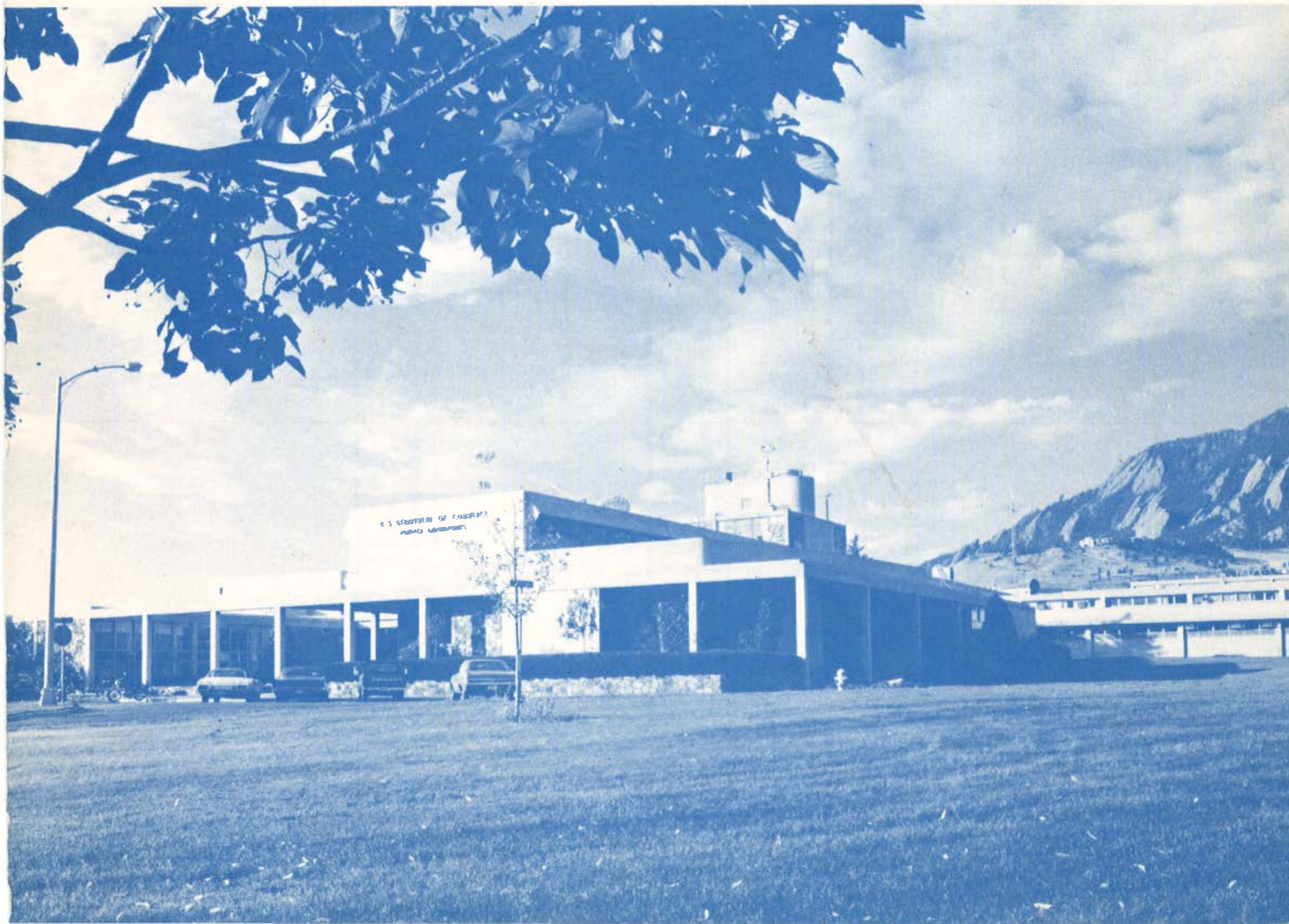
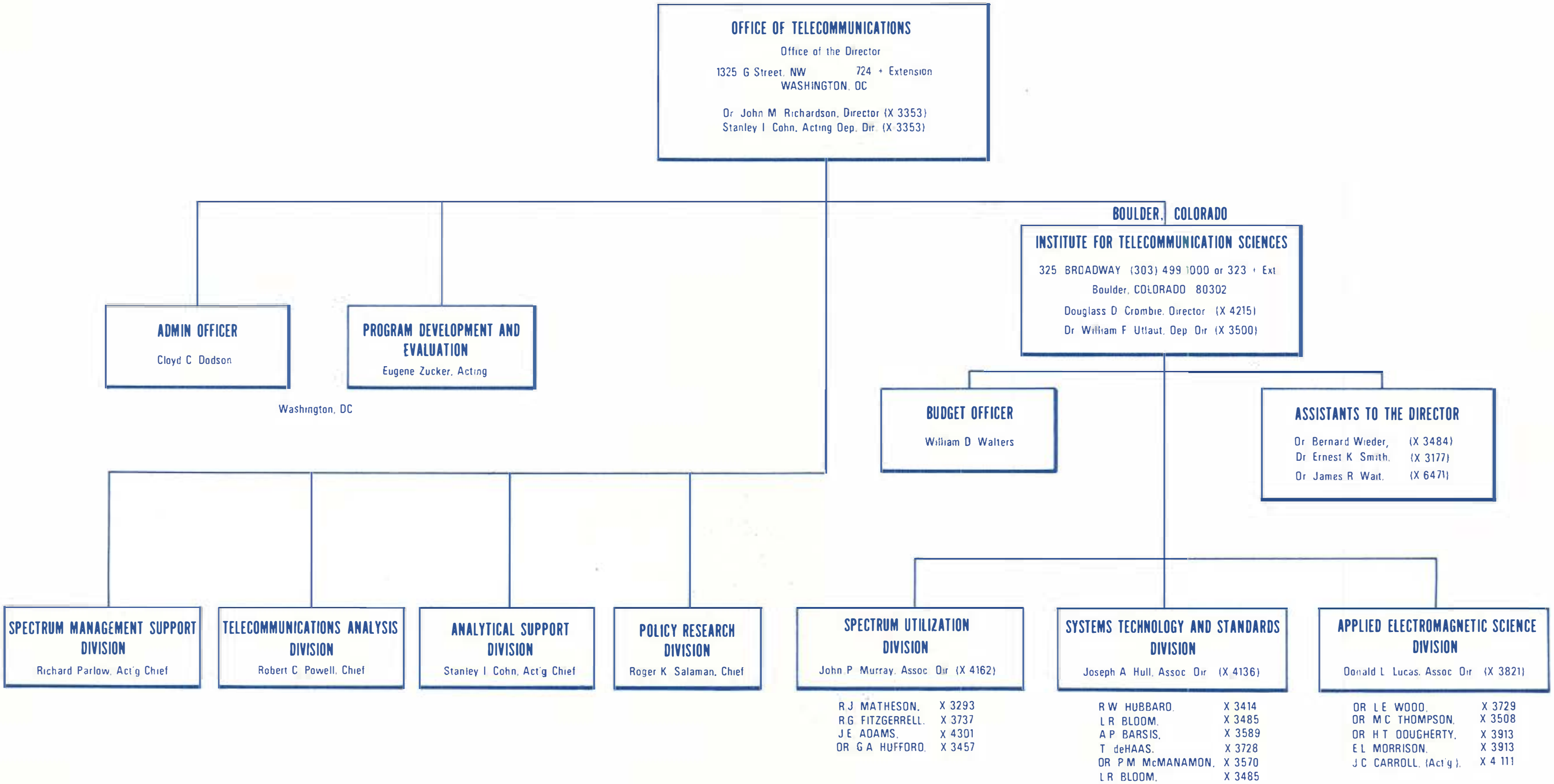
INSTITUTE FOR TELECOMMUNICATION SCIENCES
OF THE
OFFICE OF TELECOMMUNICATIONS

ANNUAL TECHNICAL PROGRESS REPORT 1976

For the period from July 1, 1975 through June 30, 1976





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ITS

ANNUAL TECHNICAL PROGRESS REPORT 1976

For the period
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U.S. DEPARTMENT OF COMMERCE
Elliot L. Richardson, Secretary

Betsy Ancker-Johnson, Ph. D.
Assistant Secretary for Science and Technology

OFFICE OF TELECOMMUNICATIONS
John M. Richardson, Director

INSTITUTE FOR
TELECOMMUNICATION SCIENCES
Douglass D. Crombie, Director
Wm. F. Utlaut, Dep. Dir.

FOREWORD

This annual report describes progress of the technical program of the Institute for Telecommunication Sciences (ITS) during FY76. ITS is the research and engineering arm of the Office of Telecommunications in the Department of Commerce.

The role of the Office of Telecommunications can be stated succinctly:

> To provide specialized research and analysis essential to successful application of telecommunications technology.

OT and ITS goals which form the focus of ITS activities are:

- Increase the availability of usable spectrum by engineering methods.
- Increase the likelihood of satisfactory telecommunication system performance, as affected by natural, engineering, and economic factors.

ITS' contribution to the achievement of these goals is provided through implementation of three major program elements:

- Efficient use of the spectrum,
- Engineering and evaluation of systems,
- Electromagnetic-wave transmission research and services.

These three program elements are not independent of each other, but have a high degree of interaction. For example, transmission phenomena play an important role in determining whether radio systems will work in the field, as do questions of mutual interference between systems or subsystems. Variability of transmission loss through the atmosphere determines the physical separation between systems sharing the same frequency and thus affects the efficiency of spectrum use. Engineering of systems to obtain the required performance demands adequate knowledge of transmission loss and distortion, as well as the effects of interference.

Efficient Use of the Spectrum

The objective of this program element is:

> To show how to substantially increase the permissible number of users in congested regions of the spectrum.

The spectrum is a limited natural resource being subjected to ever-increasing demands. Our role is to examine and understand the basic scientific and engineering factors which affect the efficiency of spectrum utilization, and to foster and encourage the use of techniques which maximize the number of spectrum users receiving satisfactory performance in a given geographical area, under interference-limited conditions.

Major opportunities for improving the efficiency with which the spectrum is used include the proper application of bandwidth expansion; reduction of radiation in unwanted directions from directive antennas; improving the predictability of the signal strength of both wanted and unwanted signals; understanding the interactions between systems which are closely-spaced geographically; recognizing that interference from co-channel signals may constitute a stronger and different performance limitation than natural or man-made noise; recognizing the desirability of maximizing the <u>joint</u> performance of many links rather than that of single links; and developing usable criteria for evaluating system performance versus spectrum requirements.

Most of the directly-funded portion of this program element is concerned with the basic issues mentioned above. In addition, work for other Federal agencies is concerned with electromagnetic compatibility analysis and radio coverage estimation. A major part of the effort is in support of the OT Spectrum Management Support Division in its role of assisting the Office of Telecommunications Policy (OTP), which manages the Government portion of the spectrum.

Highlights of FY76 activities include:

- Application of the Spectrum Efficiency Trade-off model to evaluate the effects of modulation index, required signal to interference ratios, and uncertainties of transmission loss.
- Measured the performance of six digital modems in presence of interference and Gaussian noise.
- Investigated the conditions necessary to allow small mobile satellite earth-terminals to operate in the U.S. in the 7-8 GHz band.
- Issued a report summarizing available knowledge about the

location variability of transmission loss in the VHF and UHF bands, with particular application to land mobile and broadcasting systems.

Engineering and Evaluation of Systems

The objective of this program element is:

- To provide user-oriented telecommunication system performance criteria and methods of performance measurement, and to relate these to more conventional engineering parameters.

ITS has recognized that there is a significant need for adequate means of specifying, evaluating, and measuring the performance, from a user's point of view, of telecommunication systems, and is attempting to fill this void. Criteria which are system independent, and which represent performance at the user's interface with the system, are badly needed for comparing alternative or competing services and for evaluating their benefits versus cost. In addition, improved techniques for the measurement of performance in the engineering sense of multiplexed, encrypted signals, in real time on message trunks, are badly needed to detect incipient failures. ITS is developing criteria and measurements for both voice and data transmission.

In addition, this program element is concerned with channel simulation and evaluation of modem techniques, and communications via fiber optics. Channel simulation is concerned with making available, in the laboratory, simulated channels which reflect accurately, in a statistical sense, the various multiplicative effects or distortions which occur on real channels, and which may cause a greater limitation to performance than additive noise. Such laboratory channel models are used to test and compare real hardware under controlled conditions much more economically than can be done in the field.

Communications by fiber optics promises to have significant impact on the transmission of very wideband signals, and may eventually replace terrestrial and submarine coaxial cables and mm waveguides for high data rate transmission.

Significant achievements in FY76 include:

- Provided assistance to the U.S. Postal Service in evaluating proposals from industry for work on electronic message handling systems.

- Served as Technical Management Organization for FCC, overseeing technical performance certification. circuits involved in determining user reactions to telephone conversations relayed through one, two, or three satellite circuits.

- Completed engineering handbooks on design of Line-of-Sight microwave systems and transhorizon microwave systems.

- Completed measurements on 12 proposed digital microwave links in Europe, using the ITS channel probe, to determine optimum antenna heights and link design parameters.

- Continued participation with industry, university and government workers as part of the activity of the Task Force on Optical Communications established by OT/ITS.

- Completed procurement and installation of an ARPA network host computer facility at ITS to initiate a measurement program for testing the ability and practicality of the data communication performance measures specified in Federal Standard 1033.

Electromagnetic Wave Transmission

The objective of this program element is:

- To provide complete, quantitative EM-wave transmission characteristics of communication channels for the many spectral regions of current interest.

ITS efforts in this area are aimed at improving the successful deployment of radio systems designed to operate near the state-of-the-art, insofar as propagation is concerned. Deleterious propagation effects form a basic limitation to the performance of radio systems. Attenuation, scattering, ducting, and refraction affect both wanted and unwanted signals. Scattering and multipath may limit the available bandwidth.

ITS efforts in FY 76 continued to be directed mainly at the higher-frequency end of the spectrum, above 10 GHz. Notable achievements include:

- Constructed a three-frequency test facility operating simultaneously at 9.6, 28.8, and 57.6 GHz with 1 Gb/s modulation capability, to collect comparative data about atmospheric effects on microwave and mm wave transmission through the atmosphere.

- Demonstration of the use of tilted antennas to reduce outage time of microwave links subject to fading caused by atmospheric multipath.
- Improvements to the mm wave transmission spectrometer which reduce instrumental errors resulted in measurement of the strength and width of 21 lines of the O_2 microwave absorption spectrum.
- Survey of atmospheric refractive index profiles in the Persian Gulf and the Gulf of Mexico for use in determining radar coverage.
- Further improvement and verification of methods for predicting the effects of rain on terrestrial and satellite microwave paths.
- Prepared FM broadcasting coverage maps of the U.S.
- Development of improved models for predicting multihop high frequency propagation.
- Development of a model of the ionospheric D-region, for predicting LF and VLF field strengths, based on over 500 D region profiles measured in various locations and at different times.

Other Highlights

Other significant achievements during FY76 by the ITS staff include:

- Dr. Hans Liebe received a Senior U.S. Scientist award from the Alexandra von Humboldt-Foundation of the Federal Republic of Germany.
- Dr. Mark T. Ma was selected by the Republic of China to join a panel of foreign scientists to advise on national reconstruction priorities.

A conference was held in May 1976 to identify problems associated with increasing the use of the 15-100GHz region of the spectrum so as to reduce pressures on the congested lower frequency region of the spectrum.

OT's policy concerning participation in CCIR and CCITT activities has been reviewed and reaffirmed. As a result, ITS staff will continue to play an important role in these organizations, particularly with respect to U.S. preparation for the World Administrative Radio Conference in 1979.

Support for Other Agencies

Much of the work described in this report is in support of other Federal Agencies and is funded by them. This work helps solve the immediate problems of the sponsoring agency. Such activities are mutually beneficial. They allow ITS to collect data which when combined with other data obtained under different sponsorship enables more comprehensive data bases to be maintained and developed inexpensively. By doing such work we are kept in contact with "real world" problems and our staff competence is kept relevant and up to date. The work for various sponsors enables us to recognize key problem areas whose solution benefits all users of telecommunications technology as well as the individual agencies sponsoring various aspects of the work.

In FY 76 our work for other Federal Agencies was oriented closely towards OT goals. Our criteria for acceptance of Other Agency work were reviewed, and as a result, even closer alignment will be achieved in the future.

OT's criteria for acceptance of work from Other Agencies can be summarized as follows:

1. The work falls within the authority of the Secretary of Commerce to undertake the work.
2. The work is relevant to national goals and commitments and has impact on these goals and commitments.
3. The work cannot be readily performed by the private sector (with certain exceptions such as unavoidable conflict of interest, intolerable delays, excessively higher costs, or unique facilities or capabilities within OT).
4. The work contributes to OT goals.
5. The work does not conflict with other ongoing work within OT. All these criteria must be met.

The revised criteria will continue to ensure that the work we do for Federal

Agencies will be a proper function of Government and consistent with the mission of OT and the Department of Commerce.

Acknowledgement

Dr. E.K. Smith was responsible for the preparation of the report, from material provided by Associate Directors - J.P. Murray, J.A. Hull, and D.L. Lucas, and by Dr. B. Wieder, Assistant to the Director. He was ably assisted by other ITS staff, particularly R. B. Stoner, and Mrs. M. Detmer.

Douglass D. Crombie
Director, ITS

Annex IV contains a listing of reports and articles describing work done by OT/ITS during FY76. A limited number of journal reprints are generally available and may be requested from the author. The journals themselves are usually available in technical libraries. OT Reports may be purchased from the National Technical Information Service, P. O. Box 1553, Springfield, Virginia 22161. Technical Memoranda are not available for general distribution but further information may be obtained by contacting the author or the Institute.

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CHAPTER 1. EFFICIENT USE OF THE SPECTRUM

The radio, or electromagnetic, spectrum has seen dramatic growths in demand and use since the beginning of World War II. Since that time, a great range of new spectrum-dependent services has evolved. American industry, government, and private citizens have put the spectrum to work in such profusion that now saturation appears imminent and, in some cases, has already occurred. To provide for new and expanded use, two major alternatives exist. One is to exploit new regions of the spectrum at progressively higher frequencies. The second is to provide for a better understanding of the basic physical principles upon which spectrum use depends and, complementing this understanding, provide for more effective means of managing spectrum use.

Spectrum use by the U.S. Government alone is growing nine percent annually in those frequency regions where equipment is readily available. Embryonic efforts are being made to use the even higher frequencies above 10 GHz where equipment still remains to be developed for many applications.

The Office of Telecommunications, Institute for Telecommunication Sciences (OT/ITS) conducts a program of research and development which addresses both of these alternatives. Much of the work being done to extend the use of the spectrum to higher frequencies is discussed in Chapter 4 of this report -- Electromagnetic Wave Transmission. Chapter 4 also provides brief mention of some of the work being done to improve our understanding of propagation problems in these regions of the radio spectrum that are already extensively used.

In this chapter, some highlights of the OT/ITS program directly concerned with spectrum engineering are reviewed. Many of these spectrum engineering projects draw heavily on experience from other programs in ITS, including antenna design and measurement, channel characterization and system performance, and the many propagation related efforts.

SECTION 1.1. SPECTRUM ENGINEERING FOR EFFECTIVE SPECTRUM USE

A wide range of research and engineering has been conducted to provide federal agencies with the means to assure adequate performance of proposed new systems which will face potential interference from other signals.

Compatibility of Collision Avoidance Systems. The prevention of mid-air collisions between aircraft has become an increasingly important problem as aircraft populations have increased and air travel has become an accepted method of public transportation. As steward of the air space, the Federal Aviation Administration has been instructed by Congress to make recommendations for the implementation of a National Standard for a Collision Avoidance System (CAS) for the United States. Candidate systems for an air-borne CAS were developed by three private companies. The systems were designed to operate in the frequency range 1592.5 to 1622.5 MHz, which was the provisional frequency assignment made by the Federal Communications Commission for the exploratory development of an air-to-air CAS. This assignment is in the radio navigation band, which extends from 1535 to 1660 MHz.

The Institute for Telecommunication Sciences was asked to investigate the electromagnetic compatibility of the CAS with other occupants or proposed occupants of the radio navigation band. It was determined that no serious potential for compatibility problems was likely except between the CAS and five models of radar altimeters which are operational in the band.

A laboratory measurement program was conducted in which each of the three CAS were tested for interference problems with each of the five "L" band radar altimeters. Values of Interference-to-Signal ratios (I/S) at which each of the CAS failed due to interference from the radar altimeters were determined. The I/S ratios were then used in the analysis of several scenarios to determine the extent of problems which would exist in actual flight situations. In addition, the I/S values were used in a statistical analysis in conjunction with an air traffic model of Los Angeles Basin for the year 1980 to determine the magnitude of the problem under simulated dense air traffic conditions.

The work on the project has been completed and a final report, FAA-RD-75-229, has been printed.

In order to make better use of the radio spectrum, many frequencies in the spectrum can be shared between satellite and terrestrial systems. However, we need to know the magnitude of the signals at the satellite from all of the terrestrial transmitters so that the systems will perform as designed in orbit. The *Interference to Geostationary Orbit* project developed a cost-effective method for predicting the signal levels at the geostationary orbit from the thousands of terrestrial emitters in the 5.92 to 6.425 GHz common carrier band. The method is based on frequency assignment files and a mathematical formulation of the system's antennas and their signal structures. The evaluation of the method has been based on comparison to ATS-6 signals recorded during 1975. The schematic representation of this situation is presented in figure 1-1.

This year the prediction model has been improved with the inclusion of the in-orbit measured gain for the ATS-6 antenna, a current set of assignment data, and a modification in the spectral shape of the terrestrial signals. The data for several patterns have been combined, and a generalized least square fit to the data obtained and used for the antenna pattern in the model. Measurements of the signals transmitted by AT&T were obtained at their Pleasant Valley, Colorado, facility. Of particular concern in predictions of this kind are the pointing angles of the terrestrial antennas with respect to the geostationary orbit location. This information has, in the past, been very difficult to develop. Figure 1-2 presents the distribution of these pointing angles for one orbital location.

A number of measured data were obtained for the ATS-6 antenna pointed at Ithaca, New York, and Columbus, Ohio. These data were then compared to prediction of signals at these same two locations. Samples of the signals for a 100 kHz bandwidth are shown in figure 1-3 for the Columbus, Ohio, target. There are a number of signals predicted that do not appear in the measured data. These are probably the result of frequency assignments that have not been implemented by the users. For those signals that do occur in both the measured and predicted data, a good agreement is shown in their amplitudes, although the measured signals are slightly higher. Estimates for terrestrial antenna side-lobe patterns are thought to be slightly below actual values, although measured data are not available. This is one factor expected to contribute to the measurement versus predicted disparity.

OTP A continuing OT/ITS responsibility to the Office of Telecommunications Policy (OTP) is the Support to Spectrum Analysis work done by the Office of Telecommunications, Spectrum Management Support Division. The project supplied special analyses and measurements as they were needed. The project utilized interference analysis models previously developed by ITS, tailored to the specific telecommunication systems studies being conducted by OT.

During FY76, ITS provided analysis support for studies in the government land-mobile bands (162-174 MHz and 406-420 MHz), the efficient use of the 7-8 GHz band, the efficient use of the 2700-2900 MHz radar bands, and the efficient use of the 13-15 GHz band. Analysis support was also provided for the 1030 MHz radar beacon measurements. One class of output is shown in figure 1-4, where potential interference from an airborne transmitter sharing the same frequency band with terrestrial microwave systems is shown. The analysis method (known as ATTIC) allows great flexibility in the definition of various problems to be studied. This method operates directly from computer data bases of equipment locations and technical characteristics.

6536

Man-made Noise causes interference which is, quite often, the limiting factor in communications/electronics system performance. This interference results in communication systems being required to use excessive powers and/or spectrum space, thereby hampering the efficient utilization of the limited spectrum resource. The main purpose of this project was to:

1. assess the adequacy of information presently available and being collected,

2. define and assess the adequacy of recent abatement measures,

3. make specific recommendations on additional required abatement measures, and

4. make specific recommendations as to necessary additional research.

These items were covered in detail with the results given in OT Report 76-85, "Man-made noise -- The problem and recommended steps toward solution," April 1976.

This report concentrates on incidental radiation devices, summarizes all existing standards and abatement measures for these devices, and makes recommendations as to additional required measures. General and specific examples of degradation to systems by man-made noise are given. It is shown that, both technically and economically, further suppression of automotive ignition noise at the manufacturing level is required. Means of achieving this required suppression are given. Other sources (e.g., power transmission lines) are also discussed.

Existing programs for noise measurement, analysis, and model development were summarized, and recommendations for the attaining of required additional information on the noise environments were given. In addition, the role that better information on the noise environment should play in the proper arrangement of the spectrum was covered.

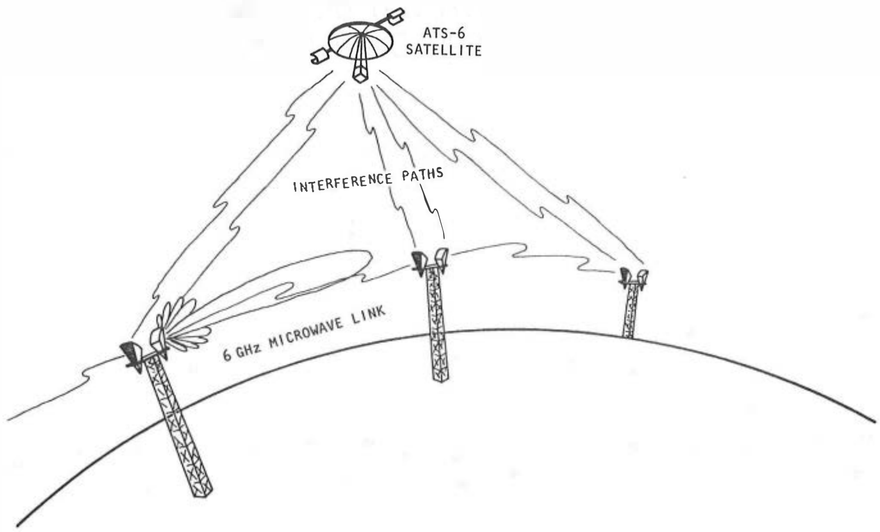


Figure 1-1. Sketch of ATS-6 and terrestrial interference relationships.

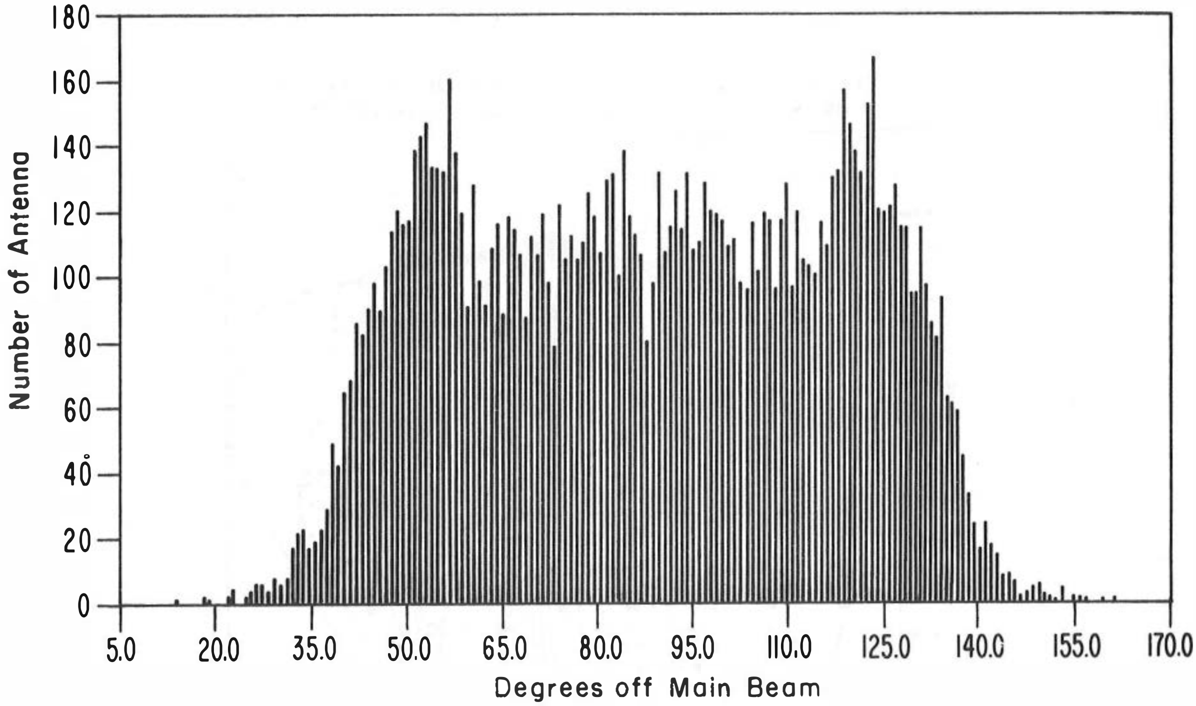


Figure 1-2. The distribution of the angles between each terrestrial stationary main beam, and the ATS-6 satellite location.

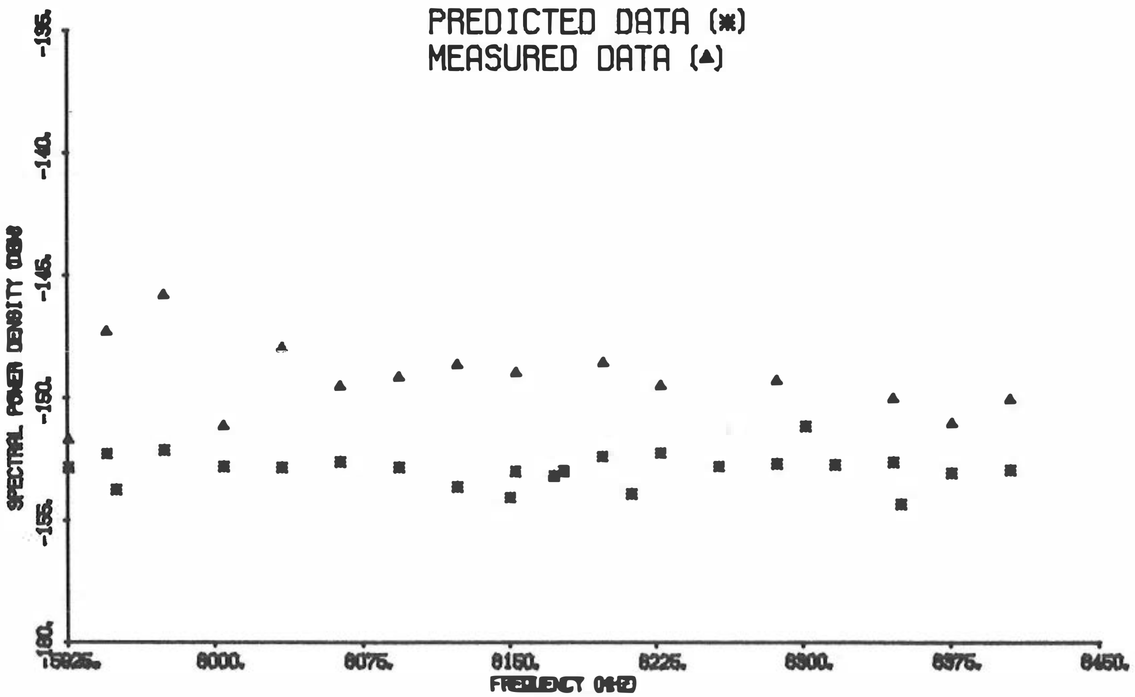


Figure 1-3. ATS-6 signals measured at Columbus, Ohio.

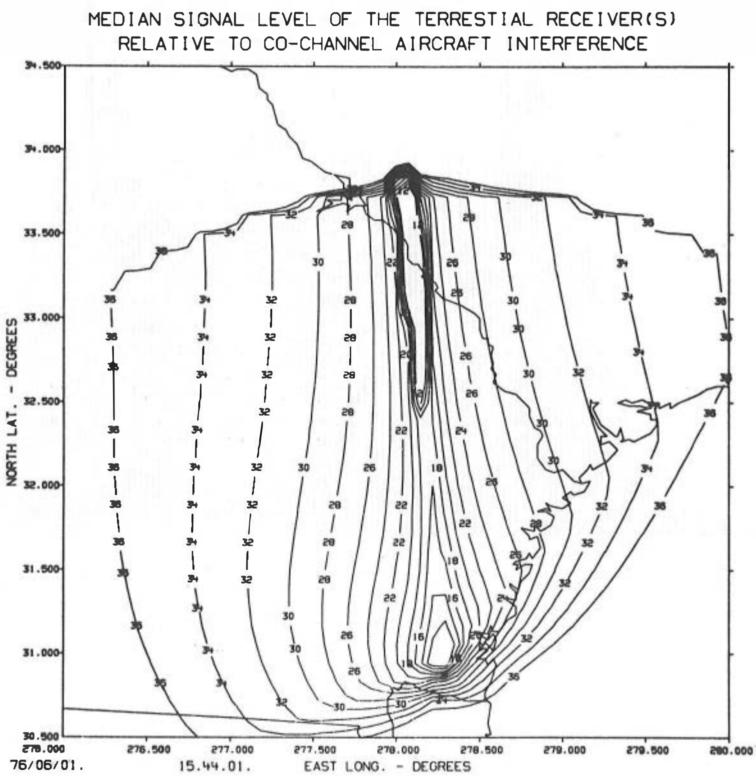


Figure 1-4. Interference contours generated by the program ATTIC considering interference from an airborne transmitter to terrestrial microwave links.

The results of this study will be used by the OTP and IRAC, especially with regard to FCC Docket No. 20654, a Notice of Inquiry on "interference from spark-type ignition systems in motor vehicles."

Previous work resulted in the development of algorithms to determine the optimum performance of existing communication systems in narrowband impulsive noise (generally the result of various combinations of intentionally radiated signals). (See OT Report 75-67, "Optimum reception in an impulsive interference environment," June 1975.) Another task accomplished under the present project was extending these detection algorithms to include broadband man-made noise.

3414 RFI Surveys for WSR-74C Radar Installations were performed for the U.S. Department of Commerce's National Weather Service to assess the radio frequency interference environment for the installation of approximately sixty (60) C-band (5.6 to 5.650 GHz) weather radars. The project studied interference potential between the radars and microwave systems operating in the vicinity. Data from the Interdepartment Radio Advisory Committee (IRAC) computer files were used along with OT/ITS propagation models to predict potential interference, to recommend optimum radar site locations, and to suggest technical and operational means for minimizing interference. The effects of terrain shielding were considered in these studies. Figure 1-5 is a typical output from program SHADO -- one method used to consider terrain effects.

3416 The Automotive EMI Research conducted this fiscal year was the second phase of a study, performed for the National Highway Traffic Safety Administration, to determine the potential problem of electromagnetic interference from all sources (internal and external to the vehicle) that may cause malfunction of motor vehicle electronic control and electronically activated safety control devices.

The Phase I study produced documents and models including:

1. a file of potential interference sources internal to the vehicle,

2. a file of potential interference sources external to the vehicle,

3. a computer analysis of the conducted and coupled transfer of signals in typical cabling and wiring circuits of the vehicle,

4. computer analysis to determine sensitivities of typical automotive electronic circuits and subsystems, and

5. an outline of validation tests and preliminary guidelines identifying potential problem areas.

The Phase II effort was designed to validate and expand the files on the internal interference sources through measurements of signals generated by normal equipment functions and subsequent transfer and coupling of these signals via the cabling and wiring harnesses. An electromagnetic field-to-wire coupling analysis program was used to further study the impact of cable length, impedances, and aperture (openings in the vehicle body) sizes on the potential coupling of signal fields onto typical vehicle cables.

A series of susceptibility tests, also performed in Phase II, were designed to describe a testing procedure and to obtain system upset (malfunction) levels in the presence of interference signals characteristic of those described in the environmental files. Candidate systems for this testing were a speed control system and an anti-skid braking control module.

The results of the environmental measurements, the subsystem tests, and information obtained from the current research and study efforts of the electronic and automotive industries served as a basis for refining the EMC guidelines set forth in Phase I.

Figure 1-6 identifies and describes some of the potential external and internal interference sources which may cause conditions of upset or malfunction in automotive electronics. These signals are considered to be the worst-case situations which will exist under normal vehicle operating conditions. A further example of the vehicle internal environment is illustrated in figure 1-7. This figure is one of a set which resulted from the measurements program designed to evaluate signals that are generated and coupled within the vehicle. The waveforms in figure 1-7 are typical of those generated (and coupled) from normal operation of electrical devices in the vehicle.

Several sets of data resulted from the susceptibility tests conducted on the speed control system and the anti-skid control module. Representative of these data is figure 1-8. Upset levels (of injected signals) are shown as a function of frequency. These data show that the velocity sensor is almost immune to interference below 15 MHz and very susceptible above 50 MHz. A region of intermediate susceptibility occurs between 15 and 50 MHz. The injected interference signal was continuous wave, and the upset criterion was defined as a departure from

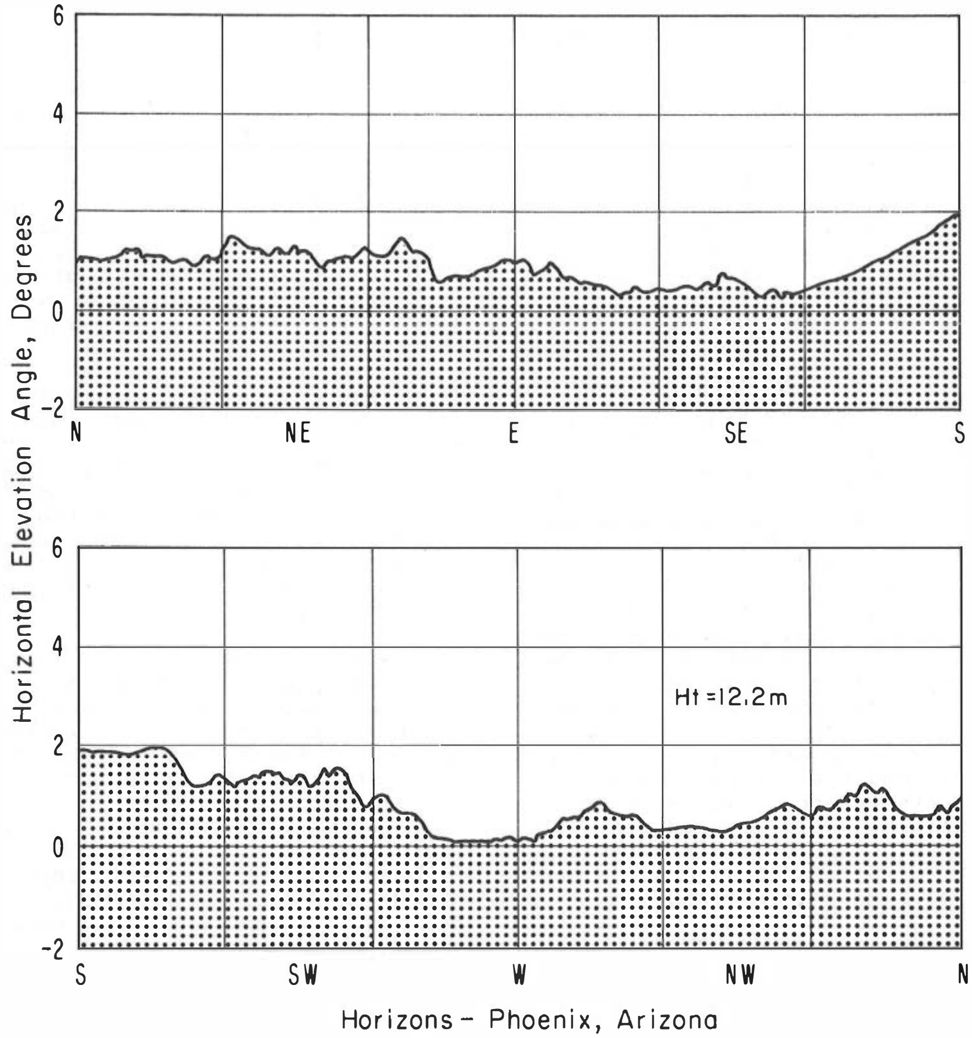


Figure 1-5. Horizon angles around a proposed radar site.

