dependence of the meteor echoes on the motion of the Earth, differences between the diurnal variations of various echo characteristics over the two paths are expected to be largest for this configuration. The Alaska path was chosen so as to provide data on those propagation characteristics peculiar to the auroral regions.

The equipment for measuring and recording meteor-burst amplitude as a function of time was completed and measurements started on all three test paths in September, 1959. Operation of the paths from Norman, Oklahoma, to Fargo, North Dakota; and from Barrow, Alaska, to Kenai, Alaska, was terminated on 30 June 1960. Operation of the Havana, Illinois, to Boulder, Colorado, path was terminated on 1 January 1961. Additional calibrations of the apparatus, including antenna calibrations, were performed prior to the shutting down of the paths so that the various results can be reduced to a common basis. Since then, most attention has been given to the computer programming required to reduce the data to a meaningful form. Some preliminary analyses have been done, especially of the Arctic data, and some of the results obtained from these observations are being prepared for publication.

The completion of the basic reduction of the data is expected early in the fiscal year. As the reduced data become available, they will be examined for diurnal and seasonal variations, effect of antenna patterns, correlation with other propagation phenomena, frequency dependence and other factors. It is expected that the analyses of the data will be completed, and the projects terminated during the fiscal year.

Support for this work has been partially furnished by the AFSC-ESD.

Personnel who worked on the Meteor Burst Propagation project were: G. R. Sugar (project leader), L. D. Breyfogle, W. S. Burkey, W. H. Daniels, F. J. Eggert, R. P. Graham, A. M. Gray, C. E. Hornback, R. N. Lyons, M. L. West, and D. C. Whittaker.

Personnel who worked on the Arctic Wolf project were: G. R. Sugar (project leader), A. O. Crawley, and W. H. Daniels.

# AIRGLOW AND AURORA SECTION

## Airglow and Aurora

87171

The purpose of this project is to study the physical and chemical processes in the upper atmosphere which lead to optical emissions. The quantitative photometric study of the optical radiations (airglow and aurora) is now being carried out systematically at a number of stations, including the Fritz Peak station of the Boulder Laboratories

A. Observational Program: Systematic observations were made at the Fritz Peak station during 140 nights. This represents a significant increase in observing activity due to the fact that nights are now used for which the zenith is clear even though the horizon may be cloudy.

B. Instrumentation: The use of a new zenith photometer (mentioned in last year's report) has greatly improved the quality of our absolute calibrations. The photometer has proven especially adaptable to field use, including installations at Thule, Antarctica, New Mexico, Hawaii, and Fritz Peak.

C. Data Processing: The zenith observations for the calendar year 1960 have been completely reduced and are under analysis. A digitizing photometer has been put into pilot service. The results appear on punched paper tape. Within about six months it is planned to convert completely to this type of recording.

D. Publications and Analysis: During the year six research papers have been published or are now in press. Of particular interest in the current studies is the correlation between the ionospheric parameters foF2 and h'F and the intensity of the 6300 Angstrom units line of atomic oxygen. A weak positive correlation is found for the Colorado observations, but a very high positive correlation is found in the tropics. The study has been stimulated by collaboration with Dr. Daniel Barbier who visited the Boulder Laboratories during the latter part of the fiscal year.

Work has continued actively on the study of stable red (6300 Å) arcs over Fritz Peak. With the decline of solar activity, their frequency of incidence has decreased.

E. Teaching Activity: F. E. Roach was in charge of a course on "Physics of the Aurora and Airglow" offered jointly by the Colorado University's department of Astro-Geophysics and NBS during the Spring semester of 1961. Guest lecturers included C. G. Little, J. W. Chamberlain, W. Campbell, N. Carleton, and J. M. Malville. Eight students took the course for credit.

F. Photometers in the Antarctic and at Thule: One of our turret photometers was installed at Hallett Station, Antarctica, and was operated from 16 May to 11 September 1960. The operation was under the auspices of AFCRC and was carried out by Mr. Mark Gordon who will complete the analysis of his data in Boulder as a graduate student at Colorado University. A similar photometer was installed at Thule but too late for effective operation before the close of the short observing season. An AFCRC scientist, Mr. Frank Barmore, spent a short time in Boulder during the latter part of the current fiscal year in training for the operation of the Thule photometer during the 1961-62 season.

G. IGY Book: The tabular material for the international IGY book is completed. The textual material is about two-thirds finished. The principal table contains 298 pages of hourly values of absolute zenith intensities of several airglow radiations made at 28 IGY stations. The distribution among radiations is as follows:

| Radiation | Number of Pages |
|---|---|
| 5577 | 94 |
| 5893 | 53 |
| 6300 | 58 |
| OH | 34 |
| Controls (5300, 6050) | 59 |
| Total | 298 |

Personnel who worked on this project include: F. E. Roach (project leader), R. B. Alexander, H. V. Blacker, H. M. Mann, E. Marovich, D. J. McCollum, R. W. Owen, C. M. Purdy, L. L. Smith, B. L. Stone, and V. M. Syfie.

## Airglow and Aurora Emission Studies

87178

This project sponsored the work of a post-doctoral fellow, Dr. N. P. Carleton, who spent the summer and autumn of 1960 and late spring of 1961 at the Boulder Laboratories. Dr. Carleton is an assistant professor of physics at Harvard University and has been very active in laboratory studies of atomic and molecular reactions pertinent in auroral and airglow reactions.

During his stay in Boulder, he worked on two projects:

(1) The development of a photometer for the measurement of the $N_2^+$ band at 3914 Å.

(2) In collaboration with L. R. Megill, a definitive study of discharge processes in the upper atmosphere.

The 3914 photometer has been systematically operated during about six nights, and the records are under analysis.

The discharge study is now ready for routine calculations with the 1604 electronic computer. Trial runs have been successful, yielding curves of degree of excitation of atomic oxygen as a function of energy. The principal parameters are: (1) the electrical field strength, and (2) the excitation energies of the various atmospheric constituents.

Dr. Carleton's post-doctoral fellowship was for one year and expired on June 11, 1961.

The following personnel worked on this project: F. E. Roach (project leader), N. Carleton, and Nancy Potter.

## Research in Zodiacal Light

87476

The zodiacal light is a significant component of the light of the night sky and enters as a contaminant in all airglow studies. It is of special interest in connection with the interpretation of interplanetary dust and electrons.

A research program on the zodiacal light is under the joint sponsorship of the University of Hawaii, the High Altitude Observatory and NBS. Our part in the program is (a) the assistance with computing, and (b) consultation on the program.

A new zodiacal light photometer has been constructed at HAO. It has been and is being tested at Fritz Peak and is due to be installed at the Haleakala station of the University of Hawaii in August. The instrument records (a) the absolute intensity of the zodiacal light, (b) its degree of polarization, and (c) its angle of polarization. Two graduate students are working at HAO on the problem, both under the supervision of the chief of the airglow-aurora section.

Work under this project was supported by NASA.

F. E. Roach (project leader), worked on this project.

## Low Latitude Airglow Studies

87478

One of the interesting recent developments is the discovery of considerable structural detail in the airglow at low latitudes. The joint program (87476) on the zodiacal light also includes studies of the tropical airglow. The responsibility of NBS is to install the photometric equipment on Mt. Haleakala, Maui, Hawaii.

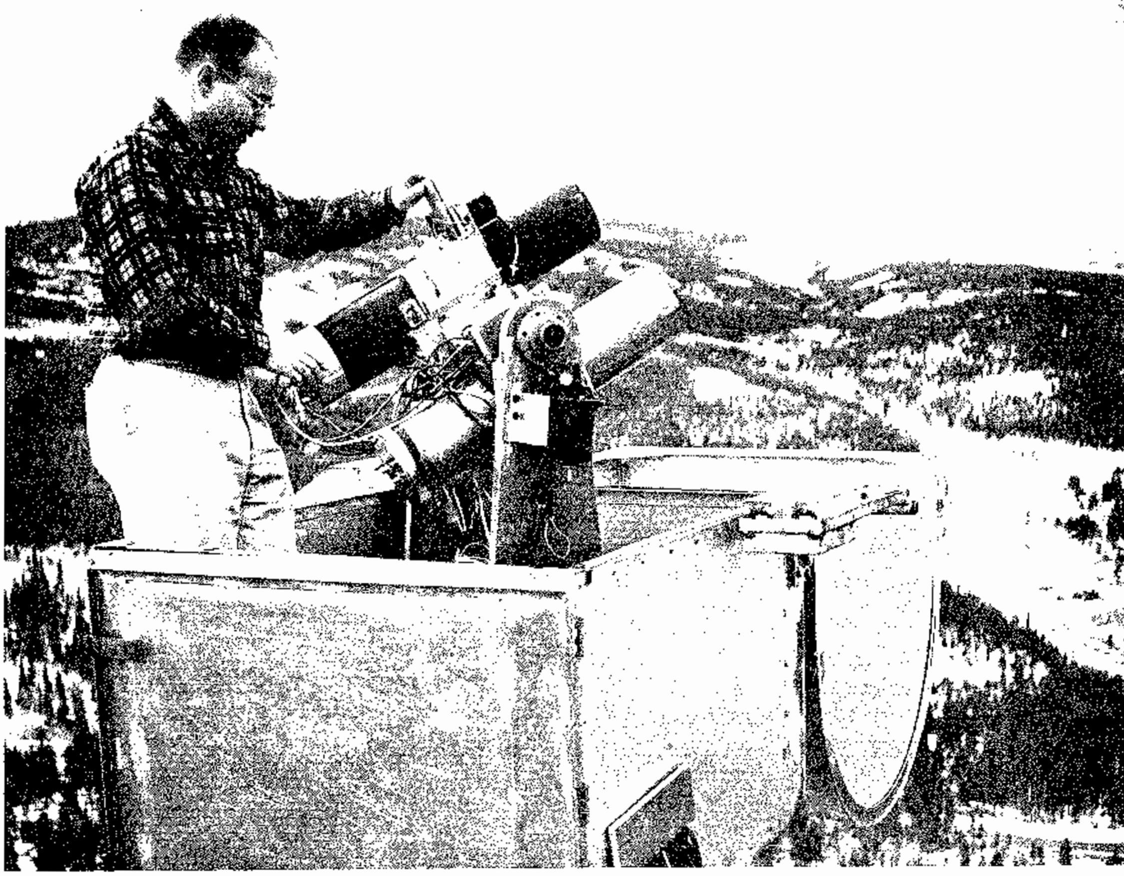
The photometric equipment includes (a) a turret photometer, (b) a birefringent photometer, (c) an astronomical component photometer, and (d) a zodiacal light photometer (87476). Component (a) was put into operation in April, (b) in May, (c) is now en route, and is scheduled for installation in July, and (d) is scheduled for transfer to Haleakala in August.

From April through June 1961, observations were made on 29 nights. Of particular interest is the striking activity of 6300 which correlates with changes in the F-layer. It is possible to test the correlation by comparison of our recent Haleakala observations with ionospheric sounding data from the NBS Maui station. Some very interesting correlations have already been obtained.

It is planned to continue an active collaboration with the University of Hawaii and HAO during the next year.

Work under this project was supported by NASA.

Personnel who worked on this project include: F. E. Roach (project leader), H. M. Mann, E. Marovich, and C. M. Purdy.



Photometer used in studies of the night airglow.

# IONOSPHERIC RADIO ASTRONOMY SECTION

## Solar Noise Patrol

87182

The objective of this project is to provide to the Radio Warning Service, on an up-to-the-minute basis, a simple, single-frequency recording of solar radio noise, in order to supplement the data which comes from co-operating observatories. Experience has shown that recordings of the fluctuations in the intensity of solar radio emissions can be used to help predict disturbances of the terrestrial ionosphere, and hence the occurrence of disturbed radio propagation conditions. This program of routine observations serves to give immediate warning to the Central Radio Propagation Laboratory Radio Warning Service of major solar disturbances.

Since the end of the International Geophysical Year, the observational program has been limited to a solar patrol on a single radio frequency. During this year, the receiving site has been transferred from Gunbarrel Hill to Table Mesa, where the receiver may be attended conveniently on a part-time basis. The antenna system has been simplified by substituting an equatorially mounted Yagi antenna for the old Wurzburg reflector. The observing frequency has been changed from 167 Mc/s to approximately 108 Mc/s to avoid radio interference which had been an increasing problem at 167 Mc/s.

New receiving equipment, requiring less maintenance and less frequent calibration than the old receivers, has been constructed and placed in operation. A leased telephone line is used to transmit the signal from the receiver directly to the Boulder offices of the CRPL Radio Warning Service, where it is recorded on a paper chart.

The following personnel worked on this project: E. R. Schiffmacher (project leader), and W. I. Nodine.

# Evaluation of Transistorized Riometers

87402

The objective of this project is to test and evaluate in considerable detail the performance of two transistorized riometers which were originally developed on project 87185. The use of the riometer (cosmic-noise) method of measuring ionospheric absorption is rapidly expanding, with several tens of units being used by various research groups in equatorial, temperate, and polar latitudes. Experience with the U. S. IGY equipments showed these particular units to require experienced and careful operation, and led to the design, on NBS project 87185, of transistorized riometers with revised specifications. It is the purpose of this new AFSC-sponsored project to test and evaluate in considerable detail the performance of these transistorized units, in the hope that reliable, light-weight units of low power consumption can be prepared. When available, such units are expected to become standard research equipments at many NBS ionospheric research sites.

This project commenced late in the fiscal year with support from AFSC-ESD. The two available transistorized units were first modified to operate on the same frequency of 30 Mc/s. Both units were thoroughly tested in the laboratory and modifications incorporated in order to eliminate drifts due to variations in ambient temperature and in supply voltage. One unit has been operated successfully at the Table Mesa field site for about two weeks; the second unit will be installed at that site in the near future and used for comparison and test purposes.

The two transistorized riometers will be operated side-by-side on identical antennas in order to evaluate their performance in the field. Any further improvements required will be incorporated, and then the design standardized by means of circuit and construction diagrams, equipment specifications, and operator's manual.

The following personnel worked on this project: E. R. Schiffmacher (project leader), and S. S. Barnes.

## Satellite Ionosphere Studies

87481

The purpose of this project, which was sponsored by the National Aeronautics and Space Administration, is to study the ionosphere and earth-space propagation, using radio transmissions from artificial earth satellites. Most techniques for studying the ionosphere can only give information which refers to the structure below the region of maximum ionization. Satellites usually sweep quickly across the sky and thus can be used to study the ionosphere over a wide area by making observations from a single ground station. Various parameters of the satellite radio wave could be studied, but the main emphasis has been applied to recording the changing polarization angle of the received signal. The radio signals from satellites are affected by the whole ionosphere between the satellite and the observer; hence, a comparison of simultaneous measurements, referring to the lower ionosphere, can give otherwise unavailable details of the ionospheric electron content and irregularities above the region of maximum density.

On the observational side, most of the year has been spent in preparing an elaborate array of receiving equipment for the proposed NASA satellite S. 45. The facilities include:

(a) a special six-channel receiver supplied by NASA,

(b) additional phase-locked and non-phase-locked receivers to supplement the NASA equipment, and

(c) a special system which electronically rotates the polarization angle of a linearly polarized ground-based antenna in order to obtain a continuous measurement of the polarization angle of the satellite signal.

Unfortunately, both attempts to launch the S. 45 satellite failed, and as an alternative, some of the apparatus is now being used to observe the satellite Explorer VII. A mobile receiving station has been assembled in a small trailer to allow recordings of the satellite to be made at various distances from the permanent site. A comparison of the records taken at the trailer with those taken simultaneously at the fixed site will allow a measurement of the irregular structure of the ionosphere. A variety of site separations (from 100 m to 100 km) is currently planned and will indicate effects due to irregularities of a large range of sizes. A few records have already been made and unexpected differences between the records are immediately apparent.

Work has continued on the analysis of almost two years of Sputnik III records, taken during the lifetime of that satellite. The rate of Faraday rotation of the polarization vector has been scaled from the records of about 300 satellite passes. Scintillation indices have been estimated from nearly twice that many passes. The interpretation of these data has been proceeding with the aid of a ray-tracing program on the digital computer. This analysis is expected to result shortly in synoptic information concerning both the total electron content and the irregular structure of the ionosphere in the vicinity of Boulder.

During the next fiscal year, it is hoped to continue work with the mobile station to cover the whole range of spacings suggested. In addition to a comparison of the polarization records at the two sites, rapid amplitude changes in the signal (scintillations) will be compared, and this should lead to a determination of the height of the electron density irregularities which cause the scintillations.

It is also planned to study the incidence and intensity of scintillations at the equator. To accomplish this, attempts are being made to obtain the systematic recordings of satellite passes which are made by the Minitrack station at Lima, Peru.

The following personnel worked on this project: R. S. Lawrence (section chief), H. J. A. Chivers (project leader), G. Kamas, D. J. Posakony, R. F. Carle, M. A. Andrews, H. A. Erickson, W. I. Nodine, G. G. Risley, E. K. Arinaga, W. B. Hogwood, L. D. Matheson, L. D. Lewis, and E. L. Phillips.

## Scintillations

87482

The purpose of this project, which is supported by the Ballistic Missiles Division of the United States Air Force, is to supplement the general knowledge of the ionosphere using radio-astronomy techniques and satellite signals. Particular emphasis is placed upon a study of the perturbations imposed upon radio waves which penetrate the ionosphere from outer space.

The use of satellites and radio stars as sources of extra-terrestrial radiation permits the observation of the effect of either a portion of the ionosphere or of the entire ionosphere upon the radio waves. An important difference, however, between the use of radio stars and satellites as sources of extra-terrestrial radiation is that the radio star can be treated as a source at an infinite distance, whereas the satellite must be treated as a source at a finite distance. This distance effect can materially alter the pattern of the radio waves as they are observed at ground level. In the past, observations have been made entirely with radio stars; with satellites, it is now possible to study these distance effects.

In addition to the direct measurement of the effects listed above, it is possible to deduce from the observations information about the structure of the ionosphere, since the fluctuations of the observed radio waves are due to irregularities in the ionosphere. Present sponsorship of the project by the U.S. Air Force arises because of its interest in the effect of the ionosphere on radio signals traveling between the ground and space vehicles.

The main activity during the past fiscal year has been directed toward the development of sensitive receiving equipment necessary for the observation of satellite signals. Due to the component of motion of the satellite along the observer's line of sight to the satellite, there is a Doppler shift in the carrier frequency of the satellite signal. With conventional receivers, the input bandwidth would have to be large enough to accommodate the Doppler-produced variation in carrier frequency. For most satellites, the required input bandwidth is considerably greater than would be required for the observation of scintillation effects in the absence of Doppler effects. In order to reduce the input bandwidth, and thus increase the output signal-to-noise ratio, a tracking filter system is being used. This system keeps the tracking filter centered about the incoming carrier frequency by phase-locking the incoming carrier to a locally generated signal. The bandwidth of the tracking filter need only be wide enough to accommodate the desired scintillation information.

Some preliminary records have been taken using this system in conjunction with low gain antennas. The small antennas will be replaced with forty-foot diameter parabolic antennas which will result in a considerable increase in the quality of the records.

Next fiscal year will be devoted to an observing program with subsequent analysis of the observations. The observations will consist of recording signals from satellites in varying positions in the sky and on different frequencies (depending upon available satellites). Some of the observations will be made using spaced antennas. Also, observations will be made of radio stars in order to compare these records with the satellite records.

The records will be analyzed with a view toward determining the effect of source distance upon scintillations, the spatial and time correlation lengths of the scintillations, the frequency dependence of the scintillations, the effect of source size upon the scintillations, the scintillation characteristics as a function of position of the satellite, and (if satellites with low angular velocity become available) the relationship between the phase and amplitude scintillations.

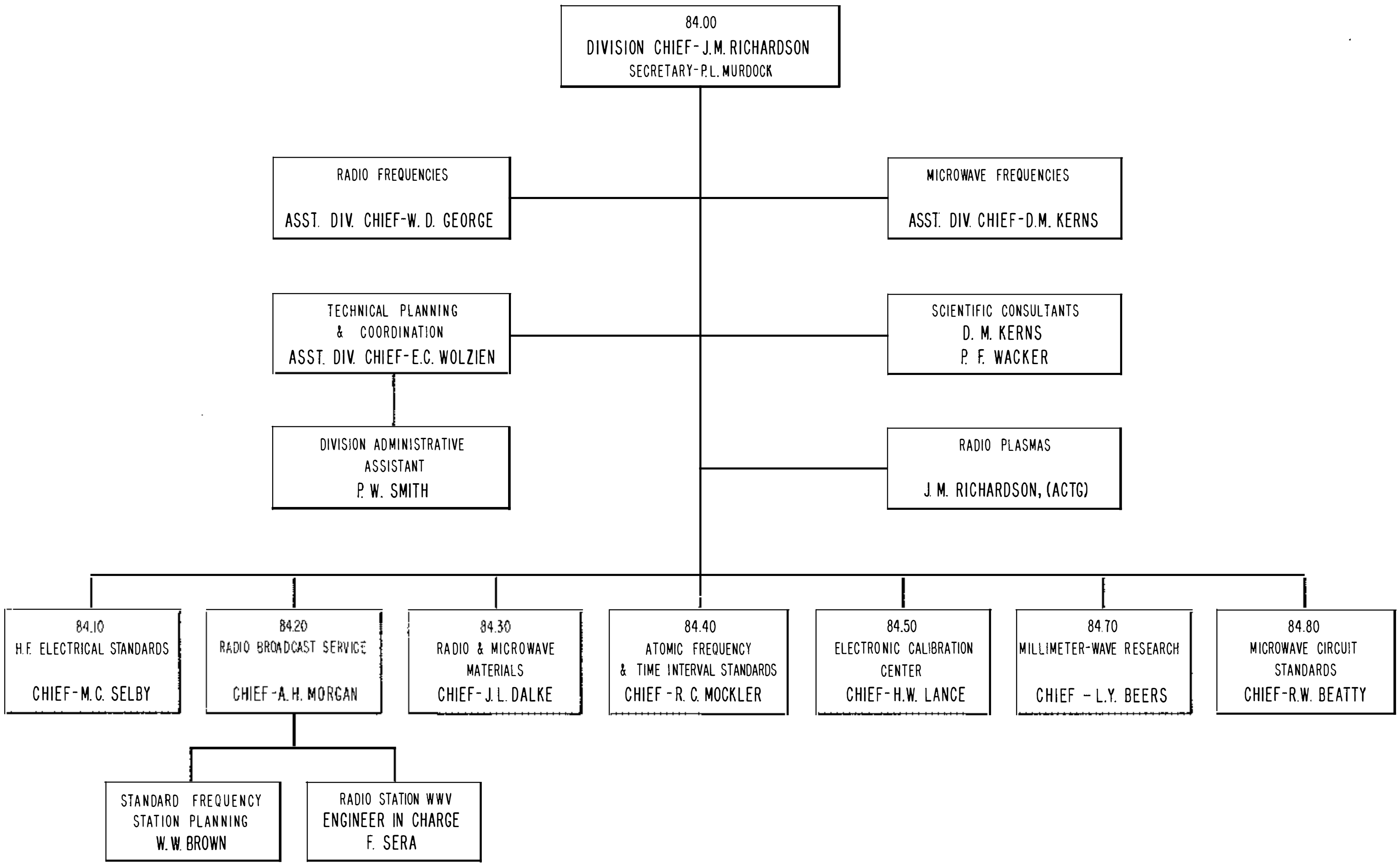
The following personnel worked on this project: R. S. Lawrence (section chief), J. L. Jespersen (project leader), G. Kamas, D. J. Posakony, E. R. Schiffmacher, R. C. Lamb, R. F. Carle, M. A. Andrews and H. A. Erickson.