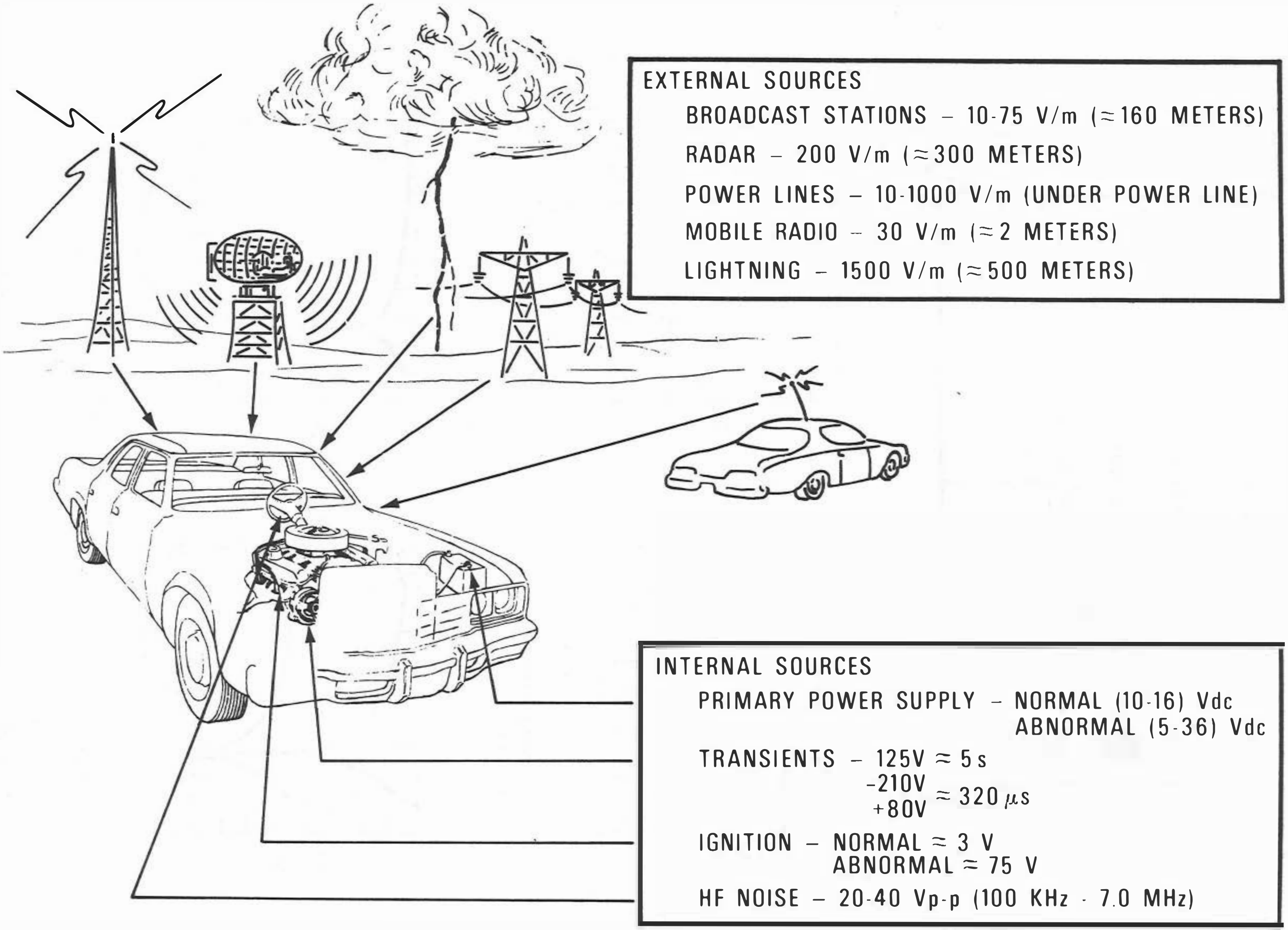
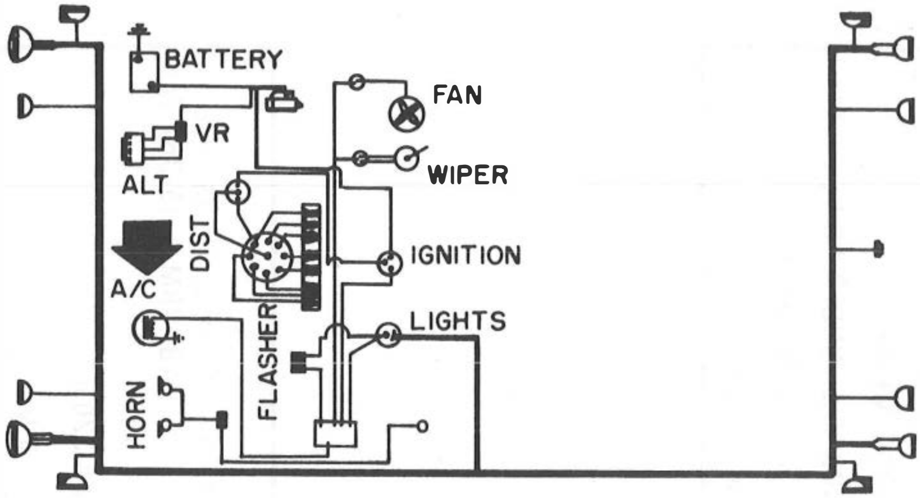
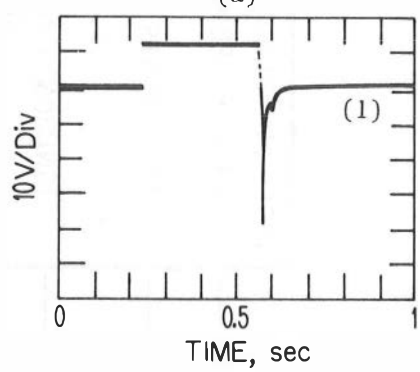


Figure 1-6. Sources of electromagnetic interference.

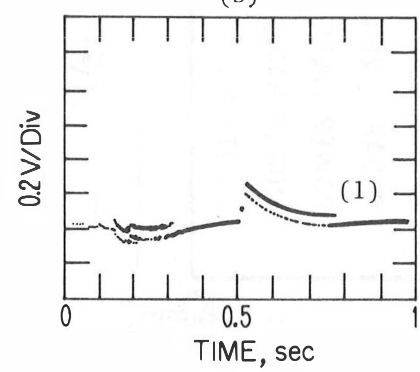


(a)



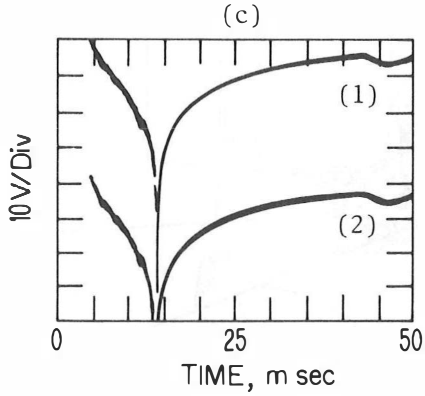
1 Air-conditioner clutch (on-off)

(b)



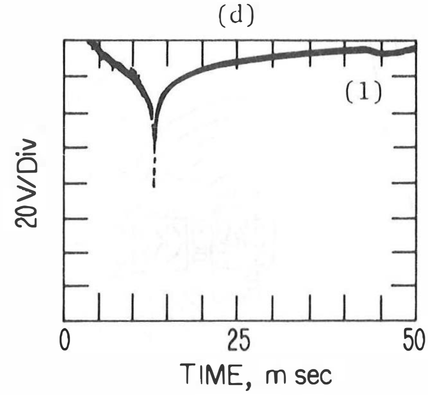
1 Main bus (clutch on-off)

(c)



1 Air-conditioner clutch (off)
2 Air-conditioner switch (off)

(d)



1 Air-conditioner clutch (off)

Figure 1-7. Air-conditioner clutch waveforms.

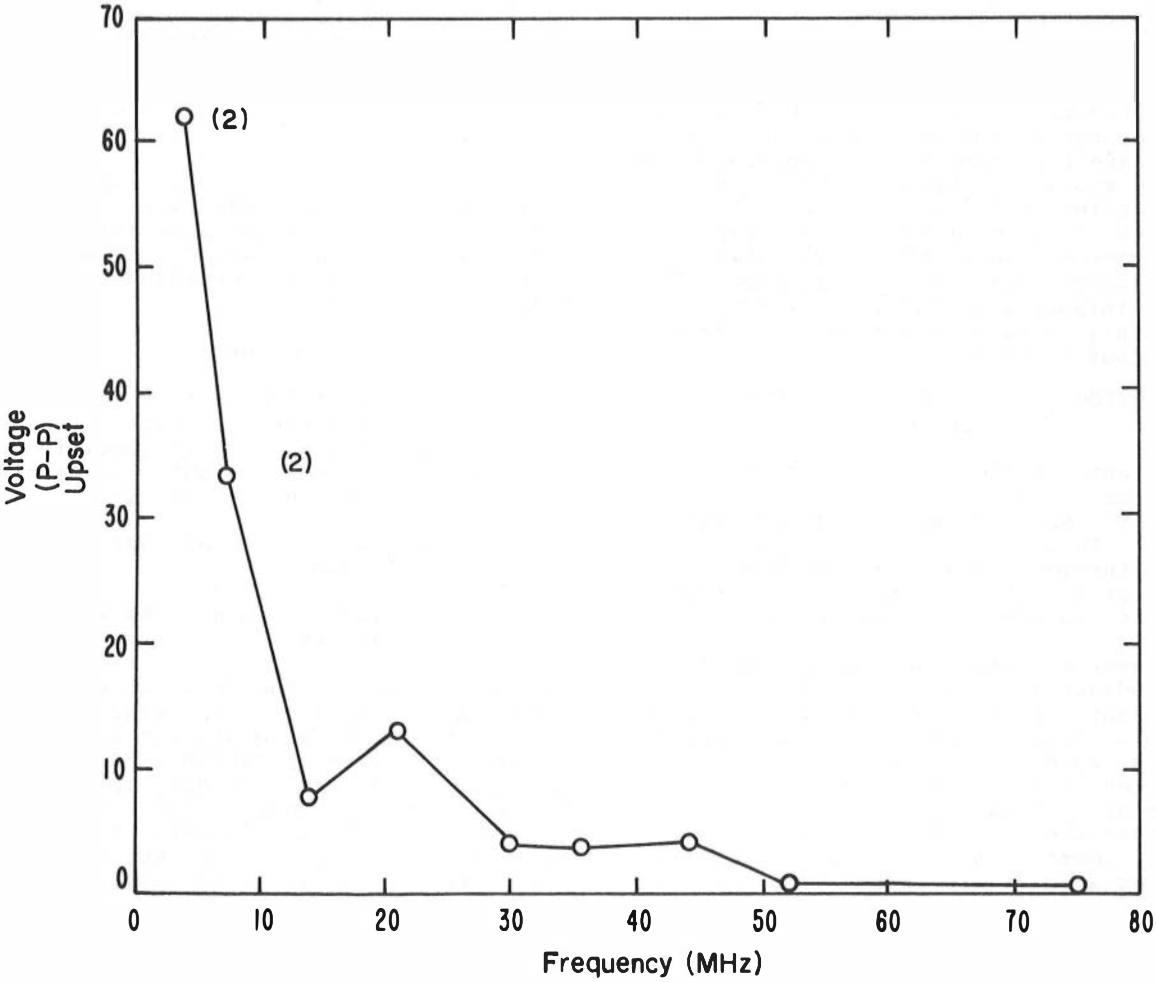


Figure 1-8. Anti-skid sensor line test results (dual input - cw).

a brake modulation rate measured during a noninterference condition.

The EMC guidelines resulting from this study will serve to emphasize and highlight those factors in the use of electronics for automotive safety and control that are important to the accomplishment of EMC among the various subsystems. In considering rules or standards for electronics in automobiles, it is important to remember that the applications of electronics for these purposes are in their infancy and that the trend is most certainly toward a modular or central processor concept.

SECTION 1.2. SPECTRUM ENGINEERING TECHNIQUES

Important methods and techniques for Spectrum Engineering are under development to meet a wide range of requirements. These methods address very specific situations as well as the broad questions of optimization to provide maximum benefit to the total user community.

For over a decade, government, academic, and industrial groups have advocated development of methods for improving the overall effectiveness of the utilization of the spectrum (as opposed to the optimization of the performance of individual systems). This concern paralleled and even predated similar realizations that ideal common use of environmental resources such as air and water may not coincide with economic maximization of an individual user's profits.

6737 The objective of the Tradeoffs for Optimum Spectrum Use project is to develop a quantitative model which can evaluate the complicated interaction of spectrum use factors and determine the specific tradeoffs which result in maximum aggregate service in a congested frequency band and area. The methods will be useful to spectrum policy makers, frequency managers, and organizations operating spectrum-using systems.

The initial model developed last year was extended to accommodate narrow-beam antennas with probabilistic patterns, time-occupancy probabilities, and consideration of the distribution of equipment in frequency. Ways of including distributions of antenna heights and tuning errors in the calculation were formulated. The basic output parameter of the model is "spectrum utilization efficiency," but there is no generally accepted definition of that term. The general form chosen for this project is:

$$\frac{\text{communications achieved}}{(\text{bandwidth})\bullet(\text{geometric space})\bullet(\text{time})}.$$

A paper justifying this choice appears in the Conference Proceedings of the IEEE 1976 International Symposium on Electromagnetic Compatibility, and CCIR Study Group 1 adopted a new report incorporating this concept at its 1976 Interim Meeting.

Some possible tradeoffs in a proposed new citizens' band at 225 MHz were analyzed making a number of reasonable assumptions about equipment and service type. The spectrum utilization efficiency, E, was defined as follows:

$$E = N/(B\bullet A)$$

where: N is the number of users with satisfactory service (satisfactory service is specified by a given output signal-to-interference level, Q),

B is the total bandwidth in MHz, and

A is the total area served in square km.

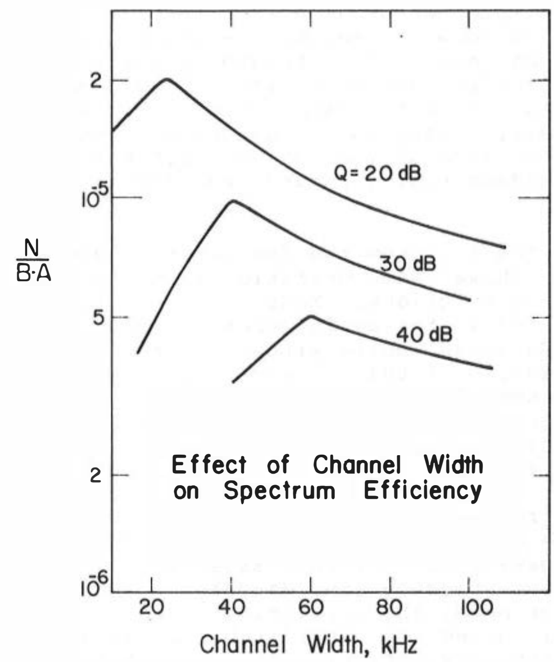
Figure 1-9 shows the spectrum use efficiency as a function of individual channel width for three qualities of service assuming FM voice operation. For a low quality service (Q = 20 dB), the optimum channel width is about 25 kHz. For high quality service (Q = 40 dB), the optimum channel width is more than 60 kHz, and only one-fourth as many users can be served.

Figure 1-10 shows spectrum use efficiency as a function of the uncertainty in transmission loss and the likelihood of achieving the desired quality of service. Decreasing the uncertainty in transmission loss increases the number of users who can be served, and relaxing the service probability required also increases the number of possible users.

6733 Digital Interference Evaluation. The performance of digital systems in interference has been the subject of a number of studies during the past few years. Most of the work, however, has been theoretical and is based on ideal modems and filters. Experimental verification of the predictions is either rare or nonexistent. Thus, the following project was undertaken to measure the performance of various types of digital systems in noise and interference, and then compare the results with predictions using analytical methods developed earlier in this project.

The performance of six different digital modems was measured in Gaussian noise and additive interference. These modems represent five different types of digital

Figure 1-9. Spectrum utilization efficiency in proposed Citizen's Band as a function of channel width for three qualities of service. Notice the optimum channel width for each quality of service.



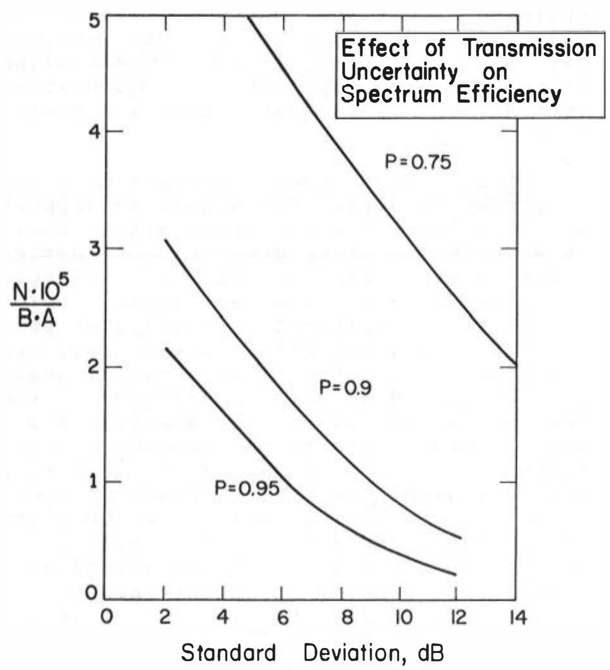


Figure 1-10. Spectrum utilization efficiency as a function of transmission loss uncertainty, for three service probabilities.

modulation. Two of the digital modems used phase-shift-keying with coherent detection (CPSK), and one of the modems utilized phase-shift-keying with differentially coherent detection (DPSK). Modulation formats used by the other modems include noncoherent frequency-shift-keying (NCFSK), minimum-shift-keying (MSK), and a third technique that is presently classified only as a bandwidth conservation type of modulation. Bit rates of the modems tested ranged from 300 to 9600 b/s.

The results from the laboratory measurements showed some deviation from theoretical predictions. Most of the deviation appeared in the performance of the modems in Gaussian noise without interference. An example of this is given in figure 1-11 where the probability of error of one of the CPSK modems is shown with only Gaussian noise. As can be seen, the actual modem performance is about 3.5 dB from theoretical predictions. This is also reflected in the prediction for this modem in interference. Figure 1-12 shows the performance of this same modem with cw interference and Gaussian noise. As can be seen, the prediction based on an ideal modem is considerably optimistic. If the predictions are corrected for nonoptimum performance, however, they agree reasonably with the measurements.

The modems were also measured with a variety of different interference situations. Data were collected showing the effects of frequency offset between the victim and interferer. The performance of the modems was also studied with modulated interference as well as cw interference, and the effects of interference on acquisition time were also measured.

Currently, a report is being prepared describing the test results. Plans for future studies on the subject include measurements of complete digital systems in interference. Also, procedures are to be developed for theoretically predicting degradation to digital systems from any type of interference. These procedures are to take into account the nonoptimum performance of the modems.

EMC of Small Earth Terminals. The U.S. Army is developing a series of transportable or mobile satellite terminals for use in the 7-8 GHz band (figure 1-13). These systems must share this band with a large number of terrestrial microwave systems. Procedures are needed to insure that the systems will operate compatibly.

This program has examined the impact on the radio rules and regulations caused by the introduction of transportable terminals into this frequency band, and has developed procedures for making frequency assignments to these systems that will insure electromagnetic compatibility with the other occupants of this band.

The project reviewed the national and international radio regulations as they affect operation of transportable terminals in the 7-8 GHz band. The project developed a procedure by which area frequency assignments could be made to transportable systems. This procedure is based on a comprehensive calculation of signal-to-interference ratios over the desired operating area of the satellite terminals. The calculations of EMC are made using actual operating equipment parameters, and actual earth topography. A model for the earth terminal antenna was also developed, and trade-off studies were made to show the effects on orbit utilization of the 65λ transportable earth terminal antenna in comparison to the larger 48λ dishes used by some fixed terminals.

The study has shown that these Army transportable terminals can operate compatibly with the existing terrestrial assignments where the proper frequencies are chosen for earth terminal operation as a function of area. An area assignment procedure produces restricted area maps (RAM's) that show regions to be avoided (figure 1-14). The study has recommended that the concepts of mobility, transportability, and area assignments for earth stations be discussed in the national and international forums so that provisions for this type of operation can be clearly established. The results of this study will be used by the Army and OTP to develop a procedure for compatible use of these terminals at four training locations in the U.S. The program STATIC developed for this project may also be readily used to establish restricted area maps for any region where terrestrial system data bases are available.

The Model Development project develops spectrum-use design techniques in support of the Office of Telecommunications Policy which would offer greater confidence/lower risk in the analysis of inter-system interference. The techniques, which usually are implemented as computer programs for ease and efficiency of use, are developed to meet the OTP's system-analysis needs and are made available to the IRAC-member agencies. The analysis tools and techniques assist the frequency managers and spectrum analysts in making more efficient use of the frequency spectrum by developing methods which allow the managers and analysts to vary system-design parameters. The results of such parametric studies pinpoint needs for lower antenna sidelobes, or lower transmitter out-of-band emissions, or optimal operating frequencies, etc., to minimize

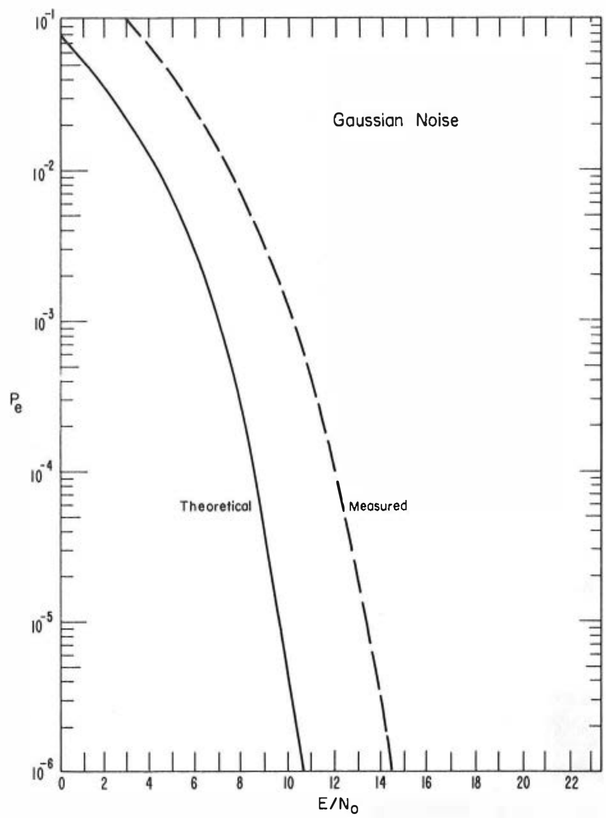


Figure 1-11. Measured performance of CPSK modem in Gaussian additive noise.

Figure 1-12. Measured performance of CPSK modem in interference Gaussian noise.

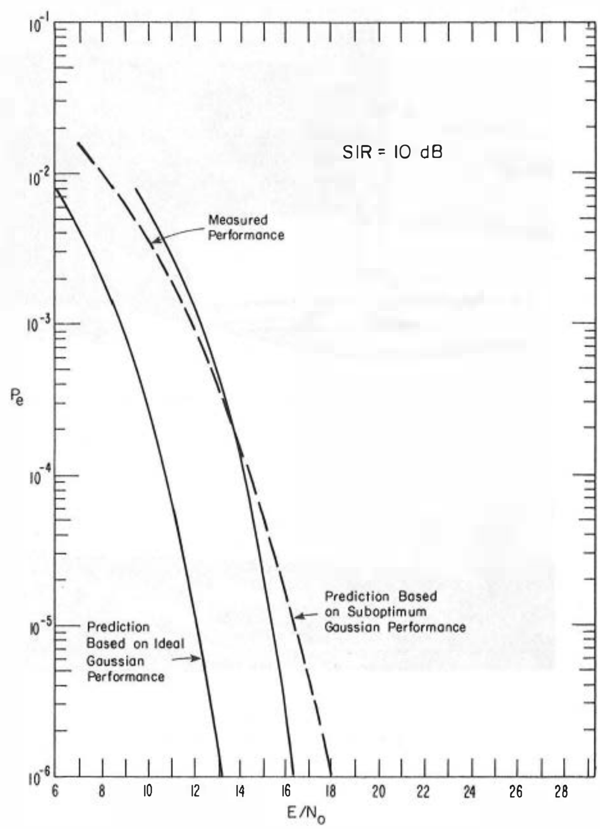


Figure 1-13. The U.S. Army Small Earth Terminal AN/TSC-85.

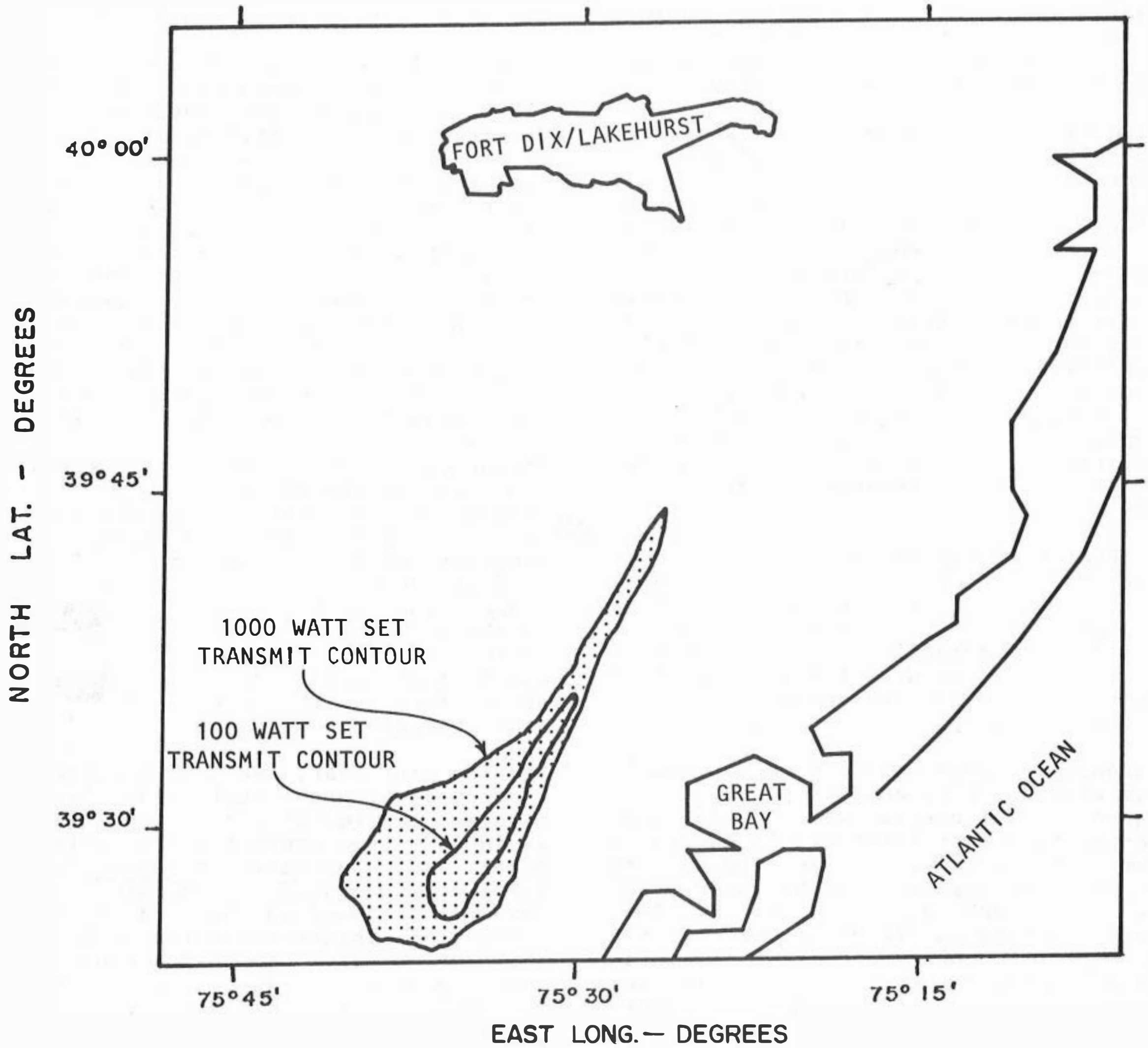


Figure 1-14. A sample restricted area map produced by program STATIC for small earth terminal operations in the central New Jersey area.

potential interference between systems which are sharing the same frequency bands.

The objective of using these techniques is to maximize the probability of success when introducing a new system into its operational environment. Large pay-offs are potentially available if frequency managers and system designers consider the EM environment during a new system's design phase and before the operational phase when retrofits can be costly.

During FY76, this project developed techniques for 1) computing statistical interference-to-noise ratios between fixed terrestrial systems, 2) computing earth footprints from geostationary satellites with idealized antennas or with user-supplied antenna patterns, 3) computing interference from airborne transmitters to fixed terrestrial receivers, and 4) computing antenna pointing angle and EIRP restrictions from fixed terrestrial transmitters to the geostationary satellite orbit. Figures 1-15 and 1-16 are examples of earth footprints from a geostationary satellite showing contours of constant satellite-antenna gain on the earth's surface.

The Probabilistic EMC Model project concluded the first phase of a long-range project to support the OTP and IRAC by developing analysis tools that allow statistical consideration of the variability associated with each of the many factors affecting spectrum use and electromagnetic compatibility.

Frequency managers need the best possible tools with which to analyze possible new frequency assignments which could cause or experience interference. In the past, a deterministic, "worst case" approach to frequency management often has been practiced for lack of better tools. This practice denies an efficient use of the radio spectrum, because conclusions indicate more need for spectrum than is actually the case. This project has undertaken statistical characterization of each factor which can cause variability to an interference situation and, thus, to achieve an understanding of a situation which is realistic. These factors are pictorially enumerated in figure 1-17.

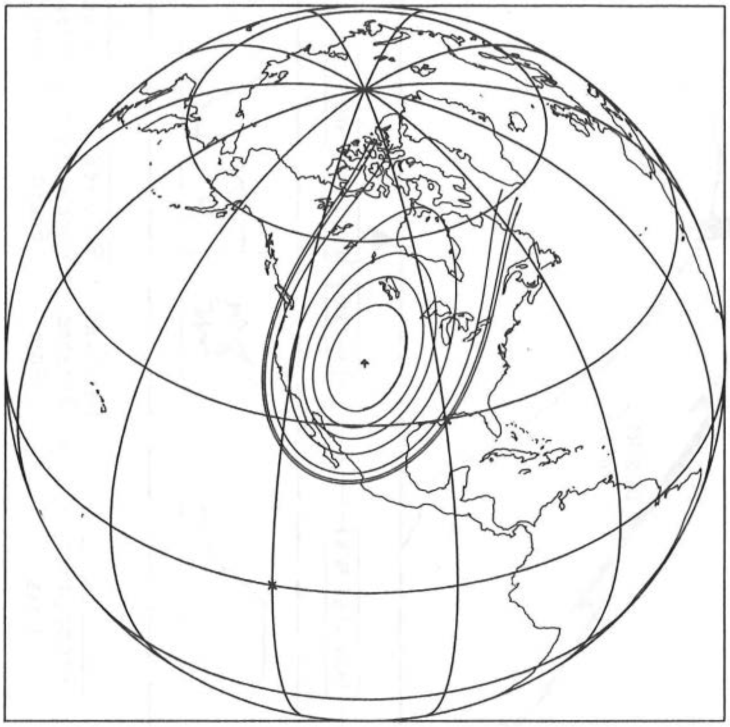
The initial phase of this project involved the statistical characterization of the transmitting and receiving antenna gains and the propagation loss, then the development of a model for statistical frequency-distance curves. Such curves provide an estimate of the minimum distance separation that is required between a victim receiver and an interfering transmitter as a function of the frequency offset between them. The curves are parametric in the probability or percent of time that interference no greater than a specified level can be expected. The model used statistical variations in the antenna gains and propagation loss to compute the probability of interference. This model has been documented in OT Report 76-84, "Statistical Frequency-Distance Curves, Initial Model."

A plot of frequency-distance curves such as are typically computed by the model is shown in figure 1-18. These curves show the frequency separation-distance separation relationships which on the average will realize interference no greater than the noise power of the receiver (-88 dBm) 5% (solid curve), 10% (dashed curve), and 50% (dotted curve) of the time. The model also will provide separate output data on the computed frequency-dependent rejection of the receiver. This measure is the combined value resulting from off-frequency rejection and bandwidth rejection when the receiver bandwidth is narrower than the emission spectrum width.

Frequency managers at the FAA require a knowledge of the service and interference ranges of the various air navigational aids. The Air Navigational Aids project supplies part of this knowledge. The project includes the development of a propagation model specifically addressed to the kinds of systems used in air navigational aids, the implementation of this model in various computer programs, and the delivery to the sponsor of the consequent computer output.

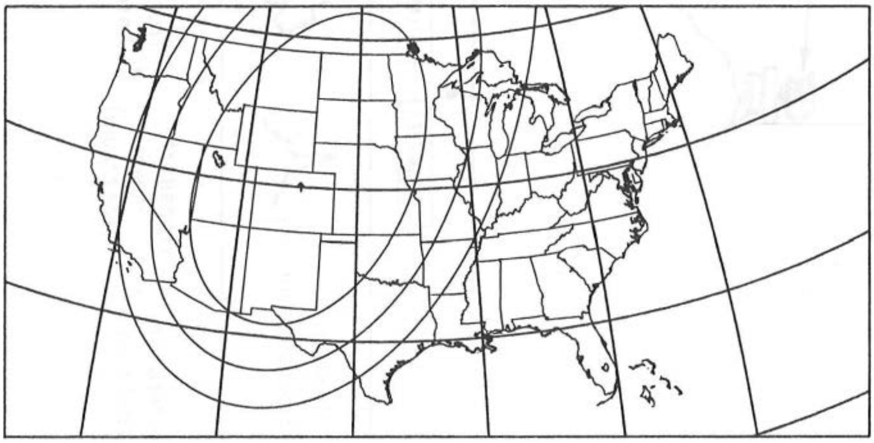
In the past year, new programs have been developed using the basic model for particular configurations. Among these was an "atlas" type presentation. Using the model, numerous curves (figures 1-19 and 1-20) were produced for background for a new FAA handbook in the area of ATC communications interference for both the UHF and VHF bands. Another computer capability developed during the past year was the ability to compute and plot required station separation as a function of relative antenna orientation. Antenna azimuth patterns are included in these calculations.

ITS is currently involved in a program to compare predictions using the current model with experimental data and with predictions made by other propagation models, the emphasis being on air/ground and air/air data. Ground-to-ground data is also being compared wherever applicable. Contributions are also being made to the new handbook for ILS (instrument landing system) planning and installation.



PARABOLA

Figure 1-15. Example of earth footprint from a geostationary satellite showing contour of constant satellite antenna gain on portion of earth, plotted by FOOTPRINT.



U.S.-PARABOLA

Figure 1-16. Example of earth footprint from a geostationary satellite showing contour of constant satellite antenna gain on the U.S., plotted by FOOTPRINT.

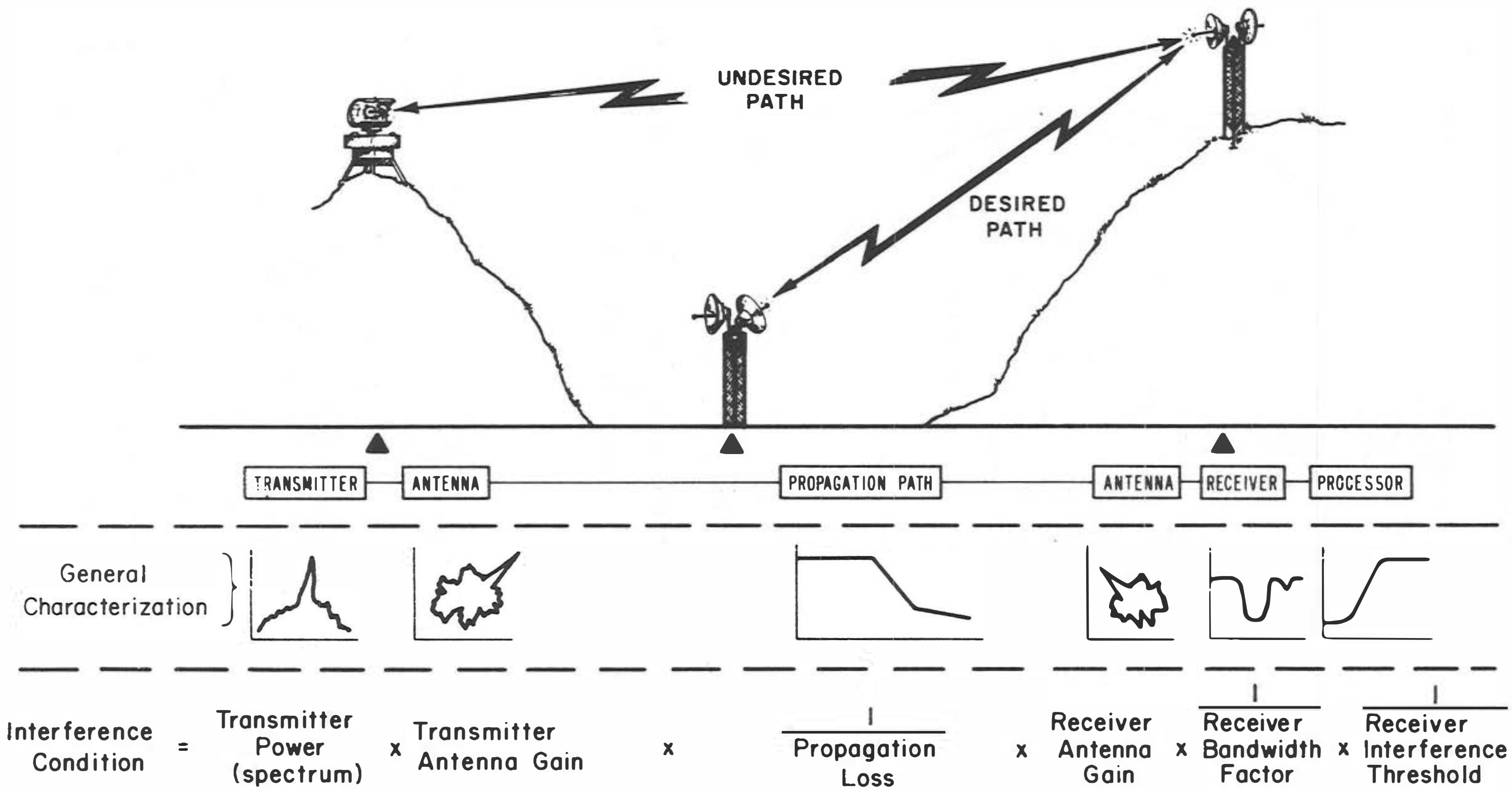


Figure 1-17. Pictorial representation of the basic factors considered when analyzing radio interference.

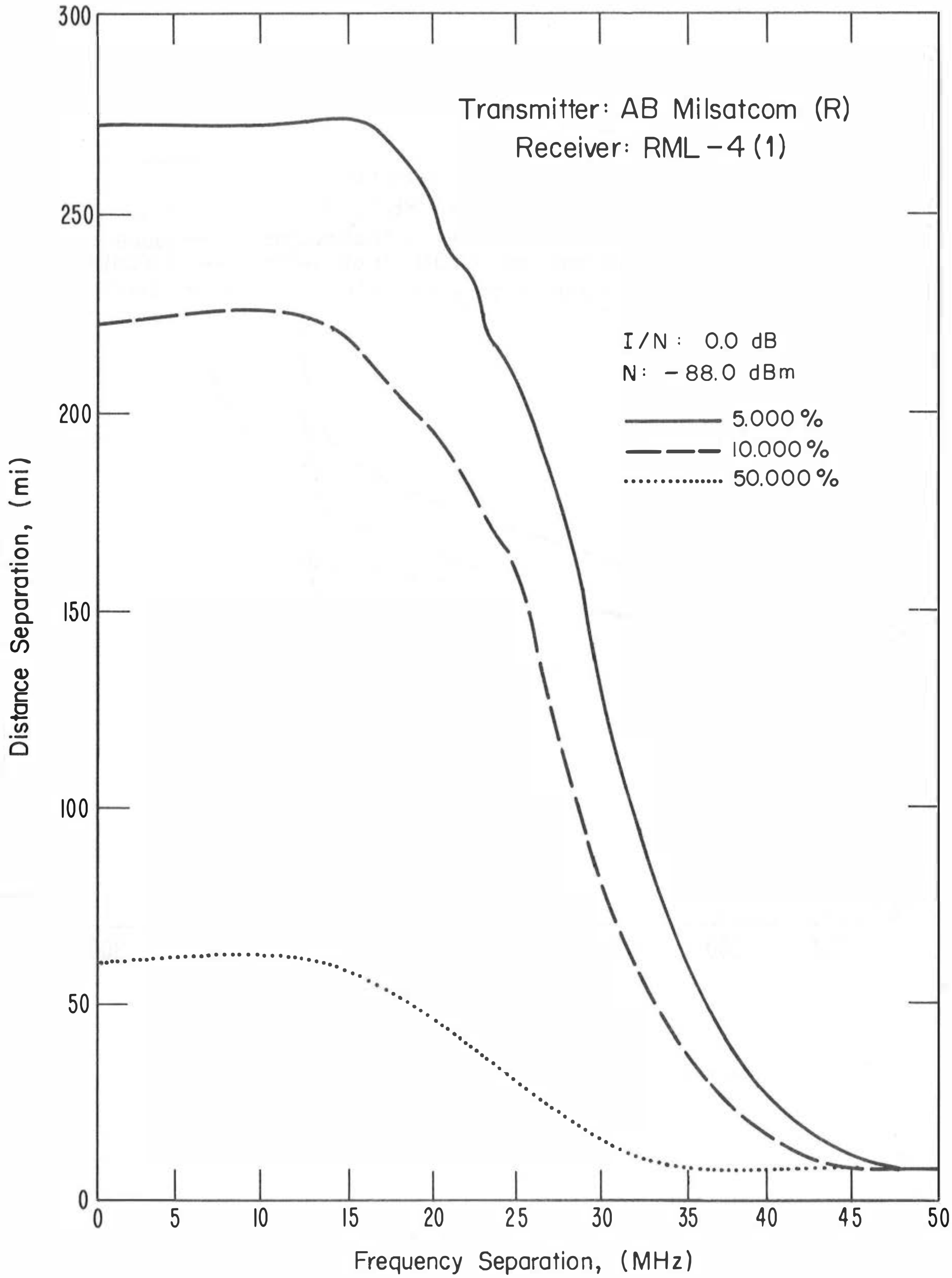


Figure 1-18. Statistical frequency-distance separation curves for a satellite earth terminal transmitter and a microwave receiver.