Two 40-foot radio telescopes on Table Mesa, north of Boulder, used to study scintillation of signals from artificial satellites.

# RADIO STANDARDS LABORATORY

DIVISION 84

RADIO STANDARDS LABORATORY



# RADIO STANDARDS LABORATORY

The scientific function of the Radio Standards Laboratory is to provide the central basis, within the United States, for the complete, consistent, uniform, and accurate measurement of physical quantities and material properties pertaining to radio science, and to assure adequate international coordination of such measurements.

Both scientific and technological progress rests squarely on the adequacy of the standards available. The growing magnitude and complexity of the industrial and military output in radio electronics is evidence of the primary importance of this laboratory. For example, if the precision and accuracy of standards are improved, the degree of performance error in electronic systems can be held to smaller values, resulting in higher attainable performance, or in greater economies of manufacture for a given performance.

Fulfillment of the above function requires research on all aspects of the interaction of radio frequency fields with materials or geometries having possible application as devices or transmission media; and, conversely, it implies using any unique applicability of existing radio technology to discover both the atomic and aggregate properties of matter and to determine constants of physics. It further requires development of its own research results and those of others to produce measurement standards exhibiting improvement as to principle of operation and variety of quantity dealt with, as well as extension of range, frequency, and accuracy. The results of the foregoing research and development are distributed throughout the nation and the world by the provision of standardization services, such as standard frequency and time signal broadcasts, calibration of electronic instruments in terms of the national standards, measurement of the radio properties of materials, consultation, and publication of scientific and engineering results. The subject matter areas of concern to the Radio Standards Laboratory may be thought of as the frequency and time standards area, the radio circuit standards area, the area involving the radio properties of materials, including plasmas, and research of both a theoretical and experimental nature which may stem from or interconnect all these areas.

Significant accomplishments have been made in each of these technical areas during the past year. Perhaps the greatest strides were made in the area of frequency standards. The United States Frequency Standard, a cesium beam apparatus, is showing outstanding performance both nationally and internationally as the most stable and accurate in the world. Our working standards of frequency have been greatly strengthened by the addition of several atomic devices. The performance of the United States standards, and standards elsewhere in the world has led to the active international consideration of a redefinition of the second in terms of an atomic transition. In circuit standards, the ground work has been laid for the establishment of national standards of phase shift to precisions of $10^{-4}$ radians; standards of microwave reflection coefficient have been pushed to a high degree of refinement; the national standards of microwave and high-frequency power have been compared internationally and have been found to excel in accuracy and precision; good progress toward a novel noise standard at high frequencies has been made; and gratifying results have been obtained in the calibration of inductive voltage dividers by a new technique. A good beginning toward the study of electron paramagnetic resonance at cryogenic temperatures has been made; and the study of modes of electromagnetic propagation along cylindrical plasmas has been advanced. The development and understanding of new kinds of resonators applicable in millimeter wave studies was advanced. Many of the foregoing accomplishments have been due to careful and exact theoretical support in electromagnetic theory and mathematical physics.

One summarizing estimate of the significance of the National Bureau of Standards in the world wide radio field was made by the chairman of the United States delegation to Commission I of the 1960 URSI General Assembly in London. He said, "the outstanding contributions made by the National Bureau of Standards undoubtedly established it in a position of leadership in these fields."

The future objectives of the Radio Standards Laboratory are determined, firstly by its study during the past year of the adequacy of its standardization services to science and technology, and secondly by the impact on radio science of recent research results in quantum radio physics. On the one hand, we have been in close and frequent contact with many industrial measurement engineers in order to discover what standardization needs are not being met. On the other hand, we see the rapid onset of many applications of quantum radio physics such as atomic frequency standards, the use of masers as low noise amplifiers, the use of masers to extend spatially and temporally coherent radiation to shorter and shorter wave lengths down to the optical, the use of Stark broadening or Stark shifts as a possible standard for voltage measurement, the investigation of magnetic resonance, the investigation of energy levels in semiconductors, and the study of noise in the quantum limit of low temperature or high frequency,as contrasted to the classical limit of high temperature and low frequency.

The measure of our adequacy in the above responsibilities continues to be very small compared to what should be provided. Our continuing objective must be to make progress toward these goals. Hopefully, some of this progress will be made in the coming year by formulating specific and detailed plans for the increase of staff and facilities. We possess an excellent base of trained, mature, and capable personnel, of unsurpassed equipment, and a backlog of capital ideas on which to build.

John M. Richardson, Chief
Radio Standards Laboratory

## Consultative and Advisory Services
84101

The general aims of this project are to give consultative and advisory services as needed in accomplishing the mission of the Radio Standards Laboratory (RSL).

Work in this area is important because the services of experts in matters pertaining to radio science, standards, and measurements are continuously needed in government, science, and industry. The giving of such services to technical committees and in meetings where recommendations are formulated is nearly always helpful to the RSL in planning and steering its work.

Representatives of the Laboratory participated in a number of committees, sub-committees, or meetings of national and international organizations. For example, IRE, AIEE, AIP, ASA, AGEP, IRIG, BIPM, CCIR, IEC, and URSI. The RSL acted as host for a number of groups meeting at the NBS Boulder Laboratories; e.g., AIA Measurement Research Conferences, DOD technical committees, and joint committees with professional societies arranging for technical conferences in Boulder.

Consultative and Advisory Services will be provided as required.

A list of personnel on this project is inappropriate. All professional personnel used this project when giving consultation to those outside the Bureau.

## Theoretical Physics
84102

Performance of basic work in theoretical physics and applied mathematics (including numerical analysis) on problems of interest to the Radio Standards Laboratory, and provision of consultative service to the Radio Standards Laboratory.

Scope of project spans the more basic aspects of the work of the entire Radio Standards Laboratory. The project is not only a direct source of output, but it also enables increased quantity and quality of output of the division as a whole by: (1) provision of consultative services; and, (2) on occasion, provision of key theoretical developments on which further work in other projects may be based.

Perturbation formulas, based on a "compensation theorem" stated for waveguide junctions, were used to obtain approximate results in a variety of waveguide problems. One of the problems considered was that of reflection at the junction of perfectly rectangular waveguide with a filleted rectangular waveguide of the same main dimensions. This problem is of interest to Section 84.80; the theoretical results are being compared with experimental results obtained by Anson and Beatty. These results are to be published. Examples for which theoretical results are already available were worked using the perturbation formulas. It was noticed that the common expedient of using an unperturbed field as an approximation to an unknown field does not always lead to a correct lowest-order approximation.

An analytical examination of the effect of "mirror tilt" on observed wavelength in the microwave Michelson interferometer was made. It was shown that this effect is of the second order in the angle of tilt, provided certain fairly realistic symmetry properties are assumed for the radiation pattern of the instrument.

A largely expository paper, entitled "Introduction to the Theory of Waveguide Junctions," was prepared by Dr. Kerns and printed as a Memorandum Report.

Work on the microwave spectral tables continued. All source material for these tables has been collected, reproduced, and filed. Input and output formats for the tables were devised, and programming for intensity computations was begun. An electric typewriter was modified to read punched paper tape. (Data are to be recorded first on magnetic tape, and then transferred to punched paper tape.)

Work of the programming and computation group, under Dr. Wacker, included some retraining and some translation of programs on account of the change from one type of computer to another. Examples of the work of this group include computation of Stark energy levels, provision of Bessel function sub-routines, programming for Division 84 budget computations, additional computations of the microwave Michelson interferometer, and computations for the WWV program. An appreciable percentage of time was spent in assisting other programmers in the division.

During the next year, a sufficient amount of old work may be completed to permit some freedom for theoretical progress and exploration. Tasks for the next year, mostly in the category of old work, may be outlined as follows; (1) Completion of perturbation calculations for finite conductivity and geometrical imperfections in half-round obstacles as impedance standards (The successful use of special quarter-wave shorts as impedance standards has reduced the need for more extended numerical tables for the half-rounds.); (2) Preparation of a consolidated report of further analytical work, based on the Kerns-Dayhoff theory, that has been done on the theory of the microwave interferometers; (3) Preparation of expository notes on the more advanced part of the theory of waveguide junctions; (4) Completion of the microwave spectra tables (This last is strongly dependent on the possibility of obtaining a sufficient amount of sufficiently competent additional manpower on the project.).

Personnel contributing to the theoretical physics part of this project were David M. Kerns (project leader) and W. Thomas Grandy, Jr.; to the work on the spectral tables, numerical analysis, and computation, Paul F. Wacker (supervisor of this group), Joe Ballard, Jack Hursch*, Patricia Pearce, Jean Peterson, Marlene M. Pratto, and Malcolm Randall. (*part-time)

## Mechanical Engineering for RF Standards
## 84103

The object of this project is the development of new mechanical designs and construction techniques, the investigation of principles and methods for producing more precise radio frequency and microwave standards and instruments, and providing general mechanical engineering service to the Radio Standards Laboratory.

The accuracy and precision with which certain types of rf and microwave standards and measurements can be made is increased by the development of new techniques in mechanical motion and new processes to produce components. New and novel fabrication methods must often be investigated, adapted, or developed in order to construct some of the components which cannot be produced by conventional machine operations. New and novel principles must be investigated, adapted, or developed in order to produce mechanical motions of the utmost accuracy.

Designs and drawings were produced for such equipment as attenuators, precision-sliding loads, and stub tuners. Of primary importance in such instruments is the precision and accuracy of mechanical movement and, as an example, a rotary-vane attenuator was designed that enabled an increase in reading accuracy by a factor of ten. Other general mechanical design was undertaken, such as microwave interferometer mounts, and components of the VLF standard broadcast station.

Consultation was provided the division with regard to mechanical aspects of electronic equipment. An investigation of methods of producing more precise linear motion was undertaken.

Drafting activities of the division were included in the project, and research data were prepared for presentation by various media such as reports, journals, and meetings.

Work of the nature outlined above will continue during the coming fiscal year, except for the drafting activities which have been removed from the divisions and centralized as a laboratory function.

Personnel contributing to this project were: Bruce Haviland, Victor Lecinski, Maurice Oshima, and Marilyn Schmitt.

## Microwave Analysis of Plasmas

84107

The objectives of this project are to devise and investigate methods of microwave diagnostics of plasmas, and to investigate the interactions of electromagnetic radiation and plasmas.

The physics of partially and wholly ionized gases (plasmas) is of considerable importance to problems of radio propagation, to missile communication and control systems, and to atomic and nuclear physics. The intimate connection of radio waves and plasmas is such that each can be used to further the state of the other. For example, radio and radio techniques are used to determine the properties of plasmas, and plasmas are used in such microwave devices as TR switches, noise sources, modulators, couplers, and harmonic generators.

A microwave diagnostic technique, utilizing a helix structure excited by millimicrosecond pulses, is in the process of being developed. This technique of measuring electron densities offers a particularly valuable feature in that a theoretical time resolution of $10^{-8}$ to $10^{-7}$ seconds is possible. Present development of this system, however, is to the order of a microsecond time resolution.

A high-mode, high-Q resonant microwave cavity, operating at one centimeter wavelength, has been designed and built to selectively populate one of the higher vibrational levels in an electronically excited state of cyanogen, CN. By combining this technique with the observational techniques of optical spectroscopy (Project 84207), measurements will be made of transition probabilities.

In the forthcoming year, it is planned to complete the development of the helix technique, and utilize it for detailed investigation of the structure of a shock front and the region immediately following the front. Further tasks include the fabrication of other diagnostic systems, including microwave cavity, waveguide, and Langmuir probe to extend the scope of operation and permit cross-checking of results by independent methods.

Personnel contributing to the work on this project include A. J. Estin (Project Leader), H. W. Wassink, F. B. Haller, and J. L. Hursch, Jr.

## Propagation of Plasma Oscillations

84108

The objective of this project is to experimentally determine the dispersion relationship for the propagation of plasma waves in a plasma-filled tube through microwave interaction with the plasma.

The most important aspect of the present investigations is to provide verification of heretofore unchecked theory. This predicts that energy may be carried by plasma oscillations in a hot plasma at frequencies slightly higher than the plasma frequency. The phase and group velocities of these waves depend on both the electron density and the temperature of the plasma. The results of the experiment will be of importance in the field of astrophysics, upper atmosphere physics, and the physics of controlled thermonuclear reactions where collective plasma effects play an important role in the nature of the phenomena observed.

During the past year, the experimental apparatus was designed and built to accomplish the objectives of the project. Although a strong interaction between the plasma and the microwaves was detected, pulse delay measurements indicate that the transmission of energy was due to electromagnetic waves rather than electron plasma waves. The nature of the results indicates that the wave propagation depends strongly on electron density and collisions within the plasma.

The nature of the interaction measured in the experiments is such as to provide a good measure of both electron density and collision number in the plasma. Present plans include measurements, and the development of the theory to fully exploit this new technique for determining plasma parameters. Also, different methods of excitation will be tried in an attempt to excite the plasma oscillations originally sought.

Personnel contributing to the project were: B. Wieder (Project Leader), G. D. Ward, and M. M. Anderson.

## Beam-Plasma Interactions

84109

The objective of the project is to study the interaction of an electron beam with a plasma. It is expected that the beam will interact with the plasma to give waves growing in space.

The experiment is important in the field of plasma physics in that the use of electron beams interacting with plasmas may be useful as a diagnostic tool for the study of plasmas. Further, it has been suggested that the source of certain exospheric and solar phenomena lies in the interaction of beams or bursts of charged particles with plasmas. Laboratory observation of similar pheonmena would be of great interest to the astrophysicist and ionosphere physicist.

An apparatus was designed and built with appropriate electron guns and plasma generator. Special attention was given to the design of the beam electrodes in order to minimize the effects of plasma sheaths. No positive experimental results can be reported.

In the forthcoming year it is planned to pursue the tasks defined under the objectives of the project. The experiments will test for the interaction of an electron beam with a mercury plasma under various conditions of temperature and pressure.

Personnel contributing to this project were: Robert S. Powers, Jr. (Project Leader), and Robert H. Manka (part time).

## Plasma Spectroscopy

84207

The objectives of this project are to make measurements of the optical absorption characteristics of certain materials in the gas and low temperature solid phases; these materials to include C, $C_2$, $C_3$, CH, CN, etc., and to analyze the absorption data for information pertaining to the perturbation mechanisms involved in the frequency shift between the gas and solid phases.

Additional information is sought on perturbations encountered by atoms and molecules trapped in low temperature matrices. Such information will be correlated with optical interstellar absorption lines which are thought to be due to absorption by molecules in low temperature matrices.

An electron-heated furnace for producing gaseous carbon has been constructed. A specially designed liquid helium dewar has been obtained which will allow carbon from the above furnace to be deposited with other materials on an optically transparent surface maintained at liquid helium temperature. The solid will be observed with a transmitted light continuum, the intensity vs. wavelength being recorded with photomultiplier techniques.

An additional program is underway, in conjunction with Project 84401, to investigate the mixing of electronic levels of the CN molecule. Both microwave and optical techniques are needed for this investigation. Microwave radiation is needed to change the relative population of the rotational levels, and optical techniques to observe the effects.

Plans for next year are to continue with the carbon and CN investigations.

Personnel contributing to the work on this project were: R. L. Barger (Project Leader), and H. P. Broida.

## Plasma Rate Coefficients

84401

The general objective of this project is to make measurements of atomic and molecular reaction rate coefficients using electromagnetic techniques of stimulation and detection.

A quantitative understanding of the basic physics of atoms and molecules in high planetary atmospheres is essential to progress in physical interpretation of experiments and observations performed in these atmospheres. Such understanding is vital to the solution of basic problems of astrophysics, and to the design, for example, of adequate systems of radio communication between earth and experimental vehicles.

Activities over the past year have been conducted jointly with Project 84107 (q. v.). A diagnostic technique, utilizing a helix structure excited by millimicrosecond pulses, is being developed. This technique of measuring electron densities offers a particularly valuable feature in that a theoretical time resolution of $10^{-8}$ to $10^{-7}$ seconds is possible. Present development of this system, however, is to the order of a microsecond time resolution.

Plans for the next year are to inaugurate a measurement program, including determination of such parameters as attachment coefficients, recombination coefficients, free and ambipolar diffusion coefficients, and collision cross sections.

Personnel contributing to this project include: A. J. Estin (Acting Project Leader), H. W. Wassink, F. B. Haller, M. M. Anderson, and J. M. Richardson (Acting Section Chief).

# HIGH FREQUENCY ELECTRICAL STANDARDS

## H-F Voltage & Current Standards

84111

The purposes of this project are to establish and maintain the primary standards of cw and pulsed, balanced, and unbalanced voltages from $10^{-7}$ to $10^{5}$ volts, and standards of current from $10^{-3}$ to $10^{3}$ amperes, at all frequencies from 30 kc to approximately 1000 Mc, with a required accuracy at least one order of magnitude better than that required by industrial and other laboratories.

H-F voltage standards are needed for all types of rf voltmeters, all types of rf voltage sources and generators and waveforms, modulation meters, wave analyzers, etc. H-F current standards are needed for all types of rf ammeters and both pulsed and sinusoidal current sources.

Consultative and committee services are required for the standardization of instrument design, measurement methods and techniques.

Two NBS Technical Notes were prepared for publication - "Functional and design problems of the NBS rf voltage bridge," and "Calibrating vacuum tube voltmeters."

Experimental work on the 0.1% bridge was continued to obtain a comparison with a second independent method above 10 Mc.

Further work was done on the existing cathode-ray tube slide-back voltage standard. One phase was concerned with improving the accuracy of measurement to 0.1% for rf levels of 100 v rms and above, over the frequency range from audio to 40 Mc. Another phase dealt with an investigation of resonance and transit-time errors in the present system to ascertain whether these errors could be accurately evaluated. This investigation is not yet completed, but, if this approach is feasible, the useful frequency range of the present standard could be extended to perhaps 300 mc using suitable correction factors.

Further study was made on AT voltmeters. By modifying construction and revising measurement techniques, the short-term reproducibility of the waveguide-below-cutoff and capacitive type voltmeters was improved to ± 0.1%. Another object of the study was to find a means whereby a response independent of frequency could be obtained.

The effect of ambient temperature changes on the resistance elements of rf micropotentiometers for resistance values in the range from 1 milliohm to 1 ohm was investigated. Evaluation of results is pending.

A study of negative resistance parametric amplifiers was initiated to improve the sensitivity of our detecting systems so that rf voltage measurements might be extended down to 0.1 microvolt.

Plans for the next fiscal year include: (1) completion of the investigation of the 1/10% bridge to at least 100 Mc, and publishing a research paper on the bridge; (2) continuation of the investigation of parametric amplifiers to improve detection methods as one step in extending the range of voltage measurement standards below one microvolt; (3) extension of voltage measurements to 3000 Mc; (4) resumption of pulse voltage measurements; (5) completion of the investigation of resonance and transit-time errors in a cathode-ray system; (6) development of a method of measuring several kilovolts to ± 5% for frequencies of 10 Mc and below; and (7) resumption of work on rf current standards.

Personnel contributing to the work in this project were M. C. Selby (Section Chief and Project Leader), L. F. Behrent, R. P. Chariton, J. R. Fielder, A. C. Newell, and G. Rebuldela.

## H-F Field-Strength Standards

84112

The objectives of this project are to develop, improve, and maintain accurate national reference standards of radio field-strength, for the calibration of commercial and military, cw and pulsed field-strength meters; to measure directly these quantities, as a service available to industry and governmental agencies, in the approximate frequency range 10 kc to 1000 Mc; and to provide related consultative and committee services as required for the standardization of instrument design, measurement methods, and techniques.

National reference standards and uniform calibrations of the above instruments are necessary to the government and industry in evaluating the performance, efficiency, and signal coverage of radio communication systems of all types, including AM, FM, and TV broadcasting. The Federal Communications Commission relies on accurately-calibrated meters for evaluating the above factors in determining compliance with, and in the enforcement of, their various rules and regulations in the interest of the most efficient use of the radio-frequency spectrum.

Further work was performed in extending the standards to 1000 Mc. Development of precision methods of measuring both insertion loss and unbalance in baluns was partially completed. Thermistor bridge development for measuring balanced voltages to 1000 Mc was in the initial planning stage. A basic theoretical study was initiated of the electric field component, E, at ground levels at frequencies below 30 Mc; information published to date seems inadequate for standardization needs.

Plans for the coming year consist of completion of the thermistor bridge development, intercomparison of silicon-crystal voltmeter calibration with thermoelement standards, and continuation of the study of the electric field problem mentioned above.

Personnel contributing to the work in this project were F. M. Greene (Project Leader), and E. L. Shallenberger.

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## H-F Noise Standards

84113

The objectives of this project are to develop, maintain, and improve national standards of noise power together with instrumentation and techniques capable of accurately comparing other generators of noise power with the national standards. The project also provides related consultative and committee services, as required, for the standardization of instrument design, measurement methods, and techniques. The frequency range encompassed by this project extends from 30 kc to 1000 Mc, and may involve continuous or pulsed, and balanced or unbalanced service.

National reference standards and uniform calibrations of generators of noise energy are necessary to the government and industry in the evaluation of the performance of practically all types of communications systems and numerous other scientific apparatus. With instruments perfected to the point where noise phenomena are limiting performance, the knowledge and measurement of noise phenomena have become of prime importance.

Work has continued on the precision low level noise comparator. A low noise rf amplifier and mixer for the comparator have been developed. Tests show it to have a noise figure of 1 db and a gain of approximately 60 db.

A comprehensive theory of the noise comparator under development has been worked out, and a report has been prepared. Additional techniques in using the noise comparator have been devised which will increase the accuracy of measurement.

An experimental electrodynamometer-type rf voltage multiplier was developed for use in verification of the above theory. Poor stability and a non-Newtonian friction phenomenon showed this model to be unsuitable. A second electrodynamometer multiplier was developed and proved promising.

The theory and a model of a thermocouple bridge-type voltage multiplier and its associated driver amplifier were developed. This device is sensitive to input signal level instabilities, but its performance is satisfactory with the addition of an automatic level control system.

One of the basic components of a noise comparator is a band pass filter which is stable with respect to time and signal level. Filters meeting these requirements have been designed and are being constructed.

For the most accurate comparisons between a standard noise source and an unknown source, it is desirable to adjust the impedance of the standard so that it duplicates that of the unknown source. However, the varying impedance of the standard must not decrease the accuracy with which its available noise power is known. Various approaches for variable-impedance noise sources have been considered and investigated theoretically, and some appear to afford a solution to this problem.

The stable experimental temperature-limited, thermionic-diode noise generator, having its plate current stabilized to the equivalent of 0.001 db of noise power, has been modified, and construction is nearly complete on a permanent laboratory instrument. A first draft describing this instrument has been prepared.

Plans for the next fiscal year include completion of the first working model of complete noise comparator and a written report; finalization of design of variable impedance, hot resistor type noise standard -- standards operating at various temperatures will then be constructed; and continuation of work on improved stable and sensitive voltage multipliers.

Personnel contributing to the project were C. M. Allred (Project Leader), M. G. Arthur, W. J. Blank, M. K. Cannon, M. W. Randall, and M. C. Selby (Section Chief).

## H-F Power Standards

84114

The objectives of this project include: the development and maintenance of accurate standards for the measurement of radio-frequency power, both cw and pulsed; the improvement of measuring techniques; and aid in establishment of calibration services in the dynamic range $10^{-6}$ to $10^{6}$ watts. The frequency range extends from 30 kc to approximately 3000 Mc in coaxial and balanced line systems.

RF power is a fundamental electrical quantity for which measurement standards are required to determine the range of commercial and military transmitting equipment. Power standards are also needed to verify the output level of various laboratory type rf signal generators which are used in many fields of scientific endeavor.

Several radical changes were made in the dry static calorimeter to improve its accuracy to the order 0.1%. This standard is an rf-dc substitution type, and the accuracy is determined primarily by repeatability and rf-dc substitution error. Repeatability was improved from 0.2 to 0.05% by placing the calorimetric load inside a specially designed constant-temperature environment. An analysis of the system indicates an rf-dc substitution error of approximately 0.1% to 1000 Mc. The power range of the calorimeter is 0.05 to 5 watts, and is useful up to 1600 Mc with reduced accuracy.

A major portion of project time was devoted to the design, construction, and calibration of a series of high power (megawatt peak), directional coupler power meters for Divisions 85 and 87. No previous data were available so that the design was based on an extension of theory for smaller lines and on past experience and design in the laboratory. One set of four coaxial couplers was constructed for Division 85 for use at 40.92 Mc and power levels of 300 kw cw and 1.5 Mw peak pulse. The couplers for Division 87 (Dr. K. L. Bowles' group in Peru) were designed for the same power levels but at a frequency of 49.92 Mc. Maximum error of cw power measurement was 4% of full scale range. Data obtained as a result of this work will aid in the design of similar couplers at any frequency for which 6-1/8 inch coaxial line can be used.

A coupler for 600-ohm balanced-line power measurements was designed and constructed for Division 85 for use in the frequency range, 4 to 60 Mc, at 1 Mw peak pulse power. As on the previous units, sufficient design data was not available, and it was necessary to conduct a certain amount of research before beginning the design.

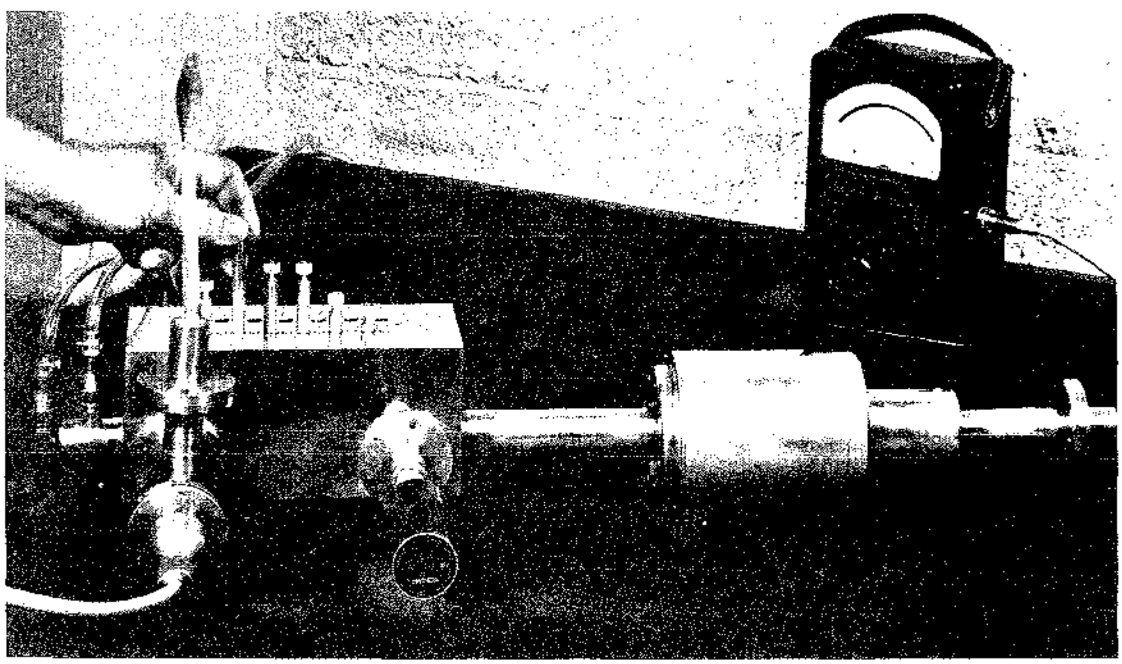
Investigation was continued into the properties of thin film resistive elements made by the vacuum evaporation of a metal alloy. A number of studies were made to determine the cause of long-time resistance drift at high temperature. These studies were based on theories of oxidation, and change in crystalline structure at elevated temperatures. While results are not complete, indications are that changes in the crystalline structure are responsible for the greater part of the resistance changes.

During the coming fiscal year, the frequency range of rf power measurements in coaxial systems will be extended to include frequencies up to approximately 3000 Mc. Accurate measurements in coaxial systems in this part of the spectrum are difficult because of the lack of a universally accepted precision connector.

Research and development work will continue on means for the accurate measurement of peak pulse power in coaxial systems. It should be mentioned that with the present state of the art, accuracies are no better than ± 15%, and hence, a great improvement and further contributions are needed.

Further studies will be made on the electrical properties of thin films with the limited research equipment available at these laboratories and in the Washington laboratories. Specifically, work will be done on doping of films to produce certain desired properties such as a high positive temperature coefficient.

Personnel contributing to the project were P. A. Hudson (Project Leader), W. L. Ecklund, P. D. Josephson, P. L. London, A. R. Ondrejka, D. O. Webster, and M. C. Selby (Section Chief).



Stability comparator being used to detect minute impedance variations. Adjustment is being made to obtain a null on the output meter.

## H-F Attenuation Standards

84115

This project is concerned with development of standards of measurement, instruments, instrumentation techniques, methods of measurement, and analysis of attenuation. The range extends from about 30 kc to 1000 Mc, and from zero to the maximum practical attenuation.

RF attenuators are used in many electronic measuring instruments and equipment, e.g., signal generators, receivers, field-strength meters, power meters, etc.

Theoretical analysis of a method of assessing the errors due to unwanted modes in a TM mode attenuator was made, and showed that provided certain conditions were met, the method was feasible. Design and construction of an experimental high-power launching and matching unit was begun. Construction was essentially completed.

Initial experimental investigation of a step displacement measuring system showed the possibility of using such a method for accurate measurements in the order of a few millionths of an inch. An experimental unit is under design to further study the problems of this method.

When attenuation measuring systems have sensitivities of 0.001 db or better, the stability of the various components of such systems can be very critical. A special unit for indicating and evaluating instabilities was designed and constructed. Impedance changes on the order of 0.001% were detected.

A special sensitive detector to be used for precision attenuation measuring systems is under design and construction. The system will simultaneously indicate direction of adjustment of phase and magnitude controls in complex attenuation measuring systems. The correlation techniques used will enable desired signals obscured by noise to be more easily detected.

A unit was designed, constructed, and put into use to permit investigation into optimum design of launching systems for the TE mode in waveguide-below-cutoff attenuators.

## Coaxial Microwave Power Support

84412

This project, sponsored by the Navy, Bureau of Weapons, was initiated towards the end of the year to furnish detailed drawings, operating instructions, and techniques to the sponsor for NBS primary and secondary standards of rf power measurement. The frequency range is 20 to 1000 Mc at power levels up to 1000 w. Some assistance is also given for the development of standards for power measurement in coaxial systems above 1000 Mc where no standards now exist.

It is important and necessary that arms and services of the Department of Defense have accurate standards for electrical quantities close at hand. The measurement standards to be furnished by NBS are capable of holding a calibration for long periods of time, and, frequent comparison with primary standards will not be necessary.

Detailed drawings for NBS primary and secondary rf power standards will be furnished to the sponsor within the next fiscal year. Included with the drawings will be instructions for construction and operation of the equipment.

A portion of the funds furnished will be used to purchase needed equipment to extend the frequency range of rf power standards from 1000 Mc to 3000 Mc.

There was no activity on this project in fiscal year 1961.

Tests were commenced on a unit that measures ratios of powers absorbed by two different loads without regard to their impedances. Tests are underway to evaluate various aspects of the unit.

"A precision RF attenuation calibration system," was published in the September 1960 issue of IRE Transactions on Instrumentation.

"A multiple isolated-input network with common output," was published in the July-Sept. 1960 issue of the Journal of Research, Section C, Engineering and Instrumentation.

Two reports are under preparation on the subject of a precision phase shifter and self-calibrating attenuation measuring systems.

Plans for the coming fiscal year include continued investigation of various uncompleted problems listed above, and solution of problems of stability and mechanical control in the complex insertion ratio measuring system.

Personnel contributing to the work on this project were C. M. Allred (Project Leader), C. C. Cook, R. A. Lawton, M. A. Mulligan, D. J. South, and M. C. Selby (Section Chief).

## H-F Interference Standards

84116

The primary objectives of this project are to develop and improve standards, instrumentation, and measurement techniques for evaluating broadband,man-made interference in the approximate frequency range 30 c to 1000 Mc; to study the correlation of such measurements with the interfering effect on various types of radio communications systems; to develop, improve, and maintain accurate national reference standards for the calibration of commercial and military interference meters; and to provide related consultative and committee services as required for the standardization of instrument design, measuring methods and techniques, including adequate international coordination.

From a long-range point of view, the very future of radio communications may hinge on the successful solution of the radio interference evaluation problem.

The entire radio communications industry relies on the NBS to develop accurate national standards and uniform measurement techniques for the proper evaluation of all types of radio interference. The Federal Communications Commission in 1955 (see communication from Chairman of FCC to Director, NBS, dated March 3, 1955) has desperately requested the aid of NBS in providing standards and measurement techniques for the accurate evaluation of radio interference. This is needed in determining compliance with, and in the enforcement of, their various rules and regulations in the interest of the most efficient use of the radio-frequency spectrum.

Some studies and discussions were conducted of the overall man-made interference problem for other agencies. Project personnel attended interference conferences and symposia conducted by Rome Air Development Center, Rome, N.Y., and by Armour Research Foundation in Chicago. Further work was curtailed because of lack of personnel.

Subject to availability of personnel, the following tasks are planned for the coming fiscal year: (1) An analysis of factors affecting the relationship of the electric and magnetic fields at typical calibration sites. (2) Theoretical and experimental analysis of methods for evaluating the spectral intensity and spectral distribution of presently available "impulse" generators. This involves (a) analysis of the "impulse" waveform, using high-speed traveling wave CRO, and Fourier and LaPlace transforms, and (b) spectral analysis using a relatively narrow-band receiver of known impulse bandwidth determined in (3) below. (3) Theoretical and experimental study of the various factors influencing the impulse response of receivers used for the studies outlined in (2b) above and for interference measurements in general. (4) Cooperation with ASA and IRE committees involved in interference studies, and attendance at related symposia or other meetings.

Personnel contributing to the work on this project were F. M. Greene (Project Leader), M. C. Selby (Section Chief), and E. B. Larsen.

F-R Field Studies
84117

The primary objective of this project is to perform NBS standardization duties towards a project sponsored by the ASA, the Navy, and AIEE in regard to hazards arising from electromagnetic radiation at frequencies up to 1000 Mc.

The definition of the problem is quoted from the organizational program dated April 8, 1959, as follows:

"A radio frequency hazard problem, as used herein, refers to a situation where there exists an electro-magnetic field of sufficient intensity to: (a) cause harmful or injurious effects to humans, (b) be discharged in a spark which can ignite an inflammable mixture of material, (c) induce currents and voltages of magnitude large enough to actuate electrically-operated explosive devices.

"These problem areas are of interest and concern to many activities within the armed forces. For their effective resolution in an efficient and rapid manner, it is necessary that standardization be established for the following: (a) units of measurement, (b) instrumentation, (c) measurement techniques, (d) protective measures."

Project personnel attended a symposium conducted by Rome Air Development Center, Rome, N. Y., and a conference conducted by Armour Research Foundation, Chicago, at which subjects of interest to the project were included in the agendas. Further activity was curtailed due to lack of personnel.

Subject to availability of personnel, the following tasks will be included in the project program during the coming fiscal year: (1) Theoretical study of the various factors involved in the measurement of radiation-hazard electro-magnetic fields. (2) Theoretical and experimental analysis of field-strength measurements when made in the Fresnel Region. In this region, the transmitting and receiving antennas are in relatively close proximity, and the field distributions involved are quite complex. (3) A study of cw field-strength calibration techniques for high-intensity fields (up to 1000 v/m), at frequencies of 30 to 300 Mc. (4) A study of the factors involved in high-intensity pulse calibration of field-strength meters.

Personnel contributing to the work on this project were F. M. Greene (Project Leader), M. C. Selby (Section Chief), and F. B. Larsen.

## Spurious Interference Standards

84411

The objectives of this project which is sponsored by the Navy, Bureau of Ships, are: (1) to develop an improved standard method, technique, and means for the measurement of conducted spurious power output of radio transmitters, at frequencies from 14 kc to 1000 Mc, and carrier power output levels to 1000 watts; and (2) to obtain adoption of this method in government and industry as a uniform standard.

The outputs of radio transmitters should be limited to their principal emission at their assigned carrier frequency to minimize interference. This is especially true when several transmitters and receivers are in simultaneous operation in close proximity. In order to maintain uniformly low values of spurious power output in new transmitter designs, reliable measurement techniques are necessary.

The electrical and mechanical design of the tunable band-rejection filters to be manufactured for BuShips by NBS was completed. Experimental models of filters were constructed for 17 frequency ranges and their performance determined. (Each filter tunes over approximately an octave of the overall frequency range of 14 kc to 1000 Mc.) Insertion loss measurements were made at both the principal tuned frequencies and at the skirts. The spurious responses were carefully and thoroughly measured for each filter to 1000 Mc. The design of each was modified, as required, to minimize these unwanted responses. Fifty detailed drawings were completed, and quotations obtained for the special components required. Project personnel attended the Sixth Conference on Radio Interference Reduction, conducted by Armour Research Foundation.

Plans for the coming fiscal year are as follows: (1) Preparation of approximately 50 additional detailed, manufacturing drawings covering the fabrication of the 17 types of rejection filters. (2) Assemble and check performance of 187 rejection filters. (3) Preparation of an Instruction Manual covering the operation of the 17 types of rejection filters. (4) Preparation of Progress Report No. 5. (5) Preparation of final report on the project. (6) Paper on "Spectrum signature measurement technique."

Personnel contributing to the work of this project were F. M. Greene (Project Leader), E. B. Larsen, W. E. Jessen, and M. L. Crawford.

# RADIO BROADCAST SERVICE

## Standard HF Broadcasts

### 84121

The main objective of this project is to distribute widely the US standards of frequency and time by means of the standard HF broadcasts from WWV, Beltsville, Maryland; WWVH, Maui, Hawaii, WWVB (60 kc), Boulder, Colorado; and WWVL (20 kc) Sunset, Colorado. Several other technical services are given on WWV and WWVH, such as: (1) UT-2 time (obtained from the U. S. Naval Observatory), (2) special radio propagation forecasts (prepared by Division 82) for the North Atlantic (WWV) and North Pacific (WWVH) radio paths, and (3) special signals, when needed, for the International Geophysical Cooperation (IGC).

The distribution of the U. S. Frequency and Time Standards via radio signals is recognized as of great importance to scientific, industrial, and government research laboratories and agencies, as well as to all types of radio broadcasting activities such as communications, television, air and ground navigation systems, guided missiles, radar, etc.

During the past year, all the standard broadcast frequencies from radio stations WWV, WWVH, WWVB, and WWVL were maintained very close to a value of 150 parts in $10^{10}$ below the U. S. Frequency Standard [see "National Standards of Time and Frequency in the United States," Proc. IRE, 48, 105-106 (January 1960)].

Two rubidium frequency standards were procured and placed under test with plans for their use as a part of the U. S. Working Frequency Standard.

Coordination of the NBS time and frequency transmissions was continued and close agreement maintained with the U. S. Navy and the UK stations.

By means of improved measurement methods based on LF and VLF transmissions, the values of the frequency, as transmitted by WWV, were improved to ±5 parts in $10^{11}$ with respect to the United States Frequency Standard.

A regular broadcast of a timing code was commenced on WWV. The code gives the second, minute, hour, and day of year.

Personnel contributing to the work on this project were A. H. Morgan (Section Chief), V. E. Heaton and F. Sera (Project Leaders), John H. Shoaf, C. Barclay, R. Grill, H. Patterson, E. Keefe, and H. Luzier.

## HF Frequency Standards

84122

One primary objective of this project is to carry on the R&D required to maintain and improve the US working standards of frequency and time interval, which involves quartz oscillators and resonators, atom frequency devices, quartz clocks and associated apparatus.

Another primary objective of the project is to devise means of improving VLF measuring techniques, along with establishing an atomic time scale and studying means of synchronizing or relating it to clocks at any remote location.

This project is of utmost importance in that it provides the means whereby the USFS (maintained in another section) is distributed to many users, both inside NBS and throughout the United States, and much of the rest of the world. Obviously the USFS is only as useful as the degree to which other frequency standards can be compared with it, and therefore, any degradation of quality connected with its transfer must be kept to an absolute minimum. There is urgent demand for expanding and improving the standard frequency and time broadcasts, especially for space and defense agencies.

Emphasis during the fiscal year was placed on developing frequency synthesizing circuits, using various multiplying, dividing and mixing techniques. One newly designed divider, employing magnetic beam switching tubes, showed improved stability over commonly employed regenerative types. Dividers of this new type were built and placed in service for several other section projects.

R&D was begun on an automatic data handling system which will allow more efficient statistical methods for analyzing VLF monitoring data, thus improving the precision of frequency comparisons. VLF measurements of atomic frequency standards throughout the world have been analyzed statistically in order to define the precisions with which a comparison may be made.

Part of the redundant circuitry for supplying an unfailing frequency source, referenced to the U. S. Frequency Standard, was completed. This will be used to drive a frequency divider in a system to establish an atomic time scale.

Experimental circuits, such as balanced crystal oscillators, buffer amplifiers, and pulse type phase detectors were investigated, which showed promise of improved performance over currently used types.

A method for self calibrating attenuation measuring systems was devised, an NBS Report, No. 6760, on it issued, and a paper approved for publication.

Personnel contributing to the work on this project were A. H. Morgan (Section Chief), Philip A. Simpson and R. L. Fey (Project Leaders), J. B. Milton, K. W. Hartkopf, R. L. Peck, and H. L. Binkly.

## Standard VLF Broadcasts

84123

Although action was deferred in connection with preliminary plans for a high power, standard 20 kc broadcast station near Fort Collins, Colorado, capable of providing world-wide coverage, plans were made to install a standard 60 kc station on this site adjacent to the area planned for the high power facility. This project is closely allied with projects 84422 and 84423.

Propagation data from various sources continue to demonstrate the superiority of low and very low frequencies for distributing standard frequencies, and also to have the potential for transmitting time signals with much higher accuracies than at HF.

The new station will have facilities for transmitting on 20 kc (WWVL) and 60 kc (WWVB) simultaneously, with radiated power much greater than at the existing stations, which the Fort Collins station will replace.

It is vitally important to make these greatly improved services available for the widest possible use, and as soon as possible.

Accomplishments to date consist in establishing designs of major components for the entire station; including antenna masts, antenna cable system, RF power transmission lines, power and control system, 50-KW transmitter tank inductances, and buildings.

Personnel contributing to the work on this project were A. H. Morgan (Section Chief), and W. W. Brown (Project Leader).

## Standard Broadcast Research

84124

The objectives of this project are to develop techniques for distributing the United States Standards of Frequency and Time Interval by narrow band radio broadcasts, having high phase stability with minimum attenuation, and to develop receiving and comparison techniques having maximum accuracy and utility.

This project will enable the NBS to accelerate the basic work and establishment of facilities for conducting research and development and services related to standard VLF frequency and time broadcasts. The HF (WWV and WWVH) broadcasts are completely inadequate for many applications, such as those related to satellite and missile programs of NASA and the Armed Forces. Because of the high phase stability of VLF signals they promise to provide a good vehicle, with the required accuracy, for world-wide frequency and time signals.