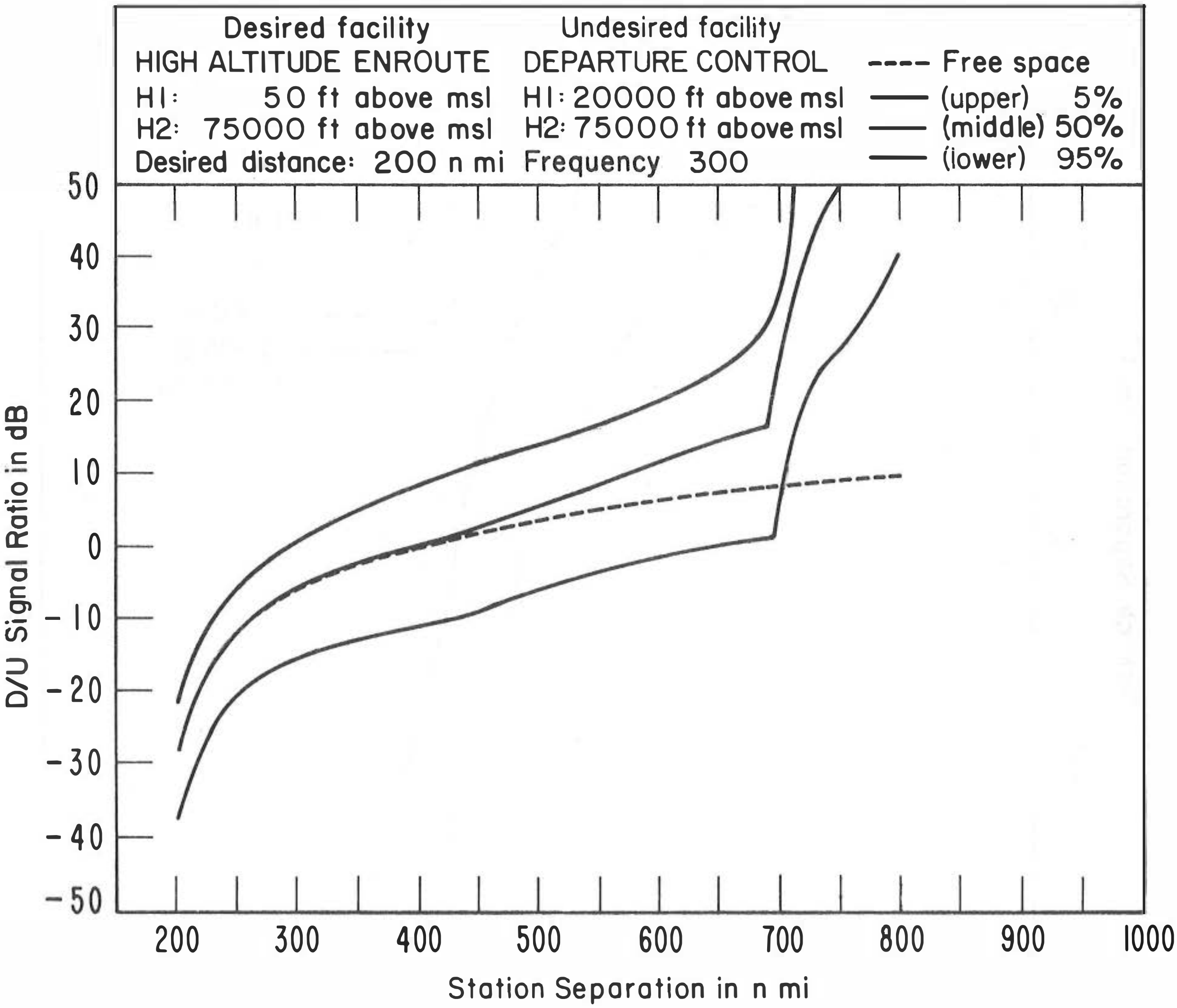


Figure 1-19. Interference curves for the FAA handbook on ATC communications interference.

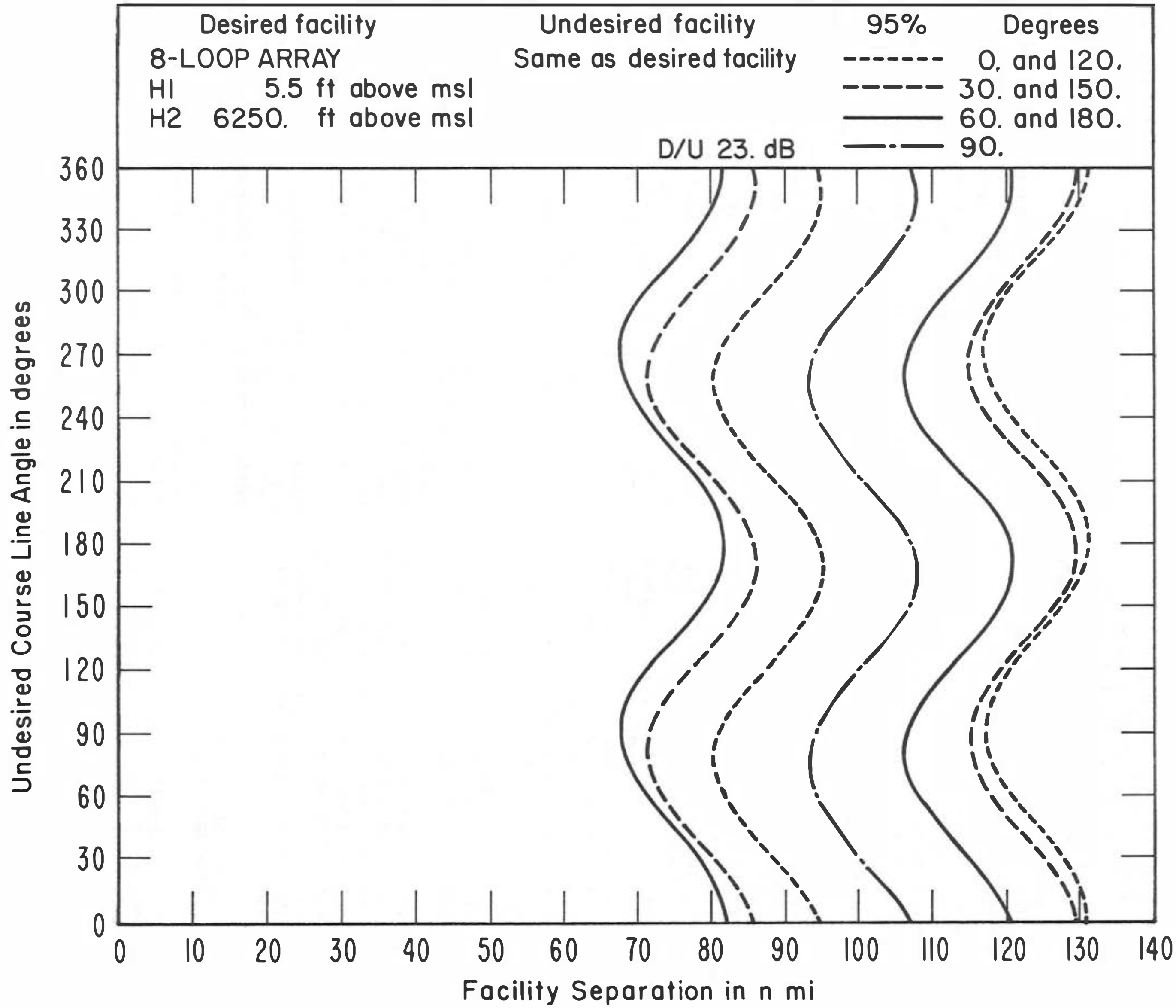


Figure 1-20. Separation between facilities vs. relative antenna orientation.

In the future, we will continue to acquire more data and compare with predictions made by the model in order to find weak points in the model and to find ways to improve it.

FAA ground-based and airborne communications and navigation aid receivers are subject to potentially degrading interference from other "intended" sources of radio signals as well as "unintentional radiators" such as arc welders, automotive ignition, and a wide range of other industrial, commercial, and consumer equipment. The objective of the Emission Spectrum Simulation project is the development of an analysis method which will determine the influence of these unwanted radiations on the performance of Air Traffic Control receiving systems. The technique is to accommodate the characteristics of both existing and future radiations and ATC receiving systems.

Under this project, a computer simulation model has been developed. The model consists of computer subroutines, each of which either simulates a basic component of a communications system or calculates characteristics of a component. Currently, the model simulates a system for AM, FM, FSK, Phase Modulation, or SSB desired signals. The interfering signal can be AM, FM, FSK, Phase Modulated, SSB, white Gaussian noise or pulsed cw, or any combination of these. The output is given in terms of either time-voltage samples of the output waveform or in terms of the output signal-to-interference ratio spectrum. The output can be used to compute performance measures such as probability of error of a digital system or articulation index.

Detailed documentation on this model will continue and will be published as an FAA technical report. Future work will include work on additional types of interfering signals such as those from incidental radiation devices. Also the model will be adjusted to simulate particular FAA-ATC systems.

SECTION 1.3. SPECTRUM RELATED MEASUREMENTS

Some aspects of spectrum efficiency require measurements either to augment or validate analytical estimates or to provide a characterization of some particular factor that is analytically intractable.

Small Earth Terminal Antenna Measurements. One characteristic of particular concern is the pattern of antennas outside the main-beam.

A knowledge of antenna side-lobe characteristics is as important as the performance characteristics represented by maximum power gain and main-lobe beamwidth for studies of electromagnetic compatibility of terrestrial and satellite communications stations, susceptibility of electronic counter measure antennas to jamming, and susceptibility of search radars to interference. For terrestrial stations, side-lobe characteristics of on-site antennas over the entire hemisphere are required for determining coordination procedures and criteria for frequency sharing.

A technique was developed for measuring the complete hemispherical power-gain radiation pattern of microwave antennas and was first used in the measurement of the pattern of a 2.44 m diameter paraboloidal reflector antenna mounted atop a mobile small earth terminal operating at 7.5 GHz. Antenna power-gain data were measured versus azimuth and elevation angles with the earth terminal centered on a heavy-duty turntable flush with test range ground. Test site illumination was achieved with airborne transmitting antennas. Conventional and statistical power-gain patterns are presented for left-hand circular polarization and cross polarization. Results indicate that similar systems cannot rely upon orthogonal polarization to provide isolation or compatibility beyond the angular region of the main lobe.

Measurements of larger diameter earth terminal antennas are scheduled for next fiscal year.

Figure 1-13 (which appeared earlier) shows the AN/TSC-85 Antenna situated on the turntable at the OT/ITS antenna range north of Boulder. The helicopter carrying the illuminating source is shown in the distance. Statistical results of the first set of measurements compared to CCIR curves are shown in figure 1-21.

Measurement Van Operations. This project supports the OT and OTP frequency management operations, when measurements on real systems and measurements on the electromagnetic environment are needed to provide data not available from frequency management records. These data are typically used in support of spectrum planning for new systems, validation of analytical models, and to resolve EMC problems.

The frequency management process requires a great deal of information about the existing signal environment before making decisions concerning adding more signals or changing operating standards. Although much general information already exists in frequency managers' data banks, there are instances where actual measurements of the electronic environment are

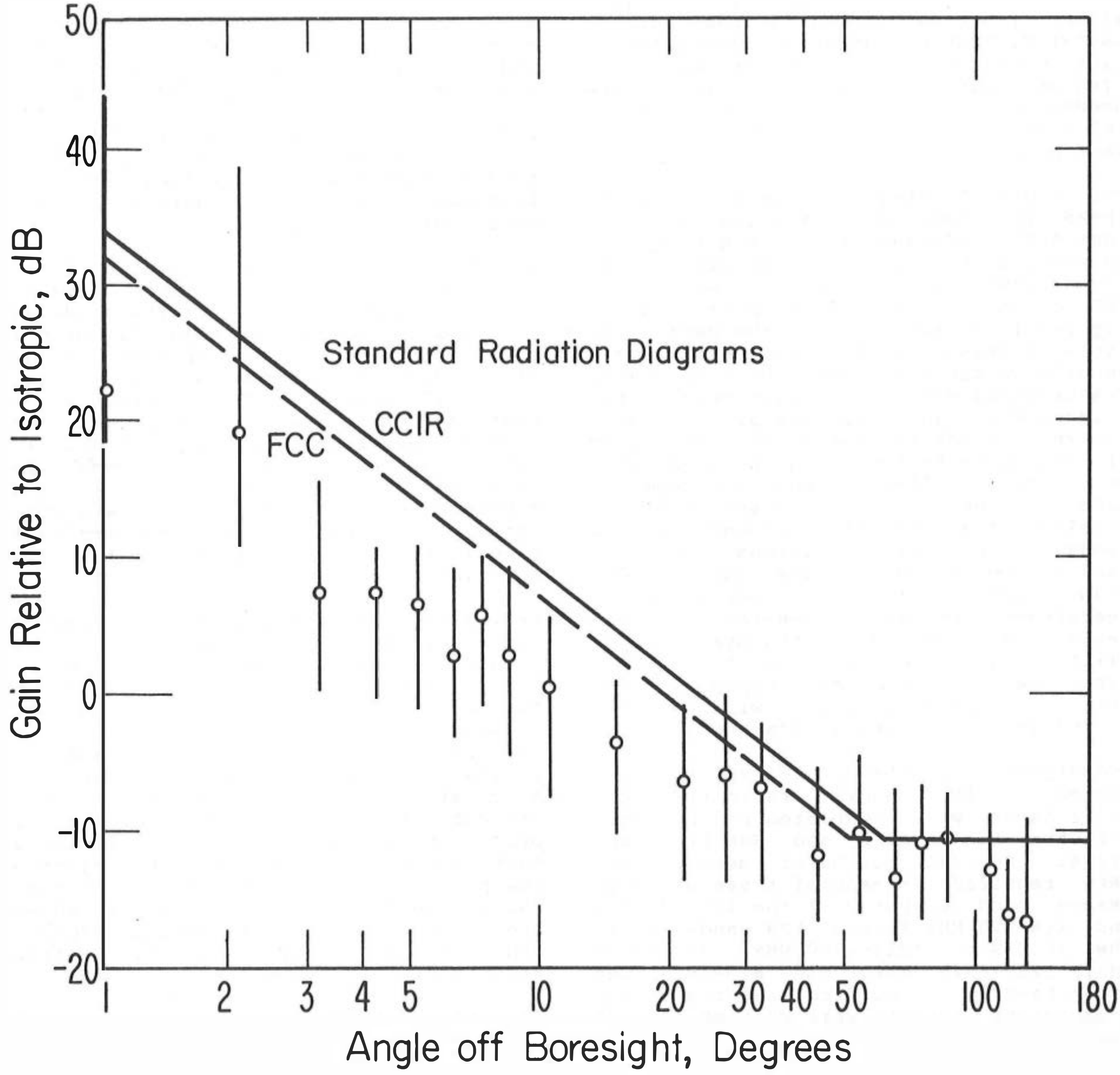


Figure 1-21. Statistics of a hemispherical antenna pattern compared to CCIR curves.

necessary. Radio spectrum occupancy, as distinct from frequency assignments, is a type of valuable data which can be obtained only by measurement. Often very detailed measurements of particular situations (such as propagation loss antenna patterns, spurious emission characteristics, interference between systems operating at nearby frequencies, etc.) are needed to verify or improve the theoretical models used in the frequency management process.

The Radio Spectrum Measurement System (RSMS) is a computer-controlled measurement system designed to provide frequency managers with needed measurements of the signal environment at frequencies between 100 MHz and 12 GHz. It is portrayed in figures 1-22 and 1-23. The particular types of measurements made change, depending on current requirements for data. Measurements made in the past year by the Measurement Van Operations are representative, but not inclusive, of the types of measurements for which the RSMS might be used. Similarly, the improvements made in the RSMS under Measurement Van Development are greatly influenced by the needs of the field operations. Specialized equipment and software may be designed and built for a very specific measurement project. General improvements are also made in the system capabilities, which are expected to improve system performance in many types of measurements. These activities will be discussed in the following paragraphs.

Measurements of the general spectrum occupancy in land mobile radio (LMR) and radar bands were completed and analyzed for the Los Angeles and San Francisco areas. Several months of measurements were required in each of these areas to assess band occupancy in the 162-174 MHz and 406-420 MHz Federal LMR bands and in the 1030 MHz, 1215-1400 MHz, 2700-3700 MHz, 5250-5925 MHz, and 8.5-10.5 GHz radar bands. Classified reports of the measurement results were written for OTP distribution.

A major objective of the measurements in the LMR bands was to determine band occupancy. Although several users are typically assigned to a single LMR channel, measurements are necessary to determine how much of the time a channel is actually used. Measurements suggest that many channels are infrequently used by holding the assignments, thus making tolerable a situation which on paper indicates serious crowding.

The studies in the radar bands provided an opportunity to identify the characteristics and identity of operating radars. The operating characteristics of radars which were measured include frequency emission spectra, pulse repetition frequency (PRF), pulse width, antenna pattern, and antenna rotation period. These characteristics were used to identify the radars, to establish whether the radar met nominal and regulatory specifications, and to see how closely the actual radar environment matched the data in the Government Master File (GMF). This type of data has been used by other groups to write new engineering standards for radars, and is useful to frequency managers to determine how accurate their frequency listings are and to determine major causes of inaccuracies.

In addition to the general studies in the Los Angeles and San Francisco areas, a special study of radars in the 2700-2900 MHz band was made. The objective of this study was to learn to predict how many radars could be located in a small geographical area (25 miles in diameter) in that frequency band and not have the radars interfere with each other. The number of radars in this band was expected to double, but good analytical models were not available to show whether mutual interference would require additional frequency allocations for the additional radars.

Extensive measurements of radar spectral characteristics were made to obtain frequency-dependent interference factors. The distance-dependent factors were obtained by predicting propagation loss between all of the radars in the Los Angeles and San Francisco areas and comparing these predictions to measurements made at each of the radar sites. Measurement data were used, in turn, to improve the prediction process. Visits at each of the sites confirmed (or rejected) the presence of predicted radar interference. Additional tests on radars showed the susceptibility of various types of radar signal processing to various amounts of interference.

The final report will show that tools exist to predict radar interference with accuracies of + or -20 dB, with most of the inaccuracy being caused by the propagation loss prediction. Furthermore, there are many techniques available to operate radars with less frequency separation than currently used, including cleaner coaxial magnetrons, interference-rejecting digital processing, better control of antenna sidelobes, etc. Some of the newer radars incorporate these features.

Another special field measurement experiment involved looking at the 1030 MHz and 1090 MHz frequencies of the air-traffic-control radar beacon system (ATCRBS) in the Los Angeles area to determine the cause of occasional system malfunctions.

Figure 1-22. Radio Spectrum Measurement System (RSMS).

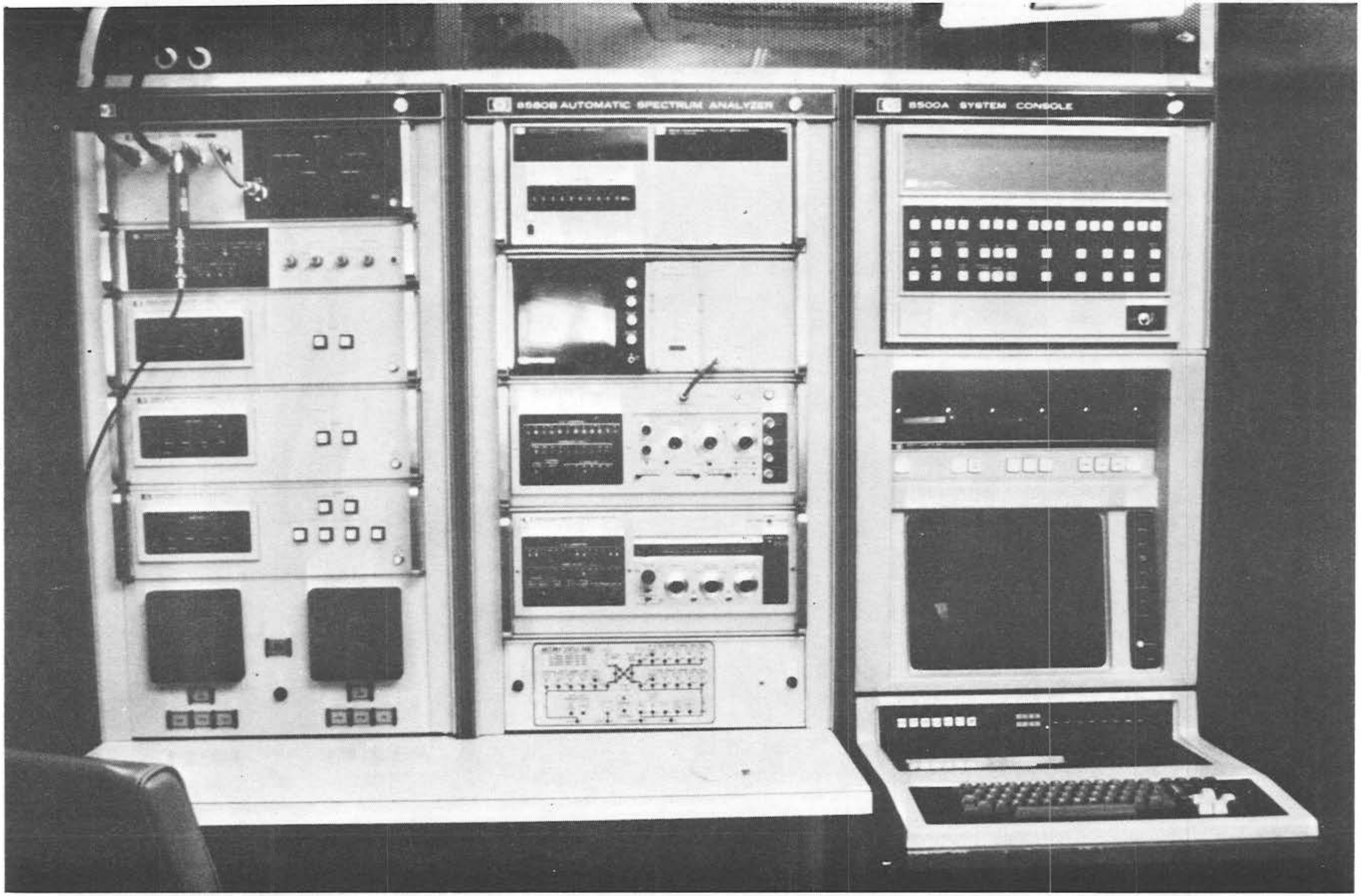


Figure 1-23. RSMS interior - equipment layout.

Although these malfunctions are an infrequent occurrence, there is concern that the problems may grow and prevent the effective operation of planned additions to the system. The RSMS spent three weeks at an FAA radar site looking simultaneously at the 1030 MHz and 1090 MHz environment and the operation of the ATCRBS, attempting to establish a "cause" for each of the ATCRBS' malfunctions.

The experiment depended on two hardware systems built up especially for these measurements -- a pulse sorting system that allowed small pulse trains to be separated out of the very crowded 1030/1090 MHz environment, and an interface to the digital processing equipment of the ATCRBS which allowed us to monitor its performance. The RSMS was configured (figure 1-24) with a PIN diode switch at the input from the antennas, controlled with blanking pulses derived from the local site radars. This eliminated all of the local radar pulses from the measurement. Further pulse sorting was done with a decoder that selected only the P3 and F2 pulses from the 1030 and 1090 MHz signals, followed by pulse sorting done on the pulse repetition frequency (PRF) of the P3 and F2 pulses. Gating signals were developed which allowed only those pulses which passed all the tests to be measured. The antenna pattern of an ATCRBS interrogator about 15 miles away was measured at 1030 MHz (figure 1-25). It should be noted that this signal was only one of many at 1030 MHz, and was at least 80 dB below the local interrogator; and that the pulses from a collocated omnidirectional antenna radiating at the same PRF have been eliminated.

Graphs were produced automatically every 30 minutes which showed how the 1030/1090 MHz environment affected ATCRBS performance (figure 1-26). Whenever strobes occurred, the signal environment at 1030/1090 MHz was examined to find a cause.

SECTION 1.4. ADVANCED INSTRUMENTATION FOR SPECTRUM MEASUREMENTS

The Radio Spectrum Measurement System (RSMS) discussed above represents the prototype of several mobile spectrum measurement systems. The initial system is continually being upgraded to meet new long-range requirements as well as special ad hoc measurement needs. In this past year a floppy disc has been added to the system to improve the general data processing and system control capabilities. A detector log video amplifier has been built which increases the system measurement bandwidth to 10 MHz. The addition of a transient digitizer to the RSMS has begun. When it is finished, we will be able to make a burst of digital measurements with 10 nanosecond resolution, which will be particularly valuable for studying radar pulse shapes.

The EMC Data Recording System represents a low-cost, semi-automatic capability that complements the large, complex systems like the RSMS. The U.S. Army Communications Command has requirements that include immediate response to electromagnetic compatibility (EMC) problems that affect the communications capability in their systems throughout the world. The EMC Group of ITS agreed to provide the U.S. Army with a portable EMC data recording and analysis package that is to be operated by Army personnel.

The objective was to put together a portable EMC system that could be used for general spectrum occupancy measurements of the power spectral density of potentially interfering signals. This system is modular in design, and is small (each unit is less than 9 in. high by 18 in. wide and 22 in. deep) (figure 1-27), lightweight, and is equipped with its own shock mounted transport container.

The EMC package consists of a spectrum analyzer, one controller and display chassis, and a dual drive magnetic tape unit. The spectrum analyzer is used as a tunable wide-band receiver, and provides outputs of signal level and signal frequency.

The control and display unit uses a microprocessor as the controlling element, plus other associated electronics to record, monitor, and display the desired signals. The control chassis also contains front panel switches and indicators for control and display. The controller also formats the data and controls the data transferred to the magnetic tape recorder (which is a dual drive cartridge type).

FY76 activity included building two portable EMC packages which consist of one control and monitoring unit and one tape recorder unit per package. Along with the two field-portable packages, a laboratory development package is provided, which includes the same units that the field packages have. It also has a microprocessor development unit and communications terminal. This laboratory package can be used in the same manner as the field packages, plus it allows system software programs to be developed and programed in programable read-only memory chips which are used to control the field system microprocessors. The EMC data is also monitored and analyzed (to a limited extent) by the laboratory package.

The unit is a small, compact, powerful EMC data package that is easy to operate

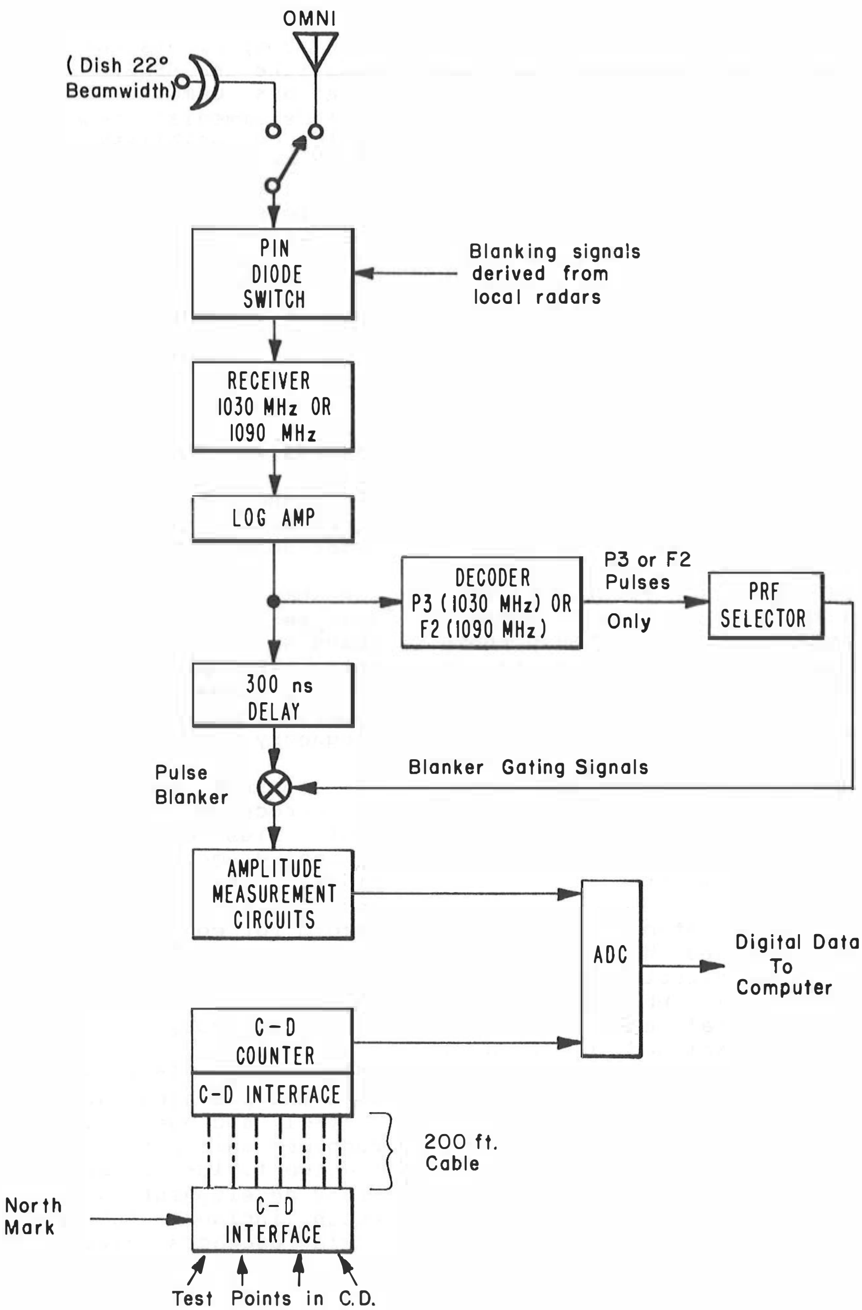


Figure 1-24. RSMS configuration for ATCRB system measurements.

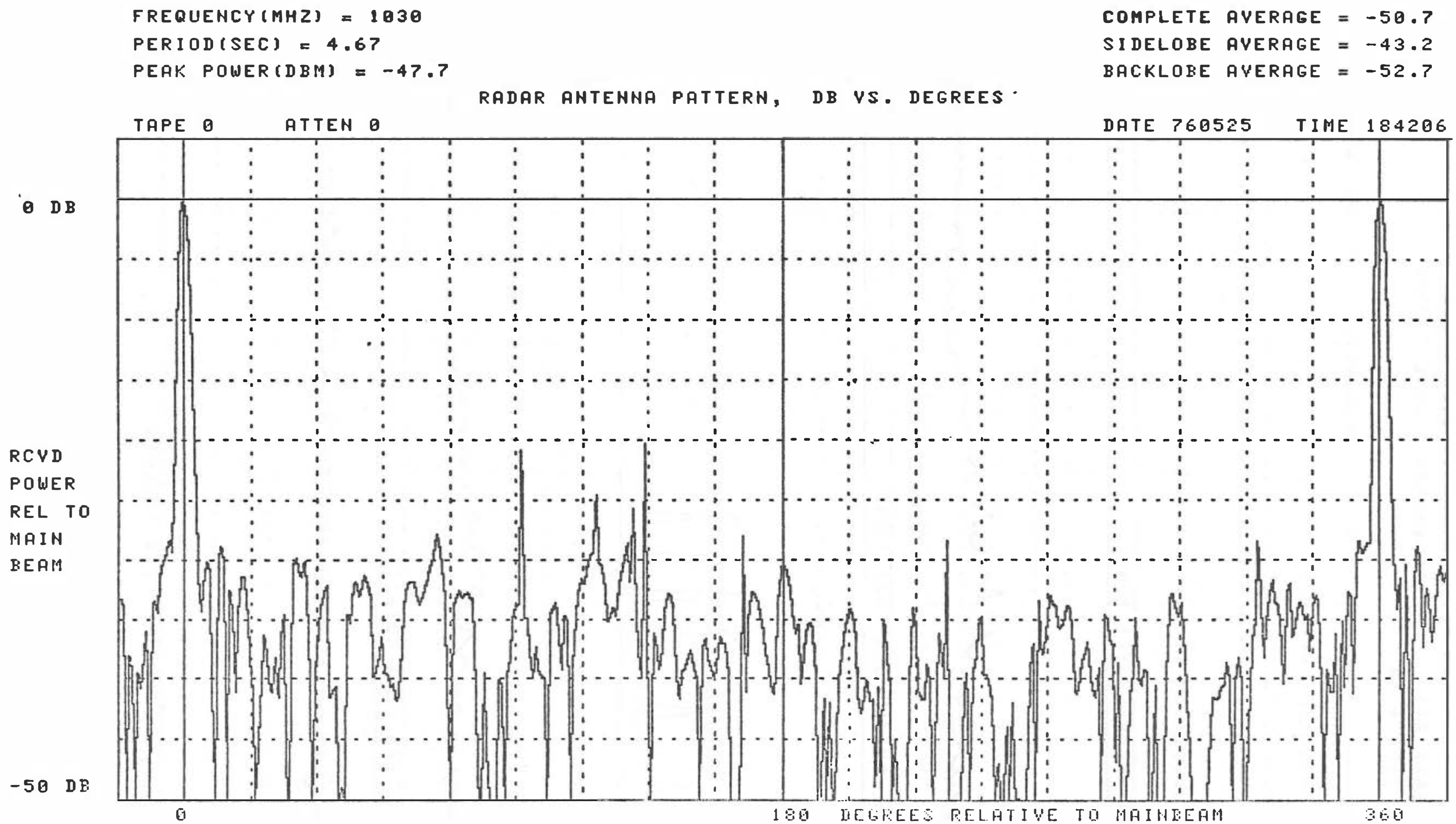


Figure 1-25. ATCRBS antenna pattern as measured by the RSMS.

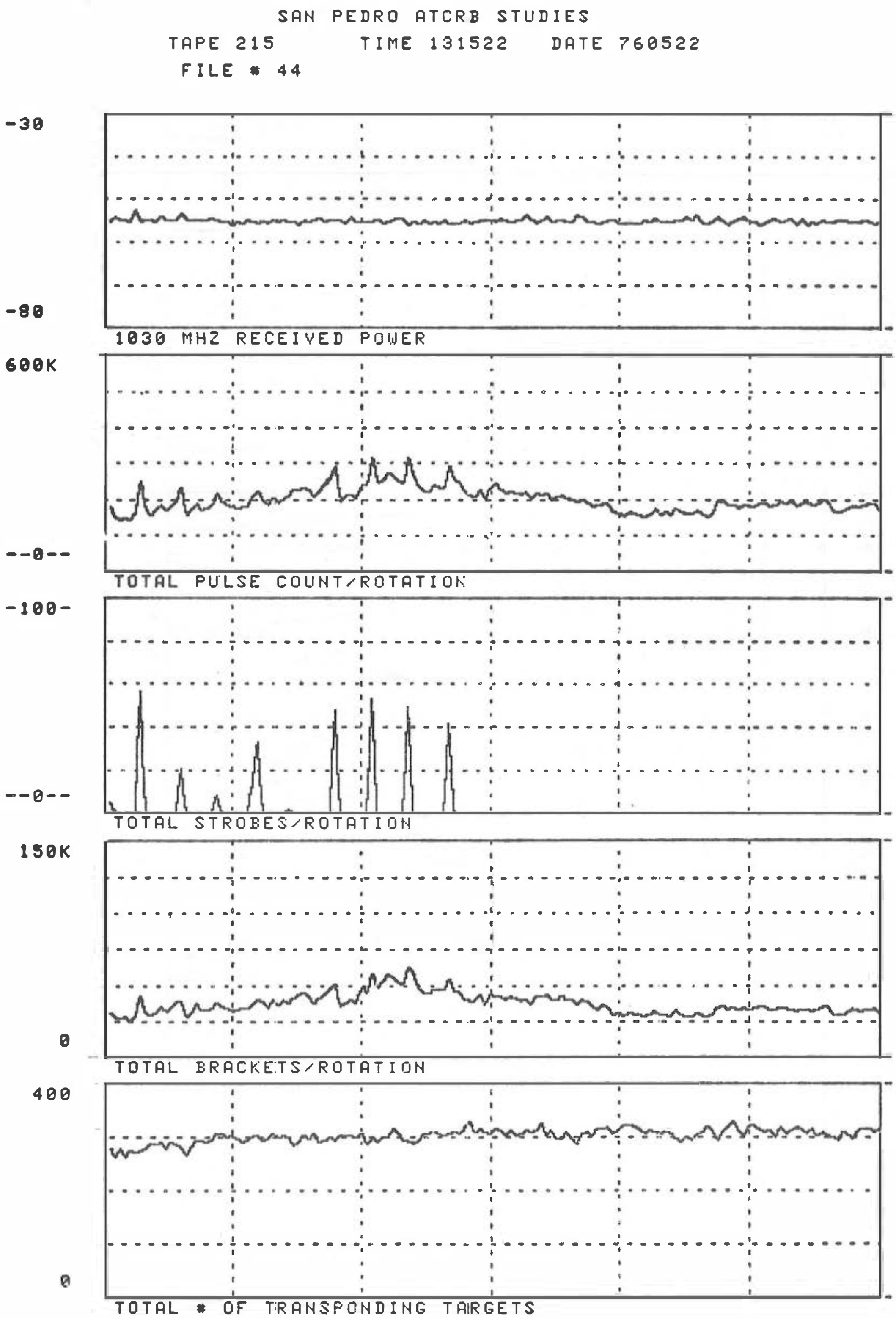


Figure 1-26. ATCRBS signal environment as measured and plotted by the specially modified RSMS.

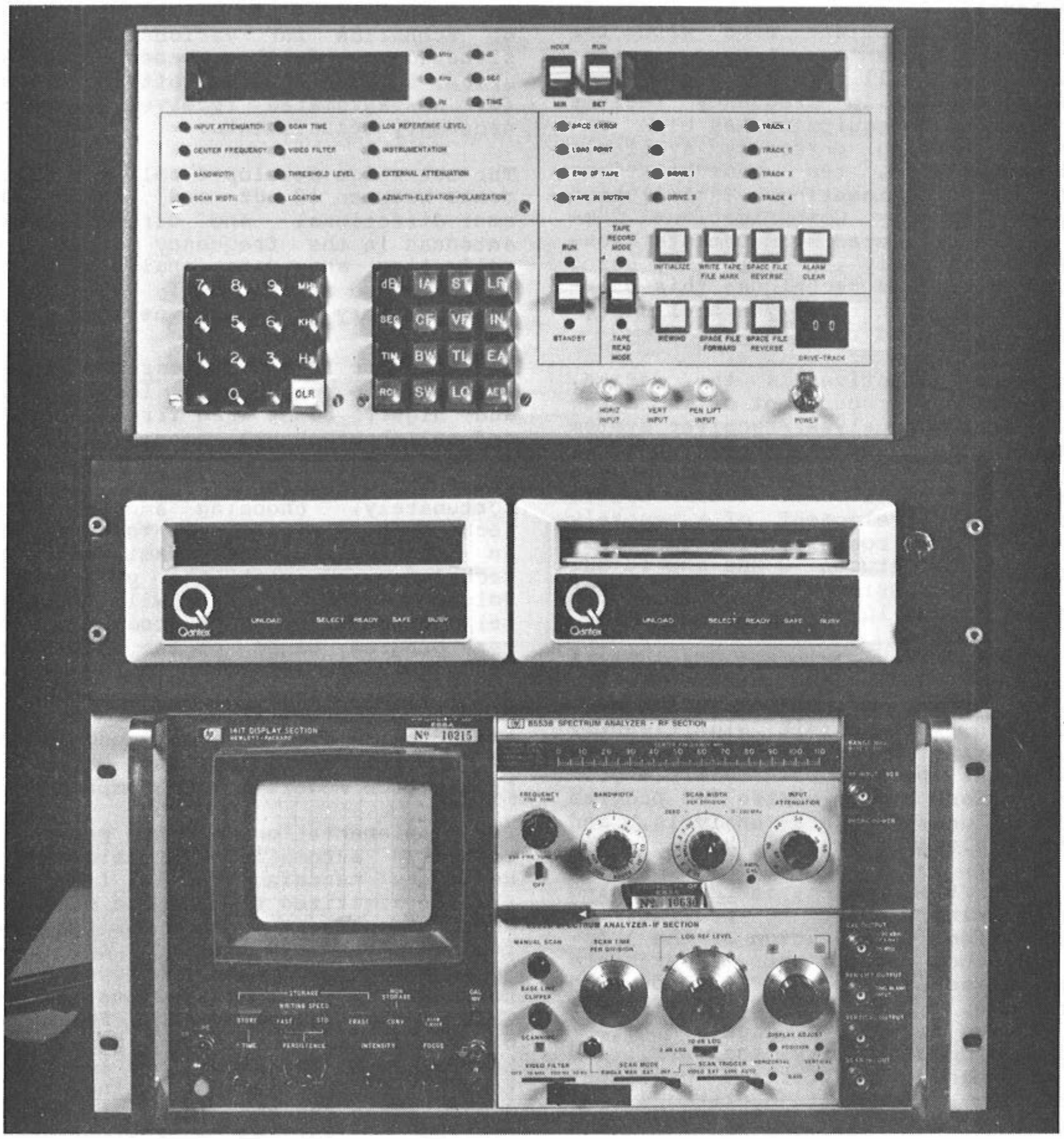


Figure 1-27. The EMC Data Recording System shown with the Hewlett-Packard Spectrum Analyzer.

and will perform many functions. It is also versatile in that the overall operating configuration can be easily changed with software changes.

Army Automatic Receiver System. There is a critical and immediate need with the Army frequency management community for equipment which will permit a high volume of measurements in frequency regions where measurement equipment has been unavailable. Using presently available manual techniques, the Communications Electronics Engineering Installation Agency of the Army Communications Command, has an estimated measurements backlog of approximately ten years. By using advanced automated techniques this backlog is estimated at three years with significantly improved results.

The project objective is the design, development, and procurement of an automatic spectrum analyzer/receiver system capable of completely hands-off control for measurements in the frequency region between 10 Hz and 40 GHz. This system requires the development of a remotely locatable rf down converter for the frequency region between 2 GHz and 40 GHz and a time compression analysis converter between 10 Hz and 10 kHz.

In addition, the equipment development requires an extensive real time executive operating system. This is a software system which will permit significantly enhanced system operating capability by providing the operator with multiple program operation, highly controlled program scheduling, on-site data analysis, and program development capability.

Along with the system, an EMC Training Course is being prepared to provide for the most effective operation of the automated frequency management measurements systems directed toward EMC theory and measurements. This course will cover basic topics in radio propagation, electromagnetic compatability analysis, and radio frequency interference problems. In addition, equipment operations and measurements scenarios will be made a part of the course material.

The course material and one instruction course will be provided for each Army personnel student. This course will be conducted by ITS personnel in Boulder. A second joint course with Army personnel participating will be conducted at Ft. Huachuca, Arizona, after which all instructional materials will be delivered to the Army for a series of future courses to be delivered by the Army.

Another companion project is Software Applications. To use automated receiver systems to measure interference at communications-electronic site, to evaluate satellite ground station receiver sites, or to determine potential hazards to equipment and personnel requires an extensive applications software library. The objective of the project is to develop scenarios for various measurements situations and then, based on the scenarios, to develop the software required for an automated receiver to make the necessary measurements.

The scenarios developed call for measurements between 10 Hz and 40 GHz using omni-directional and direction-finding antennas in the frequency range. Data collection and data analysis are to be accomplished automatically with provision for a variety of field generated reports.

Software for Irregular Terrain. In estimating radio propagation losses at VHF and higher bands when irregular terrain and an inhomogeneous atmosphere must be allowed for, the NBS Technical Note 101 has long been a standard reference. Unfortunately, choosing among its many techniques is a difficult task requiring an engineer thoroughly familiar with the techniques and with the phenomena involved. This project will attempt to help out here. It will produce a computer program based on the techniques of Technical Note 101 but able to examine a terrain profile and to select the proper technique for the situation. Hopefully, the program will be good enough to serve as a "reference" against which other propagation models may be compared.

The implementation of the program will emphasize automatic extraction of the necessary terrain profile from the OT file of digitized topographic data. The model should be usable for frequencies from 30 MHz to 100 GHz and for antenna heights from the ground to super-synchronous satellite orbits--almost anywhere that involves the earth. Furthermore, our treatment has already gone beyond the techniques of Technical Note 101 and back to their original sources, since the regions where the techniques are valid are limited by various approximations and assumptions.

CHAPTER 2. SYSTEMS ENGINEERING AND EVALUATION

The objective of this program sub-element is to provide user-oriented telecommunication system performance criteria and methods of performance measurements. These performance criteria and measurement methods are used by Federal agencies in planning, designing, specifying, procuring, leasing, and operating telecommunication systems.

The project elements described below generally deal with existing or proposed telecommunication systems and/or subsystems, and the objective of most tasks is to develop criteria, procedures, methods, and instrumentations for testing, evaluating, and/or upgrading the performance of such systems. Section 2.1 addresses work relating to data communications. Section 2.2 presents several projects oriented toward satellite communications. Section 2.3 summarizes the terrestrial radio system performance efforts. Section 2.4 deals with radio channel simulation and radio system performance standards, and Section 2.5 presents related work in fiber optical communications.

SECTION 2.1. DATA COMMUNICATIONS

The rapid growth of digital communications to permit transfer of data between computers, the encryption of voice communications for security reasons, and the growth of specialized networks for busiess, health care, electronic message transfer, etc. provides incentive to develop measures of performance and cost, and procedures for selecting alternative approaches for procurement or leasing such capabilities. Three projects are described; namely, Data Communications, Undersea Data Collection Network, and Local Digital Distribution Subsystem Concepts.

Data Communications. Rapid growth of computer communications and the emergence of "specialized" common carriers have intensified the need for effective, uniform, user-oriented means of describing and measuring the performance of digital communication systems. This project in Data Communications has been organized to fulfill this need through the development and experimental validation of standard communication system performance parameters and measurement techniques. The project has three major long-term objectives:

1. Federal Performance Assessment Standard. The Federal Telecommunications Standard Committee (FTSC) has assigned Lead Agency responsibility to ITS for the development of Federal Standard 1033, "Criteria for Assessing the Performance of Telecommunication Systems Used to Support Federal Information Processing." This standard will be developed under the authority of the National Communication System. When approved, it will be promulgated by GSA and will be mandatory for use by all Federal Agencies in the planning, procurement, and design of digital communication services and systems.

2. Measurement Standards. We have initiated a series of statistical studies aimed at development of confidence intervals for performance parameter measurements. Results of these studies will provide communications users and suppliers with standard methods of describing the accuracy of measured performance parameter values. The measurement standards will be published either as a part of Federal Standard 1033 or as a separate Federal standard.

3. Interconnection Standard. OT/ITS plans to develop, as a follow-on to Federal Standard 1033, a Federal standard defining performance requirements and "performance classes" for interconnection of dissimilar digital networks. The purpose of this standard will be to promote and facilitate interoperability between telecommunication systems used to support federal information processing.

Results of the Data Communications project will provide planning organizations, such as the National Communication System, with the tools necessary to assess the compatibility and interoperability of Federal telecommunication networks and will provide Federal Government users of digital telecommunication services, for the first time, with uniform means of defining their performance requirements, comparing service alternatives, and monitoring delivered performance. The potential for actual cost savings in each of these areas is substantial.

Major FY76 objectives and results in the four project activities (Applications Analysis, Statistical Analysis, Standards Support and Liaison, and ARPA Network Measurements) are summarized below.

The major objective of the Applications Analysis program for FY76 was to develop and define the final performance parameters to be included in Federal Standard 1033.

A summary of the performance parameters selected for inclusion in the final draft version of Federal Standard 1033 is provided in figure 2-1. Note that, in the case of the block-oriented parameters, values are to be provided for two separate block lengths: a block of length one (i.e., one bit) and a characteristic block length specified by the communica-

CRITERION \ PHASE	ACCESS	USER INFORMATION TRANSFER	DISENGAGEMENT
EFFICIENCY	ACCESS TIME	• BLOCK TRANSFER RATE • END-TO-END BLOCK TRANSFER DELAY • BLOCK RATE EFFICIENCY • BLOCK EFFICIENCY	DISENGAGEMENT TIME
ACCURACY	INCORRECT ACCESS PROBABILITY	• BLOCK ERROR PROBABILITY • BLOCK LOSS PROBABILITY • BLOCK MISDELIVERY PROBABILITY • ADDED BLOCK PROBABILITY	-----------------
RELIABILITY	• ACCESS DENIAL PROBABILITY • ACCESS DENIAL TIME	• SERVICE TIME BETWEEN OUTAGES • OUTAGE DURATION	DISENGAGEMENT FAILURE PROBABILITY

Figure 2-1. Performance parameters for Federal Standard 1033 (Criteria for Assessing the Performance of Telecommunication Systems Used to Support Federal Information Processing).

tion system operator. These results were provided to FTSC in the form of presentations and meeting reports, and the draft of a forthcoming OT Report is undergoing editorial review.

During FY75, we developed a method of establishing confidence limits for binary error-rate measurements under the assumption of "Bernoulli trials" (i.e., independence between successive bit transfer attempts). The major objective of the Statistical Analysis activities for FY76 was to extend these results to the more general and more practical case where there may be dependence between successive bit transfer attempts. The necessary statistical techniques were successfully developed during FY76 for one widely-used dependence model, the so-called "Gilbert" model. Experiment design procedures and statistical tests for applicability of the Gilbert model were also developed. Results will appear in an OT Report to be published in the near future.

Major FY76 objectives in the Standards Support and Liaison activity were: (1) coordination of Federal Standard 1033 with FTSC, and with the FTSC Technical Subcommittee members, and (2) continued support of the FCC's efforts to develop quality and reliability standards for the "specialized" communication services (Docket 18920). OT/ITS conducted seven FTSC Technical Subcommittee meetings during FY76. These meetings served to identify the performance assessment needs and practices of the participating Federal Government agencies, and provided an interagency forum for discussion of performance parameter definition issues. The meetings culminated in a consensus on the performance parameters summarized in figure 2-1.

In support of the FCC's standards efforts, OT/ITS developed during FY76 a summary of the industry comments on the FCC's Quality and Reliability inquiry, and a refinement and amplification of OT's FY75 Docket Submission in this area. The results are scheduled for publication in a forthcoming OT Report.

Other standards support and liaison activities during FY76 included participation in ANSI's Data Communications Standards Task Group (X3S3.5), various other agency briefings, conference presentations, and open literature publications.

Major FY76 objectives of the ARPA Network Measurements activity were to complete procurement and installation of an ARPA Network Host computer facility at ITS, to interconnect the Host Facility with the ARPA Network, and to initiate a performance measurement program designed to test the utility and practicality of the performance parameters specified in Federal Standard 1033. The OT/ITS Host system was successfully interfaced to the ARPA Network in March 1976. Figure 2-2 is a photograph of Host equipment, and figure 2-3 shows details of the Host/TIP interconnection.

ARPA Network measurement objectives and experimental plans were also developed during FY76. A PDP-11 computer program designed to test the performance parameter Access Time was completed.

Modulation Studies for an Undersea Acoustic Coupler and Data Collection Network. To improve utility of an existing undersea acoustic detection network (consisting of a number of hydrophones and a transmission cable system), the Naval Electronic Systems Command and the Naval Undersea Center plan to install a number of new hydrophones, to modulate a locally generated carrier with each new hydrophone signal, to project each modulated signal to an existing hydrophone with an acoustic coupler, and to transmit the modulated signal through the upper portion of the designated frequency band for the existing hydrophone and the transmission cable system.

ITS studied aspects of the proposed plan with a primary emphasis on the effects of the limited linear dynamic range (LDR) of the existing transmission cable system. The LDR's for both the existing and new hydrophone signals were calculated as a function of the allowance for an increase in the ocean noise density in the upper portion of the designated frequency band. Frequency-modulation (FM) and pulse-code-modulation (PCM)/phase-shift-keying (PSK) techniques were considered. Comparison of the two modulation techniques indicated that they were similar with regard to the performance measured with the LDR. A fifth-order Chebyshev-type band-pass filter was found to be a desirable filter to be placed after the modulator in the acoustic coupler. The original plan was shown to be feasible for certain values of the LDR and with some allowance for ocean-noise increase. Overall design procedures for the acoustic coupler were also considered from the standpoint of modulation studies.

The results of this study are contained in a classified (Confidential) report OT TM 76-224 by H. Akima.

Local Digital Distribution Subsystem Concepts. ITS conducted a study for the U.S. Army Communication Systems Agency on local distribution systems for use at selected military facilities throughout the world. The goal is to establish technical feasibility and optimal operation of systems. The Local Digital Distribution

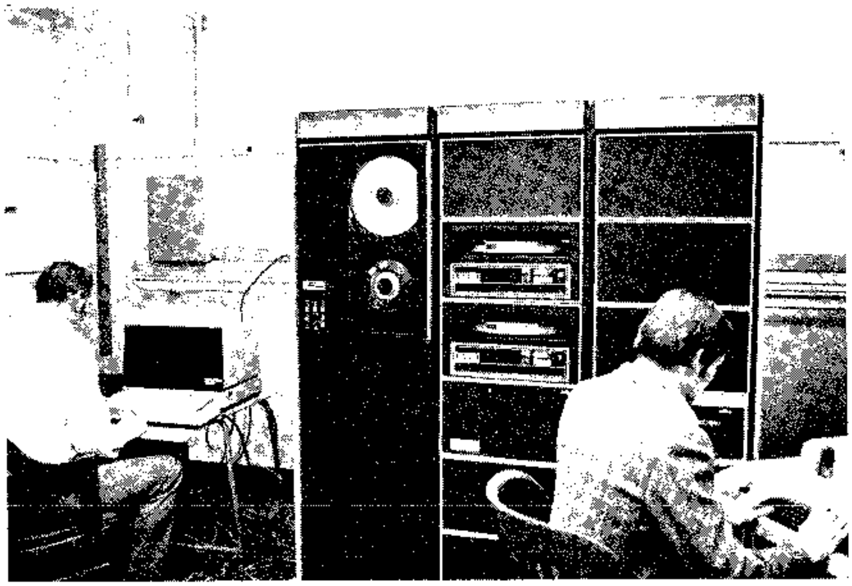


Figure 2-2. Photograph of the Boulder Laboratories Host/TIP connection to the ARPA network.

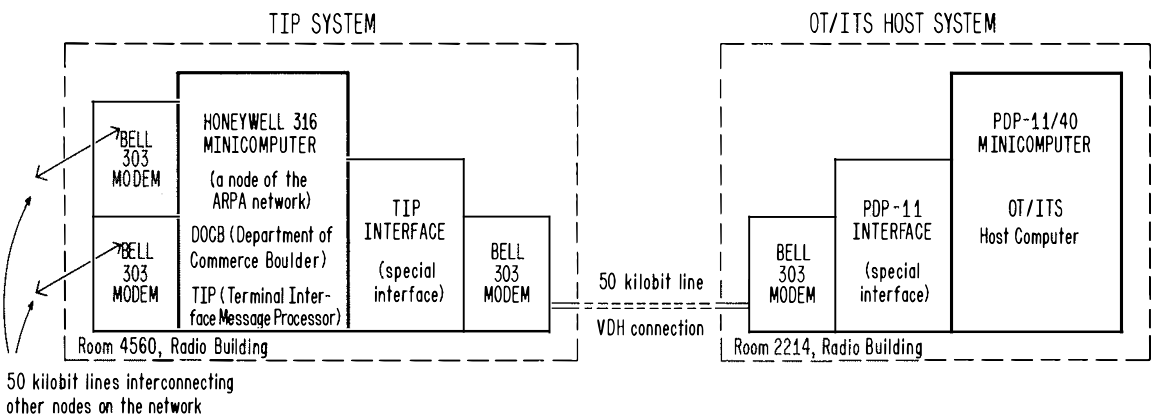


Figure 2-3. Schematic diagram of the ITS Host connection to the DOCB TIP.

System (LDDS) must also be interfaced with the military all-digital global network.

The local area distribution plant facilities must be equipped so that the long-haul digital circuits of the Defense Communications System's (DCS) Future Digital Network (FDN) and the Transitional/Integrated DCS can be extended to the local user terminals. The LDDS must also provide digital transmission capability for on-base functions and interconnection to the digital circuits used by TRI-TAC, Allied Forces and commercial facilities of CONUS and foreign carriers. As the long-haul circuits of the DCS backbone system are converted to digital transmission, the corresponding portion of the LDDS must also be converted. If this capability is not provided, then the increased reliability of the digital DCS transmission scheme will not benefit the user. Also, local area costs may increase substantially.

Local Area Distribution Systems provide the circuits to connect individual subscriber's terminal equipment to the local central office, Digital Automatic Exchanges (DAX), or Unit Level Switchboards (ULSB).

The objective of the LDDS is transmission of digital signals from the terminal equipment to the long-haul system or to other terminal equipment in the local area without the necessity of converting to analog signals for transmission.

The LDDS must transmit all types of digital signals (e.g., voice, data, narrative, facsimile, and video) from the user I/O device to the DCS access point or to the access point of other networks.

Accomplishments on the LDDS project this fiscal year are summarized in OT Report 76-95 by Martin Nesenbergs and Robert F. Linfield, "Parametric Cost Alternatives for Local Digital Distribution Systems."

The report discusses the broad investigation of LDDS system concepts. The forward-looking time frame is extended to 1985 and beyond. The work emphasizes three guidelines: development of function/service parameters; formulation of alternative LDDS concepts; and performance of preliminary analyses of service, performance, and cost.

A parametric approach to the study shows that the system cost appears to be the most prominent of all parameters considered. Other service parameters which are significant are:

(a) Size of service area

(b) Number of terminals

(c) Terminal density

(d) Variety of services offered

(e) Traffic and usage statistics

(f) Necessary housekeeping tasks - clocks, compatibility, transparency, and others.

The report outlines a parametric description of LDDS with emphasis on cost. In particular, it assembles the parameters, system alternatives, components, and their costs into a cost summary of LDDS case studies for Ft. Huachuca and the Ft. Monmouth DCS access areas.

A map of the Ft. Huachuca base is shown in figure 2-4. The subscriber density partitioning of the same map is given in figure 2-5. Figures 2-6 and 2-7 show star and hub configurations for an LDDS in Ft. Huachuca.

The report also contains tables of comparative costs for coaxial cable underground and overhead installations of star and loop configurations.

SECTION 2.2. SATELLITE COMMUNICATIONS

This activity is made up of projects carried out for several Federal agencies and ranges from technical management assistance (certification) in evaluating a controversial domestic common-carrier/satellite interconnect question to preliminary system design concept studies for natural disaster warning.

Circuit Status for Multiple-Satellite-Hop User Reaction Tests. On August 1, 1974, the American Telephone and Telegraph Company (AT&T) filed revisions to certain tariffs with the Federal Communications Commission (FCC) affording restricted connection to the public switched network of satellite circuits to be used in the Foreign Exchange (FX), Common Control Switching Arrangements (CCSA), and Tandem Tie Line (TTL) services. The restrictions were based on alleged technological difficulties arising from the unrestricted use of such satellite circuits in the above-mentioned private services on connections which accessed the public switched network. Four other parties, the American Satellite Corporation (ASC), General Electric (GE), RCA Global Communications, Inc. (RCA Global), and the Western Union Telegraph Company (WU) sought rejection of the tariffs, challenging the legality of the restrictions and disputing the alleged technological difficulties. The technological issue was referred to the Chief of the FCC's Common Carrier Bureau for resolution, and

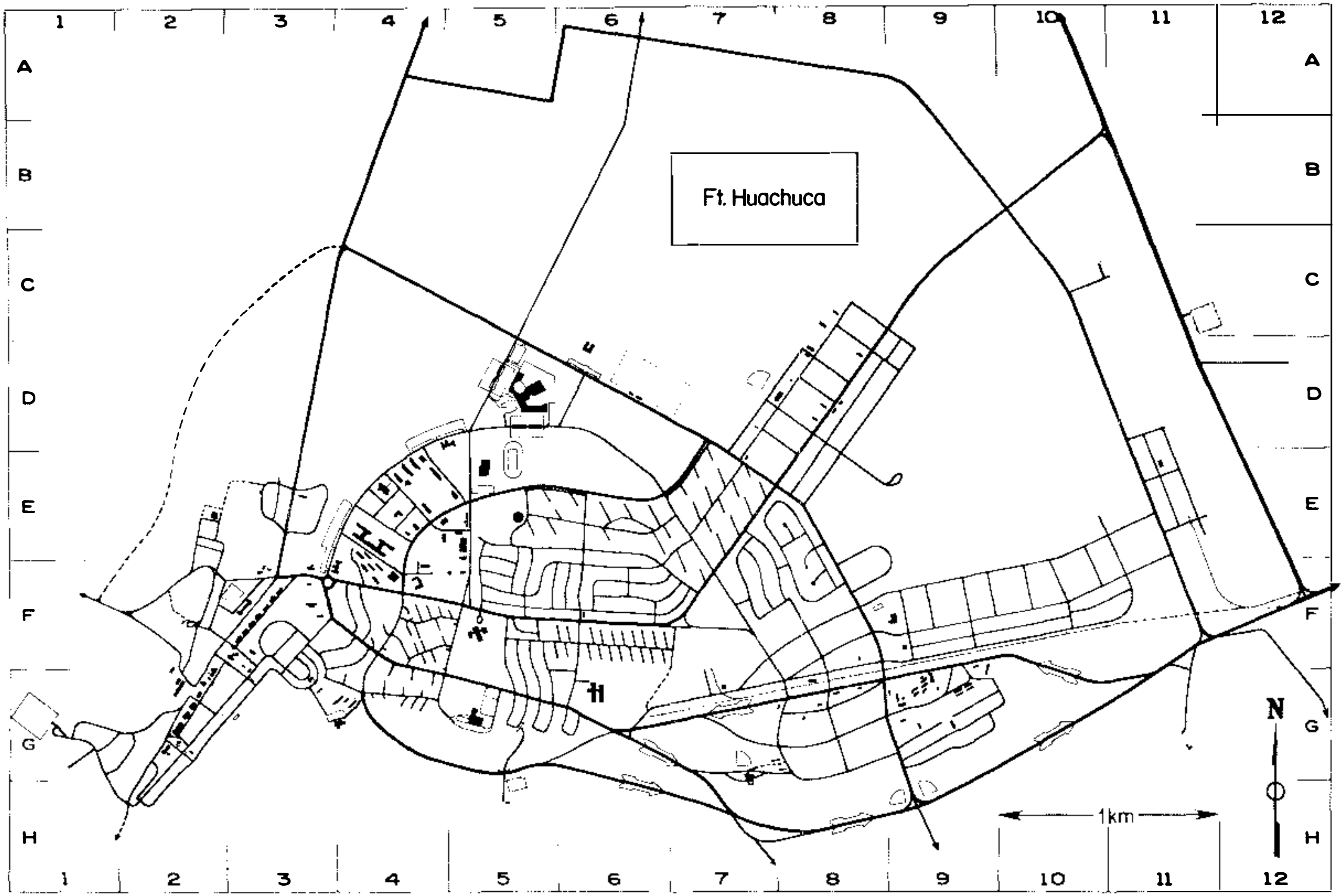


Figure 2-4. Street map of the selected example (Ft. Huachuca, Arizona) for the Local Digital Distribution Subsystem (LDDS) study.

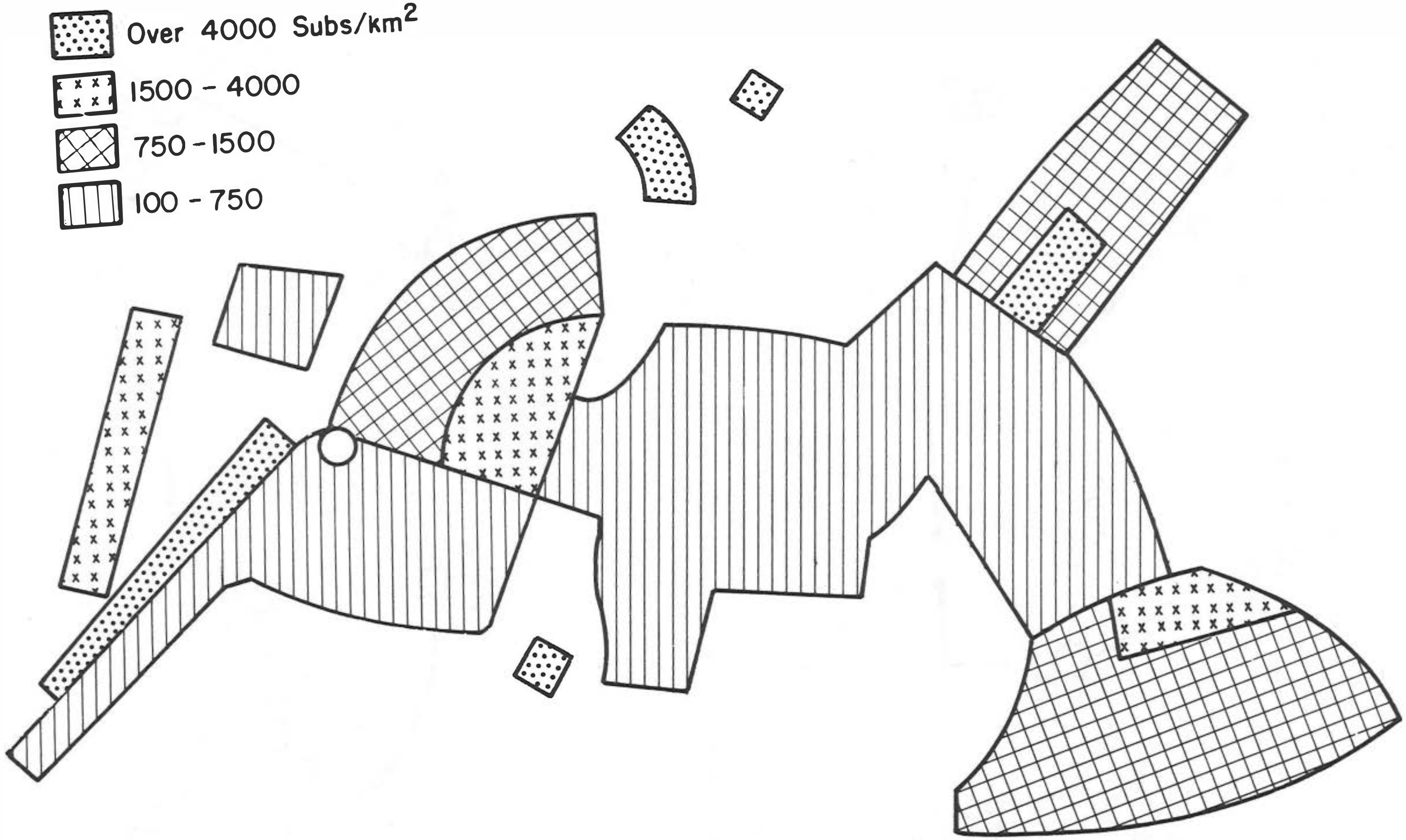


Figure 2-5. Subscriber density map of Ft. Huachuca use in the LDDS study.

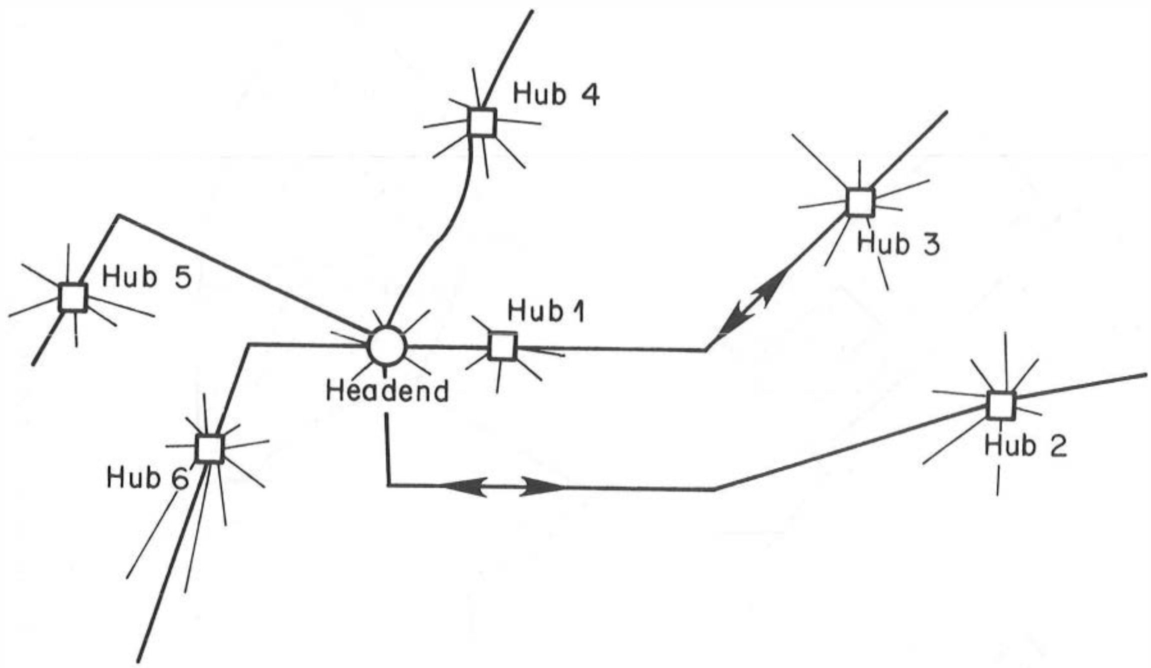


Figure 2-6. Possible star configuration for Ft. Huachuca developed in the LDDS study.

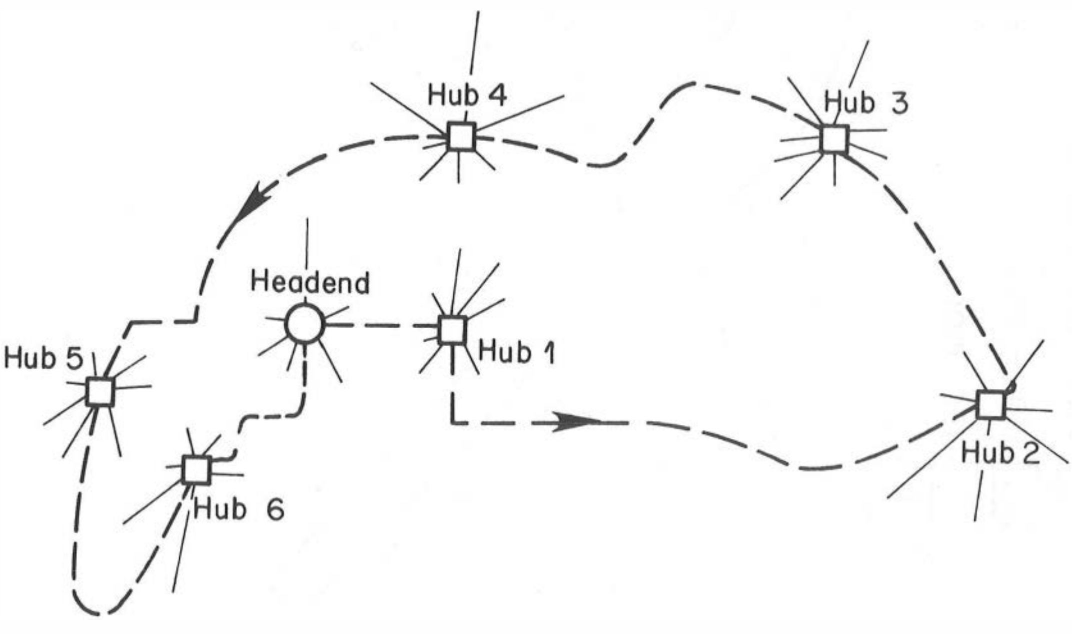


Figure 2-7. Possible hub configuration for an LDDS in Ft. Huachuca.

subsequently an agreement was entered into to undertake a program of interview tests to examine customer reaction to certain test conditions. Pending completion and evaluation of the test, AT&T withdrew the proposed tariff restrictions on connection of satellite circuits.

Pursuant to an interagency agreement with the FCC, ITS served as the Technical Management Organization (TMO) to oversee the physical implementation of the circuits and to verify their continuing suitability for use during customer interviews to be conducted by an independent polling organization.

Customer reactions were solicited by the polling organization after they had completed voice telephone conversations that were relayed one, two, or three times through the WESTAR satellite and through special trunk circuits provided by ASC, AT&T, and WU (see figure 2-8).

Circuit implementation and quality was audited through a series of inspection visits to switching offices across the country and through the evaluation of pre-service and in-service daily and weekly circuit tests observed by the TMO or reported by the carriers. The circuit tests were as follows: a) 1000 Hz loss; b) message circuit noise; c) daily propagation delay and signaling; d) pre-service pulsed signaling; e) frequency response; f) in-service echo suppressor; g) go/return crosstalk measurements; h) out-of-service echo suppressor; and i) echo-return and singing-return loss (balance) measurements. Customer interviews were not permitted by the TMO on circuits that did not meet established criteria.

The results of the tests were compiled and reported weekly by the TMO to a Steering Committee which had been formed to implement the testing and to establish test criteria with the concurrence of the TMO. The Steering Committee was composed of representatives of the Common Carrier Bureau, AT&T, WU, ASC, RCA Global, and GE.

Subsequent to the final reports by the TMO and polling organization, AT&T filed new tariff revisions with the FCC. These afforded unrestricted connection to the public switched network of multiple-hop satellite circuits to be used in the CCSA, FX, and TTL services, but with certain provisions. One of them is that there will be no guarantee of circuit quality.

Another result is an FCC plan to investigate standardizing echo suppressor test characteristics. During the course of the project, ITS compared out-of-service echo suppressor test results with those prescribed by CCITT Recommendation G.161. Certain allowances had to be made in the Recommendation because the echo suppressors that were tested were intended for satellite rather than terrestrial circuits. The TMO became concerned because there were significant differences in the results of the tests of the suppressors which had been provided by different manufacturers. The immediate effect was to have some echo suppressors replaced, while the long-term effort by the FCC will be to standardize the values of the time constants measured in out-of-service tests.

This work is reported in OT Special Publication 76-8, "Circuit status for multiple-satellite-hop user reaction tests," by Donald V. Glen, Earl C. Bolton, James C. Blair, and Peter M. McManamon.

<u>Spin Modulation Statistics of GOES Data Collection System</u>. Since 1971, the Institute has been involved in studies of the GOES telecommunication system for the National Environmental Satellite Service of NOAA. An FY76 project reported by Donald V. Glen and Martin J. Miles in OT Report 76-81 presents the results of statistical analyses of unmodulated carrier signals for the interrogation and data reply links of the data collection system. These carrier signals were transmitted through the GOES satellite between a Data Collection Platform Radio Set (DCPRS) and the Command and Data Acquisition (CDA) station. The objective of the program was to normalize the amplitude and phase perturbations of the unmodulated signals by integrating the effects of spin modulation.

The 400 MHz signals (between the DCPRS and spacecraft) and the 2.0 GHz signals (between the spacecraft and CDA station) are modulated by the 100 rpm spin stabilization of the spacecraft in its geostationary orbit and by the switching of power between the antenna elements on the perimeter of the spacecraft. The net effect is spin modulation, which influences the data-bit stream or unmodulated carrier by introducing undesired amplitude and phase modulation.

Statistical parameters studied included the mean and standard deviation of the signals, and the computer plots of a) one set of data points during one revolution of the spacecraft, b) mean values for data points from 1000 revolutions of the spacecraft, c) the differences between the sample and the mean values, and d) the mean values for 1000 differences. These parameters were determined for the output of the Data Collection Platform Interrogate (DCPI) phase detector, the output of the Data Collection Platform

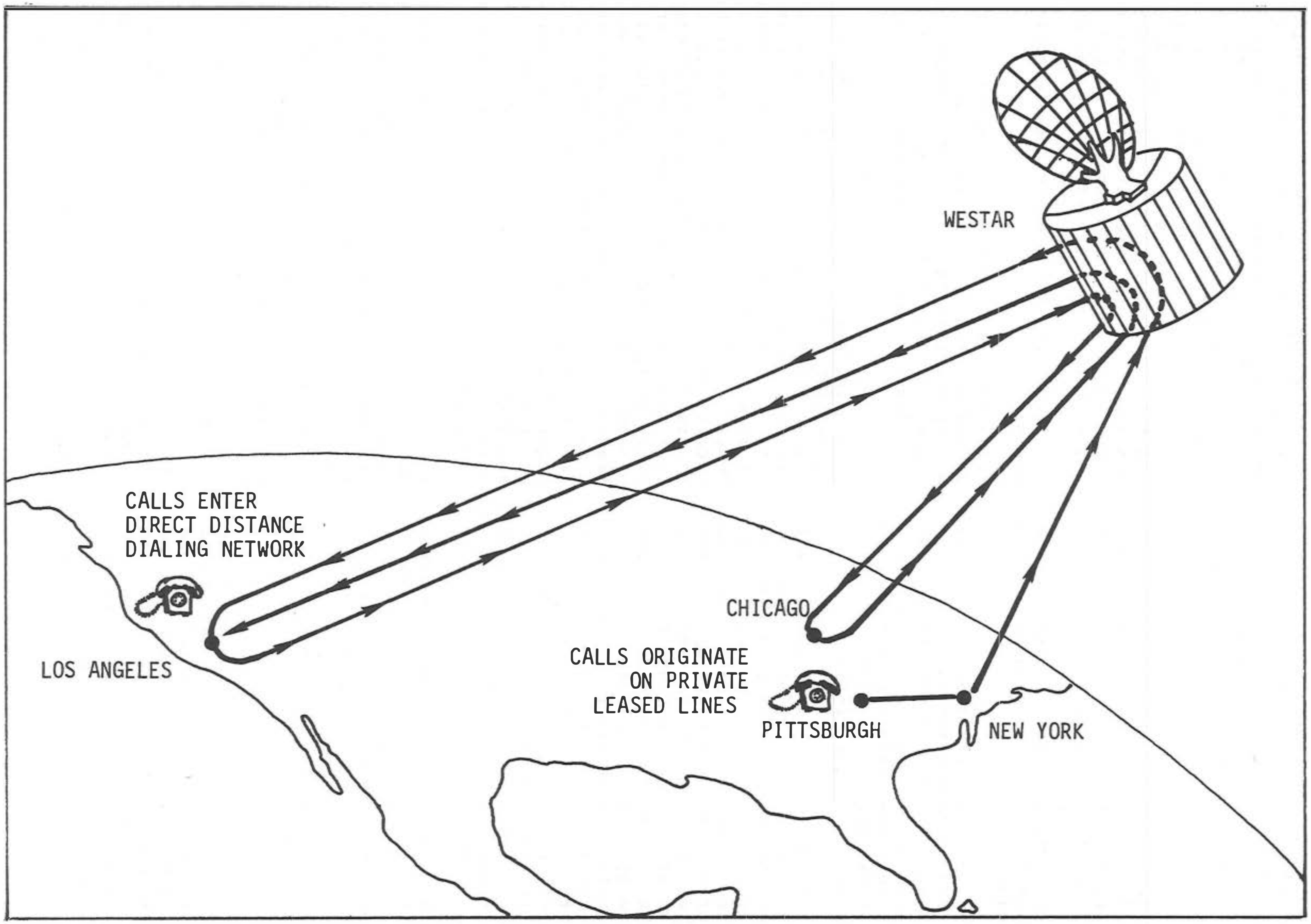


Figure 2-8. Sketch of radio paths involved in Multiple-Satellite-Hop User Reaction Tests.

Reply (DCPR) phase detector, and the DCPR amplitude ripple.

The analysis involved simultaneous sampling of three signals at 128 data points during each 600 ms revolution of the GOES. Therefore, during each revolution, a data sample was taken simultaneously, each 4.68 ms, on each signal. One thousand samples were then used for each of the 128 data points to determine the mean value and standard deviation each 4.68 ms.

By using a set of statistics that could be applied to subsequent GOES signals, the intent was to obtain a predictable cw type signal that may also exhibit amplitude and phase perturbations due to other sources, such as ionospheric scintillation. By understanding the effects of such phenomena, and their contributions to signal enhancement or fading, the intent would be to design improved communication links for GOES and other future satellite systems.

However, using the approach described to normalize the effect of spacecraft spin modulation, the study of ionospheric scintillation effects on the GOES signal is not recommended because spin modulation effects vary significantly during each revolution of the satellite.

<u>Improvement of the GOES Interrogation Link</u>. The NOAA Data Buoy Office (NDBO) at Bay St. Louis, Mississippi, has experienced difficulty with the Data Collection Platform Interrogation (DCPI) link of the Geostationary Operational Environmental Satellite (GOES). The Office determined that the percentage of succussful interrogations of Data Collection Buoy Radio Sets (DCBRS) was unsatisfactory for a reliable Data Collection System (DCS). The radio sets, sensing devices, and associated peripheral and interface equipment were mounted on buoys located in the Gulfs of Mexico and Alaska.

The NDBO requested the ITS to evaluate the problem, recommend a solution, modify a DCBRS, if necessary, and conduct performance tests to demonstrate improved performance characteristics of the interrogation link.

An assessment of the current link power budget was made. Alternate solutions to improving performance are being considered, while link interrogation and bit-error-rate (BER) tests are being made.

Early performance testing at the Boulder Laboratories indicated two problem areas: a) low received signal level, and b) co-channel and adjacent channel interference from mobile transmitters. The interrogation frequency has secondary priority in the mobile channel frequency assignment.

Possible solutions to these problems involve the use of: a) a higher gain antenna, b) a low-noise preamplifier with sufficient gain to improve the bit-error rate and received signal level characteristics, c) an input filter to limit the interference (however, this degrades the system noise figure), and d) offsetting the interrogation frequency from the mobile transmitter assignments.

Interference measurements in the UHF band, sponsored by the Office of Telecommunications Policy will be made with the Radio Spectrum Measurement System (RSMS). Results of this evaluation and testing will be used to recommend interrogation-link performance improvement. This work will be completed in FY77.

<u>System Definition Study for the U.S. Postal Service Electronic Message Service System</u>. The U.S. postal Service (USPS) has undertaken a long-range program whose principal objective is the planning and development of advanced mail systems. An important element in this program is the planning and development of a national Electronic Message Service (EMS). OT/ITS has, in past years, assisted the USPS EMS program with system studies related to satellite communications and frequency allocations, satellite communications network design and queueing delay, and input/output EMS conversion systems for conversion of USPS customer messages into digital form and vice versa.

The objective of this OT/ITS project has been to assist the USPS in planning, preparing, and reviewing a statement of work for an industrial contractor who will conduct a detailed system definition effort for the purpose of establishing the technical and economic feasibility of a nationwide EMS concept.

The attractive economics of available wideband telecommunications systems strongly suggest that the USPS should look at such large-scale message systems as a new means of providing basic message services at reduced costs to the USPS customer.