Receivers and associated phase-locked systems for precise measurement of VLF transmissions were developed. Receiver circuit arrangements were improved. Monitoring data were recorded on a number of VLF stations and distributed to interested persons. Studies were begun to determine the frequency-comparison accuracy obtainable over great distances of LF and VLF. Improvements were made in techniques for comparing the local reference oscillator with the United States Frequency Standard.

Personnel contributing to the work on this project were A. H. Morgan (Section Chief), D. H. Andrews (Project Leader), C. Barclay, P. A. Simpson, K. Roe, H. L. Binkly, and N. Winchester.

## Standard 20-kc Interim Broadcast (WWVL)

84125

Objectives of this project are: (a) transmission of standard VLF signals with high phase stability as a service to the United States, (b) as an experimental facility, to develop techniques of frequency phase-correction by automatic means for use at the Fort Collins station.

This project will enable the NBS to accelerate the basic work and establishment of facilities for conducting research, development, and services related to standard VLF frequency and time broadcasts. The HF (WWV and WWVH) broadcasts are completely inadequate for many applications, such as those related to satellite and missile programs of NASA and the Armed Forces. Because of the high phase stability of VLF signals they promise to provide a good vehicle, with the required accuracy, for world-wide frequency and time signals.

Standard frequency transmissions from WWVL, Sunset, Colorado, were given continuously as scheduled since April 1960. Certain automatic devices, safety features and alarms were installed to permit completely unattended operation, including automatic fire protection.

Monitoring of the broadcast, in Boulder, was done by three different methods: film recording of phase change, recording of beat frequency, recording of the analogue of phase shifter changes necessary for synchronization of local and received signal. All methods were referred to the USFS, and all results were the same except for very small instrumentation errors.

The long term stability of the transmitted signal (quartz oscillator control) was normally maintained within ±2 parts in $10^{10}$ of its assigned value.

Personnel contributing to the work on this project were A. H. Morgan (Section Chief), J. H. Shoaf (Project Leader), D. H. Andrews, R. F. Carle, H. Williams.

## Standard 20-kc Broadcast Development

84422

The objectives of this project are: (1) to provide a radio closed-link system which will phase-lock the VLF 20-kc carrier at Sunset to a standard frequency at the Boulder Laboratories, (2) to obtain experimental data which will aid in designing the phase-locking system for the Fort Collins standard broadcasts.

This project will enable the NBS to accelerate the basic work and establishment of facilities for conducting research, development, and services related to standard VLF frequency and time broadcasts. The HF (WWV and WWVH) broadcasts are completely inadequate for many applications, such as those related to satellite and missile programs of NASA and the Armed Forces. Because of the high phase stability of VLF signals they promise to provide a good vehicle, with the required accuracy, for world-wide frequency and time signals.

The year's work consisted of designing, procuring, and constructing the overall system, calibrating and bench testing the completed equipment, and field testing it in actual operation. Experimental closed-link radio tests were in progress on Saturdays, and the results indicate that the phase of 20-kc transmissions (WWVL) can automatically be held well within one microsecond of the US Working Frequency Standard.

The closed-loop system includes an fm radio signal transmitted at VHF from Boulder, and the reception of the 20-kc transmission from Sunset. Any errors in the received phase of the 20-kc signal are detected, and the necessary corrections are then transmitted back to the station via a 2-kc frequency modulation of the 49.65 Mc carrier. Various fail-safe controls have been designed and constructed, and are ready for tests.

Personnel contributing to the work on this project were A. H. Morgan (Section Chief), B. E. Blair (Project Leader), W. W. Brown, D. H. Andrews, J. H. Shoaf, P. A. Simpson, H. L. Binkly, H. Williams, and N. Winchester.

## Standard 20-kc Broadcast Improvement

84423

The objective of this project is to support and accelerate part of the R&D and acquisition of necessary apparatus and structures, aimed toward the increase of radiated power, and the inclusion of precise time information in the standard VLF broadcasts at 20 kc, with the signals directly controlled by the U. S. Frequency Standard.

This project will enable the NBS to accelerate the basic work and establishment of facilities for conducting research and development and services related to standard VLF frequency and time broadcasts. The HF (WWV and WWVH) broadcasts are completely inadequate for many applications, such as those related to satellite and missile programs of NASA and the Armed Forces. Because of the high phase stability of VLF signals they promise to provide a good vehicle, with the required accuracy, for world-wide frequency and time signals.

During the FY, many of the design studies and the preparation of the specifications and drawings for the main structures and services at the Fort Collins station were completed. Also, contracts were placed for many of these items, related to the 20-kc component of the station. A comprehensive internal report on the station was prepared which contains the details of this work.

Personnel contributing to the work on this project were A. H. Morgan (Section Chief and Project Leader), and W. W. Brown.

RADIO AND MICROWAVE MATERIALS

High Frequency Dielectric Standards

84131

The purposes of this project are to: (1) develop standards, new methods and improve existing ones, for measuring complex permittivity (solids, liquids, gases, and mixtures) as a function of frequency, temperature, applied field, and other effective parameters; (2) make measurements of dielectric properties of important scientific and technical materials.

Dielectrics are a very important part of modern technology. Standardization and the development of accurate methods and techniques are essential to the successful application of materials as well as providing fundamental data on basic physical processes. Understanding fundamental processes in turn contributes to successful evaluation and analysis of materials.

Several specimens of semi-solid beryllium oxide were measured to study drying processes after extrusion. Fourteen specimens of fused silica are now in use as reference standards. Several of these specimens have been measured twice yearly since 1952 and have maintained their values of $\epsilon'$ and $\epsilon''$ within experimental accuracy. A gold transmission line is being used to study the mechanism of decomposition of large protein molecules in strong solvents. A new method was developed for rapid evaluation of dielectric properties at cryogenic temperatures and ultra-high frequencies using commercial equipment.

Plans for fiscal year 1962 include construction of a Scheiber-Weingarten bridge and extension of its range for measuring conductance to $10^{-15}$ mho from 0.01 to $10^{6}$ cycles per second. Plans also call for extending re-entrant cavity techniques to above one gigacycle, and continuing protein work by measuring relaxation spectra during solution. Personnel contributing to this project were E. C. Bamberger (project leader), J. L. Dalke (section chief), and R. C. Powell (ass't section chief).

## High Frequency Magnetic Standards

84132

The purpose of this project is to develop standards and measuring methods for determining the magnetic properties of materials, and to investigate fundamental solid state magnetic phenomena.

The importance of magnetic materials is made evident by the fact that they are utilized in nearly every type of electronic system developed for commercial as well as military applications. Magnetism is likewise the subject of extensive research in a large number of laboratories throughout the world.

Although much of the work on this project was undertaken in conjunction with the associated Project 84432 on Radio Materials, the following items were of immediate concern to the development of measuring techniques and the study of materials at radio frequencies: The accuracy of magnetic spectra measurements, especially in the region from a few kilocycles to several hundred megacycles, was improved. Below about 100 kc, this was accomplished by completing a new improved model of a specially designed Maxwell bridge for very low loss measurements. These data are supplemented below about 1 Mc with measurements obtained with a coil of improved design which can be opened for sample insertion. In the region from about 1 Mc to 50 Mc, the applicability and accuracy of the rf permeameter was greatly enhanced through the development of exact equations describing the transformer network. Further improvements in a variable length, re-entrant cavity enable better data to be obtained from about 50 Mc to 100 Mc, and additional improvements in transmission line techniques are under development for higher frequencies. Further instrumentation and equipment were completed in the continuing effort to obtain magnetic spectra data with dc fields applied to the sample. Facilities for dielectric measurements of magnetic materials were also partially completed. In addition, efforts to obtain material standards of rf resistance for calibrating many of the above instruments were started. Construction of equipment for studying the non-linear properties of ferrites below a few Mc was likewise started. Extensive investigations of the dynamic magnetoelastic properties of some commercially available ferrites, intended for magnetostrictive applications were made. These studies have yielded a new, rather clear-cut, technique for separating the magnetization mechanisms inherent in certain ferrites. Studies of low field losses at microwave frequencies and their relationship to tensor permeability data, etc., are continuing. Some work on the effect of sample size and shape, magnetization, wall effect, etc., on microwave properties was also started. Consultative work and measurement of materials in conjunction with programs in other laboratories were also carried on during the year.

During the coming year, the initial and reversible permeability spectrum facilities will be further expanded and improved. Some basic studies of some of these properties, as well as some static properties using equipment developed under the associated Contract 84432 will be considered. Low field microwave losses will also continue to be emphasized in the program.

Personnel contributing to this project were R. D. Harrington (project leader), V. E. Bottom, B. L. Danielson, N. V. Frederick, C. A. Hoer, W. A. Pittman, A. L. Rasmussen, L. A. Steinert, W. E. Case, and J. D. Lee.

## HF Impedance Standards

84133

The primary purposes of this project are to develop, maintain and improve the material standards of high frequency immittance (impedance and admittance), and to establish standard facilities for the measurement of complex immittance from 30 kc to 300 Mc.

A knowledge of the impedance characteristics of electronic equipment and impedance measuring techniques is an essential part of the study of radio materials and often forms the basis for governmental and industrial specifications.

The major effort during fiscal year 1961 has been directed toward developing and improving the facilities of the HF impedance group in the Electronic Calibration Center. Toward this aim has been: (1) a correlation between a precision coaxial capacitor of constant derived value and the two picofarad incremental standard capacitor up to 300 Mc, verifying the calculated HF characteristics of the incremental standard; (2) the preparation for measurement of a precision dual admittance bridge by the evaluation of the general bridge network parameters and a calibration of the direct capacitance of the incremental

## Microwave Magnetic Measurements and Standards

84137

The objectives of this project are: (1) to develop or improve the methods of measuring complex magnetic permeability, tensor or scalar; (2) to make such measurements on important scientific and technical materials, and to interpret these measurements in terms of the structure of the material.

Magnetic research has made great contributions to the understanding of physical solid state processes. In addition, such materials are a very important part of modern technology.

The hollowed-out $TM_{110}$ resonators previously developed have been used for rather exact measurements of the intrinsic tensor permeability of ferrite rods. The effective susceptibility of a sphere, computed from the intrinsic data, is in good agreement with measured sphere data for some ferrites. Experimental facilities have been improved by completion of a crystal-controlled frequency multiplier chain, and by experiments and design work on a technique for locking a klystron to the resonance of a cavity. Either the klystron or the cavity is slightly frequency modulated. The method shows promise of improving the speed or accuracy of our measurements. A semi-automatic data recording system was completed to facilitate the measurements of ferrites (see Project 84433). A tape punch records the counter frequencies and data from sixteen manual entry dials. All pertinent data concerning the cavity, the magnetic field, and temperature are thus quickly and accurately recorded.

The measurement of tensor permeability will be extended down to liquid helium temperatures. The comparison of effective susceptibility computed from intrinsic data with measurements will be extended to disks, especially for the lower frequencies.

Personnel contributing to the work on this project were John L. Dalke (section chief), Howard E. Bussey (project leader), John H. Rogers, and M. Lojko (1 month).

arms; (3) the design and construction of an improved set of coaxial resistor standards having an order of magnitude better high frequency response than those previously supplied to the Electronic Calibration Center. The Center was also benefited by the following basic accomplishments: (1) the design, construction and 1000-cycle measurement of a unique three-terminal capacitor by which the open-circuit, fringing field capacitance of the NBS coaxial connector was evaluated directly; (2) the design and construction of coaxial adaptors for three quality bridges, and the careful analysis of the residual parameters of one, a Schering bridge, followed by its calibration; (3) the revision of the audio frequency, three-terminal ratio transformer bridge to allow comparison of capacitors to one part in a million with $10^{-18}$ farads as the lower limit; (4) the design and construction of portable thermally and mechanically insulated boxes for a set of four commercial three-terminal capacitors on which the first calibration and stability test has been started; (5) the construction of an oven for the study of resistor temperature-coefficients in the range of 23-50°C; (6) project personnel have acted as hosts and round table discussion moderator for a meeting on high precision connectors.

Plans for fiscal year 1962 include: (1) editing the proceedings of the June 1961 Meeting on High Precision Connectors; (2) continuing to aid other projects, especially those in 84.50, which can benefit from the specialized knowledge of project personnel in the impedance field; (3) research on the use of three and four terminal bridges in the RF region; (4) designing and constructing sets of incremental conductors and inductors; (5) designing and constructing a second model of a three-terminal capacitor to determine the fringe-field capacitance of the Woods connector. Personnel contributing to this project were R. M. Jickling (project leader), R. C. Powell (ass't chief), A. E. Hess, and L. E. Huntley.

## HF Conductivity Standards

84134

The purpose of this project is to study the charge transport behavior of materials acted upon by electromagnetic radiation.

The electrical conductivity under specified conditions is generally a basic property of materials, both in practical applications and in aiding in the understanding of the underlying physics of macroscopic materials.

The model of a single electron, moving in a periodic potential field, forms the basis of most of the present understanding of the electronic properties of solids. A study of the modifications effected by the electron-electron interactions upon the electrical conduction was considered desirable. A theoretical study has been made of the electric current in an electron gas, acted upon by an electromagnetic field, utilizing a general quantum field theoretic formalism of the many body problems which may be extended to various other models.

The theoretical work described above will continue with applications to semiconductors of simple crystalline structure. Conductivity measurement experiments will also be performed upon semiconductors at microwave frequencies.

Personnel contributing to this project were L. A. Steinert (project leader), and T. A. Fulton.

## HF Properties of Materials

84135

The objective of this project is to establish and maintain evaluation facilities for electromagnetic properties of radio materials, and to support a reference testing capability for the thorough investigation of certain classes of materials as a function of a variety of control parameters.

Precise knowledge of the electromagnetic properties of materials at radio and microwave frequencies is necessary for their efficient application. A reference testing service is not presently available elsewhere in this country.

In fiscal year 1961, emphasis has been on placing facilities for measuring magnetic and dielectric properties in service. Close liaison was maintained with the magnetic and dielectric standards projects. The following were accomplished: Initial complex permeability measurement facilities were placed in operation for toroidally-shaped rf materials in the frequency range of 1 kc to 300 Mc. Complex dielectric constant measurement facilities were placed in operation, and techniques developed for disk and rectangular ferrite rod samples in the frequency range of 10 kc to 100 Mc. Facilities are being constructed, or placed in operation, for complex dielectric constant measurements at frequencies of approximately 0.5 kc to 10 kc, and of 100 Mc to 1000 Mc. The types of electrodes to be used for dielectric measurements of ferrite samples have been adopted. Parallel (at 1 Mc to 50 Mc), and perpendicular (at 1 Mc to 15 Mc), reversible permeability measurement facilities for ferrite toroids are being set up. Total power loss measuring facilities (at approximately 1 Mc to 3 Mc) using calorimetric techniques are also being established.

The work discussed will be continued and additional service facilities will be provided. They will be further evaluated for accuracy and agreement with various techniques. Personnel contributing to this project were A. L. Rasmussen (project leader), R. D. Harrington, C. A. Hoer, W. A. Pittman, R. C. Powell (ass't chief), and L. A. Steinert.

## Microwave Dielectric Measurements and Standards

84136

The objectives of this project are: (1) to develop new methods and improve existing methods of measuring dielectric constants and losses of substances; (2) to do fundamental research on dielectric properties such as temperature dependence, and explanation of very high or very low losses, using the methods of solid state physics; (3) to measure accurately the properties of new or technologically important materials, and of materials that reveal fundamental scientific information; (4) to extend the measuring range to extreme temperatures and to other frequencies, especially to the short mm-wave part of the spectrum.

Dielectric materials are used in many applications where the designer must know the properties accurately. The interaction of electromagnetic waves with electrical charges (dielectrics) is an important basic tool for scientific research.

The dielectric measuring method, employing a centered dielectric post in a $TE_{011}$ mode cavity, was further developed by constructing similar equipment for use at 30,000 Mc. This is a first step in developing millimeter wave measurements. A large number of dielectric loss measurements were made at 9000 Mc which confirmed the accuracy of the convenient method reported last time, utilizing the change in transmission of a cavity and a theoretical port-Q in order to measure sample losses. The development of the 800°C pure silver test cell has been continued by writing an automatic computer program to correct for the errors introduced by the transition between the high temperature cell and the slotted line instrument. The transition is represented by an equivalent electrical network. An additional program was written to speed the calculation of permittivity from slotted line measurements. Also, subroutines for Bessel functions of complex argument for the new computer were written. Two glass compositions, Corning 9606 and Corning 1723, have been investigated for issue as dielectric standards. Measurements at 9200 Mc and 23°C recommend these compositions for further testing. During this work, a correction was developed for the error arising from imperfect fit of the dielectric specimen in the slotted transmission line. This advance brings values of permittivity measured with the slotted line into agreement with values measured with a $TE_{011}$ cavity to within 0.3%. Since these measurements are independent, their absolute accuracy is probably very high. A paper describing this work is in preparation. Measurements of the Q of microwave cavity resonators have been significantly improved, with a corresponding increase in the accuracy of properties of materials measurements depending upon cavity Q. The present accuracy for Q is estimated as one per cent, in the 900 Mc region. The calibration of surface impedance was improved by developing a method for measuring the difference in the complex surface impedance between a standard metal surface and some unknown metal surface. However, no absolute measurements are available because only the absolute loss of the standard is known. An effort is being made to develop a standard with a known loss angle. A method was perfected for determining the conductivity of the quarter-wave shorts being developed as reflection standards by the Microwave Circuit Standards Section. This has furnished an independent check on the reflection coefficients quoted for these units. Dielectric losses were measured in beryllia ceramic with five different impurities added. An oven for growing single crystals of copper oxide was constructed. Our calibration service continued to be in demand for various low loss porcelain and plastic compositions.

Dielectric losses in copper oxide single crystals will be investigated. Dielectric properties of single crystals, and other interesting materials at liquid helium temperatures, will be investigated. Standard dielectrics and a standard of complex surface impedance will be further developed. High temperature facilities will be improved.

Personnel contributing to this project were John L. Dalke (section chief), Howard E. Bussey (project leader), James E. Gray, and John H. Rogers.

400

Solid State Phenomena

84138

This project was established, beginning with fiscal year 1960, to meet the needs for methods of measurement, standardization, and the investigation of classes of materials for the radio and microwave electromagnetic quantities associated with gyrotropic devices, masers, parametric amplifiers, and semiconductors such as transistors, diodes, memory cores, etc. In general, these materials involve non-linearity, or non-reciprocity in entirely new classes of active devices and a multiplicity of passive ones. Magnetic, conductivity, and dielectric materials, per se, are not covered by this project.

The advent of unusual solid state devices such as gyrators, isolators, masers, parametric amplifiers, transistors, and diodes is related to recognition and progress in understanding fundamental processes which govern material characteristics. It is essential that the Radio Standards Division be fully aware of the understanding and operation of these phenomena, in order to extend or improve its own basic instrumentation for measurements and standards of appropriate electromagnetic quantities in the radio and microwave spectrum.

Investigations were continued on the accuracy of fine wire mixers, high precision transformers for high frequency use, a new high accuracy-high frequency standard inductor, the interaction of conductivity and ferroelectric switching, using pure and lead-cesium-and iron-doped single crystals of barium titanate, the out-of-phase component of the conductivity of strong electrolytes, and measurement techniques for ferroelectric-ferromagnetic materials at UHF.

Plans for fiscal year 1962 are to build an air-core permittimeter to obtain maximum $\mu$-Q-stability product for electrolyte measurements, analyze measurements of conductivity and polarization on the ferroelectric crystals, and determine the LF and microwave relaxation frequencies, and to build a high frequency ratio transformer and associated inductance standard.

## Magnetic Resonance Phenomena

84139

The purposes of this project are to determine the magnetic energy levels, relaxation times, and transition probabilities of paramagnetic and antiferromagnetic cyrstals through the use of magnetic resonance techniques.

The data obtained will add to our knowledge of the solid state and its interaction with electromagnetic radiation, and provide the basic information needed for the practical application of these materials in microwave and sub-microwave standards and technology.

This is a new project, begun in the latter half of FY 1961. An electron paramagnetic resonance (EPR) spectrometer, for use at X-band and at temperatures from $2^{o}$ to $300^{o}K$, is nearing completion. A machine calculation of the energy levels of manganous ion in calcite was initiated in order to explain more adequately the EPR spectrum observed in this system, under conditions that make the standard perturbation calculations from the spin Hamiltonian inapplicable.

The EPR spectrometer will be operational, and the experimental determination of the spectra of various crystals will begin. First attempts will be devoted to the detection and measurement of ferric ion in zinc fluoride single crystals. Attempts will be made to incorporate chromic and manganous ions into single crystals of zirconia and beryllia, and to determine the EPR spectra of these systems. The spectrometer will be extended to K-band frequencies. Personnel contributing to this project were L. M. Matarrese (project leader), and T. A. Fulton.

## Materials Synthesis

84231

The objectives of this project are to provide radio and microwave material specimens of known and controlled composition and structure, and to investigate and contribute to the related chemistry and preparation techniques as necessary.

The progress of basic and applied science depends, to a great extent, on the availability of suitable materials for experimental verification of theoretical investigations. Frequently, a better understanding of a fundamental process is handicapped by the lack of materials of controlled composition. This project is necessary to supply controlled materials for electromagnetic research investigations, and to determine the effect of composition, structure, purity, etc., on electromagnetic properties.

As this was a new project beginning in fiscal year 1961, considerable time was devoted to procuring necessary laboratory equipment. A temperature programer-controller, for use in conjunction with a high temperature furnace, is currently being placed in operation. The preparation of high-purity nickel metal for investigating the effect of impurities on saturation magnetization, as determined by static and NMR measurements, has been started. Chemical methods of purification have been used, starting with commercially available nickel ammonium sulfate hexahydrate. Some impurities can be eliminated by precipitation followed by recrystallization, and the purified nickel compound can be ignited to the oxide and reduced to metal with hydrogen. A series of polycrystalline nickel zinc ferrite specimens, containing varying trace amounts of silica, are being prepared to evaluate the effect of this trace constituent on magnetic properties. Starting materials for the ferrite specimens were purified by chemical means.

It is planned to continue the preparation of ceramic oxide materials having the spinel, garnet, or perovskite crystal structures, with particular emphasis devoted to the effect of trace impurities on magnetic properties. An effort will be made to determine which variables affect the saturation magnetization of nickel to establish the minimum requirements for use of this material as a magnetization standard. Zone melting as a purification technique for starting materials will be initiated during the fiscal year.