Functionally, the EMS system would accept messages in digital or paper-copy form; convert inputs, as required, into a digital form; transport message inputs electronically from source to EMSS destination over communication networks; and either convert the message back to paper copy form for carrier delivery to the recipient or deliver it to the customer by alternative electronic delivery systems. The possible collocation of EMS facilities with existing USPS facilities is a major consideration in reducing EMSS costs and in providing suitable EMS/conventional-mail interfaces.

We developed the EMS system requirements and system alternatives study requirements, as well as the system evaluation concepts specified in the EMS system design statement of work. Additional efforts involved the technical areas of message traffic analysis, network architecture, operational procedures, link design, error control, network cost, and trade-off studies.

A USPS statement of work was released to bidders in April 1975, and proposals from industry were received in June 1975. OT/ITS served as part of the USPS technical proposal evaluation team until the completion of the project term in October 1975. The proposal evaluation activities have continued beyond October 1975 under the continuing project described below.

A separate activity of this project was to perform a review of all rulings and other actions of the Federal Communications Commission in the field of digital communications for both common and specialized carriers. Letter reports were submitted to the USPS.

Electronic Message Service System Definition. ITS has continued to provide technical assistance in the telecommunication aspects of EMS to enable the USPS to work more effectively and productively with U.S. industry in the EMS development.

During FY76, ITS has provided technical assistance to the USPS in execution of the Electronic Message Service (EMS) System Definition and Evaluation program. We participated on the USPS technical proposal evaluation team to evaluate industry proposals. This effort led to a contract award to RCA for a two-year System Definition and Evaluation Study to develop and evaluate EMS system alternatives, select an EMS system design for nationwide USPS implementation, and conduct planning and economic studies.

We also studied system service and performance requirements for the USPS EMS and assisted the USPS in development of the parametric requirements for the EMS system definition effort. Figure 2-9 shows a sample of these parametric studies. The scope of the requirements involves systems which may have traffic volumes from 25 to 200 million EMS messages per day from 25 to 15,000 EMS stations, most of which would be collocated with present USPS facilities. Others would be at customer facilities; provide for both manual and telecommunication input and output; may have EMS services for digital data, magnetic tape, card or disc, OCR, facsimile (black and white and possibly color), and microfilm; and involve a variety of terrestrial as well as satellite communication networks.

Building Attenuation of Satellite Signals. This project is one segment of a broader study being conducted by NASA to determine the feasibility of a future disaster warning system using direct broadcast from a geosynchronous satellite. For such a warning system to be practical, one concept calls for the warning signal to be receivable by a small receiver inside a house.

The project was organized in three parts: the design of an experiment for measuring building attenuation using signals from the ATS-6 Satellite (Phase I), the measurement of building attenuation (Phase II), and the analysis and assessment of the measured attenuation data (Phase III). Phase I and II were completed during FY75. The objective of the data analysis was to evaluate the building attenuation data as a function of frequency, elevation angle, type of building construction, weather condition, and climatic area. The analysis included a review of information on housing occupancy and trends to assess the impact of the building attenuation measurement results on the design of a future satellite warning system.

During the building attenuation measurement phase, measurements were made on 27 buildings of different construction. All buildings were single-family residences and were located in Boulder, Colorado; Duluth, Minnesota; Kansas City, Missouri; Houston, Texas; and Little Rock, Arkansas.

In the evaluation of the measured attenuation data, the data were classified according to city, frequency, type of building construction, and type of insulation used in the building. Each room was also classified according to effective window surface area (6 groups) and degree of exposure (9 groups); i.e., classified by degree of sheltering by other parts of the building. The roof conditions of the building were also the basis for classification. Snow (3 levels) and rain (3 levels) were considered.

In the analysis of these data, the statistical technique of analysis of variance was used. The purpose of the analysis is to determine the relative contribution of each factor (e.g., frequency, type of construction, etc.) to the overall variability of the building attenuation data. The analysis showed that all factors except window aperture, snow, and rain had a statistically significant effect on building attenuation.

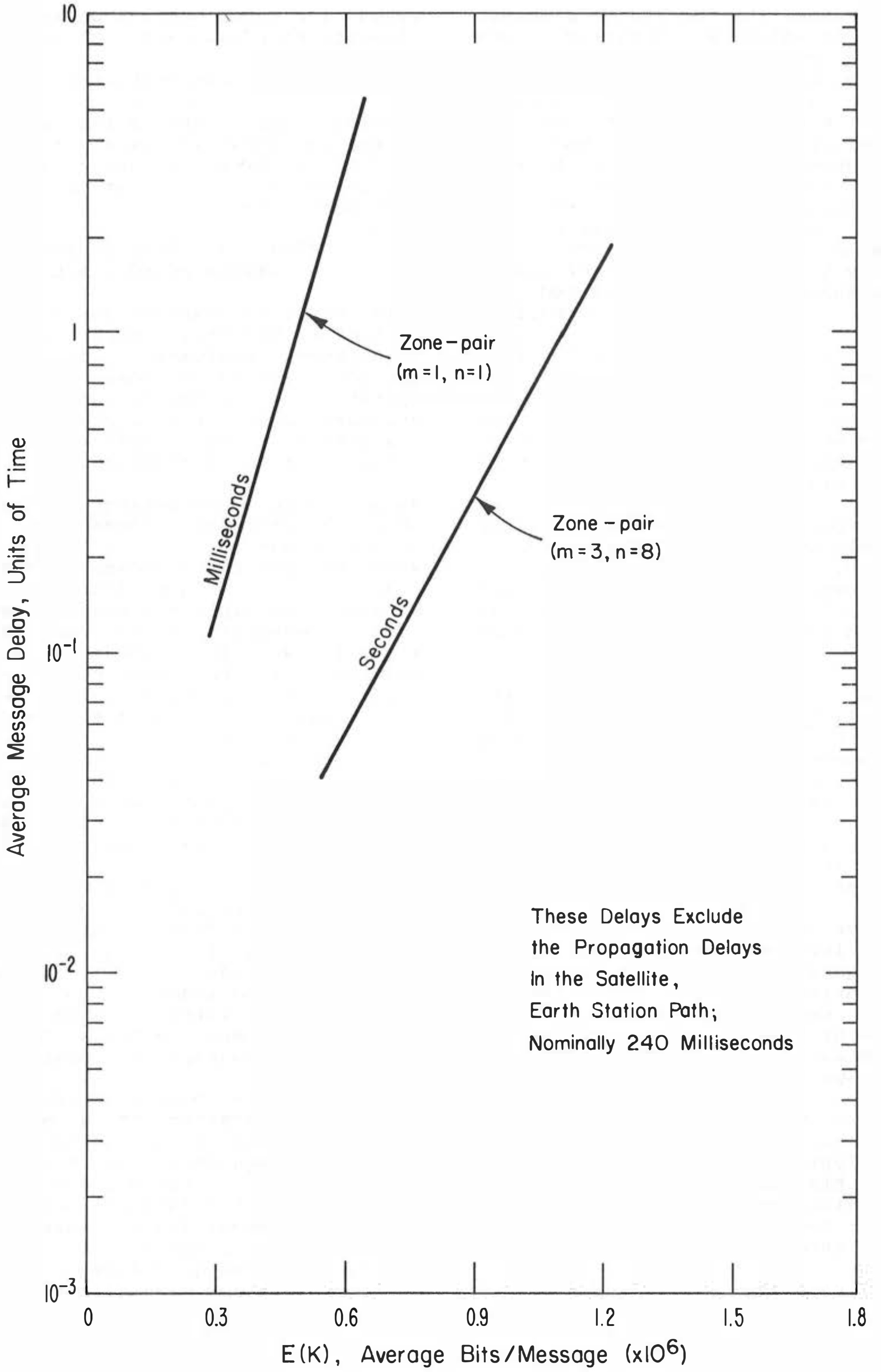


Figure 2-9. Message delays as a function of average bits per message (m, n are the geographical zones of the transmitter and receiver, respectively).

Figure 2-10 shows the results of a subset of the data in which two building types (wood siding and brick veneer), two insulation types (blown in ceiling and ceiling and walls no metal), and room exposure (one or more walls exposed and no exposed walls) were measured. While the average measured attenuation for the wood and brick veneer buildings was 6.3 dB, there were several measured attenuations which were significantly greater. Two wood-frame houses with wood exterior in Kansas City had interior walls of aluminum backed sheetrock. The measured attenuation for these houses ranged from 14.6 to 22 dB. Thus it is apparent that for some classes of housing units (frequently characteristic of an area) the building attenuation is very high. A follow-on project, described below, has been initiated to study alternative methods of receiving a direct satellite communications signal.

A final report (The attenuation of UHF radio signals by houses, by Paul I. Wells (ITS) and P.V. Tryon (NBS)), now in editorial process, contains the details and analysis of this measurement project. It is scheduled for future publication as an OT Report.

Alternative Reception Techniques for Direct Satellite Communication. The results of the building-attenuation study described above have prompted two possible areas of investigation for improving reception of warning signals: improved coupling (to compensate in those cases where building attenuation is excessively high) and improved (yet cost-conscious) home-receiver design.

The objective of this project is to evaluate novel, low-cost alternative methods and techniques for receiving radio signals in a variety of houses including mobile homes (where attenuation is high). The purpose of the radio signal is to communicate warning of a natural disaster such as a severe storm.

There are a number of potential techniques for coupling the radio signal into a house. Typical of those which will be studied in this activity are use of a simple, outside antenna; coupling through the AC-power house wiring; and use of an existing TV antenna.

The type of receiving system which may be appropriate will be dependent upon the method of modulation used in the message transmitted from the satellite.

In this study of receiving systems, primary consideration will be given to frequency modulation. State-of-the-art in receiver design techniques will be surveyed for novel designs which may be applicable to a low-cost receiver.

This project was initiated late in FY76 and will be completed in FY77. It will provide basic information which is required to assess adequately the feasibility of a disaster warning system using direct communication from a geosynchronous satellite.

SECTION 2.3. TERRESTRIAL RADIO SYSTEM PERFORMANCE

This activity represents a significant part of a long-term contribution to the acceptance, evaluation, operation, and upgrade of existing communication systems operated by the Federal government. The projects deal with system performance prediction and system performance measurement and evaluation.

Radio System Performance Studies, 10-30 GHz. The increasing congestion in frequency bands below about 10 GHz coupled with the need for increased bandwidth to support higher information rates makes it mandatory to explore potentials of wideband communications in frequency bands above 10 GHz. The effects of the transmission medium for radio communication in these bands which have been treated in this study are fading (due to atmospheric stratification and turbulence) and attenuation, as well as depolarization by precipitation. The predictability of radio system performance is closely related to the statistics and predictability of these channel characteristics.

FY76 efforts constitute the second year of this project, and the objectives included further instrumentation and data collection on the long line-of-sight links in Colorado (see also the next project below) and assembly and publication of statistical information on atmospheric refractivity and rainfall rate as a function of geographical location.

Automated data collection and evaluation equipment consisting of a minicomputer and peripherals was procured in November 1975. This equipment is scheduled for installation on Lookout Mountain as the central point for data collection on the Colorado line-of-sight links. The desired programing has not yet been completed, and design changes in the input-output interfaces have delayed installation.

Much of the initial output of this project, and also the next project below, (including data gathered on the long line-of-sight links and the assembly of statistical information on atmospheric refractivity and rainfall rate) are discussed under the EM Wave Transmission

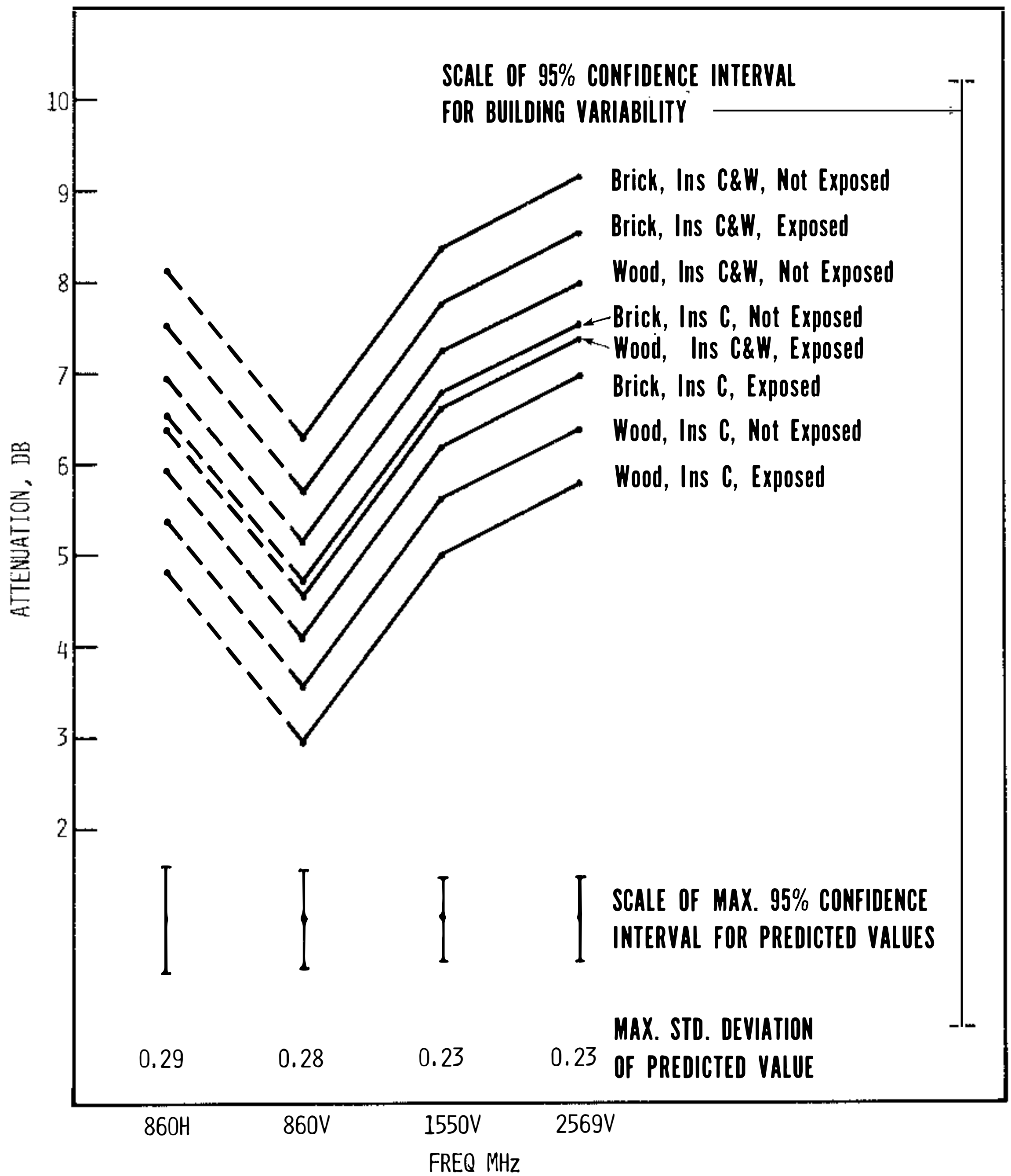


Figure 2-10. Attenuation presented by buildings to the reception of satellite signals by a receiver inside the building. Both horizontal and vertical polarization are shown for 860 MHz, just vertical for 1550 and 2569 MHz.

section of this report. The resultant material, however, constitutes basic background information for estimating reliability of microwave radio communications as a function of atmospheric characteristics. Specifically, refractivity gradient statistics may be related to multipath phenomena that affect digital transmission reliability. Rainfall rate statistics form the basis for precipitation attenuation outage time estimates that affect the feasibility of using frequencies in the 11, 15, or 18 GHz frequency ranges for communication applications in a given area.

The measurements over the Colorado links will be continued, and augmented with transmissions at 15 and 18 GHz. Further studies regarding atmospheric effects on digital communications will be made.

Radio Systems Applications Consulting. This project was originally implemented in order to enable ITS to provide a fast response to the Army Communications Command's needs in the implementation, testing, performance estimation, and performance evaluation of strategic microwave and troposcatter links and systems. This project has been in existence for a number of years, and specific objectives or tasks are imposed by the sponsor as required.

FY76 tasks were part of a cooperative program between the U.S. Army and ITS to obtain performance data over long line-of-sight (LOS) microwave links at frequencies above 10 GHz (see previous project). Specific objectives were to make long-term transmission loss measurements over two existing links in Colorado at 6 and 11 GHz, and to acquire, assemble, and install 15 GHz equipment on these same links. The results of these tests and related reports are described under the EM Wave Transmission portion of this report.

Equipment necessary for 15 GHz measurements was acquired partly on loan from the U.S. Air Force and partly by the purchase of components. This equipment was assembled and tested in the laboratory; but has not yet been installed at the sites.

Results of the work under this project contribute to the data pool on predictability of performance for long microwave LOS links, and provide additional data on expected outage time due to rain attenuation. Such data can be used as a basis for link and system reliability estimates, although they constitute only a small sample.

Test and Acceptance Upgrade. This project was initiated in FY71, and provided engineering services to the U.S. Air Force Communication Service (AFCS) in support of acceptance and performance testing of broadband point-to-point communication systems. Specific tasks for the project were the automation of tests and measurements, and development of the associated instrumentation with emphasis on signal level recordings from microwave links.

Two automatic devices, termed "RSL-1" (field tested several years ago) and "RSL-2", were designed and built by ITS. The RSL-2 is controlled by a minicomputer, and can perform signal level recordings, automatic calibrations, and on-the-spot data analysis for quadruple diversity microwave communication systems. It has the provision for recognizing the onset of fading conditions and for more detailed record-taking under such conditions. Signal levels can be graphically presented on peripheral equipment, and tape cassettes accumulate data for computer-controlled analyses at a later time. Thus an assessment of system performance can be made immediately, and a more detailed analysis is possible for a specified time block at any later date.

The FY76 work included upgrading of the RSL-2 and improvement of the software programing for the system.

AFCS Digital Data Systems. The U.S. Air Force Communication Service (AFCS) engineers, operates, and maintains portions of the Defense Communication Agency's world-wide military communication network. As the complexity of the network equipment increases, the sophistication of the instrumentation required to monitor the network has increased proportionately. Yet it is very desirable that the new instrumentation should be easy to use. Rather than utilize special purpose measurement equipment, the decision was made by AFCS to use modular, stand-alone, programable test equipment with a general purpose interface bus (GPIB) that meets the IEEE 488-1975 standard.

In order to utilize the modular instrumentation in a distributed communications environment, ITS was given the responsibility for developing the prototype Universal Performance Assessment and Control System (UPACS). This system is to be used in the operational evaluations of digital microwave radios on the AFCS Test Bed. The UPACS system consists of a central, real-time minicomputer with discs, graphics, printer, magnetic tape, and paper-tape facilities. The central computer serves as a master and polls serially three slave minicomputers for data taken via the GPIB instrumentation. ITS developed the communications protocol and software, as well as sample programs to demonstrate the use of the minicomputer network. The concepts being developed by ITS for UPACS will most likely have a major role in influencing future decisions concerning DCA long-lines testing and procedures.

A similar program of data acquisition and analysis via a distributed computer network was developed for the FKV European system and is described later in this section. Major differences between FKV and UPACS are that UPACS uses serial polling over a single communications line to all slave minicomputers, whereas FKV uses a separate communications channel to each slave minicomputer. Also, all input data to UPACS are obtained via the GPIB, while the FKV system uses special-purpose instrumentation and analog-digital converters for data input.

The UPACS system, including hardware assembly and software development, was completed in July 1976 and shipped to the sponsor.

RADC Automatic Data Acquisition and Analysis System Instrumentation. Under contract to Rome Air Development Center (RADC), Griffiss AFB, ITS has developed computer instrumentation to measure and analyze the degree of applicability of cross polarization transmissions for digital radio systems operating at 8 GHz. The purpose of the experiment is to determine the effects of cross polarization on the performance of line-of-sight (LOS), microwave, digital transmission.

To study this effect, ITS developed hardware and procured computer and peripheral equipment to make the measurements. A related ITS project (reported on in section 4.1) was devoted to the design and construction of the cross-polarization portion of the equipment.

Additionally, real-time software programs were written to measure and determine the isolation between horizontally polarized and vertically polarized microwave channels, and to record the bit-error counts of two quadriphase, phase-shift-keyed (PSK) modems.

The software package consisted of two parts: a real-time system and a post-test system. The real-time system collects data on received signal level (for both horizontal and vertical polarizations) and reads bit-error counts. These parameters are measured once each second, and plots of cumulative distributions are calculated to include 50%, 90%, 99%, and 99.9% points. Detailed data are stored on magnetic tape for use by the post-test system. The real-time system also calibrates the hardware system once each day. The post-test system reads all the magnetic tape data, and calculates and prints histograms, histogram summations, least squares curve fits, confidence limits, and corresponding point matrices.

The software programs were written, installed, checked, and, after delivery of computer instrumentation, the programs were tested at the receiver site in New York state. Real-time measurements were made and the data were stored.

In FY76 the final software and hardware tune-up was performed, and the system was turned completely over to RADC. Figure 2-11 is a photograph of the complete installation.

SELCAL. Calling ships at sea by radio is a painful affair and often accompanied by almost intolerable delays, on the average exceeding six hours.

The problem has been recognized for some time, and in 1972 the Maritime Administration (MarAd), at the request of many U.S. shipping companies, initiated the development of a digital selective calling system (SELCAL) to meet present and future needs.

Internationally, this need was recognized and the CCIR adopted a Question on this subject in 1967. Based on work done by a special committee of the Radio Technical Commission for Marine Services, as well as some MarAd in-house analyses, a specification for a digital SELCAL system was prepared and a contract was awarded to GTE/Sylvania to build six demonstration units. ITS has served as technical advisor and representative for MarAd since 1973. We carried out simulation tests in our laboratory and participated in at-sea tests. The results of these tests were presented to the CCIR in early 1974.

Concurrent with the development in the U.S., the Netherlands Administration developed a digital selective calling system as part of a direct printing communications system for maritime use. At the Final meeting of CCIR Study Group 8 in 1974, a compromise between the Netherlands system and the U.S. system was agreed upon in principle. The 1974 World Administrative Radio Conference (WARC) adopted the digital selective calling system subject to final technical definition by the CCIR. To this end, an Interim Working Party (IWP) was established to ensure that a recommendation will be arrived at before the next CCIR Plenary Assembly.

This Interim Working Party (IWP) met in 1975 and agreed on a proposed draft for such a Recommendation, which was submitted for the 1976 Interim Meeting of CCIR

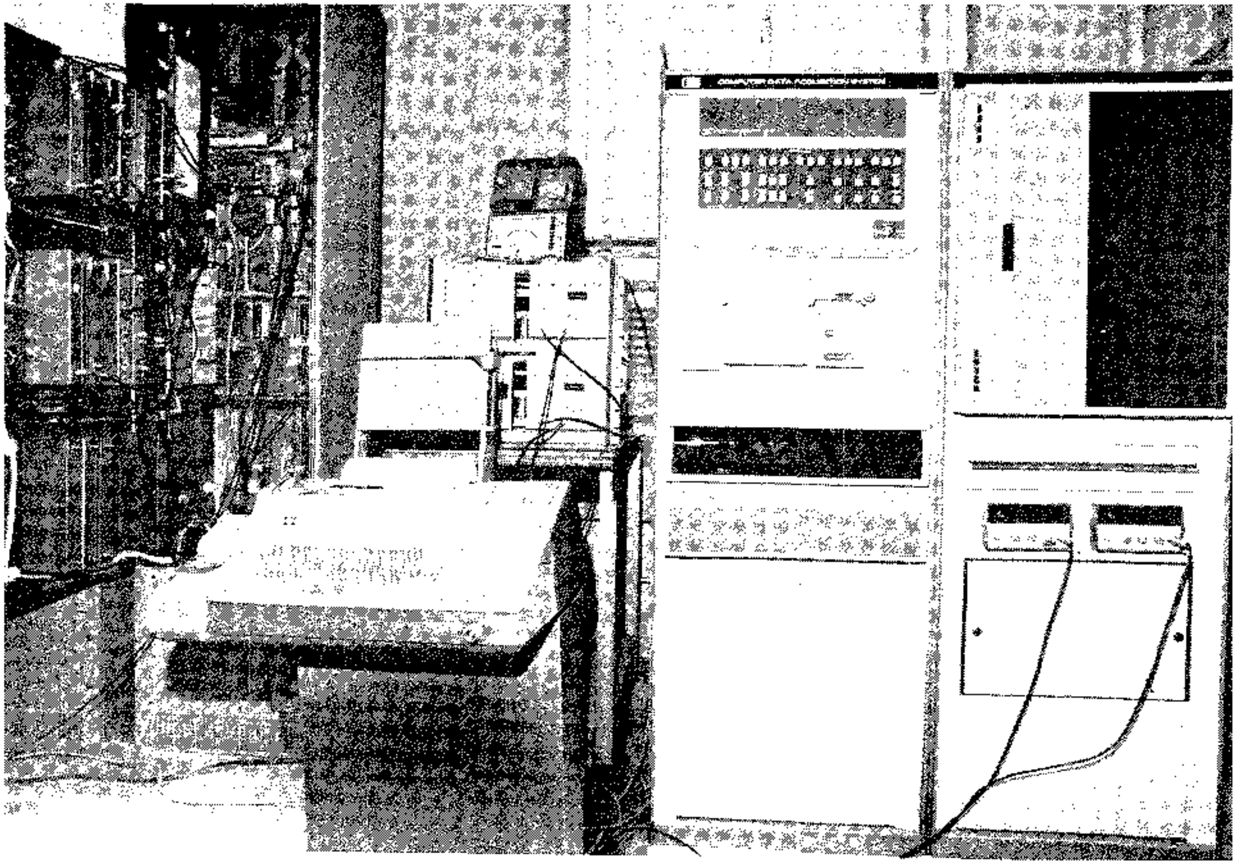


Figure 2-11. Photograph of the completed instrumentation for the RADC Automatic Data Acquisition and Analysis System.

Study Group 8, and adopted with only a few modifications.

After the SELCAL demonstration units were modified in accordance with the principles of the 1974 agreements, ITS conducted further tests with its HF simulator and supervised subsequent at-sea tests, prepared contributions to the IWP and for the Study Group 8 meeting, presented the results of these tests, and suggested the technical characteristics for a proposed Draft Recommendation. The success of the meeting of the IWP, and the adoption of a Draft Recommendation at the S.G. 8 Interim meeting, were largely due to these U.S. contributions.

A wide range of SELCAL equipment is foreseen, from elementary units in the price range of $100 to $200 for pleasure and other small craft to highly sophisticated units with many control functions priced at several thousands of dollars for large commercial cargo and passenger ships. Figure 2-12 is a photograph of a working SELCAL unit. For the U.S. alone, the potential market in the next decade will probably be tens of millions of dollars. Internationally, the U.S. is in a prime position to capture a large share of the world market due to its early lead.

FKV Data Measurement System Development. The purpose of the FKV-related projects was to develop and implement a semi-automated data collection and reduction system to be used to monitor and pre-process significant operational and technical performance parameters of a pilot digital microwave communication system consisting of five line-of-sight links. This communication system is operated by the U.S. Army Communications Command in West Germany between Heidelberg and Stuttgart-Vaihingen (see map in figure 2-13), and constitutes the first step in the ultimate conversion of the world-wide U.S. defense communications to digital transmission techniques. The pilot system is designated as the FKV Project (Frankfurt-Koenigstuhl-Vaihingen). Related ITS work is described in the project description immediately following.

Work under this project included procurement of minicomputers, related peripheral hardware, executive and other required standard software, and the development, checkout, and implementation of computer programs to collect, store, and pre-process operational performance parameters from three communication sites. Using dedicated communication channels between sites, the system permits collection of all information for storage at the Heidelberg station.

Particular emphasis in the software development was given to the analysis of "events" or "change-of-state" data. Information about events is stored on magnetic tapes, which are forwarded to Boulder Laboratories for further analyses. Additional programing activities were developed for sorting the tapes for examination on cyclic or random event occurrence, and for identification of other characteristics related to performance problems or equipment status. Monitoring events in this manner provides information regarding such things as a) cascading of errors, b) the first occurrence of error, and c) possible fault isolation.

The evaluation routines were also developed to provide a check on the grade of service or system level. A system level of 1, for example, means that all parts of the system are functioning. A level of 5 can mean that the system is off the air.

FKV Pilot Digital System Evaluation. This project supports needs in several aspects of communications required for national defense and is closely related to the work described immediately above.

It consists of several related tasks with the common objective to perform an operational evaluation for five pilot digital microwave radio links which transmit high-speed digital information between Heidelberg and Vaihingen, West Germany. The FKV data acquisition and analysis system is seen in the photograph in figure 2-14.

Specific objectives of this project for FY76 are the complete installation of the ITS-developed automated data-collection system in Europe, and operation of the acquisition system as well as collection of the less quantifiable factors such as human engineering, training, maintenance concepts, and operations concepts. Further, data analysis is to be an on-going effort to provide fast turn-around of solutions to significant problems, if they do exist, and to allow for evolutionary analysis programs on the many parameters collected.

Activities in FY76 were as follows:

1. Installation of System on Site in Germany - During July and August 1975, the FKV Pilot Digital System monitoring equipment was installed at the Heidelberg, Koenigstuhl, and Vaihingen communication sites. Considerable effort was devoted to locating and connecting the sixty-odd test points to the computer interface gear and checking all data collection programs. The final installation checkout was completed by September 1, 1975. Software development continued for approximately two months after this date.

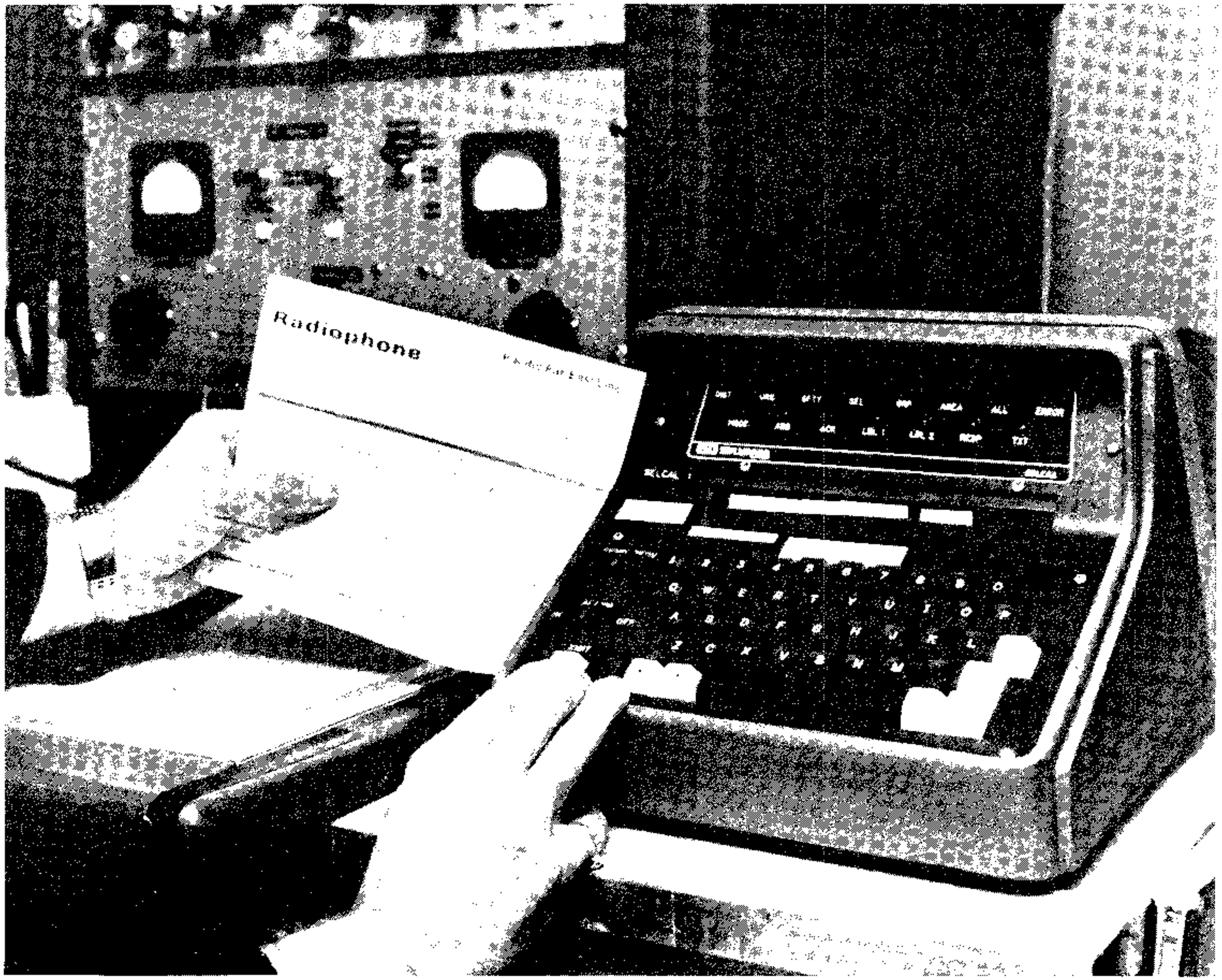


Figure 2-12. A terminal for an experimental digital selective calling system (SELCAL) for maritime use.

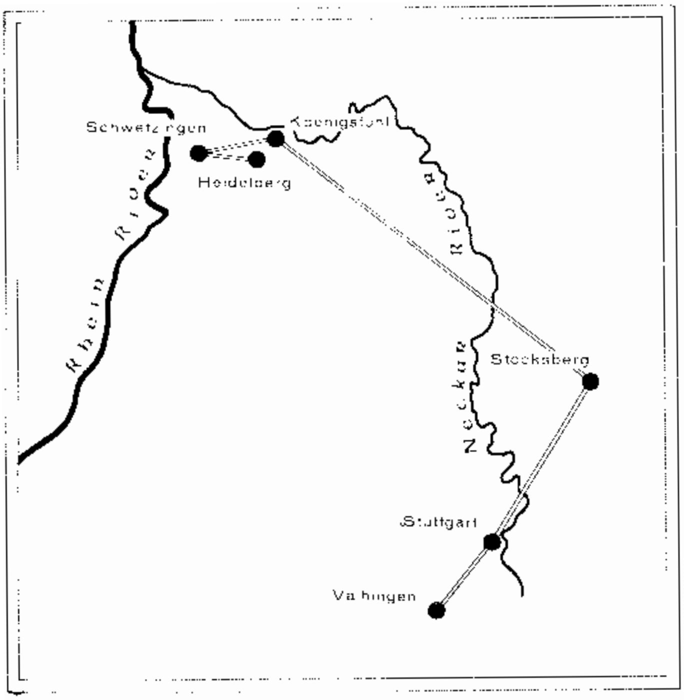


Figure 2-13. Sketch of the FKV Pilot Digital Communication System in West Germany.

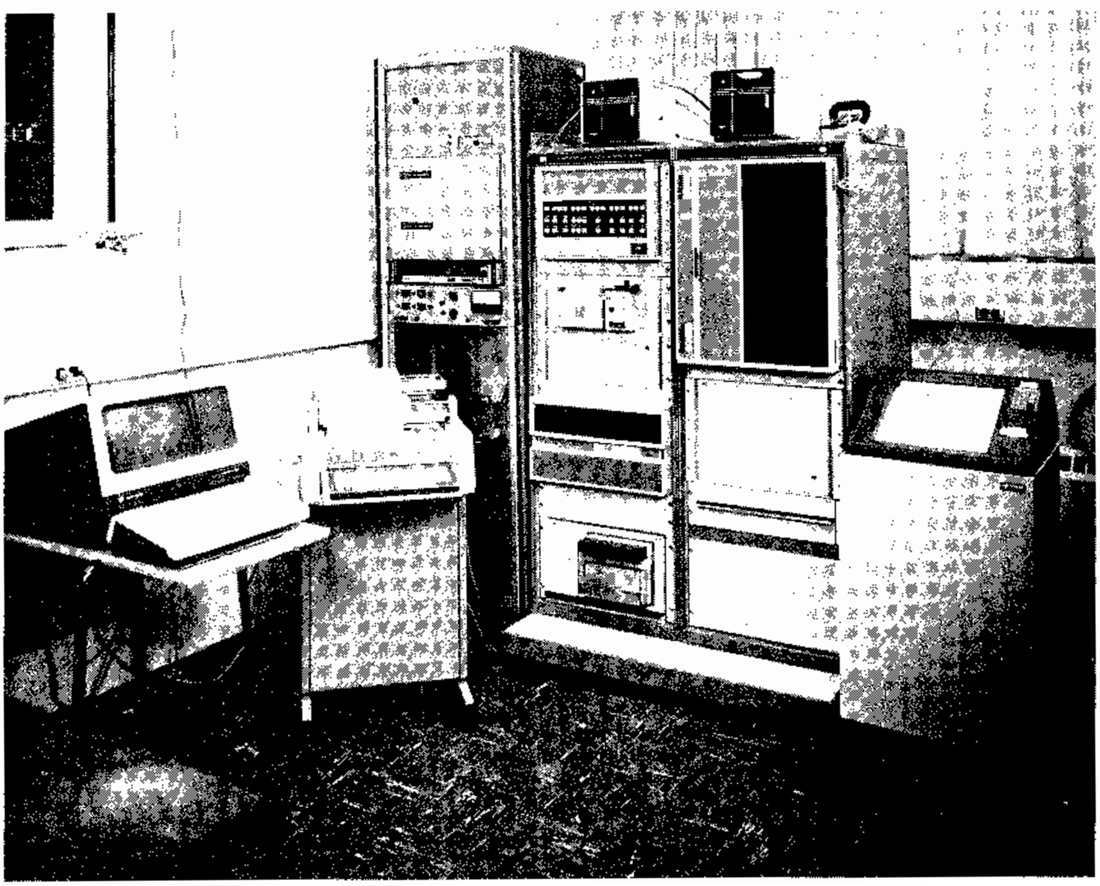


Figure 2-14. Photograph of FKV data acquisition and analysis equipment.

2. Data Acquisition and Analysis - The data acquisition system is configured such that it is able to monitor some sixty test points per terminal end of the communication system. These test points include many alarm functions that are built into the various sub-systems as well as the monitoring of framing errors, received signal levels, etc. The system as finally deployed consists of four minicomputer-based acquisition systems at four separate communication sites. The acquisition systems are interconnected by way of data modems operating over voice channels in the communication system being monitored.

The data acquisition approach is to retain data by exception or change; that is, only those data are retained which contain information indicating a change in a parameter status. To accomplish this, thresholds must be set on many of the parameters and preliminary analysis performed to arrive at a decision on whether to retain the information or not.

The data collected by each acquisition system are assimilated at a central computer and stored on a single archive tape to be used in later analysis.

3. Addition of a Fourth Computer at Stuttgart - During the early period of data collection, it became evident that a great deal of system activity was originating at the Stuttgart radio station. Since the station was not included in the original computer network, additional funding was provided by the sponsor and an additional computer and set of interface equipment were purchased. The system was assembled, tested at the Boulder Laboratories, and taken to Stuttgart and installed in March 1976.

4. Large-Scale Data Analysis - The operation of the FKV monitoring system results in the collection of a considerable amount of data, and the minicomputer system has insufficient capacity to perform the large-scale data analyses desired. Thus, the final data handling is done by the large computer system at the Boulder Laboratories. Programs have been written to change the format of the data from minicomputer to large computer language, to order the data into a time sequence, and to eliminate obviously invalid data. Programs that develop histograms of intervals between various system alarms have also been written. Work is currently going on to prepare programs that will amalgamate many individual data points into a single occurrence or event and to determine the most probable cause for the event.

5. Measurement Period - The original intent of the program was to perform a year-long measurement program initially from July 1975 to July 1976. Because of unforeseen problems and subsequent delays in the communication system and monitor system implementation programs, the time period has been adjusted to extend from November 1975 through December 1976.

6. Assistance Provided to Follow-On Digital Programs - Meetings were held between the Army Communications Command, the Air Force Communication Service, and ITS personnel late in FY76 to explore the possibilities of direct input of experiences and information to the Air Force for use on the Digital European Backbone (DEB), Phase I system which is to be implemented using the same type of equipment as is currently being used on FKV. The meetings resulted in an agreement between ACC, AFCS, and ITS which provides one individual from each of the military organizations to be on FKV sites for three months to observe the operation and maintenance procedures and to develop suggestions for improvements in these procedures. The information will be fed back through the ITS representative in Europe and will be a part of the overall data base developed by the project.

7. Preliminary Results - Some general conclusions can be reached as a result of reviewing the limited data acquired over a portion of the measurement period. The design of the system was undertaken with a conservative approach and as a result the overall performance of the system is quite good. There was adequate and sufficient redundancy built into the system to assure a continuity in service through many classes of faults. System outages are infrequent and in many cases short-lived. The character of many of these failures is such that the system is self-healing with short disruptions. In addition, there have been hardware failures although the frequency and degree have not been excessive, an indication of solid hardware design.

Finally, no conclusive success has been achieved to date in the quest to identify a parameter or group of parameters that are high-potential candidates for use in total system assessment and trends.

Radar Microwave Link Upgrade. The Radar Microwave Link (RML) systems of the Federal Aviation Administration (FAA) are used to transmit radar scope pictures and related data on air space occupancy from outlying long-range air-route surveillance radars to associated air traffic control centers. Many of the existing links are nearly 20 years old, and while modifications have been made on the equipment in order to improve performance, the basic system does not utilize currently available technology in microwave communications. Complete replacement of the present system would be very expensive; furthermore, many of the links are still working satisfactorily.

The primary objective of the RML upgrade is to improve the performance of the system in terms of available fade margin and overall reliability. The fade margin can be improved by increasing the overall system gain, by reducing the system noise, and by improving the linearity of the various modules to increase system dynamic range and to reduce system distortion. The system reliability can be improved by using solid-state devices throughout.

An RML repeater terminal and an indicator terminal were furnished by the FAA for tests and modification work. The repeater terminal consisted of six receivers and six transmitters, and the indicator terminal consisted of four receivers and two transmitters. Figure 2-15 indicates the frequency plan and the system configuration.

A survey was conducted of commercially available retrofit units. As a result of the survey, ten solid-state receiver front-end units were purchased. These units consist of a balanced mixer, Gunn diode local oscillator, and AFC circuitry, and they replace the single-ended mixer, klystron local oscillator, and associated waveguide. Ten solid-state IF preamplifiers and IF amplifiers were purchased to replace the present vacuum tube IF strips. Figure 2-16 shows the components of an unmodified receiver and those in the modified equipment. Figure 2-17 shows the components of an unmodified transmitter and those of a modified transmitter. Four 1-watt transmitter retrofit units were purchased to replace ten existing 100 mW klystron transmitters. Two different types of transmitters were purchased for comparison in order to determine the best type for replacement. These units were tested on an individual basis and then installed in the system.

The present waveguide branching network which couples the transmitters and receivers to a common waveguide can be a source of mismatch and degradation of the system if not properly aligned.

In order to make comparisons, one receiver was left unmodified, one receiver modified with only a solid-state IF preamplifier and IF amplifier, and the other receivers were modified with the balanced mixer, Gunn Diode oscillator, AFC circuitry, solid-state IF preamplifier, and IF amplifier. Two transmitters were modified with a crystal-controlled phase-locked source.

After these measurements, a series of performance tests was made. The tests performed are as follows:

1. baseband-to-baseband level and frequency response
2. measurement of transmitter power
3. transmitter frequency stability
4. modulator linearity
5. receiver noise figure measurements
6. receiver transfer characteristics
7. demodulator linearity and delay
8. receiver susceptibility tests.

The transmitter modifications, by using a 1-watt source instead of a 100 mw source, should have given a 10 dB increase in system gain, but due to filter losses only 7 dB of gain increase was realized. The linearity and delay of the fully modified transmitter and receiver shows 10% improvement in linearity and 15 ns improvement in delay. The transfer characteristics of the receivers indicate an increase in linearity and dynamic range. The use of solid-state retrofit units also reduces power consumption and increases the reliability and frequency stability of the system.

After receipt of the new branching network, laboratory tests will be completed, and a report on all measurements, test results, and recommendations supplied to the sponsor (in FY77) to conclude work under this project.

Digital European Backbone (DEB) Link Tests. Short-term measurements of the received signal level at 8.6 GHz and the impulse response in a 300 MHz bandwidth were made over thirteen links in Europe to determine the optimum antenna heights and diversity spacings for use with the high-speed digital communication system to be installed in the network known as the Digital European Backbone (DEB), Phase I. This system will operate in the 8.2 to 8.4 GHz band using horizontal polarization and vertical space diversity. The purpose of the path test program was to assist the U.S. Air Force in the link engineering phase of the DEB system by identifying path obstructions and harmful reflections.

A wideband channel probe reference system developed at ITS for evaluating multipath propagation at microwave frequencies was used for the measurements.

The DEB effort consisted of the following four tasks:

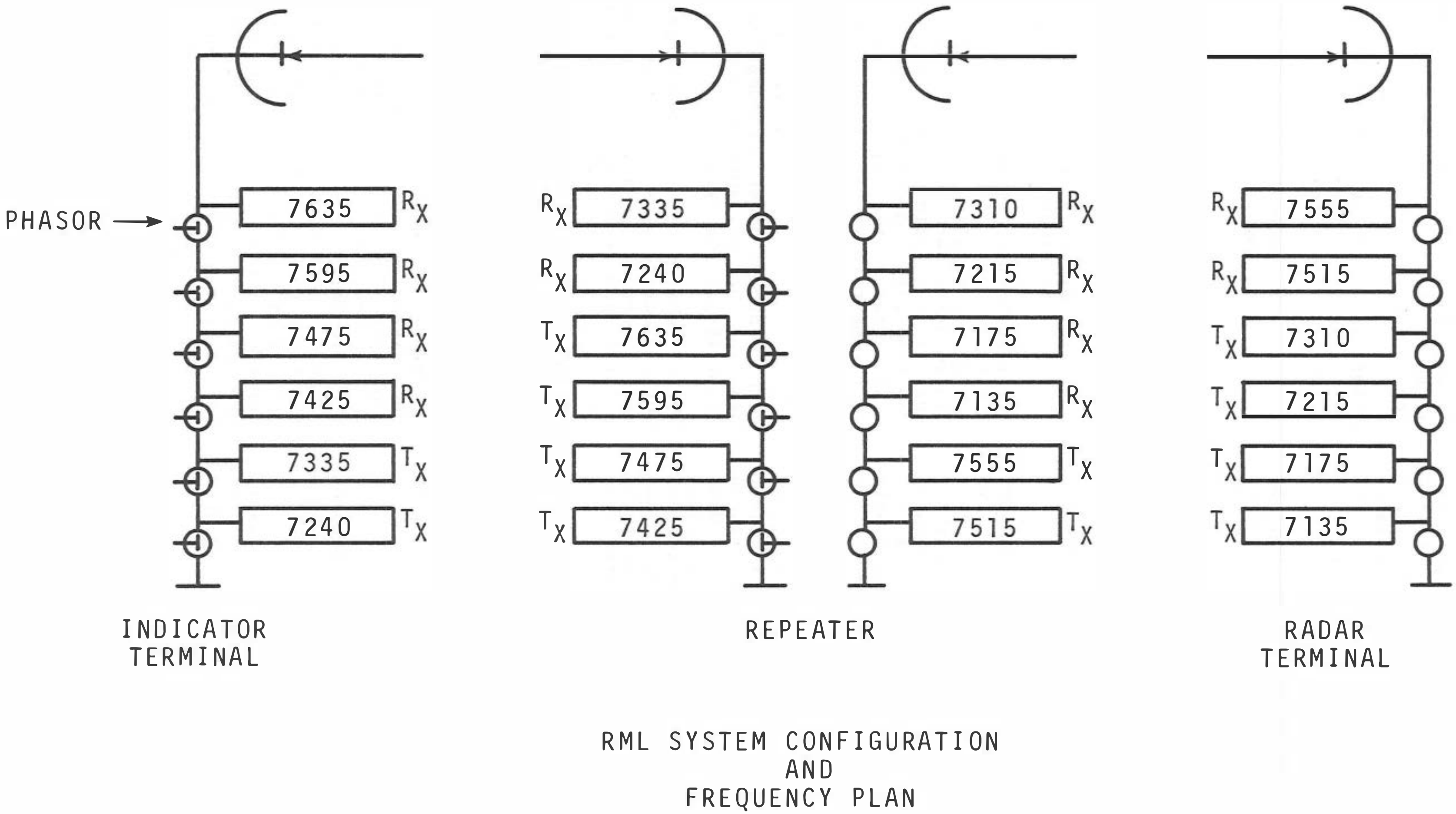


Figure 2-15. Radar Microwave Link (RML) system configuration and frequency plan.

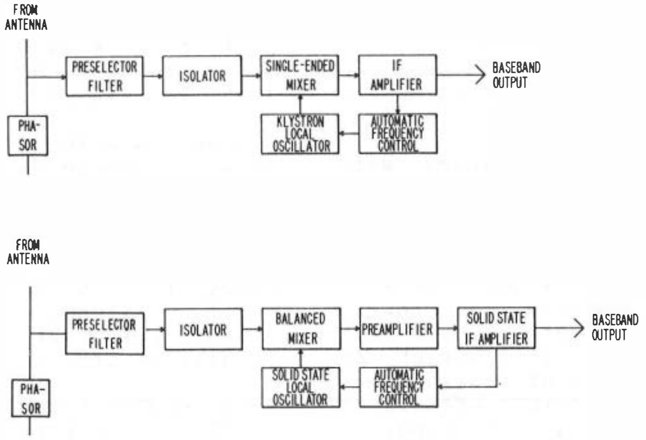


Figure 2-16. Comparison block diagrams of the standard (unmodified) RML receiver (top) and the modified RML receiver (bottom).

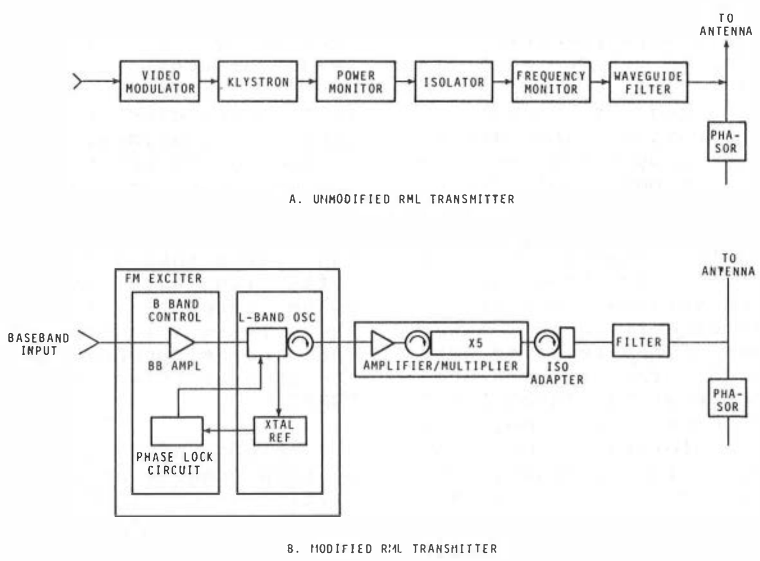


Figure 2-17. Comparison block diagrams of (A) the standard RML transmitter (top) and (B) the modified RML transmitter (bottom).

a. Review pertinent maps and profiles and compile applicable meteorological information to determine the most critical links in terms of performance uncertainties.

b. Assemble and prepare equipment needed for path loss tests.

c. Conduct the required tests in Europe and provide interim results on the basis of preliminary analyses of results.

d. Prepare a final report with recommendation for antenna heights, diversity spacings, and other pertinent parameters based on test results.

The preliminary path evaluations (Task a) were based on path profiles and tower-height information. A path-by-path computer analysis provided information on the location and effects of possible obstructions as well as possible effects of ground reflections for a large range of refractive gradients which affect the ray paths between antennas. These analyses did not take into account possible vegetation along the links, or reflections caused by atmospheric multipath or by terrain features which were not located on the great circle path between terminals.

Tests were conducted (Task c) on thirteen links in northern Italy and West Germany between 18 August and 5 December, 1975. Received signal levels were recorded for day and night periods to provide an indication of the short-term fading on each link. These RSL data and the impulse response data also provided information concerning possible propagation mechanisms causing fading and potential degradation of systems performance.

Path testing using this channel probe is similar in many respects to those procedures used for conventional cw systems. The primary difference between the methods is in the format of the received data and its application. The cw measurement provides only received signal level as a function of antenna positions, and these values must be plotted to determine height-gain curves. In contrast, the channel probe measures the impulse response as a function of time; reflected or refracted components may be resolved relative to the direct path in terms of both magnitude and time delay. The relative phase between components can also be evaluated using the quadrature components of the impulse response.

The use of the channel probe test technique does not completely eliminate the necessity for moving antenna positions on the tower, but does provide more information from a fixed antenna configuration than is possible from a cw measurement. For example, it is possible to derive a height-gain curve theoretically, given the multipath delays and magnitudes and using certain assumptions based on smooth-earth theory.

Impulse response data obtained with the probe provide valuable insight into the propagation mechanisms which cause fading. For example, if fading occurs when no multipath is apparent, the cause is probably a defocusing effect. If the impulse response envelope contains several peaks and valleys varying randomly with time, then atmospheric multipath exists. A ground-reflected component appears as a relatively stable impulse at some fixed delay from the direct component. Sketches of oscilloscope photographs and corresponding propagation paths showing these conditions are seen in figure 2-18.

Test results have identified three potentially troublesome links in the Phase I network. Most of the other links were found to be quite typical for line-of-sight paths, exhibiting only the normal atmospheric variations in RSL. No significant ground reflections were observed for any of the paths, and thus antenna heights are not considered critical in most cases. Ground reflections that were observed were on the order of 10 to 40 dB below the direct response, and were thus generally insignificant to performance. Most of these ground reflections were adequately discriminated against by antenna patterns and/or terrain blockage. Results for these measurements were found to be quite close to predictions made by computer analyses. The latter were performed by ITS prior to the actual tests, and were used as a guide in the test plan and procedures.

Two links that did indicate minor ground reflections were analyzed using the impulse response data. The results of these tests, along with a description of the channel probe, have been reported to the sponsor (Electronic Systems Division, USAF).

Los Alamos Scientific Laboratory (LASL) Systems Program Study. This program was initiated by LASL to define the Laboratory role in the management and technical support of national priority programs.

The objectives of this project were the development of a rationale for a laboratory systems analysis and engineering organization and; definition of the intralaboratory organizational relationships, priorities, and character of federal agency support, capability enhancements; and the development of an organization implementation schedule.

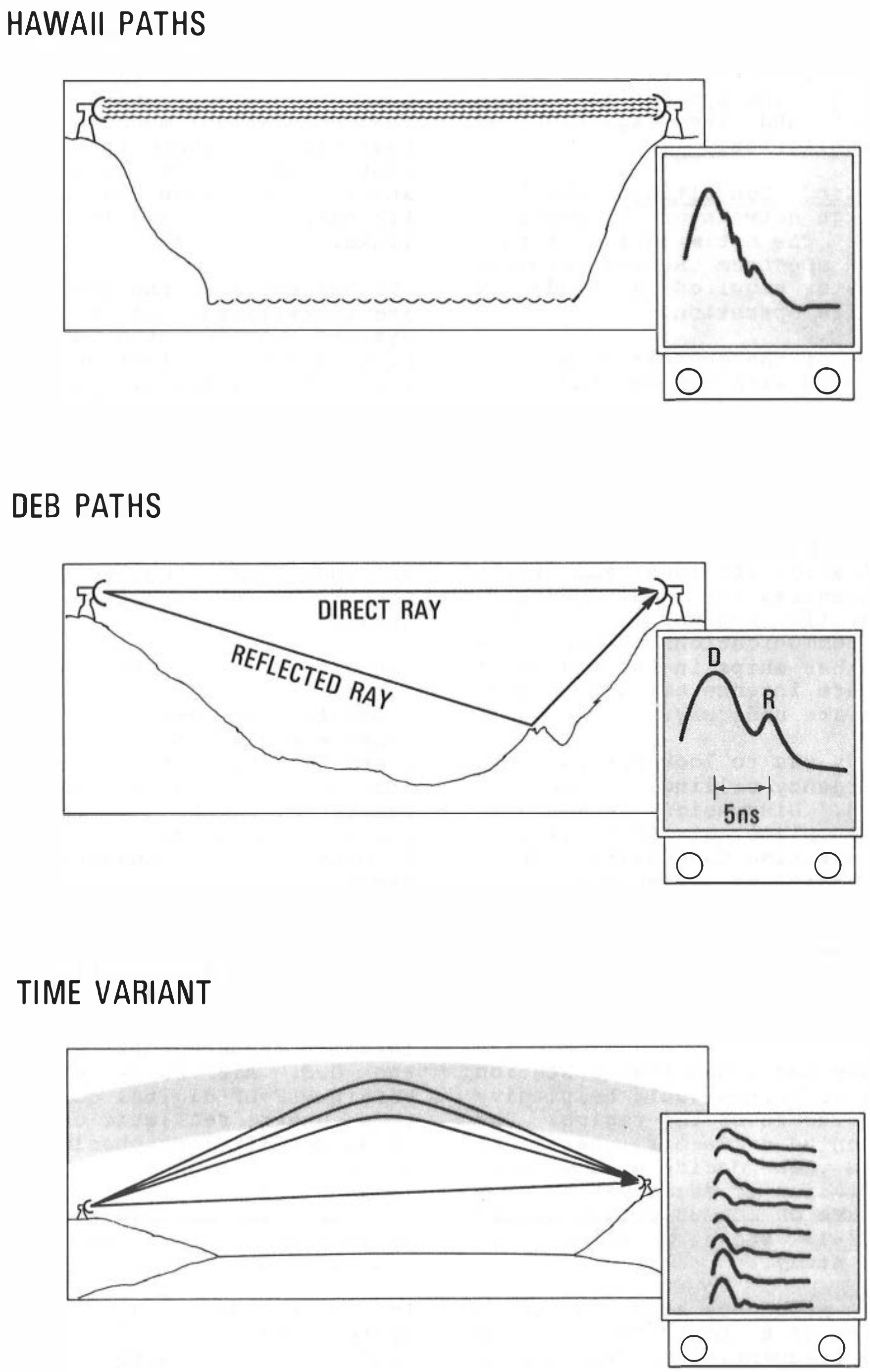


Figure 2-18. Stylized sketches of three types of paths and the corresponding oscilloscope traces observed with the channel probe. Shown at the top is an overwater path. In the middle is a typical path of the Digital European Backbone (DEB) system. At the bottom is an illustration of time variation due to changing atmospheric conditions.

The final letter report to the sponsor presented a summary discussion of the support areas in rationale for developing a systems agency within LASL, the additional resource requirements, and a schedule for acquiring systems management program support and the expansion of laboratory capabilities.

U.S. Coast Guard Consulting. The USCG maintains a large network of HF communication systems. The optimization of this net for minimum spectrum use and minimum operating costs requires a study of trade-offs in its operation.

The objective of the consulting project is to provide USCG with system studies to maintain their communication reliability while minimizing the operating frequencies.

Two major studies and many minor ones were performed in FY76. One study (the Alaskan study) was to determine the necessary communication stations and their operating frequencies for good communications to the Arctic regions. The USCG must maintain communications to their ice breakers and other ships in the region of Prudhoe Bay where intense oil well drilling operations are underway.

The second study was to look for possible world-wide emergency calling frequencies in the HF band. Discussions between nations have taken place at IMCO (Inter-Governmental Maritime Consultative Organization) for additional frequencies to be used to call for help during emergencies at sea. This study has shown the reliability predicted for several combinations of frequencies in the HF band to areas in both the North Atlantic and in the Pacific Ocean.

The Arctic study has shown that a station at either Adak or Barrow would help give the desired coverage of the region. The study has presented trade-off charts so that the USCG can decide what effects their implementation or deactivation of a station will have on communication coverage. Figure 2-19 shows a reliability chart for this study.

The emergency frequency study has shown that frequencies of 8 and 12 MHz are the best possible frequencies for world-wide guard frequencies for all conditions of solar activity, seasons, and hours, when compared to other pairs out of a group of six frequencies. In addition, single frequencies, triplets, and quadruplets of frequencies were studied in order more fully to understand the trade-offs involved. Figure 2-20 shows some representative reliability charts for the North Atlantic.

NDBP - Shore Station. The National Data Buoy Office (NDBO) of NOAA has responsibility for deploying instrumented buoys in the oceans. Additionally it is responsible for the transfer of oceanographic and weather information collected by instrumentation mounted on the buoys to base stations where it is forwarded to a center where the data are collected, analyzed, and made available for scientific purposes. Radio is used for the data links.

ITS has assisted the NDBO with the design and installation of the communications systems between the buoys and base stations and the collection center in Florida. The activity this fiscal year has consisted of the completion of a report (OT TM 76-212) giving instructions for the operation and maintenance of the NDBO equipment which was installed by ITS at the Coast Guard San Francisco Shore Communications Station. Consultative advice has also been provided in connection with antennas and frequencies to be used by the NDBO for specific communications needs.

SECTION 2.4. SIMULATION AND STANDARDS

Simulation and standards (including handbooks and glossary development) are combined here to emphasize the nature of the simulation activity, which provides a realistic, repeatable method of evaluating and comparing different sub-system elements (e.g., modems) on an objective basis.

Minimum Essential Emergency Communications Network (MEECN) Simulation. This project presently has two objectives:

1. To obtain comprehensive performance measurements simultaneously on the U.S. Air Force 616A and U.S. Navy Verdin VLF-LF digital communication systems under realistic channel conditions using the ITS Ionospheric Channel Simulator.

2. To develop and evaluate an experimental interference suppressor that can be used with such systems.

The 616A and Verdin are sophisticated systems that incorporate several modulation techniques with a number of compatible modes of operation that are used in the Department of Defense's Minimum Essential Emergency Communication Network (MEECN). The first set of channel-simulator measurements was made in one mode of operation in FY75. Figure 2-21 shows the channel simulator used in the project. A classified report on the results of these measurements was completed and published in FY76 [Watterson, et al. (1975); Comparative Evaluation 616A/Ver-

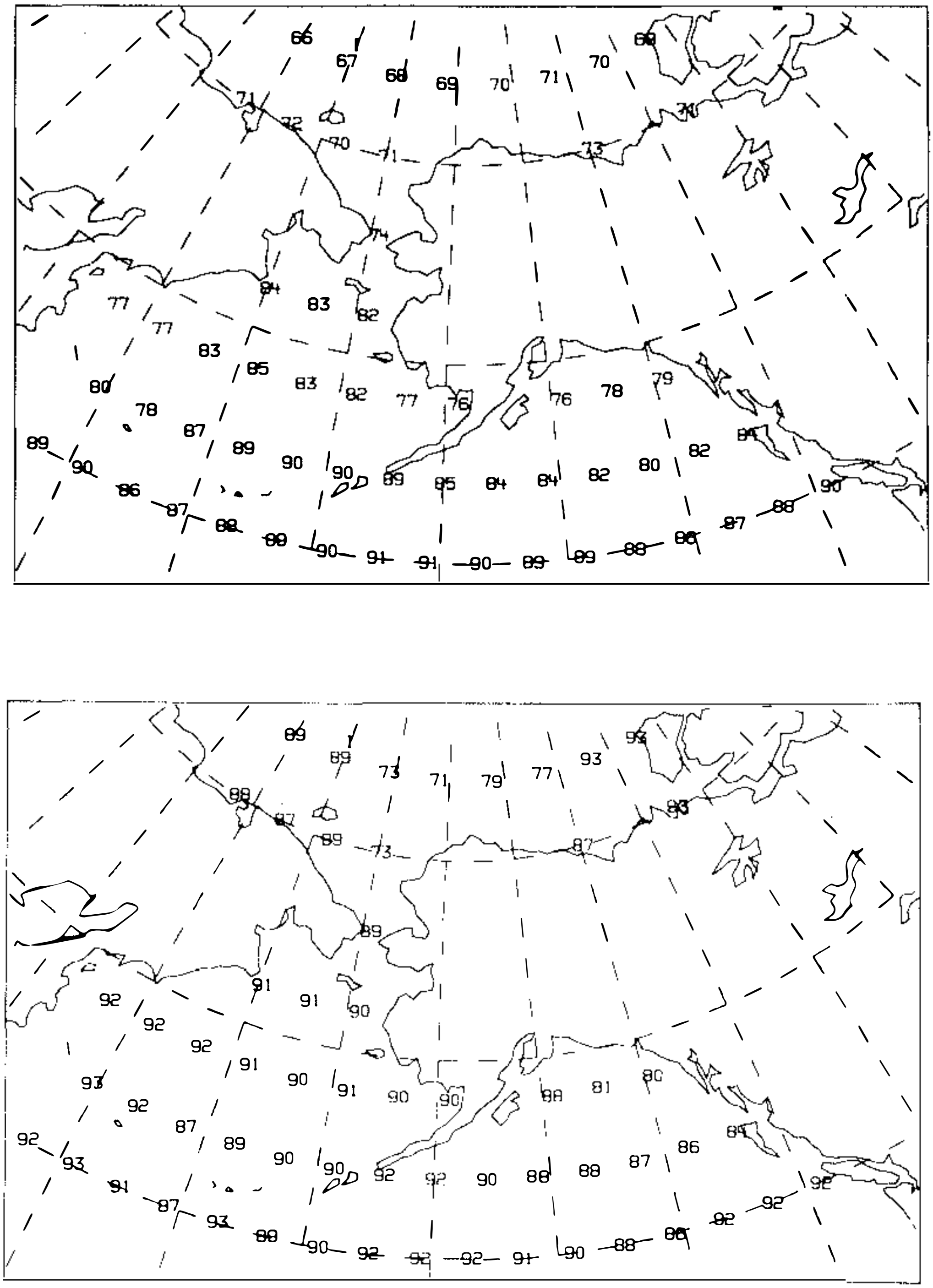


Figure 2-19. Charts comparing the expected service reliabilities (percent) with existing stations (top) and with two additional stations at Adak and Barrow (bottom) operating at 6 and 8 MHz. Conditions portrayed are winter night and high solar activity.

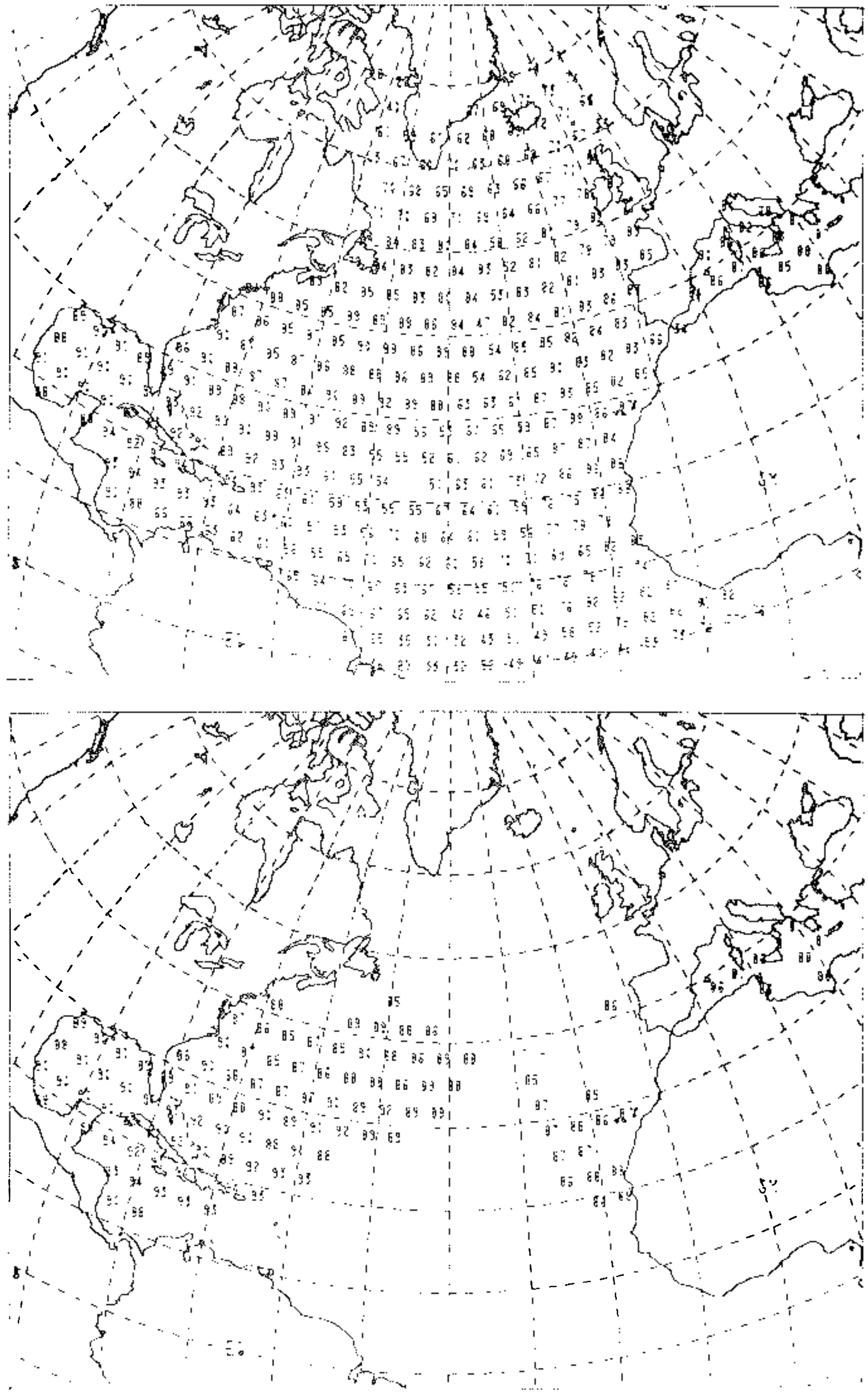


Figure 2-20. Charts showing the predicted circuit reliability in percent for locations in the North Atlantic to six shore stations at 1400 GMT for July and a sunspot number of 110 using 4, 6, 8, 12, 16, and 22 MHz. The upper chart includes all values; the lower chart those values equal to or greater than 85%.

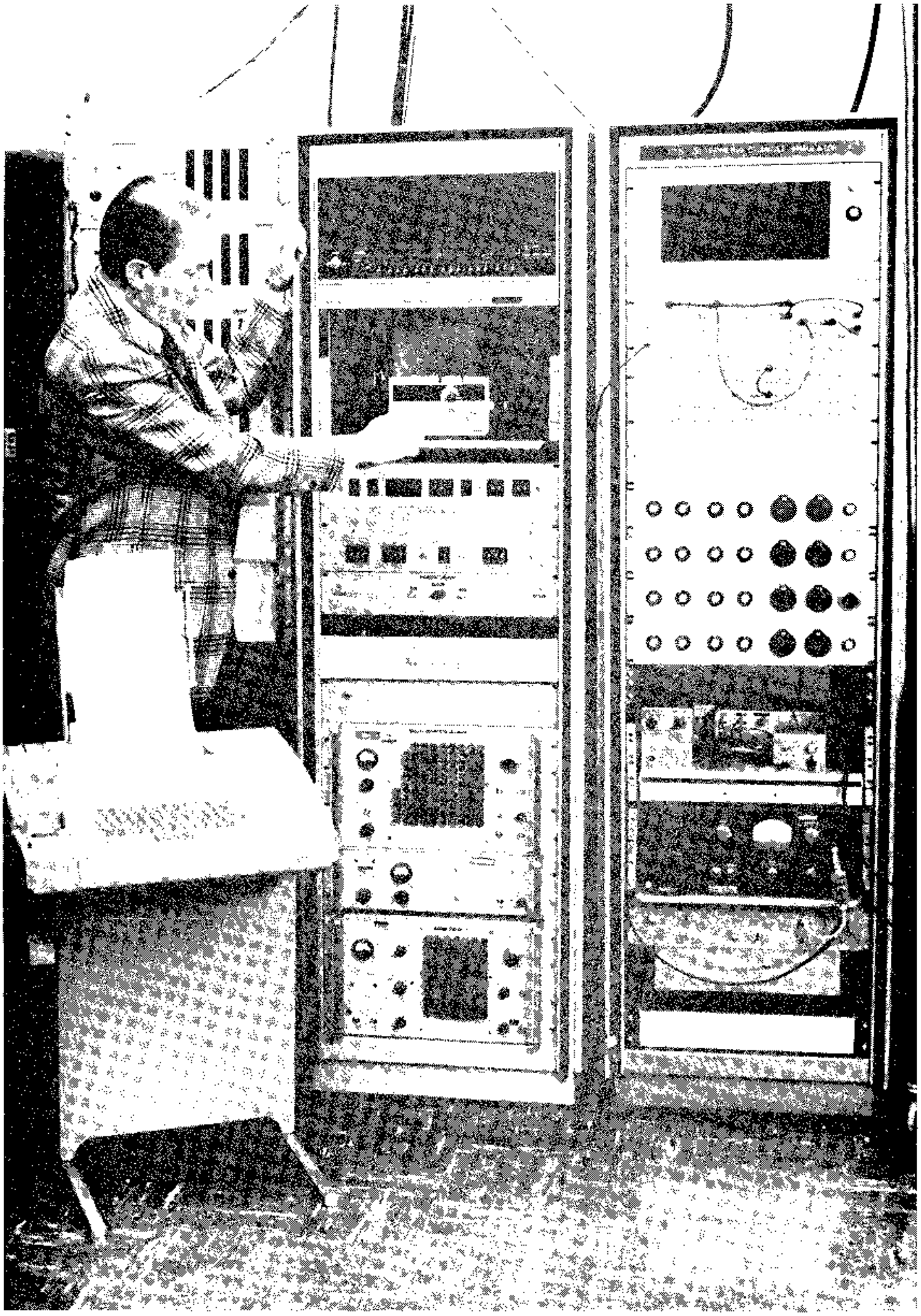


Figure 2-21. Photograph of the ITS ionospheric channel simulator used to make the MEECN measurements.

din Modems, Phase II, Part 1 (U); DCA Tech. Pub. 960-TP-75-40, 1-134 (Secret)]. Included is a description of a specially designed and built test set used to deliver data to the transmitter and to detect automatically character errors in the outputs of the receiving systems. An explanation and analysis is also presented of the on-line minicomputer processing used to determine the accuracy of each measurement as it progressed. Since accuracy improves with measurement time, the processing allowed an optimum compromise between measurement accuracy and measurement time to be achieved, particularly at lower error probabilities.

During FY76, a similar, second set of channel-simulator measurements was made simultaneously on the 616A and Verdin systems in six modes of operation common to the two systems. The performances of the systems were determined with respect to a variety of channel distortions: Gaussian noise, atmospheric noise, cw interference, multipath, Doppler, fading, and repeat jamming. In around-the-clock measurements over a six-month period, 53 experiments were performed, each of which yielded a pair of performance curves (one for each system) of character error probability as a function of the magnitude of the channel distortion. A classified report on the results of the second set of channel-simulator measurements is being prepared [Watterson and Minister (1976); Comparative Evaluation 616A/Verdin Modems, Phase II, Part 2 (U); DCA Tech. Pub. (Secret)]. The results of both sets of channel-simulator measurements provide valuable information on the performance capabilities of the two systems that can be used for performance predictions in the MEECN network.

The development of an experimental interference suppressor suitable for the 616A and Verdin systems was also undertaken and largely completed in FY76. Two methods were considered: a phasing method and a variable-clocking method. While the performance of the variable-clocking method will be poorer under some interference conditions, it was chosen because a practical design has about half the complexity of the phasing method. An all-digital design was prepared and an experimental interference suppressor using this design was constructed. At the end of FY76, bench tests on the unit were in progress. When the bench tests are completed, the suppressor will be temporarily incorporated as part of the 616A system, and channel-simulator measurements will be made to determine the improvement in the 616A performance provided by the suppressor for various interference conditions. A report on the design and performance capabilities of the interference suppressor will then be prepared.

<u>RADC Noise Simulator</u>. The VLF/LF Atmospheric Noise Simulator was supported by the Rome Air Development Center. The project's objective was to construct and test two atmospheric radio-noise simulators based on the simulators developed for the Navy Electronic Laboratory Center. They reproduce simulated atmospheric radio noise at 60 kHz. The data for the noise simulation was recorded during thunderstorm activity at various locations in the Western Hemisphere. The simulators were described on page 72 of the ITS Annual Technical Progress Report (1974). They are to be used in the U.S. Air Force 616A test program.

<u>Time Domain Objective Measurements</u>. A common procedure for determining the intelligibility of voice channels is to use a predetermined vocabulary with selected speakers and a listener panel to grade subjectively the intelligibility after the spoken words have passed through some voice channel. A variety of such testing schemes has been devised. Most of these schemes have the desirable property of producing repeatable results which can be interpreted in terms of user requirements. However, the requirement for listener panels greatly restricts the utility of these testing methods, and a long-sought goal has been to replace these listener panels with hardware. The work done on this project covered one step in the direction of reaching that goal.

This study used a 50-word, phonetically balanced word list played through six different voice systems with a range of articulation scores from 64.7% to 95% as a data base. A mathematical technique called Linear Predictive Coding (LPC), which was originally applied to the analysis and synthesis of voice, was used here to derive a distance measure for each word between the original undistorted words and the words after passing through a voice channel. This measure was compared with the subjective scoring for each word. For those words with a range of subjective scores (% incorrect), the distance measure is an increasing function of the subject scores.

A report to the FAA has been prepared and is under review. It supports the suitability of using measures derived from the LPC methodology for an objective measurement of intelligibility.

Support for this project came from both the FAA (Department of Transportation) and OT/ITS.

<u>Simulation Methodology</u>. This program was initiated in early FY75 for the U.S. Army

Test and Evaluation Command (TECOM) as one principal preparatory effort for the forthcoming evaluation of advanced combat support systems. The initial task concerned the methodology for employing computer simulation in development phase test support: detailing the forms and modes of employment for the required scenario and functional models, test design and execution monitoring applications, and the procedures for integrating the simulation processes with laboratory and field measurements and development agency performance data to maximize credibility.

The second major task involved the development of an initial complement of models (scenario and supporting functional elements) configured to emphasize the evaluation of advanced air defense systems, with the SAM-D (redesignated as the PATRIOT system) as the primary application.

For FY76, the objectives were the completion of the scenario and supporting functional models, and the development of application methodology documentation for the SAM-D system. The functional models emphasized the interactive EM components: phased-array radar, command/guidance and unit communications, tracker systems, propagation effects, and the friendly force interference (EMC) and EW environments.

The functional model development efforts concerned primarily the multi-functional Array Radar (MFAR) and the signal propagation models (SAMOFF).

Model specifications for the MFAR had been developed during the previous year. The major functional elements of the model were completed: signal detection and discrimination, KALMAN filter operation, and control functions. These models accommodate S/N and S/I (S/J) variations of the character expected through the range of time lines in the tactical scenarios to be excercised. These scenarios include BLUE and RED force deployments with specified time snapshots for codeployed BLUE units, and various levels of RED target and EW system densities. Critical radar time-line functions accommodated include acquisition, IFF, track initiate and track line dynamics, command/guidance link acquisition, command/guidance error envelopes, and engagement assessment.

The SAMOFF modifications concerned an extension of the array aperture phase distribution module to provide a time average phase distribution in the elevation plane over the array, and estimates of the range of phase fluctuation spectra within specified time windows. These modules are important in the forthcoming radar system test planning activities, particularly in identifying media-related compromises in the signal discrimination and ECCM functions of the radar and the related operational penalties in target detection and discrimination, track line and firing envelope errors, command error and delay profiles, and "kill" implications. The EMC and EW environment effects on radar performance are also complicated because of the fluctuation spectra caused by the refractive and reflective propagation modes.

These functional models are organized to accommodate test and evaluation support requirements, sensitivity analyses in operational and functional relationships to identify families of time-line critical zones, and provide detailed test specifications for laboratory and field measurements to develop radar performance descriptors with operational relationships.

The Application Methodology documentation details procedures for utilizing these simulation techniques in Development Phase testing, with the emphasis on test planning support. The processes of identifying system functional priorities, impacting environments, and doctrinal implications are fundamental to the specification of testing procedures and system performance data interpretation for a credible evaluation program.

These models will be utilized for the PATRIOT system test planning activities within TECOM agencies. A basic scenario has been selected which includes the required ranges of engagement dynamics. Functional sensitivity analyses to derive environments at the critical time-line events, and the initial performance-doctrine descriptors as inputs for subsequent measurement specifications to TECOM laboratory and field test facilities will be undertaken.

Line-of-Sight (LOS) Handbook Additions. Defense Communication Systems require standardized design criteria for worldwide strategic (fixed) terrestrial communication systems that are used for National Defense objectives. OT/ITS was tasked in FY71 through the Air Force Communications Service to prepare handbooks for design and performance estimation applicable to line-of-sight and transhorizon microwave links. Print-ready manuscripts were delivered to the sponsor previously; the FY76 project was concerned only with additions and revisions to the handbooks resulting from tri-service review of the material.

The objective of this project was to provide revisions to the drafts of MIL-HDBK-416 (Line-of-sight microwave systems) and

MIL-HDBK-417 (Transhorizon microwave systems) including an addendum to MIL-HDBK-416 on knife-edge diffraction calculations.

The revisions and the addendum were completed and supplied to the sponsor in October 1975.

It is expected that the results of the entire program will be a technically complete set of two handbooks for use by military agencies in design of and performance estimation for fixed terrestrial microwave communication systems. Publication of this material is at the discretion of military authorities.

The program is completed, and no further OT/ITS activities are expected.

Telecommunications Glossary. Communications among military personnel, and between military and civil organizations, are improved if a mutually understood language is employed. Military standards, specifications, contracts, operating manuals, etc. need a common terminology for correct interpretation.

The immediate objective of this project was to develop a common glossary for the MIL-STD-188 series, relating to Common Long Haul and Tactical Communications Systems Technical Standards. There had been previous work in this field for the military establishment; the ITS effort was in completing the glossary (based on the previous work), preparing definitions for previously undefined terms, and revising definitions for clarity, conciseness, and to reflect current usage.

During FY76, comments on an initial draft were consolidated, an interim draft was prepared, and two coordination meetings were held at Boulder with representatives of military agencies. A final draft was prepared and a photo-composed print-ready copy furnished to the sponsor in order to complete the work. This final version forms the basis for other work on the Federal Glossary (described below), and will be printed for distribution as a Military Standard. The sponsor plans to revise the glossary periodically so that it will reflect the latest technological developments in military communications as well as current usage in engineering literature.

Computer-stored word processing has been used in preparation of the glossary, so that revisions, insertions, deletions, etc. can be accomplished with a minimum of retyping if and when further efforts are required by the sponsor.

Federal Communications Glossary. Similarly a common reference list of communications terms and definitions is needed to serve as an aid in interpreting Federal communications standards; designing, developing, operating, and maintaining Federal communications systems; and enhancing communications among persons in the Federal community. This Federal glossary must be consistent with international, national, departmental, industrial, and technical society standards.