## Solid State Field Standards

84232

The objective of this project is to investigate the feasibility of utilizing natural phenomena ,or basic mechanisms of matter, for the precise measurement and control of time-variant electric and magnetic fields at radio and microwave frequencies.

The merit of NMR resonance technology in the highly accurate measurement and control of static magnetic fields, utilizing the gyromagnetic ratio and simple frequency measurements, has been clearly established. The utility of analogous techniques, providing quantum electronic measurement, or control of radio frequency fields through frequency measurement, is equally obvious. In addition to information on radio electric and magnetic fields per se, the ratio of these fields in a suitable geometrical structure may serve as quantum impedance standards.

Modulation of the static magnetic field at radio frequencies in NMR systems was considered. Relaxation phenomena in the solids considered for this application place an upper limit well below a megacycle. A further complication is the spin-lattice interactions resulting in broadened absorption lines ,resulting in low accuracy. A more promising approach uses maser technology by employing an atomic system that is thermally unstable. There, the induced emission or absorption of a two-state system is proportional to the sine squared of an argument directly proportional to the amplitude of the radio frequency field which induces transitions. This holds for systems that are sensitive either to electric or magnetic fields, and the amplitudes of the corresponding radio fields are directly obtainable from frequency measurements.

In fiscal year 1962 feasibility studies on critical fields encountered in non-linear effects will be made, and experimental work on the above phenomena will be started.

Radio Materials

84432

The objective of this project is to establish a magnetic materials laboratory for the measurement of the magnetic properties of ferrites. The results will serve to coordinate and evaluate the work being done in radio and microwave magnetism in this country.

This laboratory is being developed in part on the recommendation of the Advisory Group on Electronic Parts who recognized the need for a centralized ferrite measurements laboratory whose function would be to develop basic methods and techniques for evaluating rapid advances in magnetic materials and devices and to maintain a facility for reference testing.

Since this project is primarily concerned with the development of instrumentation for measuring magnetic properties of materials, from dc through microwave frequencies, some of the work overlaps that carried on under Project 84132 (HF Magnetic Standards). However, in addition to the high frequency instrumentation described under that project, the following work was done on measuring techniques at dc and microwave frequencies: considerable improvements were made in the vibrating sample magnetometer for determining the saturation magnetization of magnetic materials, and preliminary measurements have indicated that highly satisfactory data may be obtained. A new simple technique for calibrating instruments of this type was devised which makes it unnecessary to have a standard sample such as Ni available. Work was also started on variations in the previously constructed hysteresis loop tracer in order to increase the sensitivity of the instrument. Construction has likewise started on a torque magnetometer for measuring the magnetocrystalline anisotropy constant of single crystal materials. In the microwave region, work was carried on towards improving the tensor permeability measurement setups at 3 Gc and 1 Gc band frequencies. New improved cavities for 1 Gc band measurements are presently being constructed. Equipment for measuring the non-linear properties of ferrites at high power microwave signals is now partially completed. In addition to the instrumentation work, further effort was devoted to the standardization of microwave ferrites. Suggested values for standardizing magnetization and line width of microwave ferrites were considered. Work is also continuing on the evaluation of the properties of commercially available ferrites in order to obtain information for further standardization of their properties. This is being done both on this project and the related DOD Project 84433 (Tensor Permeability Measurements).

During the coming year, many of the above techniques for measuring static and microwave properties will be completed, and the design and development of methods for measuring other quantities (static magnetostriction, Curie temperature, etc.) will be started. Further evaluation of commercially available materials will also be carried on.

Personnel contributing to the work on this project were R. D. Harrington (project leader), J. L. Dalke (section chief), W. E. Case, D. C. Ehn, N. V. Frederick, C. C. Hastings, and L. B. Schmidt.

## Tensor Permeability Measurements

84433

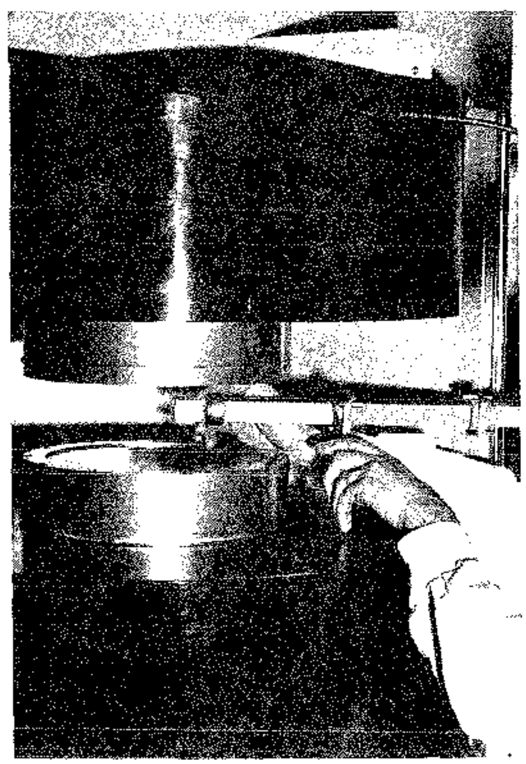
The objectives of this project are: to provide new and improved information on the magnetic spectra of ferrites by investigating their intrinsic tensor permeabilities; to analyze the structure of these spectra and correlate them with the physical properties of the ferrites; and to evaluate certain ferrites for specific electromagnetic requirements. Much experimental work in the past has been aimed at the determination of the magnetic properties of ferrites in typical applications, and obtaining an "effective" quantity. In contrast, this project is aimed at the "intrinsic" permeability tensor which is a distinctive macroscopic property.

Ferrites which exhibit Faraday rotation at ultra-high and super-high frequencies have, in recent years, enabled great advances in radio electronic systems. In this connection, it is of prime importance to measure accurately the tensor permeability and dielectric constant of selected ferrites in a single laboratory so that the data are all comparable. The ferrites selected will be from those that are commercially available, and from those still in the experimental stage that are potentially important. This program was set up to coordinate activities in this area for the Department of Defense.

Measurements of line width for sphere resonance, and of dielectric constant, were made at 9200 Mc and 3100 Mc on about forty different ferrite bodies. In addition, intrinsic tensor permeabilities for ten ferrites were measured at 9200 Mc. These measurements are important in standardizing the compositions of these new materials. They may be used by ASTM Committees and others in standardizing the compositions of ferrites and in reducing the great number of different but nearly identical compositions now being manufactured. They also provide the basis for formulating military specifications and furnish engineering data for special DOD contractors.

Microwave ferrites will continue to be evaluated under this program as in fiscal year 1961. In addition, measurements on disks will be initiated, since at 3100 Mc and below a flat shape for ferrite devices is usual.

Personnel contributing to the work on this project were John L. Dalke (section chief), Howard E. Bussey (project leader) and John H. Rogers; also, C. Kristenson, D. Blecki, and M. Lojko (part time).



A wave guide cavity, containing a crystal specimen, is placed between the poles of a magnet in studies of magnetic resonance.

## ATOMIC FREQUENCY AND TIME STANDARDS

### Modification of NBS-II

84041

The purpose of this project is to increase the length of the present United States Atomic BeamFrequency Standard.

The increased length will reduce the spectral line width by a factor of 1/2 which should provide some improvement in stability.

The project began in December of 1960. The new length of beam tube which is to be inserted has been completed, and new electronics have been constructed so that both NBS-II and NBS-I can be operated independently.

The ultimate goal of this project is to provide a longer beam apparatus, complete with a servo-system, to correct a quartz oscillator and associated frequency multiplier chain. The system will also provide an atomic time base which will require scalars to accumulate cycles and associated timing circuits. The devices will be tested for performance as a frequency standard and as a possible time standard.

Personnel contributing to this project on a part-time basis are R. C. Mockler (project leader), W. R. Atkinson, R. E. Beehler, J. A. Barnes, H. F. Salazar, and C. S. Snider.

### Manufacture of NBS-III

84042

A new atomic beam frequency standard is being constructed at NBS that will have an oscillating field separation of about 3 meters. It will provide a separate standard, independent of the others, that will ultimately operate continuously with a servo-system and timing circuits.

It is important to have more than one standard, in order that one standard will always be running during periods of servicing, and also for purposes of comparison.

Construction has begun. The mountings and beam tubes are almost complete. Its performance as a frequency standard and as a possible time standard, will be analyzed during the Fiscal Year 1962.

Personnel contributing to this project on a part-time basis are R. C. Mockler (project leader), W. R. Atkinson, R. E. Beehler, J. A. Barnes, H. F. Salazar, and C. S. Snider.

## Manufacture of Maser

84043

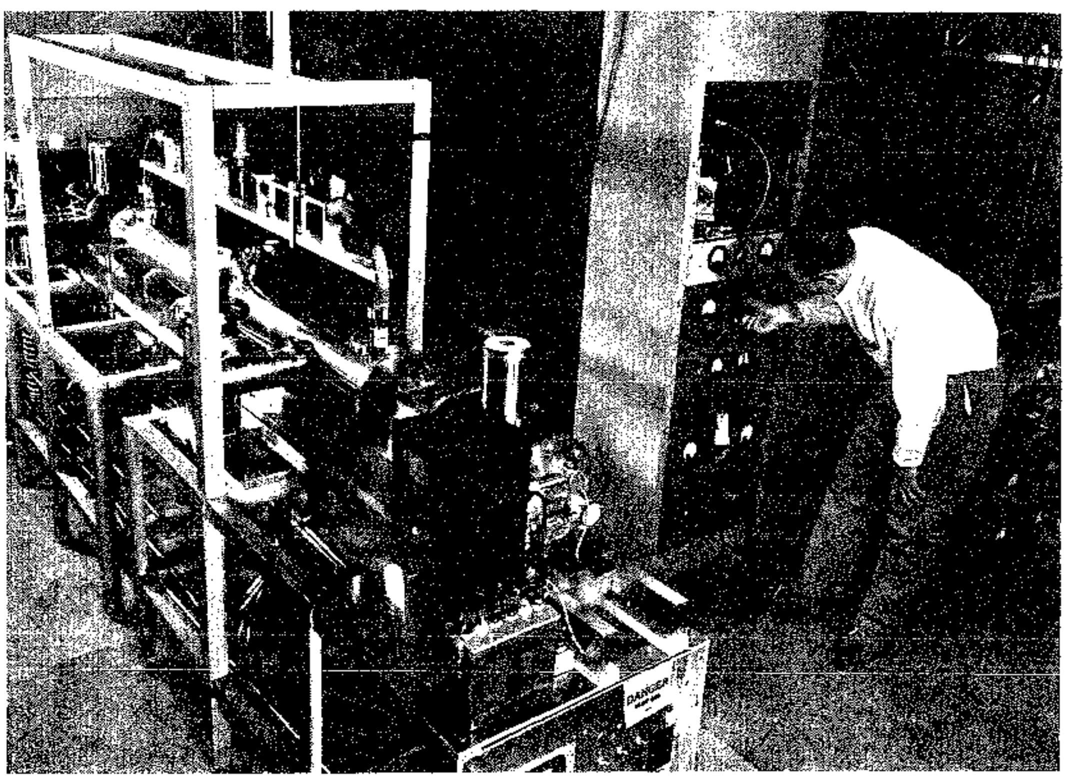
The objective of this project is to construct and analyze a hydrogen atomic beam maser.

The atomic and molecular beam group at Harvard, under the direction of N. F. Ramsey, has demonstrated that an atomic hydrogen maser is not only feasible but has a higher ultimate stability than other existing masers at microwave frequencies. The device has possibilities as a primary standard. At worst, it will provide an extremely stable signal source for frequency and time standard purposes with much better short time stability than the cesium beam devices.

The magnet assembly and frequency multiplier chain are almost complete.

During the Fiscal Year 1962, the device will be tested for its performance as a frequency standard and as a possible time standard.

Personnel contributing to this project on a part-time basis are R. C. Mockler (project leader), J. A. Barnes, and A. E. Wainwright.




NBS II atomic frequency standard and associated circuitry.

## Atomic Frequency Standards Circuitry

84044

The purpose of this project is to provide several pieces of electronic equipment required to operate and test the additional atomic frequency standard instruments being constructed by the Atomic Frequency and Time Interval Standards Section.

Item 1 is a system for exciting the thallium resonance which is less sensitive to magnetic field uncertainties than the Cs resonance. Item 2 is another source for exciting the Cs resonance so that two Cs beam machines may be operated simultaneously. Item 3 is two servo systems for utilizing atomic beam resonators to stabilize the frequency of two quartz oscillators.

The simplicity of exciters employing klystrons phase-locked to harmonic of crystal controlled oscillators, has made them quite attractive. Experience with them has been, on the whole, satisfactory so that this type of excitation will be used in the new exciters. Experiments have indicated one system of this type can probably be made versatile enough to perform the function of both Items 1 and 2. The method that is being tried uses an X-band klystron which can either be used to excite the Cs resonance, or can be slightly retuned and locked to combination-type harmonic to yield a sub-multiple of the thallium frequency. This much of the system has been tested and appears adequate. The klystron output would be multiplied to obtain the thallium frequency.

One of the servo systems of Item 3 has been operated, and has been found to lock an oscillator so that its average frequency is within about 5 parts in $10^{11}$ of the designed value. This offset has not always been found and it may not actually be present; the most probable interpretation of the experiments would indicate that it is. When the offset has been found, it has always been in the same sense and seems to be more severe with one resonator than with the other. The second system is almost ready for testing. Some features of it may make it possible to find the trouble with the first system, or with the measuring system used to check the performance of the servo.

During the next year a study will be made of the servo offset, as it is influenced by frequency of the sensing signal, amplitude of the sensing signal, second harmonic content of the signal, bandwidth of the servo amplifier, and other parameters which might influence the offset and thus give a clue to its origin. The servos will be optimized to reduce short term frequency fluctuations of the oscillators.

Contributors to this project included W. R. Atkinson (project leader), J. A. Barnes, H. F. Salazar, A. Wainwright, L. E. Heim, and R. C. Mockler. The assistance of the personnel of project 84104 was essential to the work.

Atomic Frequency and Time Interval Standards

84104

It is the purpose of this project to develop, maintain, and improve atomic standards of frequency and time. The project must, in addition, be aware of new schemes and possibilities for atomic standards applications, and enter into research associated with new developments in the field, so far as this is possible. It is intended that particularly significant experiments that may involve atomic standards, or atomic standards techniques, will be performed.

The rapid technological advances being made in the missile fields, and in many other areas requiring precision measurement of time and frequency, have been accompanied by increased demands for more precise primary standards of frequency. The development and use of a primary frequency standard, based upon the natural period of a cesium atom, has made it possible to provide standard frequencies free of the aging effects associated with quartz crystal oscillators. The standard frequencies, broadcast by NBS stations WWV, WWVH, WWVB, and WWVL, and used widely by many private and government laboratories, are measured daily in terms of the primary atomic standard. With the aid of the published corrections, frequency measurements made in other laboratories can be expressed in terms of the primary standard.

During FY 1961 both cesium beam standards were in regular operation, permitting the accumulation of considerable frequency comparison data. Measurements of the secondary standards, such as Atomichron 106 maintained by Section 84.20, were made on a daily basis and used to publish corrections for various NBS standard frequency transmissions as well as to continue the comparisons of the

U.S. Frequency Standard with those of other countries. The results indicated continued agreement to 1 or 2 parts in $10^{10}$ among the standards of the U.S., England, and Switzerland. The previously observed difference of $1.5 \times 10^{-11}$ between the two NBS atomic standards was carefully remeasured during the year and found to have remained constant to at least $2 \times 10^{-12}$ over the year period. Several experiments were performed in an effort to determine the source of this difference, such as the modification of the C field structure and magnetic shields in one machine, and the replacement of the resonant cavity ends on the other machine, but the discrepancy still remained. Comparisons were also made during part of the year between the cesium standard and an ammonia maser. The comparisons were used in determining the stability and reproducibility of the maser frequency. Measurement precisions of $3 \times 10^{-12}$ in a period of only a few minutes were obtained with the maser excitation of the cesium resonance.

Some preliminary experiments were performed to test the feasibility of using a resonance of thallium 205 as an improved frequency standard. A thallium beam was successfully detected with low efficiency, but further work was temporarily prevented by the necessity of using the machine for cesium measurements.

One servo system for locking a 5 Mc quartz crystal oscillator to the cesium atomic resonance was completed and extensively tested. Operation of the system was generally satisfactory except for a small systematic frequency shift which is at present unexplained. Tests on a second servo system for the other cesium standard were begun at the end of the Fiscal Year.

During Fiscal Year 1962 testing of the two servo systems will continue. If possible, each cesium standard will be equipped with an independent servo system, thus allowing long term operation of the standards as clocks. Long term continuous comparisons of the standards will be made in order to study their relative stability more directly.

The thallium experiments will be resumed, using the longer of the existing machines, and an attempt will be made to observe the thallium resonance at 21,300 Mc. A small test system now under construction will be utilized to investigate the advantages of using a multiple beam technique for thallium in order to reduce the amount of magnet deflection necessary.

An additional 8 ft. section will be added to the 10 ft. long cesium standard to obtain a narrower resonance line width and, as a result, higher measurement precision. The normal frequency comparisons mentioned above using the Atomichron, maser, etc. ,will be continued during FY 1962.

Personnel contributing to this project included R. E. Beehler (project leader), C. S. Snider, H. F. Salazar, J. A. Barnes, and D. W. Allan.

## High Resolution Research

84105

It is the purpose of this project to investigate the methods of improving the precision and accuracy of microwave spectroscopic methods. The results of this research lead directly to the improvement of existing primary and secondary standards of frequency, along with the possibilities of developing entirely new primary or secondary standards of frequency.

The development of atomic frequency standards is, in reality, a development of high resolution microwave spectroscopy. Thus, an improvement in time standards not only extends the uses of precise timing but also leads to a more detailed knowledge of atomic and molecular structure.

During the 1961 Fiscal Year, the maser-spectrum-analyzer has been simplified and greatly improved in its sensitivity and reliability by making direct comparisons with the maser itself instead of a maser-stabilized oscillator. With the aid of this spectrum analyzer, a "slave" oscillator system was designed, built, and tested. The resulting "slave" oscillator demonstrated an instantaneous rms frequency error from a stable master oscillator of less than 2 parts in $10^{11}$. This oscillator is now in constant use with the cesium beam to insure against possible errors due to modulation of the reference oscillator.

Also completed this year was a servo system to constantly control the cavity tuning of the ammonia beam maser to the point where small changes in the magnetic field have no effect on the maser's frequency. With this system it was found that the maser's frequency could be reset to about ± 3 parts in $10^{11}$ by comparison with the cesium beam. These experiments were conducted using ammonia gas composed of the ordinary isotope of nitrogen (at. wt. 14). This has indicated the ammonia beam maser has real merit as a secondary standard of frequency.

The experimental equipment necessary for the spectroscopic investigation of thallium fluoride by maser techniques in the vicinity of 26.7 Gc was constructed. Also some preliminary measurements of beam intensities and profiles were made.

During the coming Fiscal Year it is intended to continue the development of high purity "slave" oscillators and investigate noise sources in quartz crystal oscillators with the aid of the maser spectrum analyzer.

It is also intended to convert the maser servo system over to the use of $N^{15}H_3$ (ammonia composed of nitrogen of atomic weight 15). This will require a system capable of recirculating the ammonia since the $N^{15}H_3$ is relatively expensive. Work done by others has indicated a marked improvement in frequency resettability and stability for the maser, and thus it is hoped that this change may elevate the maser to the status of a primary standard, comparable to the cesium beam. The spectroscopic investigation of thallium fluoride with maser techniques will be carried on this year.

Personnel contributing to this project include J. A. Barnes (project leader), D. W. Allan, and A. E. Wainwright.

Electronic Frequency Multiplication and Stabilization

84106

The objective of this project is to investigate oscillators, frequency multipliers, and feed-back control systems especially as they pertain to the problems of frequency measurement utilizing standard frequencies provided by atomic transitions.

The precision and accuracy of frequency measurements, or of time scales constructed with the aid of atomic frequency sources, depend on the precision, accuracy, and stability of ancillary electronic equipment such as multipliers, mixers, transfer oscillators, and feed-back control systems, required to utilize the frequency stability inherent to atomic systems. An important phase of the study of such electronic equipment, and even of the definition of frequency itself, requires an understanding of fluctuational phenomena. The frequency of an ideal or pure signal may be defined in terms of the responses shown by the indicating instruments of several different types of measuring systems. For an ideal source and noiseless measuring systems, the application of these various operational definitions may be expected to result in a unique number, the frequency of the source. Actual sources, when tested with actual measuring instruments, fail to give a unique value; and, in fact, even when fluctuations are taken into account, the average indication with one measuring system need not agree with the average indication obtained with another measuring system. For actual sources, evolutionary and stationary noise processes cause the power generated to be spread over a spectrum of Fourier frequencies, and the problem of frequency measurement becomes for many purposes one of determining the evolutionary and stationary characteristics of this spectral distribution or suitable moments of it. In order to predict the detailed statistical response of a network to the source, even this spectrum is not adequate, and additional statistical information is needed to specify the frequency.

A phase portrait, showing the isoclines and the limit cycles of a simple oscillator, was made in order to study the rate at which the frequency could be changed by noise type or servo type parameter variation, and also in order to become familiar with the theory which is adequate to take account of the non-linearities essential to any stable oscillator. In accordance with less sophisticated treatments of the rate at which frequency may be changed, no appreciable lag was found between the time at which circuit parameters were changed to new values and the time required for the frequency to attain its new value. This analysis indicated that, should it be desirable, a servo system could be used to make rapid corrections on the frequency of a slave oscillator. Whether or not it is desirable to make rapid corrections depends on the natural noisiness of the slave oscillator and on the noisiness of the atomic device or reference oscillator used to sense the frequency fluctuations. Measurements of the spectral density of the frequency fluctuations of many of the signal generators used in the laboratory were made for Fourier frequencies ranging from .02 cps to 2000 cps. None of the sources tested were stabilized with atomic transitions, and all showed a spectral density which increased roughly as $1/f$ for $f < 1$ cps. These measurements are in agreement with the interpretation given to counter type measurements of the 1960 report which showed the mean square increment of the random phase during a time, t, to be proportional to $t^2$. Above Fourier frequencies of 10 cps, many of the oscillators showed a rising spectral density so that a minimum was present in the spectrum. Experiments have not yet indicated the oscillator parameters that influence the depth and location of this minimum. The spectral distribution of the power generated by an oscillator exhibiting $1/f$ type frequency fluctuations has been studied, and approximations for the half width have been obtained. The division consultants for numerical analysis and computation have started an analysis of the integrals involved in order to check the accuracy of the approximation for the half width.