The immediate objective of this project is to prepare a draft Federal Standard on Telecommunications Terms and Definitions. To reduce the cost of this effort and avoid duplication of effort, it was decided by the FTSC (Federal Telecommunications Standards Committee) that the draft Federal glossary would be based upon the final version of a MIL-STD glossary which was in the process of revision by ITS (see above). The MIL-STD glossary, consisting of about 1300 defined terms, was reviewed by ITS for consistency with pertinent national and international standards. A supplementary list of 200 terms was selected by ITS from Federal standards and various other national and international communications documents. Definitions were prepared for these terms, and the completed Federal supplement furnished to NCS (National Communications System) for use with the final draft version of the MIL-STD glossary in reviews by Federal agencies.

After the review of these documents by Federal agencies, revisions and additions will be made as recommended by the various agencies, and a consolidated Federal glossary will be prepared.

The availability of the computer-stored text of the military standard will make possible an enlarged (Federal) glossary at relatively low cost.

IRAC-TSC Standards Working Group Support. ITS provides the chairman and secretarial support for the Standards Working Group (SWG) of the Technical Subcommittee of the Interdepartment Radio Advisory Committee. The SWG consists of representatives of the several IRAC member agencies and is responsible for the development of spectrum management standards required to assure compliance with the regulatory functions of government spectrum allocations.

During FY76, ITS convened a working Party and led the development of a standard for Fixed Microwave Services operating within the U.S.A. between 170 MHz and 15.35 GHz. The technical contribution consisted of developing a "strawman" standard based on military specifications, FCC rules and orders, industrial standards, and the ITS extensive experience in this field. The resultant standard is currently undergoing agency coordination under the guidance of the Technical Subcommittee of IRAC. ITS is currently developing recommendations for measurement procedures needed to assure compliance with this standard.

Law Enforcement Standards Laboratory (LESL) Standards. Following a Congressional mandate to develop new and improved techniques, systems, and equipment to strengthen law enforcement and criminal justice, the National Institute of Law Enforcement and Criminal Justice (NILECJ) has established the Law Enforcement Standards Laboratory (LESL) at the National Bureau of Standards. LESL's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment. Outputs from this work are usually in the form of performance standards, user guidelines, and state-of-the-art reports.

This project is to develop performance standards on selective-calling and tone-coded squelch systems for police communications equipment. A variety of standards have been prepared by LESL in previous years for base station, mobile, and personal/portable communications equipment. Since a majority of existing law enforcement communications systems use some form of selective signaling or tone controlled squelch to minimize annoying interference and provide a variety of alerting systems, a standard for selective signaling is needed to augment the existing LESL standards.

The objectives of this project are to develop performance standards on the following systems:

1. Selective-signaling systems using burst and sequential tones above 300 Hz.

2. Tone-controlled squelch systems using tones below 300 Hz.

These standards are needed to augment those previously developed for transmitters and receivers.

Detailed tests have been performed on commercial selective-signaling encoders and decoders and on tone-controlled squelch systems. These tests were performed to establish expected performance information and to develop appropriate measurement techniques. Standards are now being written. Their development is the result of a number of considerations such as:

1. results of the laboratory measurements
2. present and proposed industry standards
3. equipment compatibility requirements
4. needs for efficient law enforcement operations
5. the state of the art in equipment development.

The project is a new one, and the standards which have been outlined are not finished. Their completion and use is expected to have a significant impact on strengthening law enforcement and criminal justice.

SECTION 2.5. FIBER OPTIC COMMUNICATIONS

The following projects result from the very rapid emergence of a new technology: fiber optics involving low-loss, dielectric waveguides, which promises to permeate terrestrial communication systems in a manner similar to the growth of transistor and solid-state devices which occurred during the decade of the 1960's.

Fiber Optic Communications. OT's mission statement specifies OT's role as "assisting the Department of Commerce in fostering, serving, and promoting the nation's economic development and technological advancement by improving man's comprehension of telecommunication science and by assuring effective use and growth of the nation's telecommunication resources." OT is specifically charged with acquiring, analyzing, synthesizing, and disseminating information for the efficient use of the nation's telecommunication resources. OT is also charged with assisting other government agencies in the use of telecommunications.

OT's role in this new technology is a role which fits properly into the Department of Commerce work as defined by the Department's charter.

In many ways, OT's role is the role of a catalyst in the emerging technology of optical communications.

OT is additionally responsible for conducting research needed in the evaluation and development of telecommunication policy as required by OTP, pursuant to Executive Order 11556. OTP must keep abreast of this new technology, so that legislation and OTP policy are based on up-to-date information in this rapidly evolving field.

OT/ITS has established a Task Force on Optical Communications to bring together the technical workers in the field as well as potential users from government and industry, and to explore the applications and advantages of the emerging technology of optical communication.

The Task Force work has been well received and the meetings well attended by representatives from industries such as GTE Sylvania, Texas Instruments, Spectronics, Hughes, ITT, Bell Labs, Xerox, and from universities such as the University of Colorado, the University of California (Berkeley), MIT, and from government agencies such as OT, OTP, HEW, USPS, NBS, DoD, and others. Currently the mailing list of people who have requested to receive materials such as summary records of the meetings is about 125 with only minor overlaps within any company or agency.

In addition to the Task Force, OT activities in optical communications include a short course on fiber optics which is held in Boulder each summer cooperatively with the University of Colorado; presentation of papers and seminars; specification, installation, test, and demonstration of a fiber data link; and acceptance by one of our ITS staff members of an invitation to become associate editor of the new International Journal of Fiber and Integrated Optics.

ITS staff members planned two sessions for US-URSI Meetings on Integrated Fiber Optics; also at URSI, one staff member presented a talk relating to design considerations for optical systems; current planning is underway for a 1976 URSI special session on optical communications; and several staff members participated in the 1975 European Conference on Optical Communications and also the World Telecommunications Forum (Geneva). ITS personnel also presented papers at the 1975 Electronics/International Laser Conference.

Another output for FY76 was a pilot study: "Fiber Optical Communications" which was a contribution to the Industrial Sector Advisory Committee on Communication Equipment and Non-Consumer Electronics Equipment. This study was also presented orally and in summary form to emphasize areas of potential concern to the U.S. position in the 1975-1980 GATT negotiations.

Figure 2-22 shows a diagrammatical representation of the Optical Communications effort as perceived in our five-year plan.

In the new telecommunications technologies for which the fiber optical waveguide is offered as a potentially attractive information transmission guide, there have been innumerable requests to OT to provide comparison data and information between the new optical fiber systems and the more conventional transmission technologies. Requests are for comparisons of overall technical performance, maintenance, and reliability to meet specific telecommunication system needs of potential users in DoD, nondefense agencies, and industrial telecommunication users. In particular, cost and economic factors must become available for comparisons of competing systems.

An OT Report, "Telecommunication alternatives with emphasis on optical waveguide systems," (OT Report 75-72) was prepared and published in October 1975 to provide perspective in the evaluation of fiber optical transmission for telecommunications in the near future. This report compares various modern communication systems with particular emphasis on optical waveguide systems. A matrix of marketing parameters was developed to compare fiber optic transmission technologies, microwave radio, waveguide, satellite, and twisted pairs against such factors as state of the technology, maintainability, convenience, EMI immunity, cost trade-offs, and other economic factors.

The report also discusses the trends in DoD and in the telephone industry of digital communications and the manner in which increasing data rates may tax existing transmission systems. The intent of the report is to give guidance for government and industrial planners in putting the new technology of fiber optic communications in proper perspective in the planning and designing of new telecommunication systems.

There is a growing interest in the use of optical waveguides to interconnect several stations via a party-line data bus. Such a data bus will allow distribution of data to several stations using a single transmission node.

In a report, "Application of the Steiner Street problem to a more economical data bus," which is nearly ready for editorial review, three fundamental approaches to the topology of a data bus network are discussed. The data bus calls for the interconnection of N terminals, each of which is connected to every other terminal. Such a data bus will allow distribution of data to several stations using a single transmission line.

The report discusses three fundamental approaches to the topology of the network: the tee network, the star network, and the Steiner minimal tree network (Steiner developed this network in the 19th century for streetcar lines in a city). The tee and star approaches are receiving most attention in the litera-

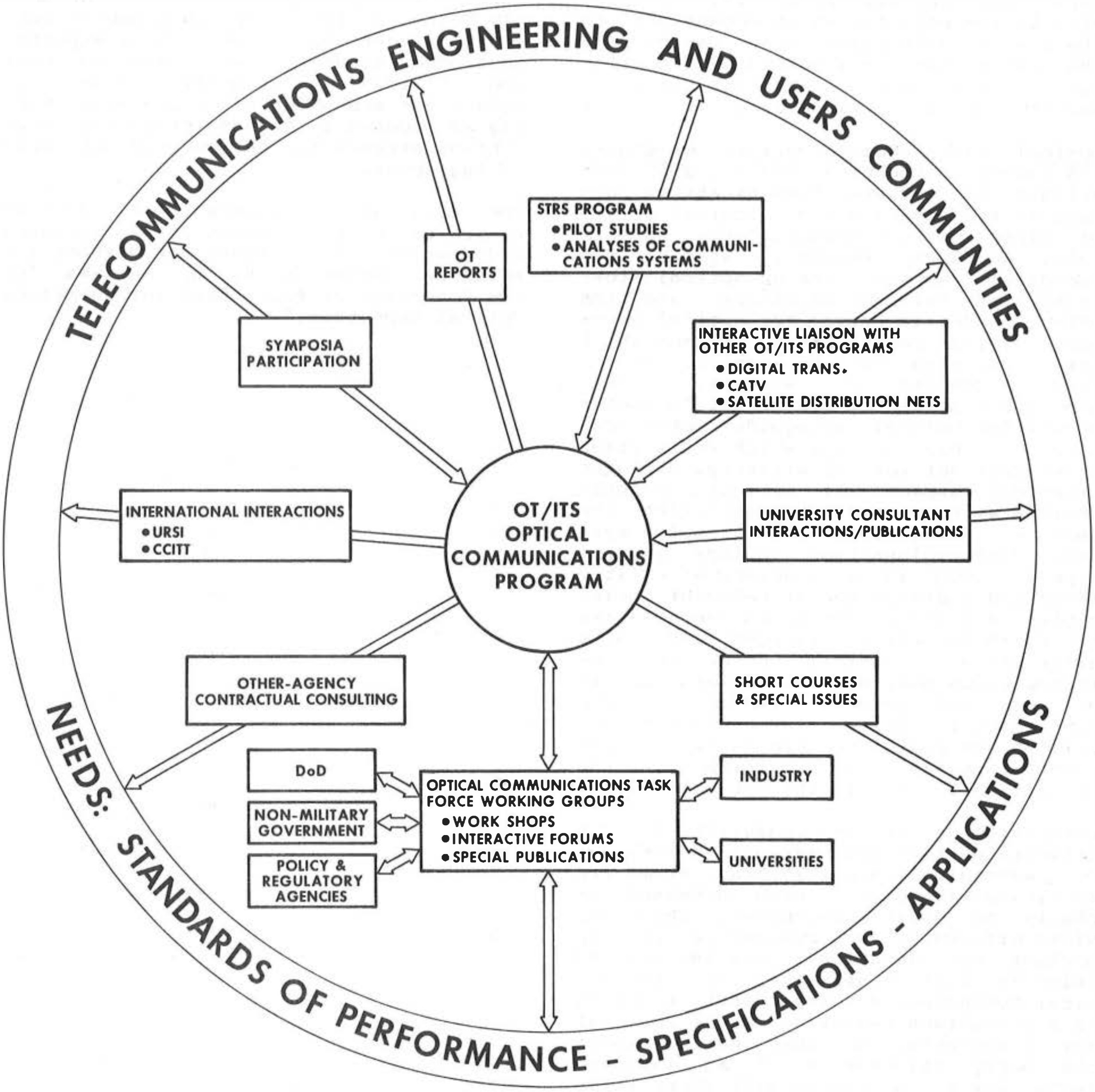


Figure 2-22. Flow chart illustrating the relationships of the optical communications program to the telecommunications sphere.

ture, but the Steiner minimal tree network is the only one which economizes on the use of cable (glass fiber waveguide). The report examines a method of locating the Steiner nodes such that the total amount of cable is minimized.

Optical Fiber Communications Handbook. ITS serves as technical advisor and consultant to the Army Communications Command in the emerging technological field of fiber optic communications. In this role, we have previously written two technical reports, one on optical fiber links for telecommunications, and the other on design curves for optical waveguide digital communication systems which were published by the sponsor. During FY76, we completed the writing, review, and publication of OTR 76-83, "A User's Manual for Optical Waveguide Communications." This report, which was written under contract for the military, explains technical aspects of optical communications with a view to assisting the engineer using such communication systems. The explanations include general aspects such as a glossary of related terms and a discussion of relevant principles of physics. Technical details are set forth on optical sources and their alternatives, optical detection, the transmission medium, modulation, multiplexing, and systems design concepts and trade-offs in design. The report was written to assist the communications engineer in making the transition from the conventional (rf) to the optical regime.

Communication Systems Consultation. The anticipated technical advantages optical waveguide communications systems are receiving wide press. With increased emphasis on digital techniques, the bandwidth offered by such systems is an important consideration in new and planned telecommunication networks. As the optical technology develops, there seems to be a fortuitous reduction in the cost of key components, so that one can expect the happy coincidence of an improved technology at an economically competitive price.

The use of optical fiber waveguides in long-haul systems will call to question the cost of providing power to supply the repeaters. This is an especially intriguing question in submarine systems for which, traditionally, the same cable is used to transmit both the signal and power. This is possible when the cable is made of conducting material. In the case of glass fiber waveguides, there are no conducting strands and power feed becomes more difficult. In this case, the options are limited. First, one could insert conducting strands for the express purpose of providing power or, second, one could place a self-contained power supply at each repeater. One power supply being considered for this use is currently under development and is expected to produce about 1/2 watt and to cost about $15,000. A key question, then, involves the economics of such a power supply as opposed to the use of special conducting strands for the purpose of providing power.

The advantages, disadvantages, and economics of the two schemes were discussed and developed in a report for NAVELEX (in editorial review) by R. L. Gallawa "On the Economies of Power Feed for Submerged Optical Repeaters."

CHAPTER 3. TRADE AND INTERNATIONAL ORGANIZATIONS

In this chapter we look at aspects of the work of ITS which are particularly directed towards relations with other countries. Thus, in section 3.1, we discuss work having to do with economic aspects, namely, trade with foreign countries. In section 3.2, we consider ITS involvement in activities of the International Telecommunication Union, the primary international body through which nations adjudicate their telecommunication problems. In section 3.3, we consider ITS activity in the International Union of Radio Science.

SECTION 3.1. SPECIAL REPORT ON LOWERING BARRIERS TO TELECOMMUNICATIONS GROWTH

The Department of Commerce has, as a principal element of its mission, the role of fostering, serving, and promoting the Nation's economic and technological development. OT shares this responsibility in the area of telecommunications. In pursuing this element of its role, the Office of Telecommunications issued in early Fall of 1976, a special report entitled "Lowering Barriers to Telecommunications Growth" (OT Special Publication 76-9).

3.1.1. Background

The purpose behind the study was to determine whether the growth of telecommunications services could be appreciably enhanced by trying to detect and lower barriers to that growth -- whether the barriers to growth be reflected in a lack of robust demand or a lack of an innovative supply.

The U.S. and the other industrial nations of the world, are entering an economic era which will increasingly involve information-related activities requiring improved access to and speedy transfer of information. This information transfer relies heavily on telecommunications facilities. To the credit of U.S. industry, existing telecommunications services are in good order. Our telephone system, which involves a complex mix of technologies, is already the most pervasive and reliable in the world. Television reaches fully 97 percent of American homes.

Yet, the nation faces important telecommunication problems. New telecommunications technology will be required to meet the growing demands of the "information era." This new technology will involve optical communications, advanced solid-state technology, and satellite communications. Other problems that will have to be faced include crowding of the electromagnetic spectrum in land mobile, terrestrial microwave, and communication satellite bands; increased competition from foreign industry; long delays in getting approvals from regulatory authorities; lags in technology transfer; and difficulty in achieving cooperation between government and industry where the demonstration of combined public and private sector services are involved.

Industry's role is to respond to the demands of the market place by assembling the factors of production and bringing the products to the market. Private industry has made major contributions to civilian research and development, product development, market identification, and pursuit of overseas trade. Where a clear market exists, there is no problem -- industry, on its own, vigorously responds to the market "pull."

There are situations, however, where industry does not react so effectively, and which may require government action. These involve concern for the public or national interest even in the absence of market forces (or even in opposition to market forces; examples are alternative energy sources, environmental protection, and highway safety regulations). Government, in pursuing the national and public interest in telecommunications, assumes a number of roles, among which are policymaker, regulator, spectrum manager, user and purchaser, coordinator of public sector requirements, and supporter of key technological developments.

3.1.2. Choice of Technologies

The OT report "Lowering Barriers to Telecommunications Growth" was prepared as an attempt to place some items on a "national draft agenda" that could be used as a vehicle for discussion, and ultimately as a basis for action. Four items were chosen from a long list of attractive candidates ranging from electronic funds transfer to the automated office. The critera for the selection process included: potential for public benefit, remediable technological barriers, timeliness, appropriateness of Federal government involvement, and impact on growth and development over a "business-as-usual" approach.

The four technologies chosen, and the reasons for their inclusion, are as follows:

1. Satellite communications, especially for services involving small earth terminals, was included because of their potential public benefit, the presence of significant technical barriers, timeliness, and potential regulatory or policy barriers to their early utilization. This subject was included also

because of the danger that early ad hoc decisions might foreclose future opportunities for beneficial use of the spectrum/orbit resource.

2. Land mobile radio, a well established and steadily growing service, was included because of its importance to business, public safety, and government operations, and because of the likelihood that there will not be sufficient spectrum available to sustain the growth of conventional, privately owned systems.

3. Broadband communications was chosen as an example of a service "whose time is yet to come." Despite many persuasive arguments concerning the benefits of such services, they are not becoming available, because the necessary networks have not been developed.

4. Fiber optic communications was included because it represents a new communications mode for the future, because of its potential for providing inexpensive, high capacity communications, and because of its potential for development into a significant new manufacturing industry.

Every effort was made to assure careful selection of those technologies that warrant Federal attention, and to solicit various viewpoints, regardless of probable support or lack of it. These technologies are viewed as having high potential for public and private benefit and are accordingly highlighted and proposed for further discussion. In each case, continued Federal attention is suggested, aimed at maximum benefit for both public and private users and for industry.

These four technologies were examined in detail from the point of view of status of the field, issues affecting growth, actions that address the issues, and impact of the proposed actions. This analysis is presented in four chapters of the special report, and is too voluminous to separately digest for the purposes of this annual report.

3.1.3. Conclusions and Recommendations

The final chapter of the report contains conclusions and recommendations. It reorganizes the issues identified in the analysis of the four technologies chosen for evaluation into four categories which serve as unifying themes illustrating common barriers to telecommunications growth. These are:

Identification of Needs for New Telecommunication Services -- This category is concerned with identification of needs for new services, options for providing the services, and evaluation of the costs of these options. In identifying needs, attention should be given to the potential for increasing national productivity, which has previously responded to telecommunications innovations.

Systems Development, Performance Criteria and Measures of Performance -- This category focuses on systems planning and research, performance criteria and measurement, and standards of practice, as well as equipment operating standards. Normal development of new telecommunications services or equipment progresses from the early phase of market identification and determination of telecommunications needs through the process of determining system performance and requirements which will meet the needs of the new service, and identification of the necessary hardware performance specifications. This process allows the costs of the service to be estimated and thus contributes to the decision as to whether it can be provided or will be wanted. The final step involves measuring the degree to which the performance criteria or specifications are being met. It is important to establish standards in such a way that they foster, rather than prevent, innovation.

Regulation -- The spectrum dependence, interstate and international operations, together with the monopoly or utility character of many telecommunication services make regulation a strong influence in their development. The regulatory process has proven in many cases to be time-consuming, and the delivery of new or improved services to the public has lagged as a consequence. While there is great pressure to speed up the process, there is also the need to preserve the right of all interested parties to be heard.

International Frequency Allocations -- Over the next three years, the International Telecommunications Union (ITU) will sponsor two more World Administrative Radio Conferences (WARC's) which are relevant to the issues addressed in the report. The first will take place in 1977 and will focus on satellite broadcasting services in the 11/12 GHz band. The second, scheduled for 1979, will revise the Radio Regulations, including the Table of Frequency Allocations. These WARC's will establish the pattern of worldwide spectrum utilization for many years to come. Moreover, their decisions may affect our own rules and regulations. It is thus imperative that the United States present its needs eloquently and persuasively.

In each category the main issues relevant to the technologies are summarized, followed by recommendations for action. These recommendations are included as a step in the formulation of a "draft agenda" to stimulate discussion among all relevant institutions in Government and industry, and to help in establishing priorities.

SECTION 3.2. THE INTERNATIONAL TELECOMMUNICATION UNION (ITU)

The ITU is a Geneva-based international organization which is controlled by its member nation states. The Radio Regulations and the Telephone and Telegraph Regulations (and the Convention to which they are appended) have treaty status among the member nations who sign them. The Convention may be changed only at plenipotentiary conferences of the ITU (the last such was based at Malaga-Torremolines, Spain, in 1973). The Radio Regulations are reviewed and updated at World Administrative Radio Conferences, either in part (e.g., World Administrative Radio Conference for Space Telecommunications, Geneva, 1971) or in toto (e.g., World Administrative Radio Conference, Geneva, 1959; World General Administrative Radio Conference, Geneva, 1979). As these latter conferences occur only every 20 years, the U.S. has devoted considerable effort to preparatory work for the next WGARC through the FCC (for the private sector) and through the IRAC (for the Federal government's allocations).

Ad Hoc 144 of IRAC is its group charged with preparation for the WGARC in 1979. ITS has four staff members who are active in Ad Hoc 144-III (technical considerations).

Due to the general interest in the forthcoming WGARC, ITS commissioned Prof. George A. Codding of the Political Science Department of the University of Colorado to deliver the banquet address on political considerations in the ITU at the Telecommunications for Government Symposium held in Boulder, November 11-13, 1975. As a consequence of the large number of requests for Professor Codding's remarks, they have been reproduced as OT Special Publication 75-6 (The U.S. and the ITU in a Changing World).

There are two semi-autonomous organizations in the ITU which are charged with the study of standards relating to technical and operating questions. These are the CCIR (International Radio Consultative Committee), the principal arena for ITS contributions, and the CCITT (International Telephone and Telegraph Consultative Committee). These two organizations are treated separately below.

3.2.1. CCIR

ITS and its predecessor organizations (the NBS Radio Section, CRPL, and ITSA) have been active in CCIR since its inception in 1927. Jack Herbstreit, Director of CCIR from 1966 to 1974, was formerly Deputy Director of CRPL and ITSA. Richard Kirby, present Director of CCIR, was formerly Director of ITS.

CCIR is organized in terms of Study Groups, each of which hold an Interim and Final Meeting in the period between Plenary Assemblies of the CCIR (currently every four years; the XIIIth Plenary Assembly was held in Geneva in July 1974, and the XIVth Plenary Assembly is scheduled to be held May 22 - June 9, 1978).

Table 1. CCIR Study Groups

S.G. 1:	Spectrum Utilization and Monitoring
S.G. 2:	Space Research and Radio Astronomy Services
S.G. 3:	Fixed Service at Frequencies Below About 30 MHz
S.G. 4:	Fixed Service Using Satellites
S.G. 5:	Propagation in Non-ionized Media
S.G. 6:	Ionospheric Propagation
S.G. 7:	Standard Frequency and Time-Signal Services
S.G. 8:	Mobile Services
S.G. 9:	Fixed Service Using Radio-Relay Systems
S.G. 10:	Broadcasting Service (Sound)
S.G. 11:	Broadcasting Service (Television)
CMTT:	Transmission of Sound Broadcasting and Television Signals Over Long Distances (Joint with CCITT)
CMV:	Vocabulary (joint with CCITT)

Thijs deHaas of ITS is currently serving as vice chairman of Study Group 3.

The U.S. parallels the CCIR Study Group structure in its own preparatory activities for the CCIR international meetings. These U.S. Study Groups report to the chairman of the U.S. National Committee of the CCIR, Mr. Gordon L. Huffcutt of the International Communications Policy Office of the State Department. At the present time, ITS furnishes the chairmen for USSG-1 (Dr. W. F. Utlaut), USSG-3 (Thijs deHaas), USSG-5 (Dr. H. T. Dougherty), and USSG-6 (Dr. E. K. Smith). Some 35 members of ITS were involved in U.S. Study Group activities during FY76, and nine participated as members of U.S. delegations to CCIR international meetings.

Drs. Dougherty and Smith were invited to write a mini-review on the CCIR for the IEEE Antennas and Propagation Society (scheduled for publication in the November 1976 issue), and E. K. Smith wrote a paper on the CCIR and URSI which was published in the June 1976 issue of Radio Science.

Not all ITS activity in CCIR was confined to the U.S. Study Groups chaired by ITS members. Five documents were contributed by ITS to U.S. Study Group 10 (three in the area of ionospheric modification).

As part of the work performed for the Maritime Administration (MarAd) of the U.S. Department of Commerce, ITS prepared U.S. contributions to CCIR Study Group 8 (see the description under SELCAL in section 2.3.).

Mr. deHaas of ITS was a member of the CCIR Interim Working Party (IWP 8/3) which dealt with the subject of digital selective calling. At the Study Group 8 Interim Meeting held in March 1976 in Geneva, Switzerland, Mr. deHaas was appointed chairman of the subcommittee charged with preparing a Draft Recommendation containing the operational and technical characteristics of a digital selective calling system, based on the work of the IWP and subsequent contributions of several countries.

3.2.2. CCITT

ITS does not have a long history of involvement in the International Telephone and Telegraph Consultative Committee (CCITT). At present, our participation consists of the contributions of one man, Thijs deHaas, who has chaired U.S. CCITT Study Group 5. In contrast to the CCIR, the U.S. CCITT Study Groups are not parallel to the international structure. USSG-5 is responsible for two international Study Groups: S.G. VII, which deals with New Data Networks, and S.G. Special A on Data Transmission. As chairman of the U.S. preparatory group, Mr. deHaas is also head of the U.S. delegations to the international CCITT Study Group VII and Special A meetings.

SECTION 3.3. THE INTERNATIONAL UNION OF RADIO SCIENCE (URSI)

The URSI was created in 1919 and was one of the original four (of the now seventeen) scientific unions which adhere to the International Council of Scientific Unions (ICSU). As was true in the case of CCIR, ITS, through its predecessor organizations, has been involved with URSI since its founding. The U.S. participates in the Unions of ICSU through the National Academy of Science/National Academy of Engineering rather than through the State Department. The structure of the U.S. URSI (which parallels the international structure) is organized under the U.S. National Committee for URSI (USNC/URSI), which in turn is under the aegis of the National Academies. Dr. J. R. Wait (ITS Consultant) is the current Secretary of USNC/URSI.

Nine members of the ITS staff were major contributors to the XVIIIth General Assembly of the International Scientific Radio Union (URSI) held in Lima, Peru, August 10-19, 1975. Douglass D. Crombie, Director of ITS, led the OT Boulder contingent which participated in the deliberations and which presented 10 technical papers.

Papers were presented by Dr. James R. Wait, Consultant to ITS, on "Electromagnetic Fields from Dielectric Coated and Braided Coaxial Cables with Interrupted Shields," "Mixed Modal and Ray Representations for VLF Propagation in the Earth-Ionosphere Waveguide," "Radio-wave Propagation - Ground Structure and Topography," "The Use of the Surface Impedance Concept in the Teaching of Electromagnetic Science," and "Some Basic Electromagnetic Aspects of ULF Field Variations in the Atmosphere."

Dr. Arthur D. Spaulding, Spectrum Utilization Division, presented "Optimum Reception in an Impulsive Interference Environment" and "Interference Measurement."

Dr. William F. Utlaut, Deputy Director of ITS, presented "Ionospheric Problems in Radio Telecommunications;" Margo Leftin, Applied Electromagnetic Science Division, "Global Ionospheric Models for Predicting the Performance of High Frequency Communication Systems;" and George W. Haydon, Applied Electromagnetic Science Division, "Predicting the Compatibility of High-Frequency Sky-wave Systems."

Crombie, Dr. Ernest K. Smith, Dr. Moody C. Thompson, and Jack W. Herbstreit attended as members of the U.S. delegation, but did not present papers. Utlaut and Herbstreit served on the U.S. National Committee of URSI and Smith assisted the chairman of URSI working Group 3.9 with preparations for the meeting.

The URSI/USNC has adopted a parallel structure and designated chairmen for the various US-URSI Commissions. Dr. W. F. Utlaut, Deputy Director, ITS, has been named chairman of U.S. Commission C (Signals and Systems).

CHAPTER 4. EM WAVE TRANSMISSION

The ground, the atmosphere, and the ionosphere degrade radio waves in varying degrees depending on circumstances. It is the purpose of the EM Wave Transmission Program to study these effects and provide models to the system designer that will aid him in providing more cost effective and spectrum efficient designs. The phenomena which cause these detrimental effects on radio and optical systems are, in general, frequency dependent; therefore, specific studies and tests are required for specific frequency ranges and applications.

Some of the phenomena which effect radio signals and are studied in this program are:

1. Attenuation by atmospheric gases, hydrometeors (rain, snow, hail, clouds, etc.), or ionization.

2. Scattering by hydrometeors or irregularities in the refractive index of the lower atmosphere or ionosphere.

3. Refraction, ducting, and multipath, resulting from atmospheric or ionospheric layers.

4. Dispersion, resulting from frequency dependent properties of the atmosphere, ionosphere, and earth.

5. Scintillation of amplitude, phase, polarization, and angle of arrival, resulting from turbulence and irregular structure in the atmosphere and ionosphere.

6. Reflection, scattering, multipath, and lower atmosphere perturbations resulting from terrain and man-made structures.

The effect upon any specific system of the above phenomena is not only highly frequency dependent, but is also dependent upon the type of service required for the specific application.

One driving force behind the EM wave transmission program is the need for more spectrum space. Therefore, this program provides models, techniques, and information to aid the system designer and frequency manager in his decisions for better spectrum use.

Experimental or theoretical determinations of radio wave transmission characteristics, or the channel transfer function, are reported in section 4.1. Measurements of transmission media properties and analyses of collections of such data are included in section 4.2. Section 4.3 describes the development and testing of models which incorporate the transmission information in engineering tools. Predictions of transmission characteristics and system performance are discussed in section 4.4. Section 4.5 reports on applications of the knowledge and tools to specific problems of other government agencies, such as mine communications and radio navigation.

SECTION 4.1. WAVE TRANSMISSION CHARACTERISTICS

Experimental determinations of the effect of the transmission media on electromagnetic wave transmissions are reported in this section, in particular, those effects produced by the atmosphere.

Broadband Transmission in the 10 to 100 GHz Band. The objective of this major in-house project is to develop a complete and quantitative description of the transmission properties of the atmosphere at frequencies between 10 and 100 GHz. This description will be used to improve design models and provide engineering standards for the effects of the transmission properties on performance of wide-band, high-data-rate systems. Progress made on the experimental phase is reported below.

In the second year of this program two lower frequencies at 9.6 and 28.8 GHz were added to the 57.6 GHz test link. The block diagram of the present system is shown in figure 4-1. All three signals are coherent, so that it will be possible to make differential time/phase delay measurements. The antennas for both X and K bands are equipped to make comparative measurements with crossed linear polarizations or with opposite circular polarizations. Since both senses of polarization can be used simultaneously, direct measurements of depolarization can be made.

Simultaneous amplitude data were obtained over a period of about 4 months and included rain and both wet and dry snow conditions over the propagation path. The results are summarized below and indicate that the 57.6 GHz signal experienced slightly fewer detectable signal fades than the lower two frequencies during this test period.

SUMMARY

Total Days of Data Collection.

Rain Rate	212
9.6 GHz	151
28.8 GHz	112
57.6 GHz	247

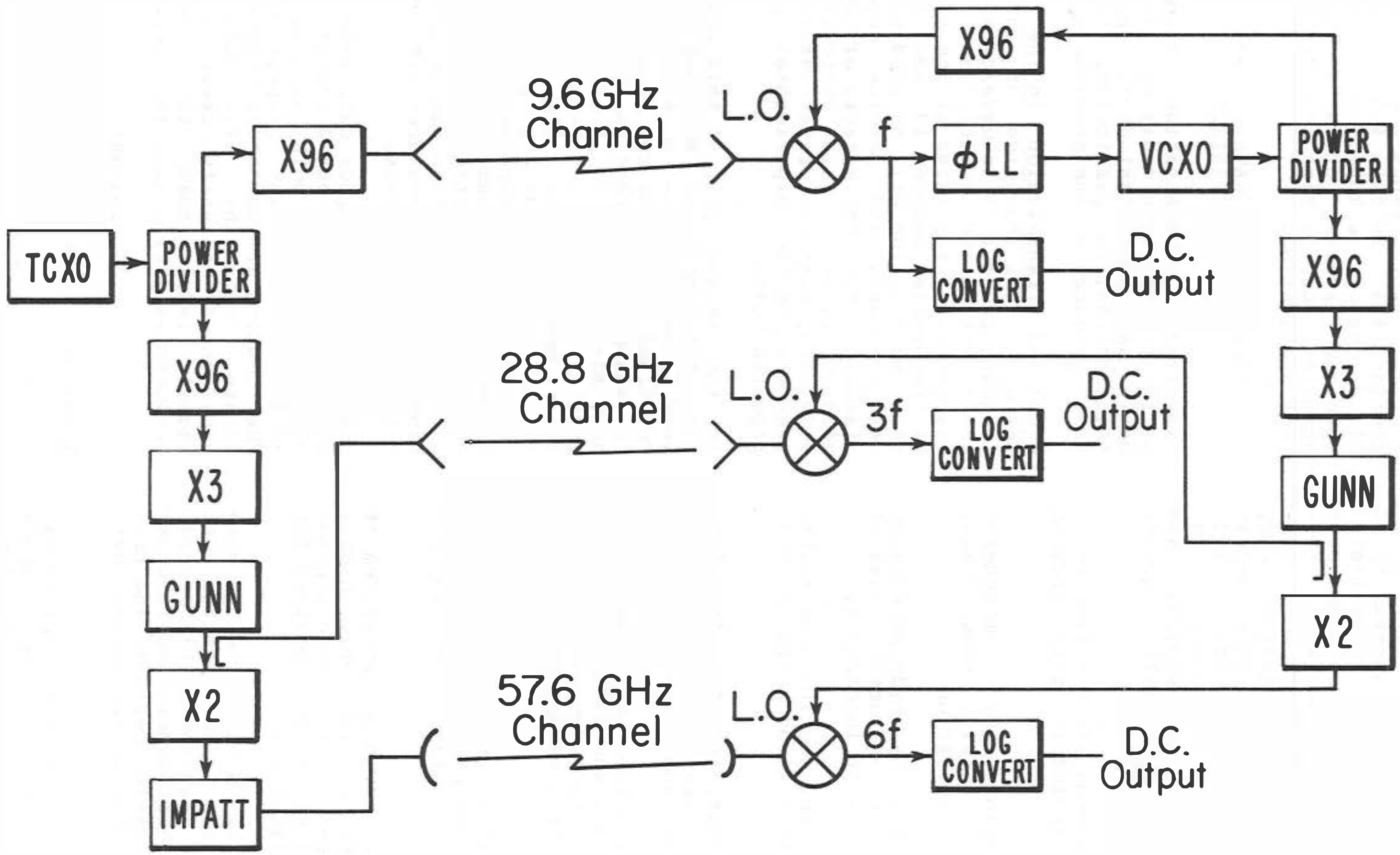


Figure 4-1. Block diagram of 3-band experimental link showing the coherent signal chains on 9.6, 28.8, and 57.6 GHz.

Detectable Signal Changes (>0.2 dB) During 111 Days of Simultaneous Operation.

Probable Cause	Number of Events		
	9.6GHz	28.8GHz	57.6GHz
Rain	5	5	6
Snow	14	15	7
Unknown	0	0	4

An example of a fade at 57.6 GHz caused by rain is shown in figure 4-2.

The screening effect obtainable on short links by operating in the absorption band near 60 GHz is illustrated in figure 4-3. The two curves show the decrease in signal with distance from transmitters at 50 (outside the oxygen absorption band) and at 60 GHz (near the peak of the band). The transmitter powers have been chosen to give the same signal strengths over a 1 km link. The protection against interference with other co-channel systems and against down-range interception is shown by the difference in ordinate values at ranges greater than 1 km; for example, the 60 GHz signal is down 60 dB below the 50 GHz at a distance of 4 km past the intended receiver.

With the cooperation of the U.S. Air Force and the Avionics Lab, Wright-Patterson AFB, it was possible to put in operation a 1 Gb/s digital data link on the test path. The modem developed for USAF by Radiation Inc. was used to drive an upconverter to K-band (30.3 GHz carrier frequency). The 2-500 Mb/s binary data streams after transmission over the path are shown in figure 4-4. Bit-error rates will be recorded along with other signal amplitudes and precipitation data over a range of atmospheric conditions on the path.

Signal Fading on Line-of-Sight Microwave Paths. Under certain atmospheric conditions, severe fading (e.g., 40 dB) is observed on microwave signals transmitted over line-of-sight paths in which no significant surface reflection is present. This phenomenon has been observed at frequencies up to 33 GHz. To obtain a reasonable data base concerning this problem, a test link at 9.6 GHz was operated from January 1973 through January 1974. The 120 km path extended from about 10 m above mean sea level at the Keahole Airport, Island of Hawaii, to Mt. Haleakala, Maui, at 3000 m elevation. The transmitter was crystal stabilized and delivered 500 mW to a 3 m parabolic antenna. A 2 m receiving antenna was used and the receiver was phase-locked to the incoming signal. With a bandwidth of 2 kHz, the dynamic signal range was about 60 dB. Received signal strength was recorded both graphically and on magnetic tape.

The data were analyzed for both signal level and fading statistics. Figure 4-5 illustrates the range of signal behavior and figure 4-6 shows cumulative distributions of fade durations for eight different fade levels. The observed dependence of fade duration on time of day is given in figure 4-7. Average fading rate versus signal level is shown in figure 4-8. A report on the results is in editorial review and should be available by October 1976.

Optical Availability Measurements. A major deterrent to extensive deployment of visible and near-infrared radiative optical communication systems is uncertainty about the availability of the channel in particular geographic regions. This is fundamental design information which must be obtained by actual field measurements.

In order to obtain optical channel availability measurements, it is necessary to develop suitable techniques, measurement equipment, and recording devices for deployment under various climatic conditions.

The primary activity during FY76 was the design of transmissometer optics, selection of appropriate optical sources and detectors, and the design of analog signal processing circuitry. The data acquisition system (shown in figure 4-9) to be used in these measurements is a microprocessor-controlled instrument which performs all supervisory functions for the self-calibration of the optical system, the acquisition of transmission data, and control of the magnetic tape cartridge system. This device was developed under a previous contract.

The optical portion of the system, shown in figure 4-10, includes a mirror-beam-splitter arrangement to allow the optical axes of the transmitter and receiver systems to coincide. In this manner, an optical signal is transmitted, reflected by a corner reflector, and returned along the same path as the transmitted signal to the receiver. By using two corner reflectors at different ranges, and by using a gated receiver, the system is made self-calibrating in order to compensate for uncertainties in the energy contained in the transmitted pulses.

The transmitting and receiving optics are both 135 mm telephoto lenses. A gallium arsenide injection laser and silicon avalanche photodiode were respectively chosen for use as the optical emitter and detector.

The analog processing circuitry developed by the program consists of a pair of fast-response boxcar integrators and

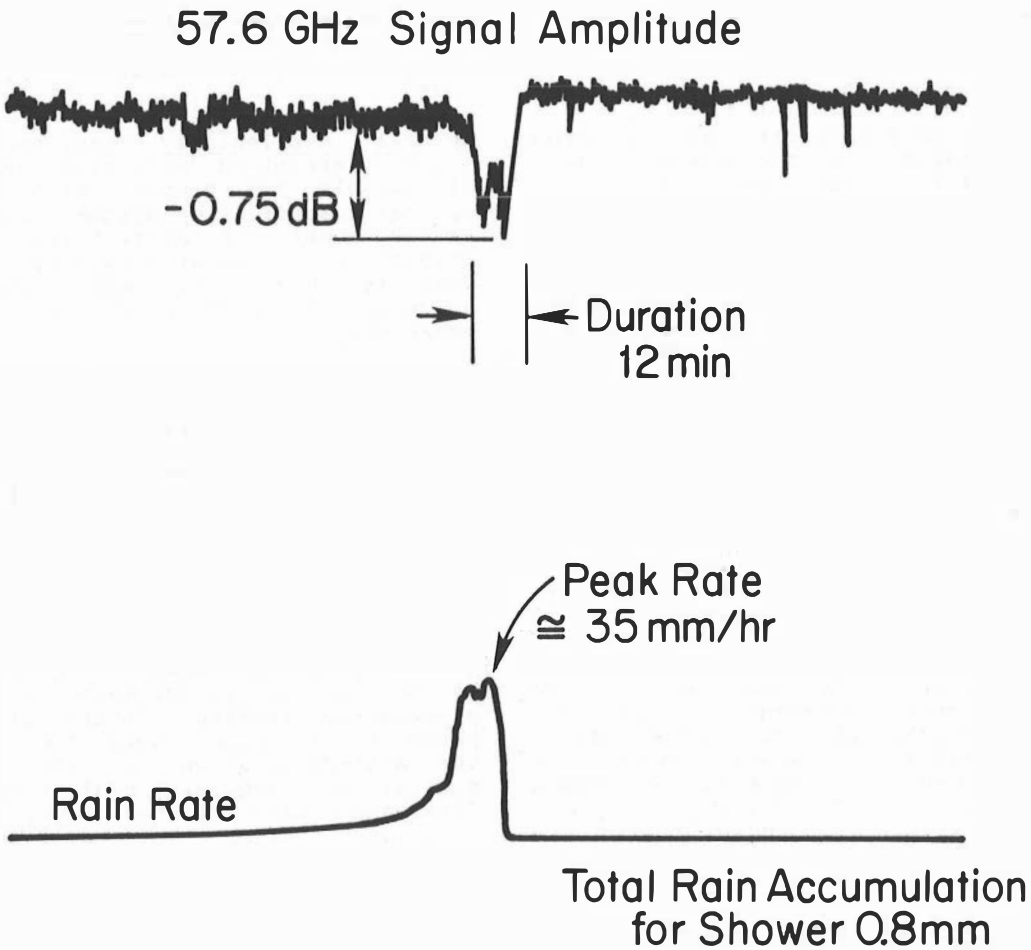


Figure 4-2. Example of rain attenuation observed on a 90 m path at 57.6 MHz.