An electron multiplier was installed as a $Cs^+$ ion beam detector in a test chamber and current gains of $10^3$ were obtained. This figure was lower than anticipated, and it is not known whether it is a result of poor optics or inactivation of the multiplier. The right angle deflector and ionizer was tested and found to direct 40% of the ions formed into a beam traveling at right angles to the atomic beam. For both resonators, when Cs is used, it has been demonstrated that the response time and sensitivity of conventional electron tube amplifiers is adequate for some servo purposes.

The constructional status and performance of several servo systems is given in the report for project 84044. The theoretical analysis of control systems has been concerned with such problems as computing the spectral density of the frequency fluctuations of a phase-locked oscillator from the spectral density of the master and the slave in the free conditions. These phase-locked oscillators are used as signal purifiers in the laboratory because they enable one to combine the long term stability of the master with the short term stability of the slave. The spectral density of the combination is for all Fourier frequencies greater than the smaller of the two spectral densities in the unlocked condition. Latent oscillations are present in such a system which lead to a peaking of the spectral density at certain frequencies even though the servo system itself is not oscillating. These systems convert a constant drift rate in the master into a frequency offset in the slave, and the magnitude of this error has been evaluated.

No major changes in the direction or scale of this work are planned for the next year. Various oscillator parameters will be changed in an effort to localize the source of the noise. There are indications that the Cs beam servo system has greater accuracy with NBS-II than it does with NBS-I. This problem will be studied experimentally and theoretically.

Contributors to this project included W. R. Atkinson (project leader), L. E. Heim, M. W. Randall, H. F. Salazar, P. F. Wacker (mathematical consultant), R. W. Woodbury, and the personnel of project 84105.

## Fabry-Perot Maser

84141

The primary objective of the project is to develop gaseous maser techniques at higher frequencies than maser devices of present-day design, and to utilize these techniques in the solution of certain physical problems.

The Fabry-Perot maser has application as a highly stable signal source at millimeter wavelengths for frequency standards purposes, and for purposes of microwave spectroscopy -- both maser spectroscopy and absorption spectroscopy -- at extremely high frequencies.

The device has been constructed for HCN, and work is in progress to observe maser oscillation at 88.6 kMc. The Q of the interferometer is observed to be 32,000.

The device will be used to investigate the spectrum of HCN, and possibly to obtain a new mass ratio of $C^{12}/C^{13}$. It will be tested for frequency stability, and generally for the performance of Fabry-Perot interferometers as they are applied to millimeter wave spectrometers and masers. If successful in this area, maser operation with different molecules at still higher frequencies will be attempted.

Personnel contributing to this project on a part-time basis are W. Culshaw of Section 84.70 and R. C. Mockler (project leaders), J. A. Barnes, G. Strine (84.70), L. Fletcher (84.70), R. Day (84.70), and A. E. Wainwright.

## Velocity of Gamma Rays

84142

The purpose of this project is to measure the velocity of gamma rays by means of the Mössbauer effect.

Calculations indicate that there is a possibility of measuring the velocity of gamma rays with an accuracy of 1 part in $10^7$ and possibly better. This would give an order of magnitude improvement over the measurement of the velocity of light at optical wavelengths. It will also be important to have a comparison of the velocity of electromagnetic radiation at both optical and gamma ray frequencies.

Calculations and estimates have been made and others are being made, with regard to the feasibility of this experiment. An NBS report (6762) has been prepared.

The method of measurement employs the electromagnetic field excitation of ultrasonic vibrations in quartz together with the Mössbauer effect. The helium-cooled quartz resonators will be set up and studied optically for performance and stability under continuous wave excitation. The gamma ray experiment will be set up, gamma ray fringes will be looked for and their width measured. The entire apparatus will then be assembled, the appropriate optics introduced for measuring length, and the velocity of gamma rays experiment will be attempted.

The personnel participating in the project are D. Jennings (project leader) and R. Mockler.

## ELECTRONIC CALIBRATION CENTER

The primary objective of the Electronic Calibration Center is to provide calibration services for electronic reference standards and instruments of the nation's top standards laboratories over the frequency range from zero frequency (dc) through the microwave region (40, 000 Mc and above). In support of this objective is the procurement, development, and construction of highly specialized equipment to provide the means of performing the calibrations. Continuous improvements are made in the instrumentation to increase the accuracy and extend the magnitude and frequency range of the many electrical quantities represented by the calibration services.

During the fiscal year, procurement and construction of equipment for the Center was continued under 26 different projects of the 84800 series. General administration, depreciation of equipment, maintenance and recalibration of equipment, and developmental work associated with the instrumentation of the Center were covered by seven projects of the 84630 series. These projects were reimbursed by charges made for calibration services. Calibration services for the DOD agencies were assigned to 12 projects of the 84450 and 84550 series. Calibration services for the public and other government agencies were assigned to eight projects of the 84620-84650 series. General consultation services were provided under Project 84151.

Due to the multiplicity of projects, it is more meaningful to summarize the accomplishments of the Center under general subject headings.

### Consultation

The Center continued to provide consultative and advisory service to the many laboratories of the Department of Defense agencies and to many industrial laboratories. Representatives of these laboratories received information from the Center both by visits to Boulder and through correspondence.

The Center took part in several of the Measurement Research Conferences sponsored by the Quality Control Committee of the Aerospace Industries Association. A series of about twenty of these conferences are being held in Washington and Boulder with the purpose of industry bringing their measurement problems to the attention of NBS experts. In turn, the Bureau hopes to assist in the solution of these problems through expanded basic knowledge and increased measurement facilities.

At the suggestion of DOD agencies, the Center provided a 5-day workshop at microwave frequencies for about 40 technical supervisors from a large number of DOD standards laboratories. Basic theory of the precision measurement of power, impedance, frequency, attenuation, and noise was covered in one-half day sessions for each quantity. An equal time was spent in the laboratory, providing the participants the opportunity of viewing measurement equipment in actual use.

Many of the Center's staff participated in this activity, usually contributing in the person's field of specialization.

## Low Frequency Region

In the low frequency region (dc to 30 kc), technical services are provided for the calibration of electrical standards and instruments, such as: standard cells, standard resistors and resistance apparatus, standard inductors and capacitors, volt boxes and other d-c ratio apparatus, standard resistors for current measurement, electrical instruments, inductive voltage dividers, and instrument transformers.

The unit of voltage at Boulder Laboratories is maintained with a group of nine saturated standard cells. This group of cells is four years old and appears to be very stable. Another group of nine saturated standard cells has been observed for a period of six months. When this group shows the required stability, it will be incorporated into the working standard; probably within a few months. A group of six saturated standard cells serves as a traveling group between the Electronic Calibration Center and NBS Washington to check the unit of voltage as maintained in each laboratory. Another check between the two laboratories was the opportunity to observe a customer's group of saturated standard cells in the Center soon after the group was measured by NBS Washington. It now appears that the agreement between the two laboratories is within 0.7 microvolt. The working group is maintained in an oil bath (Model A) which regulates at 28$^{\circ}$C. Another oil bath (Model B) which regulates at 35$^{\circ}$C is also in operation. Saturated cells may be calibrated at either of these two temperatures.

A standard cell comparator, which is a specialized potentiometer based upon the design of Dr. H. B. Brooks (now retired from the Bureau), was procured. The comparator will be used for intercomparison of the working group and for certification of customers' standard cells.

Work on the design of the volt-box console and associated equipment was reactivated. The design of the current-shunt console was completed, and the console is being fabricated at the Boulder Laboratories. A ten-microhm shunt was purchased to serve as the basic component for current measurements from 600 to 1000 amperes. Previous to the procurement of this shunt, it was not possible to make measurements with any certainty of a given accuracy due to the instability of the equipment at hand.

The annual comparison of the Center's Thomas-type resistors with the National Reference Standard of resistance in Washington was completed during the latter part of April. Of the three resistors measured, the greatest change since the preceding comparison was only 0.1 microhm. Measurements on the other standard resistors, ranging in resistance from 0.0001 ohm to 100,000 ohms, indicated good stability also.

The ac-dc transfer console was completed and will be used for measurements of ac-dc differences in the ranges from 0.5 to 600 volts, and one ma to 20 amp at any frequency up to 20 kc. The upper frequency limit will be extended to 50 kc. A dual-Lindeck potentiometer unit for use with this console was completed.

D-c calibrations on electrical instruments, at currents below 100 amperes and at voltages below 1000 volts, are no longer performed because most customers can make these calibrations in their own laboratories. Instead, development work on ac-dc difference measurements is being emphasized in an effort to increase the range of voltage and current, the frequency, as well as the accuracy.

The reduction of calibration work on variable air capacitors, which was a result of a recommendation within NBS, permits the personnel concerned with capacitance calibration to give more time to the extension of frequency range over which calibrations of capacitors can be made. A bridge, formerly used in the Center for precise measurements up to 1000 cps, was calibrated for use at 10,000 and 100,000 cps. A new bridge for capacitance measurements on air capacitors was assembled to relieve the workload on the transformer capacitance bridge. This new bridge utilizes an inductive voltage divider as ratio arms.

Calibration services on standards of inductance were provided by the use of substitution methods with standards having inductance nominally equal to that of the unknown. It is the hope that time and personnel will be available to investigate more accurate methods of performing this service, and extending the capabilities for accurate inductance measurements to other frequencies and magnitudes.

The method developed for the accurate calibration of inductive voltage dividers, using a transformer capacitance bridge, has surpassed all expectations of accuracy by a considerable margin. The results indicate that voltage-ratio measurements of inductive voltage dividers by this method are accurate within an estimated uncertainty of 0.2 part per million of input, and there is substantial evidence that this is conservative. Calibration services for inductive voltage dividers were established for certain values of ratio at an input voltage of 100 volts and at a frequency of 1000 cps. An effort will be made to extend measurement capability to lower and higher frequencies. Calibrations are performed by a very economical, yet accurate, comparison method.

Equipment for calibrating current transformers at 60 and 400 cps was installed in a console, and calibration services are now available for primary currents up to 100 amperes. Modifications on the console will enable calibrations to be made up to 600 amperes.

The Center is now responsible for the calibration of Class C weights, submitted to the Bureau by both state institutions and industrial firms, in the Rocky Mountain Region. The Russell-type balance, installed in Room 1017, Radio Building, by the Mass and Scale Section, is used for this purpose.

Personnel who contributed to the work in the Low Frequency Region include: F. D. Weaver (Head, Low Frequency Unit), K. V. Ballard, J. Bolme, L. D. Chappell, C. H. Chinburg, J. R. Connell, J. D. Droppleman, A. F. Johnson, C. H. Keifert, E. V. Kelsey, B. J. Lenox, R. V. Lisle, P. H. Lowrie, Jr., A. M. Lyons, C. J. Norton, D. T. Ramaley, W. W. Scott, Jr., J. F. Shafer, G. E. Walters, B. A. Wickoff, H. K. Wolf, and T. L. Zapf.

## High Frequency Region

The voltmeter calibration consoles, covering the range of 30 kc to 100 Mc at 0.2 to 500 volts, and the frequencies of 300 and 400 Mc at 0.2 to 100 volts, were used throughout the year for calibration of all types of rf voltmeters. Development and modification of these consoles was nearly completed in order to improve the accuracy by a factor of 10 for frequencies up to 100 Mc. This involves the use of thermal voltage converters and the dc-to-rf transfer technique.

The construction of the "microvolt" console was completed to cover a range of one microvolt to one-tenth volt, and for frequencies from 30 kc to 900 Mc. A calibration service is now being provided by means of this equipment.

Preliminary planning for the construction of a special console for the Navy Bureau of Ships was begun. This console will enable the Navy to calibrate various types of vacuum-tube voltmeters, over the range of one millivolt to several hundred volts, from dc to 500 Mc.

The power calibration workload increased from 0.5 man year in FY 60 to 1.2 man years in FY 61. The 400-Mc rf power calibration service, which had been offered on a temporary basis during FY 1960 in co-operation with the High Frequency Electrical Standards Section, was made a regular service during FY 61. Some planning and development work was done on an NBS-BL method of precisely controlling the level of rf power generators. Two precision air baths were procured to control the temperature of the air environment surrounding various types of rf power meters during calibration.

The number of high frequency impedance calibrations performed during the year increased significantly over those of FY 60. However, the number of man hours required to perform these calibrations decreased considerably as compared with FY 60, indicating an increase in efficiency in the calibration processes.

A re-evaluation of the special mount and terminal characteristics of the NBS coaxial connector was accomplished, in conjunction with a more accurate evaluation of the high frequency characteristics of the reference standard of high frequency impedance. To utilize this high accuracy, a considerable amount of effort was given toward developing a digital computer program that would more efficiently evaluate the large amounts of data needed to calibrate the present impedance standards.

New resistance standards were developed to replace the interim standards. The new resistors, ranging in value from 100 to 100,000 ohms, have much better high frequency characteristics than those of the interim standards.

An attenuation calibration console which permits very accurate measurement at five additional fixed frequencies was essentially completed. This unit permits measurement accuracies of 0.002 db + 0.001 db/10 db over a dynamic range of 60 db. The total dynamic range is 0 to 140 db, with an estimated accuracy of 0.07 db at 140 db. Frequencies of 1, 10, 30, 60, 100, and 300 Mc are now available with this accuracy. Some development was done on an 800-Mc calibration system. The accuracy and range will be more limited than at the lower frequencies, but will provide a cross reference with some of the IF substitution systems now in use.

A new field strength calibration console was completed for: (1) the measurement of attenuators, (2) the overall linearity of receivers, and (3) the calibration of receivers as two-terminal rf voltmeters at frequencies from 400 to 1000 Mc. The addition of this console now permits these calibrations to be performed at any frequency from 30 cps to 1000 Mc. The calibration workload increased approximately 75 percent over FY 61.

The effects of the ground on loop antennas, at the NBS antenna calibrating site, were investigated to determine the minimum height above ground at which calibrations can be performed without introducing additional errors.

The High Frequency Instrumentation Group, completed and has under development, several types of specialized equipment for use in the calibration of interlaboratory standards. Equipment completed during FY 61 included several crystal-controlled rf power sources, operating up to 500 Mc, with a power capacity to 150 watts.

Personnel who contributed to the work in the High Frequency Region include: H. W. Lance (Acting Head, High Frequency Unit), R. T. Adair, R. F. Bailer, J. R. Benes, R. F. Barkhaus, I. S. Berry, J. E. Chukoski, R. D. Croghan, C. A. Drotts, N. L. Groome, R. L. Jesch, R. N. Jones, L. E. Mann, S. E. Marks, Jr., R. F. Metzker, R. E. Nelson, G. C. Perrymore, F. X. Ries, D. H. Russell, L. F. Saulsbery, R. K. Spracklen, K. K. Tagawa, H. E. Taggart, I. D. Torain, and K. M. Wilson.

## Microwave Region

In the microwave region (above 300 Mc), the Electronic Calibration Center is proceeding with the establishment or improvement of precision measurement equipment for power, impedance, attenuation, frequency, and noise calibrations. Calibration systems, using waveguide transmission lines and components, are being developed and constructed to cover the nominal frequency range of 2.6 to 40 Gc.

Calibration systems, using coaxial transmission lines and components, cover the nominal frequency range of 300 to 6000 Mc. Frequency and amplitude stabilization of signal sources, and temperature stabilization of components are carried out where necessary to preserve the desired measurement accuracy. The calibration systems normally provide continuous frequency coverage for the transmission line under consideration. Where acceptable, certain calibration frequencies are used to minimize the time of calibration and reduce costs.

A Microwave Workshop was conducted during the fiscal year for invited personnel from standards and calibration laboratories of the Department of Defense. The week's program consisted of technical lectures, discussions, and laboratory demonstrations of calibration techniques and procedures.

Microwave power calibrations were made by a bolometric, direct comparison method, and were available for low-level continuous power in the microwave region up to a nominal level of 10 milliwatts, and a maximum level of approximately 100 milliwatts. The standards used were NBS-designed bolometer mounts calibrated by calorimetric methods. Present instrumentation was modified to accommodate new techniques of power measurement being developed, including the impedance method of measuring efficiency, and the transfer instrument method of power measurement. A water bath was procured and modified for operation with these new techniques. A constant-temperature air enclosure also was procured and modified for use in the calibration of dry calorimeters. A power measurement technique, utilizing a transfer instrument in the form of a magic tee, was developed for waveguide power calibration systems. Work was begun on the impedance method of measuring bolometer mount efficiency in the range of 8.2 to 12.4 Gc. This technique will be employed to obtain interim standards in large waveguide sizes.

Impedance (reflection coefficient magnitude) measurements were made by reflectometer techniques, providing direct comparison between standard and unknown reflections. The standards used were precision fabricated and evaluated quarter-wavelength short circuits. The operation of the present calibration system was improved in frequency and amplitude stability by the addition of new circuitry and components. At the same time, a more rigorous and complete error analysis has necessitated a slight downward revision in the overall accuracy obtainable with the calibration system over a portion of the range of reflection magnitude. Improvements and/or new designs in several waveguide components of the calibration system were made, including: a low-reflection sliding load, non-contacting sliding shorts, precision waveguide sections, and variable waveguide tuners. The construction of a phase calibration system in waveguide size WR 90 (8.2 to 12.4 Gc), utilizing the modulated subcarrier technique, is approximately sixty percent complete. This system contains some newly designed circuits for improving the stability of operation.

Frequency measurements of resonant cavities were made by direct comparison of the resonance indication from a cavity with a reference signal obtained by multiplication of the 100-kc frequency standard. The latter is maintained in known agreement with the United States Standard Frequency located at Boulder. The design and construction of specialized power supplies for some components has improved the reliability of the system. The design and construction of a harmonic generator in waveguide size, WR 12 (60 to 90 Gc), has added to the ease and reliability of cavity calibrations over an extended frequency range. Some preliminary studies and experiments were carried on in connection with frequency measurements on precision signal sources.

Attenuation measurements were made by the IF-substitution method for values to approximately 40 db. For higher values of attenuation, up to approximately 75 db, a combination of rf- and IF-substitution methods was used. An attenuation calibration system for waveguide size, WR 42 (18.0 to 26.5 Gc), was completed, and a system for waveguide size, WR 28 (26.5 to 40.0 Gc), will be completed for attenuation calibration service early in the next fiscal year. A calibration system for WR 90 (8.2 to 12.4 Gc) waveguide, utilizing the modulated subcarrier technique of attenuation measurement was set up and is nearing completion. Improvements in calibration systems utilizing the IF-substitution method in waveguide transmission lines have resulted in an improved accuracy to 0.05 db per 10 db for attenuation difference measurements on variable attenuators, and 0.1 db per 10 db for insertion loss measurements on fixed attenuators. Improvements in the operation of calibration systems for coaxial transmission lines have resulted in repeated measurements on fixed coaxial attenuators within a few thousandths db. Work on a high-precision rotary-vane attenuator will be documented early in the next fiscal year.

Microwave noise measurements are to be made by a null detection, direct comparison method. The reference standard will be a heated resistive termination operating at approximately $1000^{\circ}C$. An analysis of errors involved in determining the effective temperature of noise sources was completed for the X-band radiometer system to be used for calibrations. An X-band reflectometer was constructed for use in tuning portions of the noise calibration system. Components were procured for the construction of an S-band noise calibration system in WR 284 (2.6 to 3.95 Gc) waveguide, and the construction of a system in WR 62 (12.4 to 18.0 Gc) waveguide was begun. Noise measurements were made, comparing noise tubes of different manufacture. Noise measurement data is being compiled preliminary to offering a noise calibration service. A calibration service for measurements on gas discharge noise tubes, mounted in WR 90 (8.2 to 12.4 Gc) waveguide, will be offered early in the next fiscal year.

A new high-temperature oven was designed and constructed, with a temperature control circuit maintaining the temperature of the oven at a given point to $1.0^{\circ}$ at approximately $1000^{\circ}C$. This oven has substantially facilitated and simplified noise measurements with hot-body noise sources. The hot-body noise standard was redesigned into a configuration which is more reliable in its operation and easier to analyze. Investigations were made for materials for an oven which will be compatible with platinum waveguide when used in a noise standard.

Personnel who contributed to the work in the Microwave Region include: R. E. Larson (Head, Microwave Unit), N. L. Abshire, G. F. Ahl, T. H. Bremer, E. Campbell, J. H. Canaday, D. J. Collenberger, G. J. Counas, P. F. Davies, W. C. Daywitt, R. F. Desch, R. L. Ehret, R. J. Figaro, G. R. Gieseke, H. B. Haakinson, G. J. Harris, W. Larson, D. G. Melquist, C. K. S. Miller, R. A. Moss, J. S. Wells, B. C. Yates, and M. H. Zanboorie.

## Calibration Services Rendered During the Year

The Center ended its third complete year of calibration services to the public, the Department of Defense, and other government agencies. Funding of the calibration program for the Department of Defense was provided by the U. S. Air Force, the Navy's Bureau of Naval Weapons, the Army Ordnance, and the Army Signal Corps. The workload from approximately 170 private standards laboratories was supported by charges for services performed. The workload continued to increase in all areas in which calibration services were offered.

The public workload has increased from about 10 percent in the early days of the Center to about 40 percent of the total workload for this fiscal year. It decreased abnormally during the second quarter, remained about the same for the third quarter and, for the fourth quarter, returned to about the same as for the last quarter of FY 60.

A large percentage of calibrations for the public results, of course, from Department of Defense contracts.

During the fiscal year the following calibrations were performed:

| | Items | Man Hours | Man Years |
|---|---|---|---|
| Department of Defense | 2,766 | 12,608 | 7.16 |
| Other Federal Government | 38 | 190 | 0.11 |
| Public | 1,818 | 7,867 | 4.47 |
| NBS | 121 | 812 | 0.46 |
| State Institutions | 12 | 44 | 0.03 |
| Total | 4,755 | 21,521 | 12.23 |

Supervision of the Center is provided by a staff including: H. W. Lance, chief; W. F. Snyder, assistant chief; W. C. Stickler, technical assistant, and D. M. McRoberts, administrative assistant.

# MILLIMETER-WAVE RESEARCH

## Millimeter Wave Interferometry

84171

The general aims of this project are to develop both Michelson and Fabry-Perot interferometers to the point where they will be useful in more precise determinations of physical constants and length standards. One specific objective is the determination of the velocity of light.

Work in this area is important because microwave interferometry forms an effective bridge between conventional radio and electronic methods and purely optical techniques. Therefore, it has great potential usefulness in exploring that part of the electromagnetic spectrum which cannot be reached with optical or more conventional electronic means.

Work on the velocity of light project has been moving forward steadily. The interferometer reflector has been delivered and set up. Most of the preliminary adjustments have been made, and, as soon as the length standards arrive, measurements can begin. The refractometer is operable, and the instrumentation for the antenna pattern analysis is almost completely assembled.

The Fabry-Perot activity has centered on improving the design of the reflectors. This resulted in improved performance, ease of adjustment, and convenience of fabrication. In addition, a theory and method of measuring dielectric constants and loss tangents of materials in sheet form were worked out. Measurements were made on plexiglass, polystyrene, and teflon with satisfactory results.

During the coming year, the velocity of light project should near completion. The antenna pattern should be determined very soon, and the diffraction calculations performed. Actual interferometric measurements should be underway within the next two or three months.

A more concentrated study of Fabry-Perot reflector design is planned. Experimental values of transmission and reflection coefficients will be obtained for various metal films and perforation patterns.

These will be compared with certain theoretical treatments to determine the correct dependence of the design parameters on frequency. A confocal spherical mirror arrangement may also be investigated and compared with the parallel plate system currently being used.

Personnel contributing to this project include R. C. Baird (Project Leader), R. V. Gaertner, S. B. Kilgore, and Allen C. Newell.

## Fabry-Perot Maser

84172

The objective of the project is to develop gaseous maser techniques at higher frequencies than maser devices of present designs, and to utilize these techniques in various fields of research.

The development of such techniques could have important application in investigations of atomic and molecular structure, development of highly stable atomic frequency standards, precision determinations of physical constants, and the generation and amplification of coherent radiation at millimeter and submillimeter wavelengths.

The project is a cooperative effort between the Millimeter Wave Research and Atomic Frequency and Time Standards sections. The maser under development is an HCN gaseous maser for operation at a wavelength of 3 - 4 mm. The millimeter wave Fabry-Perot interferometer was adjusted and tested for 3.4 mm. A stable signal source and a detection system have been built and used with the maser, and gas absorption lines have also been observed. The interferometer Q was observed to be 32,000. During the fiscal year 1961, this effort was under the supervision of Dr. R. C. Mockler and Dr. W. Culshaw.

The device will be used to investigate the spectrum of HCN and possibly to obtain a new mass ratio of $C^{12}/C^{13}$. It will be tested for frequency stability, and generally for the performance of Fabry-Perot interferometers as they are applied to millimeter wave spectrometers and masers. If successful in this area, maser operation with different molecules at still higher frequencies will be attempted.

Personnel contributing to this project include R. C. Mockler and W. Culshaw (joint project leaders), R. Day, J. A. Barnes, Leland D. Fletcher, Gary L. Strine, and A. E. Wainwright.

## Millimeter Wave Generation and Detection

84173

This project is developing reliable sources of millimeter wave power and the devices with which to detect this power.

Upon the success of this project depends the future activity of the Millimeter Wave Research Section. Until the power sources are developed for submillimeter wavelengths, this area is excluded from experiment.

This project was activated late in the fiscal year. A new microwave resonant structure was successfully designed, constructed, and operated. It is called a re-entrant biconical sphere, and shows great promise as a tuned resonant cavity for the generation of harmonic power at millimeter wavelengths presently beyond reach. Some further work was also done on conventional diode multipliers, achieving nominal success to less than 3 mm wavelengths.

The re-entrant biconical sphere will be investigated as a multiplier source of millimeter wave power. Both the conventional diode, as well as plasma discharge, will be used as the non-linear element. This novel tuned cavity will also be examined as a detecting structure for millimeter wave power, using diodes and baretters as the sensitive element.

Personnel contributing this project include Dr. Robert W. Zimmerer (Project Leader), and Robert V. Day.

431

# MICROWAVE CIRCUIT STANDARDS

## Microwave Low Power Standards

84181

The objectives of this project are: (1) to develop standards of microwave power of high accuracy over a wide frequency range at power levels below 1 watt; (2) develop and improve calibration techniques and evaluate their accuracy; and (3) calibrate power measuring apparatus to be used as standards by others.

This project is a part of the NBS program of development of standards and precision measurement methods for frequencies above 300 Mc. The continuing and growing use of the microwave art in commercial and military applications, such as radar, navigational aids, communications systems, microwave relays, guided missiles, and television, has produced a real and growing need among government agencies and industry for standards and calibration services in the microwave region. Power is a fundamental quantity in which standard methods of measurement are required to specify the output of oscillators, determine the range of radar and microwave relay equipment, and determine the output of various power sources used in the application of microwaves. The calibration services offered by the Electronic Calibration Center to industry and the military services in fulfillment of these needs are based directly upon primary calibrations made by this project.

A new microcalorimeter in WR-62 waveguide (12.4- 18.0 Gc) has been brought very near to completion. It is still necessary, however, to develop suitable bolometer mounts for use as standards before calibrations over this frequency range can be made for the Electronic Calibration Center.

A general study of the various heat transport processes active in the microcalorimeters has begun, and experimental results indicate that the importance of radiative heat transfer may be greater than realized.

A temperature-compensating accessory instrument, for use with the self-balancing bridge, is in final stages of development. The unit is expected to replace a large temperature-controlled water bath in some measurements, and should be usable with most of the bolometer elements in common use.

Work continued on the evaluation of the reflection coefficient of 1/4-, 3/4, and 5/4-wavelength electroformed shorts for the Microwave Impedance Project, using the microcalorimeter.

Development of a coaxial system to be used to measure efficiencies of coaxial mounts by the impedance method progresses slowly. Several multi-stub coaxial tuning transformers were constructed in order to achieve better mechanical stability and less frequency sensitivity. A bolometer mount for use with this impedance method, using a 50-ohm barretter, is in the design stage.

Thirty routine calibrations of NBS standard mounts were made for the Electronic Calibration Center, using the microcalorimeter.

Two NBS mounts were sent to England in the continuing intercomparison program as recommended by Commission I of the International Scientific Radio Union.

Three papers were published: "A Transfer Instrument for the Intercomparison of Microwave Power Meters," in the IRE Transactions on Instrumentation; "A Method for Improving Isolation in Multi-Channel Waveguide Systems," as a letter to the Editor of the IRE Transactions on Microwave Theory and Techniques, and "A Bolometer Mount Efficiency Measurement Technique," in the NBS Journal of Research.

Letters Patent have been allowed on the self-balancing DC bolometer bridge.

Plans for this project for the forthcoming year include the extension of the existing power standards techniques to other waveguide sizes and coaxial systems. A notch-type wattmeter is planned for the calibration of the response of barretters to pulse type power at low average levels.

Personnel contributing to the work of this project were Glenn F. Engen (project leader), M. Harvey, J. Gilbert, N. T. Larsen, R. Macleay, and H. Reichert.

## Microwave Impedance Standards

84182

The objectives of the Microwave Impedance Standards Project are to: (1) perform research leading to the development of accurate National primary standards of impedance or reflection coefficient, at frequencies above 300 Mc, in coaxial line and the numerous other standard waveguide systems; (2) to develop accurate standards and measurement techniques suitable for the calibration of transfer standards; (3) perform special calibrations not available on a routine basis in the Electronic Calibration Center; (4) support the impedance calibration activities of the Electronic Calibration Center; (5) disseminate information on these activities by publishing reports; and (6) provide consultation on specific problems connected with microwave impedance measurements.

This project is a part of the NBS program of development of standards and precision measurement methods for frequencies above 300 Mc. A knowledge of impedance or reflection coefficients, including a recognition of matched conditions in a transmission system, is essential in making accurate measurements of attenuators, power, voltage, field strength, and other quantities, as well as in the calibration and use of wavemeters and other measuring equipment used at microwave frequencies. The impedance characteristics of antennas, directional couplers, and other microwave devices are often written into specifications, and are one criterion for accepting or rejecting manufactured equipment.

The establishment of calibration facilities for use by the Electronic Calibration Center (84.50) depended basically upon progress made in developing the required standards and calibration techniques. Support of the Calibration Center facilities, as the state of the art and calibration requirements change, requires continued basic work by this project.

Additional standards of reflection in WR-90 (X-band) rectangular waveguide were provided for the calibration service offered by the Electronic Calibration Center. These standards were quarter-wavelength short-circuited sections of waveguide, fabricated by electrodeposition of silver on accurately formed mandrels.

Components were constructed which will be used to develop standards of small reflection for rectangular waveguide.

A member of this project, with the cooperation of most of the other microwave projects, acted as instructor of a course entitled "Microwave Measurements." The course was sponsored jointly by the University of Colorado and the NBS BL, and was a 2-semester graduate course.

A paper entitled "A Guide to the Use of the Modified Reflectometer Technique of VSWR Measurement," by W. J. Anson, was accepted for publication in the NBS Journal of Research, Section C.

A Note entitled "A Microwave Impedance Meter Capable of High Accuracy," by R. W. Beatty, was published in the July 1960 issue of the IRE Transactions on Microwave Theory and Techniques.

A paper entitled "Error Analysis of a Standard Microwave Phase Shifter," by G. E. Schafer & R. W. Beatty, was published in the April 1960 issue of the NBS Journal of Research, Section C.

"Table of Magnitude of Reflection Coefficient Versus Return Loss ($L_R = 20 \log_{10} \frac{1}{|\Gamma|}$)," by R. W. Beatty and W. J. Anson, was published as NBS Technical Note No. 72.

A paper entitled "Measurement of Reflections and Losses of Waveguide Joints and Connectors Using Microwave Reflectometer Techniques," by R. W. Beatty, G. F. Engen, and W. J. Anson, was published in the September 1960 issue of the IRE Transactions on Instrumentation.

Plans for this project for the forthcoming year include development of a system for the accurate measurement of reflection coefficients in coaxial systems, in particular of the diameters IDOC = 0.276", ODIC = 0.120". The upper and lower frequency limits for such a system will be investigated, and reflection standards will be provided and evaluated.

Instrumentation for making reflection coefficients will be improved and less tedious tuning methods will be developed.

Theoretical and experimental work on simple waveguide discontinuities will be continued and the effects of waveguide loss on reflection coefficient measurements will receive further attention.

Personnel contributing to the work of this project were R. W. Beatty (project leader), W. J. Anson, E. Risley, E. Niesen, R. Williams, R. Ridge, and Dr. D. M. Kerns (consultant).

## Microwave Attenuation Standards

84183

The objectives of this project are: (1) to develop microwave attenuation standards at frequencies above 300 Mc; (2) to develop precision methods of measurement of attenuation; (3) to provide support for microwave calibration services; (4) to provide calibration services in cases where unusual or non-routine techniques must be used; and (5) to study microwave properties of various products and components used in attenuation measurements systems.

This project is a part of the NBS program of development of standards and precision measurement methods for frequencies above 300 Mc. Calibrated microwave attenuators and directional couplers are used in field strength meters, signal generators, the alignment of radar transmitters and receivers, and other applications. In power measurements, they may be used to reduce high power outputs a known amount so that the power may be conveniently measured with milliwatt level instruments. Manufacturers of microwave equipment need transfer standards checked against a National Standard to insure the accuracy of attenuators made for industry, military, and government agencies.

Consulting on a multiplier chain suitable for illuminating the cesium beam apparatus was performed for another project. A major feature of the multiplier developed was the phase-locking of a reflex klystron at a readily controllable frequency difference from a harmonic or stable source. The harmonic used was the 34th at 9.18 Gc, and was generated by a variable capacitance diode which was driven by an electron tube multiplier. An NBS Report describing this apparatus was printed. The analysis of errors in a standard microwave phase shifter was published. Further evaluation of this microwave phase shifter was accomplished by investigating the uniformity and repeatability of phase shift produced by different types of sliding short circuits. The resolution of the current model of the phase shift measurement system is approximately 0.007 degree. The system used to make these measurements was described in a publication. Errors in phase shift measurements due to mismatches were described in another publication.

Progress was made in the evaluation of environmental effects on microwave variable attenuators. To date, only one type has been tested. The results indicate that further study of other types is warranted. The power linearity of crystal response in the modulated subcarrier method of measuring microwave attenuation was studied for a number of crystals. Effects of different methods of using the transformers used as standards were checked. These studies, and a further comparison of measured values of attenuation, resulted in the submission of a technical paper describing the results.

The first items of equipment have been constructed to study ways of extending the dynamic range of microwave attenuation measurements to beyond the presently attainable 75 db.

The immediate objectives of this project are (1) further investigation of environmental effects on rectangular waveguide variable attenuators; (2) completion of development of a prototype phase shift measurement system and standard phase shifter; (3) continued development of a system to measure a greater dynamic range of attenuation; (4) investigation of usefulness of parametric amplifiers in accomplishing (3); and (5) adaptation of phase shift techniques and new microwave attenuation measurement techniques to coaxial systems.

Personnel contributing to the work of this project were G. E. Schafer (project leader), O. L. Patty, W. Downing, G.H. Fentress, and D. Ellerbruch.

## Microwave Field Strength Standards

84184

The objectives of this project are: (1) to develop standards of microwave antenna gain and field strength at frequencies higher than 300 Mc; (2) to develop precision methods of measurement of microwave antenna gain and field strength; (3) to develop a calibration service for gain of microwave antennas; and (4) to measure microwave properties of various products which affect field strength or field strength measurements.

This project is a part of the NBS program of development of standards and precision measurement methods for frequencies above 300 Mc. Calibrated microwave antennas are used in field strength meters. These meters are used in surveys for setting up communication paths for television, telephone, and armed service communication relay services. Versions of these meters are specifically designed to determine if radiation levels near transmitters are hazardous to personnel. Calibrated antennas are also used to measure the gain of microwave antennas of various types which are used in communication and radar installations. Such UHF and SHF installations are subject to rather large fluctuations in field strength, and sufficient gain of the antennas must be ensured. Manufacturers of microwave equipment and relay systems need transfer standards, checked against a National Standard, to insure the uniformity of systems made for industry, military, and government agency uses.

Pulse techniques to separate the directly propagated energy from reflected energy were studied. This would reduce the requirements of the microwave absorbing enclosure. The major effort this year has been the development and evaluation of methods to produce pulses of a few nanoseconds duration; methods to detect the amplitude of these pulses to 0.01 db; and methods to discriminate against pulses arriving as little as 5 nanoseconds after the main pulse. The short pulses have been satisfactorily produced. Means to detect their amplitude to within a few hundredths of a db are apparently succesful. Final evaluation depends on being able to discriminate against the slightly delayed pulses. A method to reduce switching time of the diode, which is presently limited to about 10 nanoseconds, seems promising.

The immediate objectives of this project are to: (1) complete the discrimination circuits; (2) evaluate the microwave enclosure with this technique; (3) compare experimentally the gain of the horn measured under pulse and unmodulated conditions; and (4) investigate theoretically the effect of short pulses on the gain.

Personnel contributing to the work of this project were G. E. Schafer (project leader), R. Bowman, and D. Belsher.

## Microwave High Power Standards

84185

The objectives of this project are to develop standards of microwave power of high accuracy for unmodulated and pulse sources in the frequency range above 300 megacycles and for power levels above 1 watt.

This project is a part of the NBS program of development of standards and precision measurement methods for frequencies above 300 Mc. The continuing and growing use of the microwave art in commercial and military applications, such as radar, navigational aids, communications systems, microwave relays, guided missiles, and television, has produced a real and growing need among government agencies and industry for standards and calibration services in the microwave region. Power is a fundamental quantity in which standard methods of measurement are required to specify the output of oscillators, determine the range of radar and microwave relay equipment, and determine the output of various power sources used in the application of microwaves. It is especially important that standard methods of microwave power measurement be available to determine whether expensive high-power equipment which must be dependable in operation is functioning correctly.

Work under this project is at present directed into two efforts: a stirred water calorimeter, and the electron beam technique of power measurement.

The construction of the calorimeter has progressed more rapidly during the last year. The stirring apparatus has been almost completed, and the calorimeter design has been changed to provide hermetic sealing. This is expected to permit greater accuracy by maintaining the heat capacity of the calorimeter more constant.

Negotiations continue on the procurement of the high power microwave sources which will be required to evaluate and use both the calorimeter and beam techniques.

A modification was made in the electrode configuration of the electron beam tube to permit returning the collector current meter to ground, instead of to the beam accelerating voltage. The change proved unsatisfactory in some respects, since other variables in the electron beam would not allow accurate determination of the effect of the measured stopping potential on the beam.

A special coaxial, metallized ceramic insulator has been ordered and construction is in progress. The insulator was designed to eliminate leakage currents, and reduce the collector-to-ground capacitance. This has been a limiting factor on collector current measurement sensitivity.

The immediate objectives of this project are to continue the above programs, or accelerate them if funds permit.

Personnel contributing to the work of this project were G. F. Engen (project leader), L. B. Elwell, T. Speiser, and H. Reichert.

## Microwave Noise Standards

84186

The objectives of the Microwave Noise Standards Project are: to develop primary standards of microwave noise, to improve calibration procedures for microwave noise sources, to study the properties of various types of noise sources, and to investigate theoretically and experimentally the noise characteristics of microwave networks and devices.

The problem of evaluating the properties of low noise devices, like masers and parametric amplifiers, has emphasized the need for accurate determination of noise source characteristics. In addition, in measurements of radio astronomy and plasma physics, the information itself is stochastic, i.e., it may be represented by a probability function, and the techniques of noise measurements are used to provide quantitative results.

One primary standard, operating near $1300^{\circ}$ K, has been in use for a year, and is currently being evaluated to determine its accuracy. Further high temperature studies have been limited because of the cost of attendant materials such as gold and platinum.

For noise source calibration, a high precision radiometer has been in use for about a year, and a new technique for synchronous detection has been studied. Noise properties of balanced crystal-mixers, preamplifiers, and other minimal noise circuits have been investigated. A new technique which allows impedance matching at both the signal and image frequencies was devised, and will increase the radiometer accuracy.

The immediate objectives of this project include continued development of the existing standard, improvement of the radiometer, and the extension of those techniques to other waveguide sizes. Studies yet to be initiated include properties of other non-coherent sources and investigations of the noise characteristics of devices such as masers and parametric amplifiers.

Personnel contributing to the work of this project were G. F. Engen (project leader), A. J. Estin, C. L. Trembath, N. T. Larsen, D. W. Schulze, and W. J. Foote.

## Waveguide Connectors

84187

The objectives of this project are to evaluate the reflections, losses, and other defects of connectors in present use to investigate the effects of connector defects on the accuracy of microwave measurements, and to develop better connectors in which the defects have been greatly reduced.

It is understood that the term "waveguide connectors" is general, and includes rectangular waveguide flanges, coaxial connectors, and all other means of connecting waveguide of various types.

Improved connectors, developed for standards work, would improve the accuracy of comparison measurements by which reference standards are calibrated against the National Primary Standards, and also improve subsequent lower-level comparisons wherever the improved connectors were used. Thus, the achievements of this project would have far reaching effects in improving the accuracy of microwave measurements on a national scale.

Because of the improved accuracy of microwave impedance measurements alone, without considering improved accuracies in measuring other quantities, an order of magnitude decrease in the reflections from waveguide connectors is needed immediately.

| | Typical VSWR | Desired VSWR |
|---|---|---|
| Rectangular Waveguide | 1.02 | 1.002 |
| Coaxial Systems | 1.15 | 1.02 or better |

The reflection coefficient magnitude $|S_{11}|$ of a simulated joint between a rectangular waveguide, having a cross-section with sharp inside corners, and one with rounded corners was determined experimentally. A theoretical calculation was also made by Dr. D. M. Kerns and W. T. Grandy. The measurement technique used was a new variation of known reflectometer techniques which is applicable to the measurement of small discontinuities in waveguide.

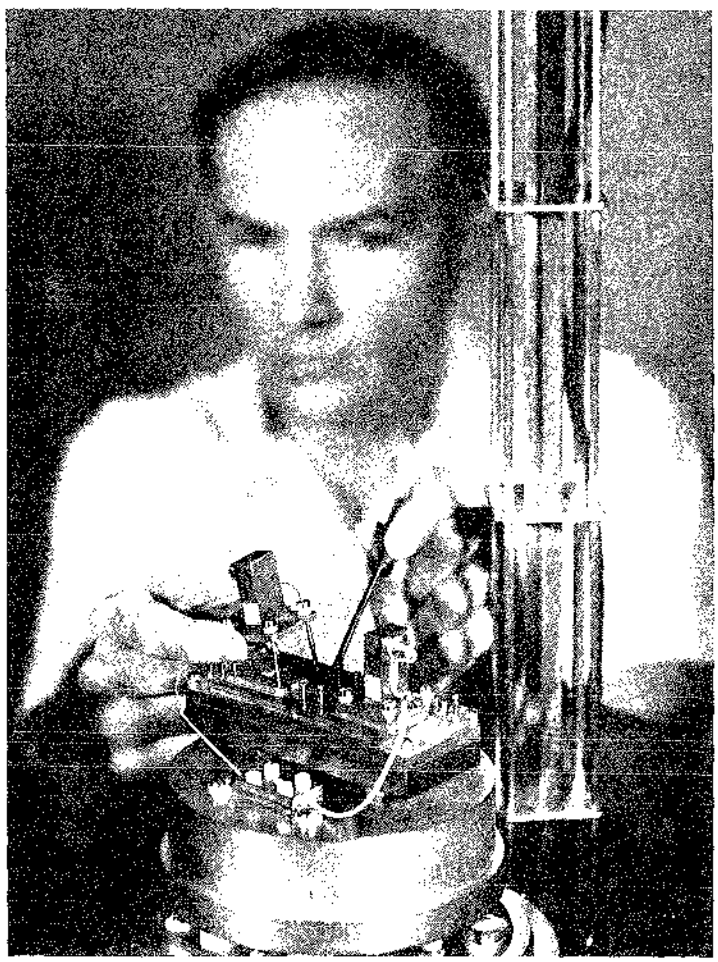
A study of the effects of a lateral displacement upon the reflection from a plane butt joint, between sections of rectangular waveguide, was begun both experimentally and theoretically. Several methods of aligning rectangular waveguide were tried in an effort to produce a waveguide joint with the lowest possible reflection. A technique was developed and the instrumentation very nearly completed for a system capable of accurately measuring the VSWR of coaxial connectors. The technique is an application to a coaxial system of the Modified Reflectometer Technique currently used in rectangular waveguide. It was noted that electrical non-uniformity of waveguide is a limiting factor in applications of the modified reflectometer. Several rectangular waveguide sections were fabricated by different methods to improve the uniformity of the waveguide.

The immediate objectives of this project are to develop further the technique for measuring the VSWR of coaxial connectors. This technique will be used to measure the VSWR of coaxial connectors both of current design and of designs which may result from these investigations.

Work will continue on the study of rectangular waveguide joints. In particular, measurements will be made of the reflection of rectangular joints under various conditions of displacement, twist, and changes of cross-section.

Considerable emphasis will be placed upon the evaluation and reduction of irregularities in rectangular waveguide.

Personnel contributing to the work of this project were W. J. Anson (project leader), R. W. Beatty, R. Williams, E. Niesen, and E. Risley.



A bolometer mount is connected to the new NBS microcalorimeter. This calorimeter measures the efficiency of bolometer mounts in the frequency range 12.4 to 18.0 Gc/s.

# LIST OF PUBLICATIONS

## (APPENDICES TO 7TH SUMMARY OF RESEARCH)

BOULDER LABORATORIES
NATIONAL BUREAU OF STANDARDS
JULY 1954 – JUNE 1961

PERIODICALS OF THE NATIONAL BUREAU OF STANDARDS

The following periodicals issued by the Bureau may be obtained by purchase on an annual subscription basis from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

Journal of Research

The Journal presents research papers by authorities in the specialized fields of physics, mathematics, chemistry, and engineering. Complete details of the work are presented, including laboratory data, experimental procedures, and theoretical and mathematical analysis. The Journal is published in four separate sections as follows:

A. Physics and Chemistry. Issued six times a year. Annual Subscription: domestic, $4.00; foreign, $4.75.
B. Mathematics and Mathematical Physics. Issued quarterly. Annual Subscription: domestic, $2.25; foreign, $2.75.
C. Engineering and Instrumentation. Issued quarterly. Annaul subscription: domestic, $2.25; foreign, $2.75.
D. Radio Propagation. Issued six times a year. Annual subscription: domestic, $4.00; foreign, $4.75.

Technical News Bulletin

Summaries of current research at the National Bureau of Standards are published each month in the Technical News Bulletin. The articles are brief, with emphasis on the results of research, chosen on the basis of their scientific or technologic importance. Lists of all Bureau publications issued during the preceding month are given, including Technical Notes, Monographs, Applied Mathematics Series, Handbooks, and Miscellaneous Publications. Annual subscription: domestic, $1.50; foreign, $2.25.

Basic Radio Propagation Predictions

The Predictions provide the information necessary for calculating the best frequencies for communication between any two points in the world at any time during the given month. The data are important to all users of long-range radio communications and navigation, including broadcasting, airline, steamship, and wireless services. Each issue, covering a period of one month, is released three months in advance. Annual subscription: domestic, $1.00; foreign $1.50.

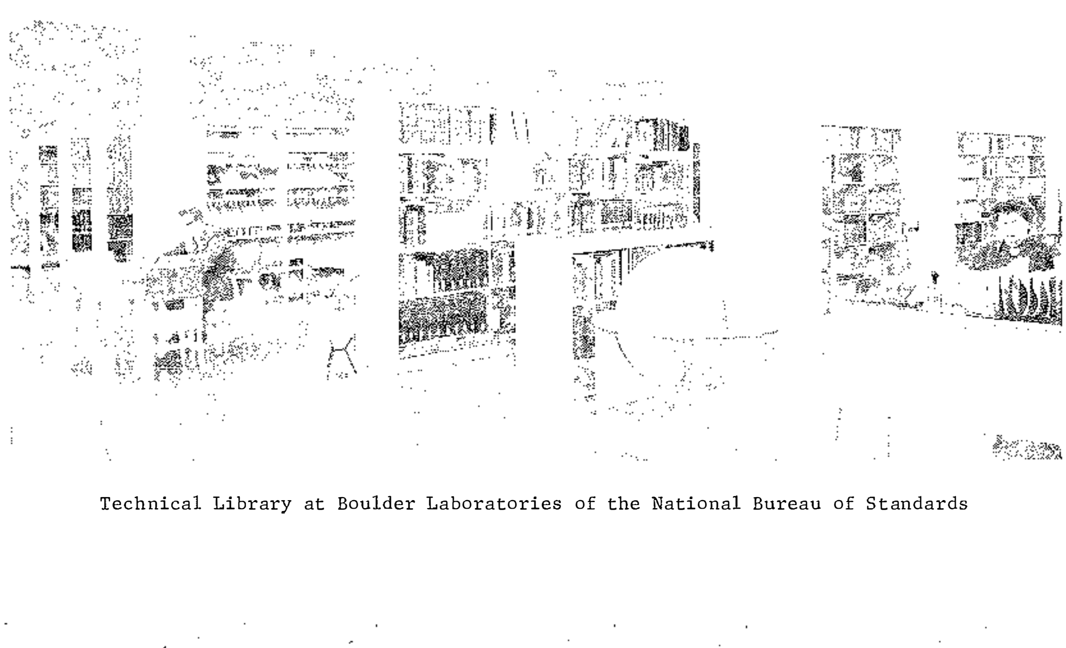
CATALOGS OF NATIONAL BUREAU OF STANDARDS PUBLICATIONS

National Bureau of Standards Circular 460 and its Supplements list all Bureau publications issued from 1901 up to June 30, 1960. Copies of these catalogs may be obtained from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., as follows:

Circular 460: 1901 to June 30, 1947. $1.25.

Supplement to Circular 460: July 1, 1947 to June 30, 1957. $1.50.

Miscellaneous Publication 240: July 1, 1957 to June 30, 1960. $2.25.



Technical Library at Boulder Laboratories of the National Bureau of Standards

LIST OF PUBLICATIONS

(APPENDICES TO 7TH SUMMARY OF RESEARCH)

Boulder Laboratories
National Bureau of Standards
July 1954 - June 1961

The following lists of publications are for the period July 1954 to June 1961. A List of Publications and Reports for the years 1946-1958 is available on request. Earlier publications issued by the Bureau in the field of radio were listed in LC 874, "Radio: Publications by the Staff of the National Bureau of Standards". This is no longer available.

Where the price is stated, except for items with PB numbers, the publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Remittance should accompany the order.

Items with PB numbers should be ordered by PB number directly from Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.

Patents are available only from the U.S. Patent Office, Washington 25, D. C.

Reprints should be requested from the Technical Information Office.

* Indicates that the publication is out of print.

[a] Figure in parentheses at end of each listing indicates number used in previous lists (1946-1960) for the same item.

The previous lists have included NBS Reports. Such reports are intended for use within the Government and are not generally available to individuals. A separate list of NBS Reports is available on request to Government Agencies or cooperating laboratories which have immediate interest in the work.

Director's Office

* OD-1 President Eisenhower dedicates NBS Boulder Laboratories. Natl. Bur. Standards (U.S.) Tech. News Bull. 38, 164-171, Nov. 1954. (D-41) [a]

Includes sections:
The Buildings and Site.
Remarks of President Dwight D. Eisenhower.
The Boulder Laboratories.
Statement of Dr. Allen V. Astin, Director, NBS.
The Scientific Conferences:
1954 Cryogenic Engineering Conference.
Conference on Radio Propagation and Standards.

OD-2 Confidence intervals for a proportion, by E. L. Crow. Biometrika 43, 423-435, Parts 3 and 4, Dec. 1956. Also published separately as Biometrika New Statistical Table no. XXIII, "Table for determining confidence limits for a proportion in binomial sampling". (D-46)

OD-3 Central Radio Propagation Laboratory, by F. W. Brown. Signal 12, 9-10, 12-13, Dec. 1957. (D-48)

OD-4 On the use of the early Balmer lines to extend the photospheric model, by R. G. Athay and R. N. Thomas. Astrophys. J. 127, 96-107, Jan. 1958. (D-49)

OD-5 Demands on teachers in a technological society, by F. W. Brown. Colorado School J., 14-15, Mar. 1958. (D-52)

OD-6 Source function in a non-equilibrium atmosphere, II: Depth dependence of source function for resonance and strong subordinate lines, by J. T. Jeffries and R. N. Thomas. Astrophys. J. 127, 667-675, May 1958. (D-53)

*OD-7 Proceedings of the Third Symposium on Cosmical Gas Dynamics, held at the Smithsonian Astrophysical Observatory, Cambridge, Massachusetts, June 24-29, 1957, edited by R. N. Thomas and J. N. Burgers. Revs. Modern Phys. 30, 908-911, July 1958. (D-55)

OD-8 Further studies of the influence of a ridge on the low-frequency ground wave, by J. R. Wait and A. Murphy. J. Research Natl. Bur. Standards 61, 57-60, July 1958. (D-56)

OD-9 The patterns of a slot-array antenna on a finite and imperfect ground plane, by J. R. Wait and A. M. Conda. L'Onde Electrique 38, no. 376 bis (Proceedings of the International Congress, Ultra High Frequency Circuits and Antennas, Paris, October 21-26, 1957), p. 21-29, Aug. 1958. (D-57)

OD-10 A property of additively closed families of distributions, by E. L. Crow. Ann. Math. Statists. 29, 892-897, Sept. 1958. (D-60)

OD-11 The mean deviation of the Poisson distribution, by E. L. Crow. Biometrika 45, 556-559, Dec. 1958. (D-62)

OD-12 Radio propagation research at the National Bureau of Standards, by F. W. Brown. Am. J. Phys. 26, 628-634, Dec. 1958. (D-63)

OD-13 Calculated patterns of slotted elliptic-cylinder antennae, by J. R. Wait and W. E. Mientka. Appl. Sci. Res. B 7, 449-462, 1959. (D-64)

OD-14 Electromagnetic radiation from cylindrical structures, by J. R. Wait. New York, Pergamon Press, 1959. (D-86)

*OD-15 Theoretical multiplet strengths, by F. Rohrlich. Astrophys. J. 129, 441-448, March 1959. (D-66)

OD-16 Downcoming radio waves: measurement of characteristics, by J. R. Wait. Electronic and Radio Engr. 36, 106-107, March 1959. (D-67)

[a] Indicates number used for this item in previous lists.

* Indicates that the publication is out of print.

Director's Office

OD-17 Source function in a non-equilibrium atmosphere, III: The influence of a chromosphere, by J. T. Jefferies and R. N. Thomas. Astrophys. J. 129, 401-407, March 1959. (D-68)

OD-18 Transmission of power in radio propagation, by J. R. Wait. Electronic and Radio Engr. 36, 146-150, Apr. 1959. (D-70)

OD-19 Diurnal change of ionospheric heights deduced from phase velocity measurements at VLF, [letter] by J. R. Wait. Proc. I.R.E. 47, 998, May 1959. (D-71)

OD-20 Stark broadening functions for the hydrogen lines, by A. B. Underhill and J. H. Waddell. May 1, 1959. (NBS Circular 603) 65 cents. (D-72)

*OD-21 Negative atomic ions, by H. R. Johnson and F. Rohrlich. J. Chem. Phys. 30, 1608-1613, June 1959. (D-73)

OD-22 The calculation of the field in a homogeneous conductor with a wavy interface, by J. R. Wait. Proc. I.R.E. 47, 1155-1156, June 1959. (D-74)

OD-23 Radio wave propagation in an inhomogeneous atmosphere, by J. R. Wait. Sept. 10, 1959. (NBS Tech. Note 24) (PB151383) $1.00. (D-61)

OD-24 Aerodynamic phenomena in stellar atmospheres - a bibliography, edited by R. N. Thomas. Sept. 1959. (NBS Tech. Note 30) (PB151389) $1.25. (D-78)

*OD-25 Radio-wave scattering by tropospheric irregularities, by A. D. Wheelon. J. Research (D. Radio Propagation) Natl. Bur. Standards 63D, 205-233, Sept.-Oct. 1959. (D-77)

*OD-26 Diffraction of electromagnetic waves by smooth obstacles for grazing angles, by J. R. Wait and A. M. Conda. J. Research (D. Radio Propagation) Natl. Bur. Standards 63D, 181-197, Sept.-Oct. 1959. (D-76)

OD-27 Departures from the Saha equation under varying conditions of Lyman continuous capacity, by S. R. Pottasch and R. N. Thomas. Astrophys. J. 130, 941-953, Nov. 1959. (D-80a)

OD-28 Pattern synthesis for slotted-cylinder antennas, by J. R. Wait and J. Householder. J. Research (D. Radio Propagation) Natl. Bur. Standards 63D, 303-313, Nov.-Dec. 1959. (D-81)

OD-29 Confidence intervals for the expectation of a Poisson variable, by E. L. Crow and R. S. Gardner. Biometrika, 46, 441-453, Dec. 1959. Also published separately as Biometrika New Statistical Table no. XXVIII, "Table of confidence limits for the expectation of a Poisson variable." (D-82)

OD-30 On the diffraction of electromagnetic pulses by curved conducting surfaces, by J. R. Wait and A. M. Conda. Can. J. Phys. 37, 1384-1396, Dec. 1959. (D-83)

*OD-31 Prepublication of papers on surface waves to be presented at (URSI) Symposium on Electromagnetic Wave Theory, June 1959. Compiled by J. R. Wait. March 31, 1959. Most of these papers were published in IRE Trans. on Ant. Prop. AP-7, Special Supplement, Dec. 1959, including the three following papers: (D-69)

OD-32 Preface to the surface wave papers, by J. R. Wait. IRE Trans. on Ant. Prop. AP-7, S132, Dec. 1959. (D-69a)

OD-33 Guiding of electromagnetic waves by uniformly rough surfaces, part I, by J. R. Wait, p. 66-91. IRE Trans. on Ant. Prop. AP-7, S154-S162, Dec. 1959. (D-69b)

OD-34 Guiding of electromagnetic waves by uniformly rough surfaces, part II, by J. R. Wait, p. 189. IRE Trans. on Ant. Prop. AP-7, S163-S168, Dec. 1959. (D-69c)

OD-35 The error in prediction of F2 maximum usable frequencies by world maps based on sunspot number, by E. L. Crow and D. H. Zacharisen. In Symposium on Statistical Methods in Radio Wave Propagation, University of California, Los Angeles, June 18-20, 1958, p. 248-273. New York, Pergamon Press, 1960. (D-87)

OD-36 A differing view of the radiation problem (based on remarks of Richard Thomas). In Plasma physics, edited by F. H. Clauser, p. 46-53. New York, Addison-Wesley, 1960. (D-88)

Director's Office

OD-37 Radiation from a slot on a large corrugated cylinder, by J. R. Wait and A. M. Conda. In Brussels. Exposition universelle et internationale, 1958. Electromagnetic wave propagation ... edited by M. Désirant and J. L. Michiels, p.103-109. New York, Academic Press, 1960. (D-89)

OD-38 Factors in terrestrial radio propagation [table], prepared by F. W. Brown. In Space/Aeronautics Research and Development Handbook for Aerospace Environments, 1960-1961, p. D-22. New York, Conover-Mast publications, 1960. (D-102)

OD-39 World days, by A. H. Shapley. In Annals of the International Geophysical Year, vol. 10, p. 59-64, 1960. (D-103)

OD-40 Summary of outstanding solar events in July 1959, by A. H. Shapley and D. Trotter. In International Union of Geodesy and Geophysics. Symposium on the July 1959 events and associated phenomena, Helsinki, July 1960, p. 72-76. Paris, Institut Géographique National, 1960. (Monographie no. 5) (D-104)

OD-41 The components of power appearing in the harmonic analysis of a stationary process, by M. M. Siddiqui. In Statistical methods in radio wave propagation: Proceedings of a symposium held at the University of California, Los Angeles, June 18-20, 1958, p. 112-116. New York, Pergamon Press, 1960. (D-50)

OD-42 Propagation of electromagnetic pulses in a homogeneous conducting earth, by J. R. Wait. Appl. Sci. Research, B 8, 213-252, 1960. (D-105)

OD-43 The electromagnetic fields of a dipole in the presence of a thin plasma sheet, by J. R. Wait. App. Sci. Research B 8, 397-417, 1960. (D-98)

OD-44 Some solutions for electromagnetic problems involving spheroidal, spherical, and cylindrical bodies, by J. R. Wait. J. Research (B. Mathematics and Mathematical Physics) Natl. Bur. Standards 64B, 15-32, Jan.-Mar. 1960. (D-90)

*OD-45 Surface-wave resonance effect in a reactive cylindrical structure excited by an axial line source, by A. L. Cullen. J. Research (D. Radio Propagation) Natl. Bur. Standards 64D, 13-19, Jan.-Feb. 1960. (D-91)

OD-46 On the propagation of ELF radio waves and the influence of a nonhomogeneous ionosphere, by J. R. Wait. J. Geophys. Research 65, 597-600, Feb. 1960. (D-92)

OD-47 The resonance excitation of a corrugated-cylinder antenna, by J. R. Wait and A. M. Conda. Proc. Inst. Elec. Engrs. (London), Pt. C, 107, 372-376, Mar. 1960. (D-101)

*OD-48 Approximate cross-section collisions of electrons with atoms, I: Allowed transitions, by S. N. Milford. Astrophys. J. 131, 407-412, March 1960. (D-94)

OD-49 The source function in a non-equilibrium atmosphere, IV: Evaluation and application of the net radiative bracket, by R. N. Thomas. Astrophys. J. 131, 429-437, March 1960. (D-95)

OD-50 Field strength calculations for E.L.F. radio waves, by J. R. Wait and N. F. Carter. March 1960. (NBS Tech. Note 52) (PB161553) 50 cents. (D-95a)

OD-51 Terrestrial propagation of very-low-frequency radio waves, a theoretical investigation, by J. R. Wait. J. Research (D. Radio Propagation) Natl. Bur. Standards 64D, 153-204, Mar.-Apr. 1960. (D-93)

OD-52 On a generalization of the index notation for absolute tensors of arbitrary order, by E. H. Brown. J. Research (B. Mathematics and Mathematical Physics) Natl. Bur. Standards 64B, 99-103, Apr.-June 1960. (D-96)

OD-53 Microwave whistler mode propagation in a dense laboratory plasma, by R. M. Gallet, J. M. Richardson, B. Wieder, G. D. Ward, and G. N. Harding. Phys. Rev. Letters, 4, 347-349, April 1, 1960. (D-97)

Director's Office

OD-54 The source function in a non-equilibrium atmosphere, V: Character of the self-reversed emission cores of $Ca^+$ H and K, by J. T. Jefferies and R. N. Thomas. Astrophys. J. 131, 695-704, May 1960. (D-99)

OD-55 A survey and bibliography of recent research in the propagation of VLF radio waves, by J. R. Wait. May 1960. (NBS Tech. Note 58) (PB161559) 75 cents. (D-100)

OD-56 Proceedings of the 1960 conference on the propagation of E.L.F. radio waves,edited by J. R. Wait. June 6, 1960. (NBS Technical Note no. 61) (PB161562) 75 cents.

*OD-57 Plasma and astrophysics research to provide accurate data on hot, ionized gases. Natl. bur. Standards (U.S.), Tech. News Bull. 44, 109-113, July 1960.

OD-58 Thermodynamic structure of the outer solar atmosphere, VI. Effect of departures from the Saha equation on inferred properties of the low chromosphere, by S. R. Pottasch and R. N. Thomas. Astrophys. J. 132, 195-201, July 1960.

OD-59 The extent of H II regions, [note] by S. R. Pottasch. Astrophys. J. 132, 269-271, July 1960.

OD-60 On the theory of the slow-tail portion of atmospheric waveforms, by J. R. Wait. J. Geophys. Research 65, 1939-1946, July 1960.

OD-61 Mode theory and the propagation of ELF radio waves, by J. R. Wait. J. Research (D. Radio Propagation) Natl. Bur. Standards 64D, 387-404, July-Aug. 1960.

OD-62 Preface to ELF papers, by J. R. Wait, editor. J. Research (D. Radio Propagation) Natl. Bur. Standards 64D, 381, July-Aug. 1960.

OD-63 Distribution of quantiles in samples from a bivariate population, by M. M. Siddiqui. J. Research (B. Mathematics and Mathematical Physics) Natl. Bur. Standards 64B, 145-150, July-Sept. 1960.

OD-64 Influence of earth curvature and the terrestrial magnetic field on VLF propagation, by J. R. Wait and K. Spies. J. Geophys. Research 65, 2325-2331, Aug. 1960.

OD-65 An analysis of the accumulated error in a hierarchy of calibrations, by E. L. Crow. IRE Trans. on Instrumentation I-9, 105-114, Sept. 1960.

OD-66 International Geophysical calendar for 1961, by A. H. Shapley. J. Radio Research Labs. (Japan) 7, 545-549, Sept. 1960. IGY Bulletin no. 42, 6-10, Dec. 1960. Am. Geophys. Union Trans. 41, 722-726, Dec. 1960. International Union of Geodesy and Geophysics. I.U.G.G. Chronicle no. 33, 272-275, Dec. 1960. CIG news no. 3, 80-83, Dec. 1960. Science 132, 1941-1943, Dec. 30, 1960. J. Geophys. Research 66, 336-339, Jan. 1961. Nature 189, 9-11, Jan. 7, 1961. J. Atmospheric and Terrest. Phys. 20, 72-76. Feb. 1961. World Meteorological Organization. Bulletin 10, 47-50, Jan. 1961.

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NATIONAL BUREAU OF STANDARDS
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**Electricity.** Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics.

**Metrology.** Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

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**Atomic Physics.** Spectroscopy. Infrared Spectroscopy. Solid State Physics. Electron Physics. Atomic Physics.

**Instrumentation.** Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

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## BOULDER, COLO.

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**Ionosphere Research and Propagation.** Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

**Radio Propagation Engineering.** Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

**Radio Standards.** High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

**Radio Systems.** High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

**Upper Atmosphere and Space Physics.** Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

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