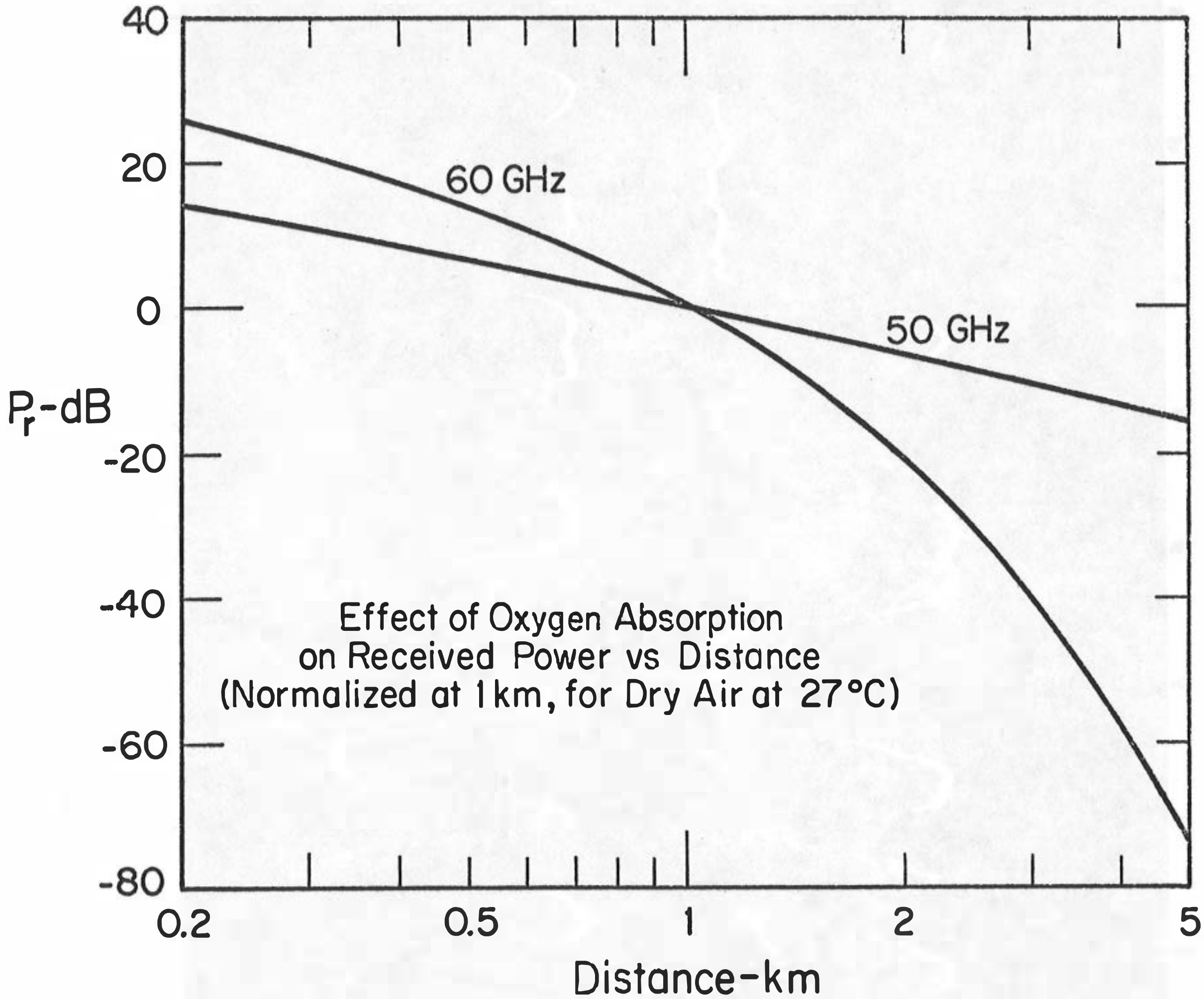


Figure 4-3. Illustration of the screening effect produced by the oxygen absorption line which peaks near 60 GHz. The received signals have been normalized to be identical at 1 km. By 5 km the 60 GHz signal is 60 dB below the 50 GHz one.

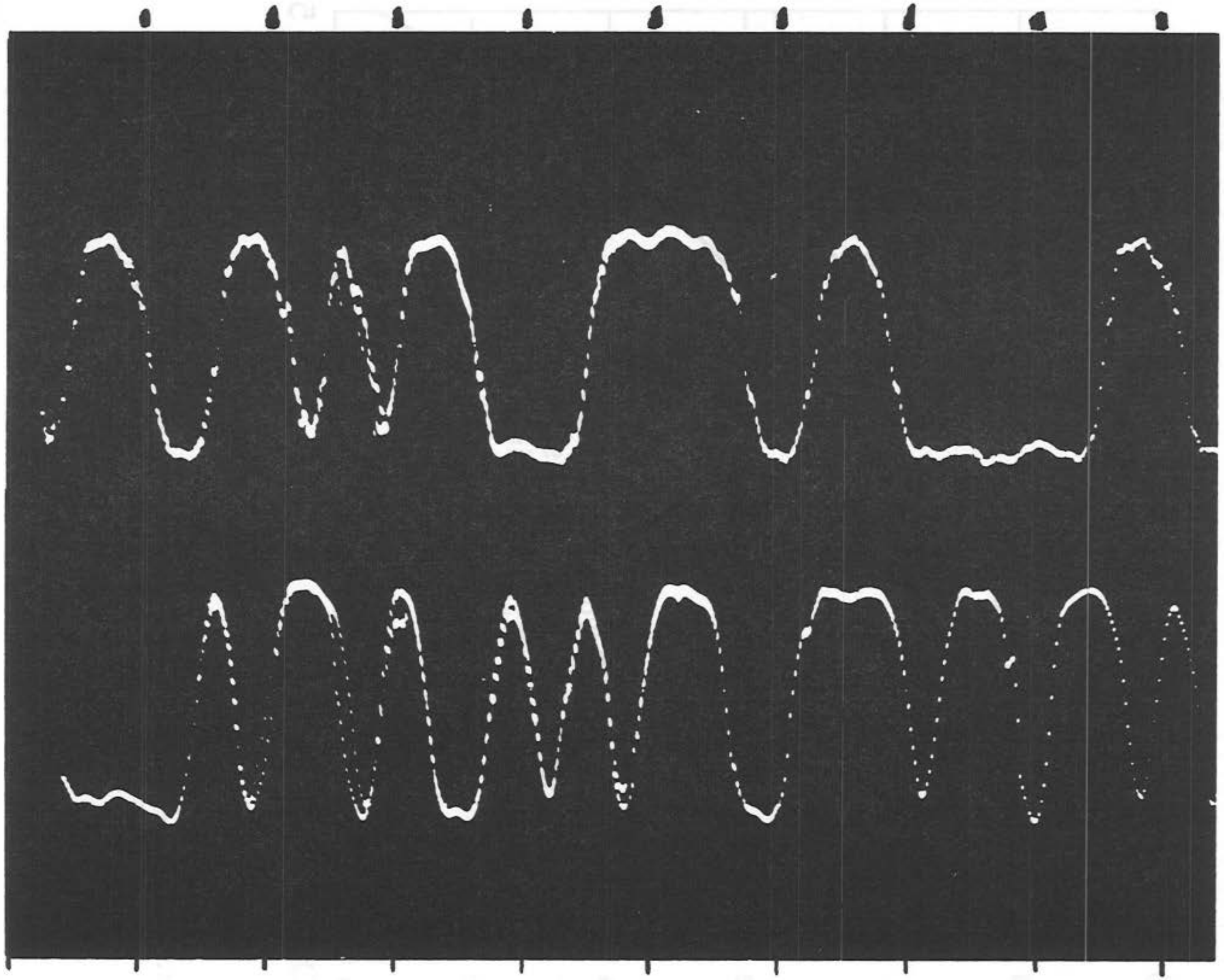


Figure 4-4. Two demodulated 500 Mb/s binary data streams of a 1 Gb/s data link after transmission over a 200 m test path at 30.3 GHz. Modulation is QPSK at a 1 Gb/s rate using a 2 GHz bandwidth. Horizontal deflection is 4 nanoseconds per division.

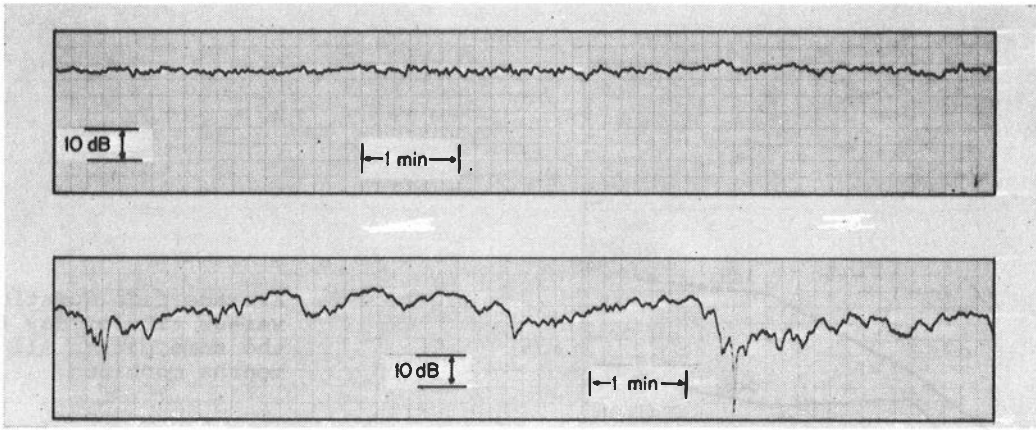


Figure 4-5. Examples of 9.6 GHz signal variations during periods of relatively shallow and relatively deep fading over a 120 km path extending from 10 m mean sea level on the Island of Hawaii to Mt. Haleakala, Maui, at 3000 m elevation.

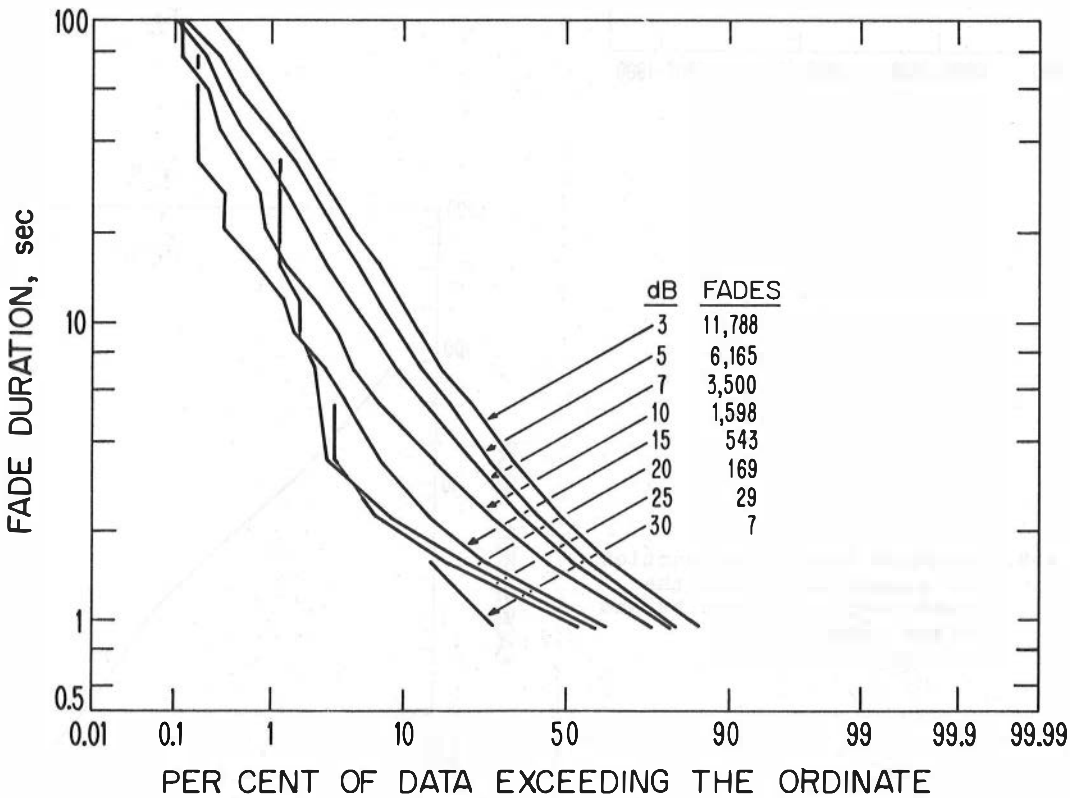


Figure 4-6. Cumulative distribution of fade durations for the same path for the period January 1973 - January 1974 for four hours per day, all months combined.

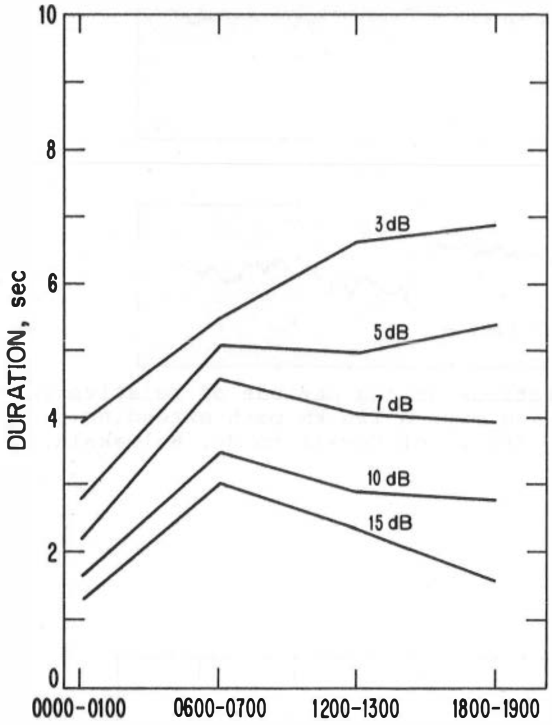


Figure 4-7. Average fade durations versus time of day for the same path. All months combined.

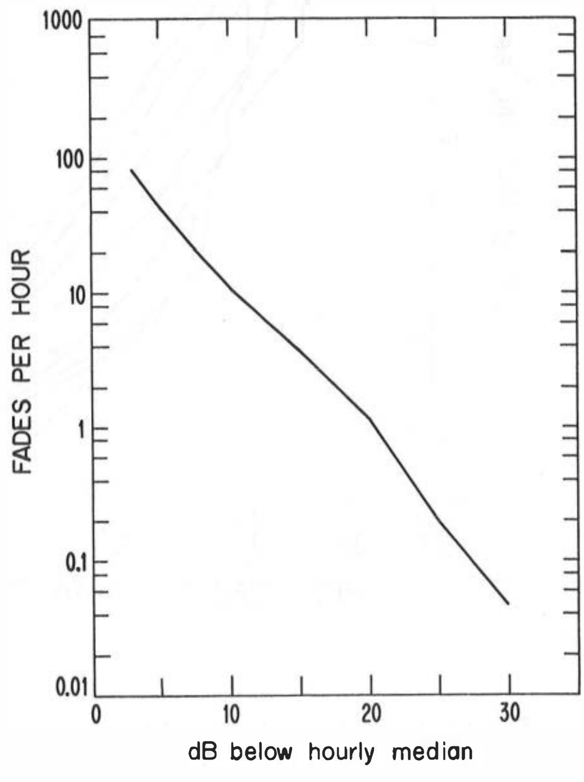


Figure 4-8. Average fade as a function of signal level for the same path. All months and hours combined.

Figure 4-9. Microprocessor - controlled instrument which performs supervisory function for the self calibration of the optical system in the data acquisition system used for optical availability measurements.

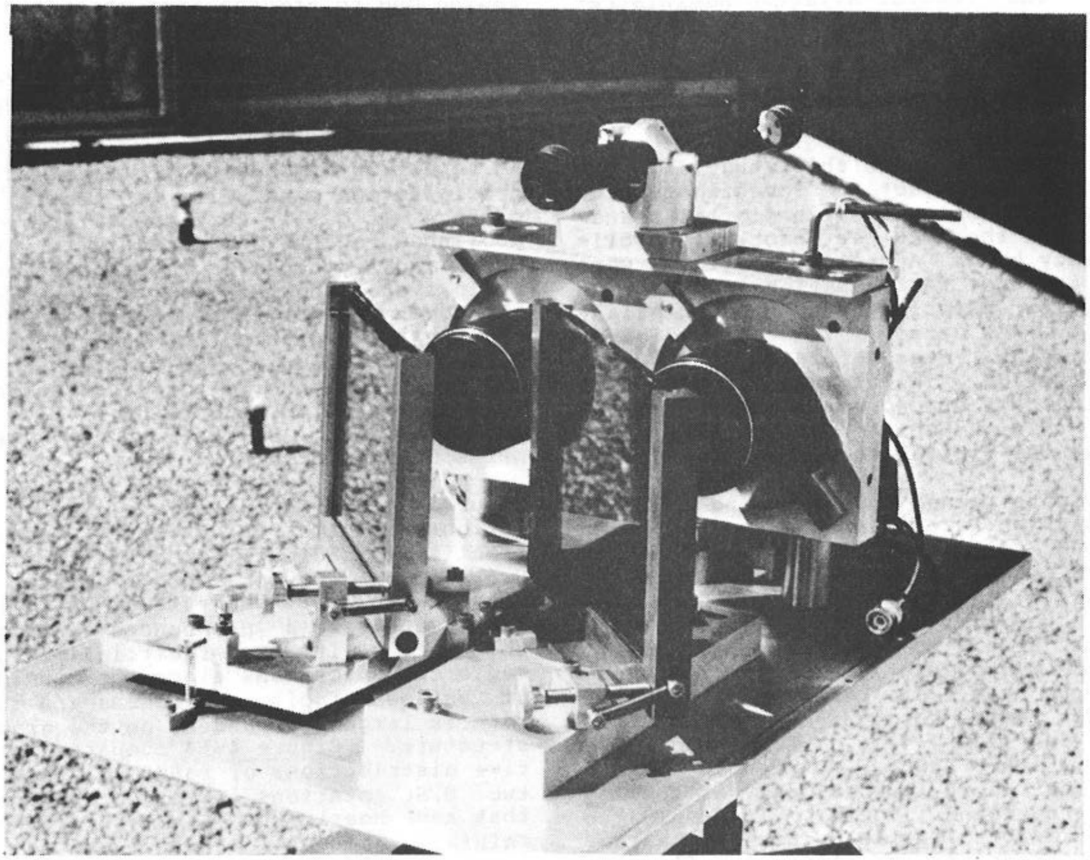


Figure 4-10. Optical portion of the data acquisition system of figure 4-9 with beam splitter in the foreground.

range-gating circuitry to steer the return from each corner reflector into its respective integrator. High-speed emitter-coupled logic was used for the range-gating function since the locations of the peaks of the narrow optical pulses need to be determined very accurately.

The completed optical systems, analog processors, and data acquisition systems will be installed at sites in Oak Ridge, Tennessee, and Seattle, Washington, in addition to the one in Boulder. Long-term availability statistics for infrared optical channels will be generated from data produced by these systems.

Data Link Tests for VHF Air Traffic Communications. The demands for VHF air traffic communications has markedly increased during the past decade. Furthermore, the demand is likely to accelerate in the next few years, particularly as new and additional services are offered. An example of this would be the implementation of a ground-based collision avoidance system, which is a new service that would require additional communication resources. Because of these developments, the Federal Aviation Administration has undertaken a program to study the feasibility of implementing a digital data link that would link aircraft and ground facilities with a digital communication system.

In conjunction with this study, ITS has undertaken a project to investigate the problems associated with digital transmission in the VHF aeronautical mobile frequency band. A series of flights were made at the FAA's National Aviation Facilities Experimental Center in Atlantic City, New Jersey, in which digital transmission rates of 2400 and 4800 b/s were studied. The tests largely used existing air/ground communication equipment. Minimum-shift-keying (MSK) was used as the digital modulation format.

The flights showed that 2400 and 4800 b/s transmission rates can be supported with existing communication equipment at an average bit-error rate near 5×10^{-5}. Both data rates were performed equally well in terms of bit-error rate. Measurements were also made on signal fading, the received signal level, and the distance to the radio horizon. An example of the radio horizon measurements is shown in figure 4-11. Arrowheads are used in the figure to denote those locations where the signal was totally lost on outbound flights. Conversely the circles denote locations where signal was first recognized on inbound flights. Figure 4-12 is an example of the signal level measurements that were made during the project, and is for those cases where the test aircraft was between 0 and 6000 feet in altitude. These results and others are summarized in a final report to the sponsor (FAA-RD-76-45).

The tests demonstrated that the VHF communication medium can be more efficiently utilized with digital communications. Data collected during the tests will help provide the FAA with a basis for deciding which frequencies are best suited for the data link. The tests also showed other problem areas that need to be explored in future work. Most noticeable among these is the intra-system interference that was experienced between voice communications and data transmissions during certain conditions.

Radio Systems Performance Studies, 10-30 GHz. The systems aspects of this program have been discussed in section 2.3, and it remains to discuss the propagation aspects. As mentioned earlier, the incentive for the study lies in the need to accommodate wide-band, high bit-rate systems which are becoming increasingly difficult to place below 10 GHz in the frequency spectrum. The propagation problems in the 10 to 30 GHz region include fading due to atmospheric stratification and turbulence, and precipitation effects (attenuation and depolarization). Long line-of-sight links in Colorado provide direct experimental data which is supplemented by other available data.

A report on atmospheric refractivity and precipitation statistics is nearly complete. It will supplement previously published reports on refractivity gradients and atmospheric considerations in radio system engineering. The new report includes cumulative distributions of refractivity gradients for 64 additional stations, including 35 in the southern hemisphere, with climatological summaries for each station, and rainfall rate distributions for 29 stations in various parts of the world.

Figure 4-13 illustrates the diurnal variations in the distribution of summer refractivity gradients for a station in the U.S. Midwest (Dayton, Ohio). These gradients are for the ground-based 100 m layer, and have a pronounced effect on the reliability of terrestrial microwave radio communications since the incidence of various fading phenomena and multipath is largely dependent on the gradient structure. Figure 4-14 compares cumulative distributions of rainfall rate for two U.S. stations (Seattle and Urbana) that have nearly the same total annual rainfall amounts. However, the much larger incidence of thunderstorm-related heavy rain showers for the Urbana area is reflected in the substantially larger percentages of time during which heavy rainfall occurs. As an example, a rate

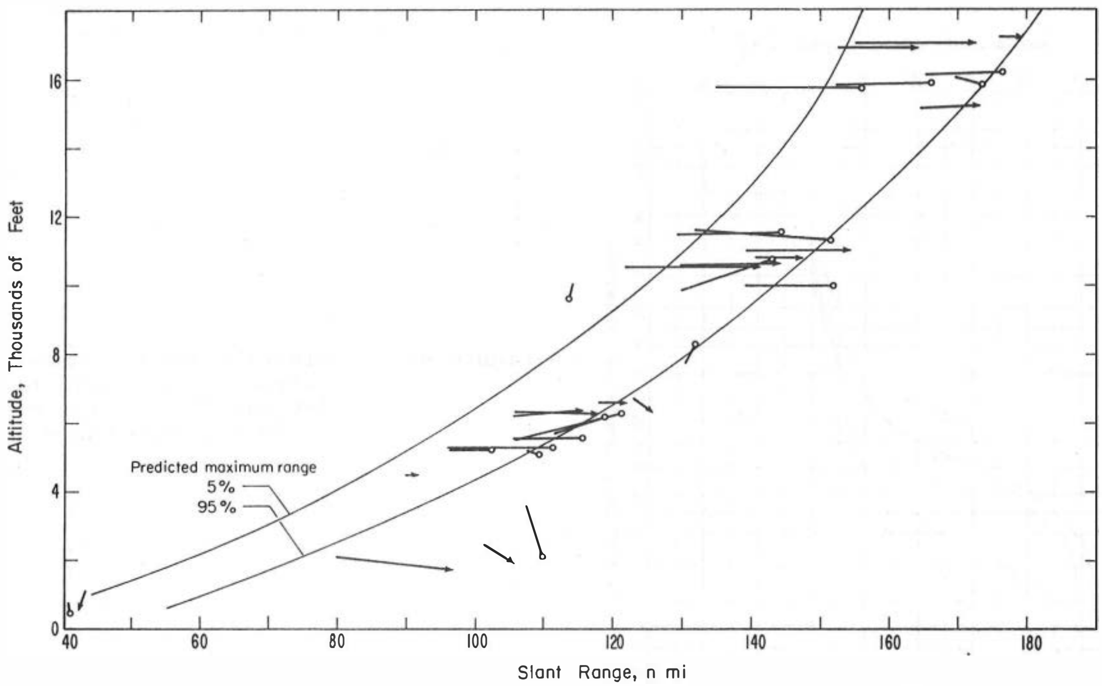


Figure 4-11. Radio horizon measurements at VHF between the FAA Experimental Center at Atlantic City and test planes. Solid lines represent regions of troubled but still usable transmission. Arrowheads indicate loss of signal on outbound flights; circles denote first signal recognition on inbound flights.

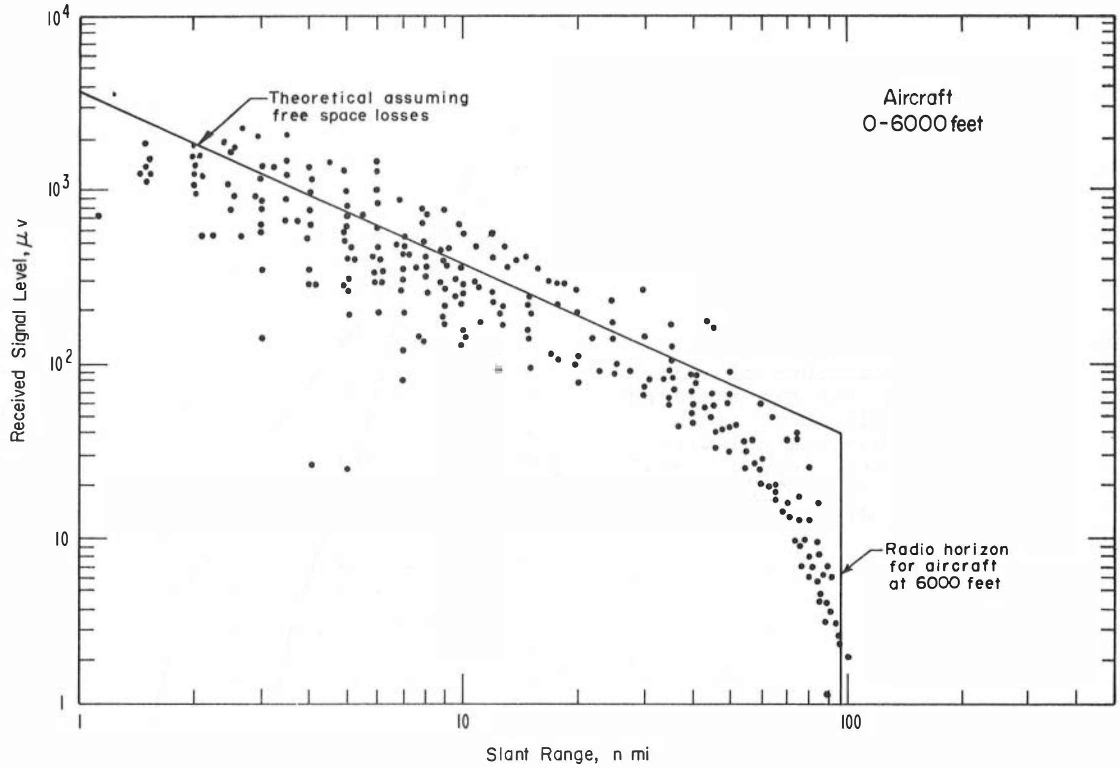


Figure 4-12. Signal level measurements made with test aircraft in the same project.

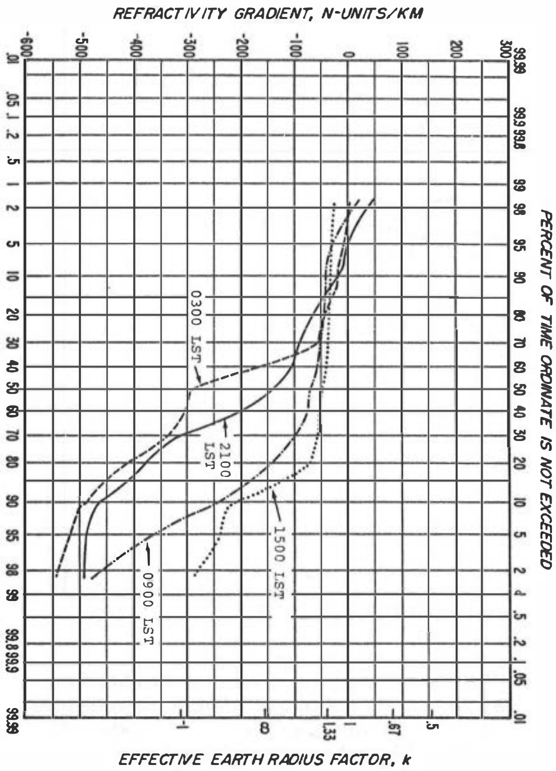


Figure 4-13. Distribution of summer refractivity gradients for Dayton, Ohio, for the 0-100 m ground-based layer.

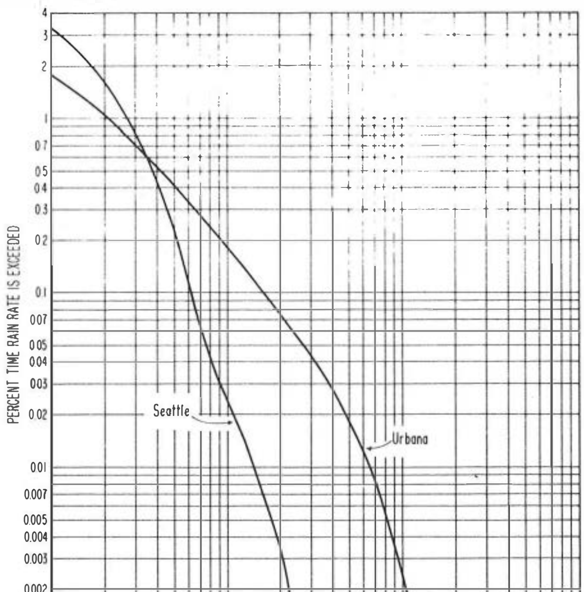


Figure 4-14. Cumulative distributions of the occurrence of rainfall rates for two stations (Urbana, Illinois, and Seattle, Washington) with similar total annual rainfall but drastically different distributions.

of 65 mm/hr is exceeded during 0.01% of the time (52 minutes out of one year) for Urbana; this rate is sufficient to cause severe attenuation at frequencies above 10 GHz. However, for Seattle, with the same total annual rainfall, the probability of occurrence of this rainfall rate is negligible.

The measurements over the Colorado links will be continued and augmented with transmissions at 15 and 18 GHz. Further studies and tests of atmospheric effects on digital communications are planned.

Long Path Polarization. During the period March to August 1974, the ITS made experimental measurements to study the depolarization of X-band signals transmitted over line-of-sight tropospheric propagation paths. Horizontally and vertically polarized signals were received simultaneously on a vertically-polarized receiving antenna, and analog recordings were made of their field strength variations. Subsequent data processing produced a record of the time variations in the discrimination ratio of the two cross-polarized signals. The data analysis provides a statistical description of the observed random reductions in discrimination ratio. The depth, rate of occurrence, and duration of these reductions were investigated, along with the correlation of these statistics with the corresponding statistics of signal fading. These results will be useful in estimating both the probability of occurrence and the probable effect of these random reductions in discrimination ratio on the performance of microwave systems which depend on cross-polarization for signal isolation.

SECTION 4.2. CHARACTERISTICS OF THE TRANSMISSION MEDIA

This section is concerned with the study of transmission media to help those who design, construct, or use telecommunication systems to better understand the characteristics of the media and their effects on radio signals. We first discuss the non-ionized atmosphere and then the ionosphere.

4.2.1. Atmospheric Characteristics

Millimeter Wave Transmission Spectroscopy, 40 to 140 GHz. The relatively stable dry air mass of the first 80 km in altitude is a unique filter and generator over the 40 to 140 GHz frequency range with transfer, shielding, and emission properties not found at any lower frequency. These effects are caused by the microwave spectrum of oxygen (O_2-MS), which is a complicated spectroscopic jigsaw puzzle due to more than 36 individual lines. The signal response of the atmospheric propagation channel is determined by a complex transfer function due to the O_2-MS, and the drastic changes with altitude in the function's attenuation and phase dispersion terms need to be known in some systems performance analysis and telecommunication prediction models.

The description of the O_2-MS requires a set of over 100 spectroscopic parameters, most of which had not been determined with adequate accuracy. Hence, since the rapid rate of expansion of EHF system applications, there have been strong recommendations by the National Academy of Sciences (1969), by NASA and NOAA (1971), by National Science Foundation (1972), by the Inter-Union Commission on Radio Meteorology URSI-IUGG (1975), and by others to improve the data base on the atmospheric O_2-MS.

The O_2 -MS is formulated as a complex transfer function in terms amenable to system engineers and is studied under controlled laboratory conditions simulating atmospheric parameters of pressure and temperature over the first 80 km in altitude. The spectroscopic parameters of line strength, width, and position are to be measured for as many lines as possible with accuracies on the order of 1 to 2 percent at low pressures (<100 torr, where 760 torr equals 1 atmosphere). The band shape intensities at higher pressures (>200 torr to 800 torr) are to be determined with accuracies better than 5 percent and compared with analytical results based upon Rosenkranz's band shape theory. A unique set of 36 interference coefficients needs to be determined from this comparison. All spectroscopic results are then combined in an EHF transfer function. The experimentally verified theory is described in terms of its variation with respect to temperature, pressure, and frequency; the results are discussed for their usefulness when treating problems of propagation limitations imposed by (turbulent) air and remote sensing of atmospheric states.

In FY76 the following accomplishments were realized: The spectrometer, developed earlier by ITS for accomplishing the objectives outlined in the preceding paragraph, benefited strongly from a newly designed, digital, millimeter-wave phase meter (see figure 4-15). Instrumental errors that plagued past measurements were reduced considerably.

Results of width and strength parameters were obtained from refractive dispersion versus pressure scans for 21 lines. Each parameter was deduced from several hundred data points. The missing parameters can be predicted with increased confidence.

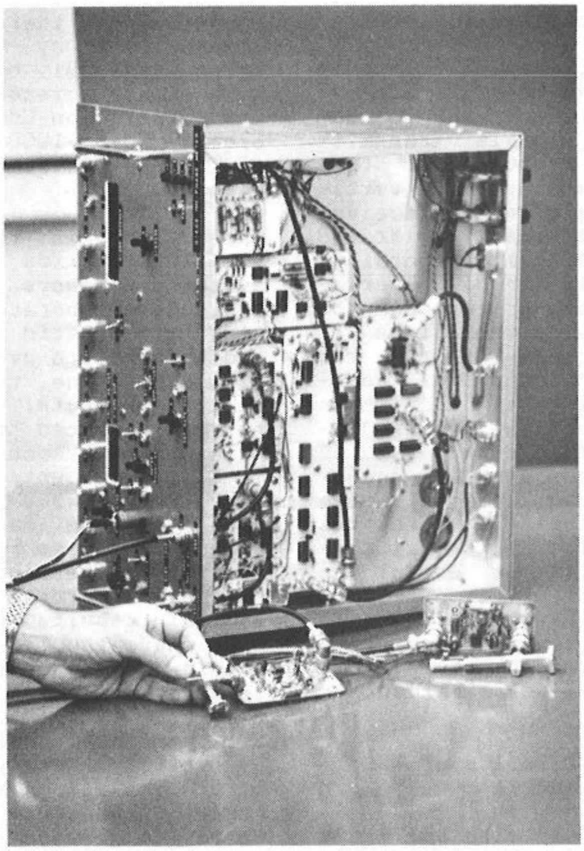


Figure 4-15. High resolution millimeter-wave phase meter developed by Arthur Diede and Hans Liebe of ITS capable of resolving the phase of a 60 GHz signal to 2×10^{-8} degrees.

The collective behavior of all O_2-MS lines appears as an unstructured band at sea level conditions, centered at 60 GHz; and the correct band shape is governed by a set of interference coefficients. The hypothetical value Γ^o= 0.8 MHz/torr for the nonresonant width produced the best agreement between calculated and measured (53 to 64 GHz, 200 to 800 torr) intensities.

The salient parameters of the atmospheric O_2-MS can now be given with some confidence. The analytical scheme, which uses these parameters to predict molecular attenuation and phase dispersion based upon easy-to-measure meteorological variables, is described in a paper (in press). Another paper (also in press) exploits the newly found EHF transfer properties of the clear atmosphere quite generally. The variability of a complex refractive index with respect to temperature, pressure, and frequency (figure 4-16) was analyzed by numerical experimentation with the state-of-the-art theory. System engineers can find the trends and extreme values of these sensitivities and thus have a better feel for the inner workings of the O_2-MS.

Atmospheric Effects, 10 to 40 GHz. With the planned increase in usage of digital systems and the re-examination of frequency allocations (in anticipation of the two 1977 World Administrative Radio Conferences (WARC's) and the 1979 General WARC), a closer look was warranted for the impact upon telecommunications of dispersive (frequency-dependent) atmospheric effects. This is particularly so for frequencies above 10 GHz and for systems employing digital modulation.

There was a need to extend previous efforts of modeling atmospheric effects (the attenuation, distortion, and depolarization of microwaves by rainfall, clouds, and the gaseous atmosphere) and to determine their impact upon microwave system performance for satellite/ground links.

In FY76, the theoretical method for estimating the atmospheric distortion of microwave signals and of evaluating their degradation of performance (increase of bit-error rate) for CQPSK (coherent quadra-phase-shift keying) systems was extended; evaluations were carried out for ground/satellite systems operating in the frequency range from 10 to 40 GHz. Also, a report was written describing a previous experimental study of the atmospheric effects upon a QPSK line-of-sight path.

Figure 4-17 shows the plots of atmospheric attenuation versus frequency exceeded for the indicated percent, p, of all hours of an average year. The propagation path is from a ground station at Washington, D.C., with an elevation angle θ = 27° to a geostationary satellite. The attenuation curves for $p < 0.2\%$ are governed primarily by rainfall; the curves for $0.2\% \leq p < 30\%$ are influenced by clouds and the gaseous atmosphere. The curves for $p > 30\%$ are those due to the gaseous atmosphere. Note that the "atmospheric window" in the vicinity of 40 GHz is available only in the absence of clouds and rain. Further, the distortion of microwaves is proportional primarily to the slope of these curves and varies with atmospheric conditions (the p value) as well as frequency.

An indication of the distortion effect is shown in figure 4-18 where the bit-error rate (BER) is plotted as a function of the bandwidth B. For a bandwidth of 0.1 GHz and for a ratio of energy-per-bit to noise power density (E/N_o) given as 15.05 dB, the BER is 0.77×10^{-8}. The curves then illustrate the marked increase in BER for a CQPSK system at 20 GHz as the bandwidth (or data rate) is increased. This increase in BER is due solely to distortion by the atmosphere, since it is assumed that the average transmitter power is being increased in proportion to the bandwidth increase. The atmospheric conditions and p values coincide with those for the previous figure.

A number of examples were prepared which illustrate the atmospheric limitations upon system performance and describe how the choice of a CQPSK digital system bandwidth (or data rate) for a specified system performance (BER) imposes quantitative requirements upon the design choices of transmitter power, antenna size, receiver noise figure, line losses, etc.

In FY77 It is planned to extend these results in several ways. The method for evaluating the impact of distortion upon the BER of CQPSK systems will be extended to permit evaluation of the impact of the known atmospheric dispersion from 40 to 150 GHz, as a function of bandwidth and path length for both terrestrial and airborne paths. Also, the mathematical expressions for the impact of distortion upon BER will be extended to include other modulation systems. Further, for frequency allocation purposes, the dispersive atmosphere between 150 and 400 GHz (which includes two water-vapor resonance frequencies) should be evaluated and applied for future digital satellite systems or digital terrestrial systems where security is important. It is hoped that this evaluation will be examined during the next fiscal year.

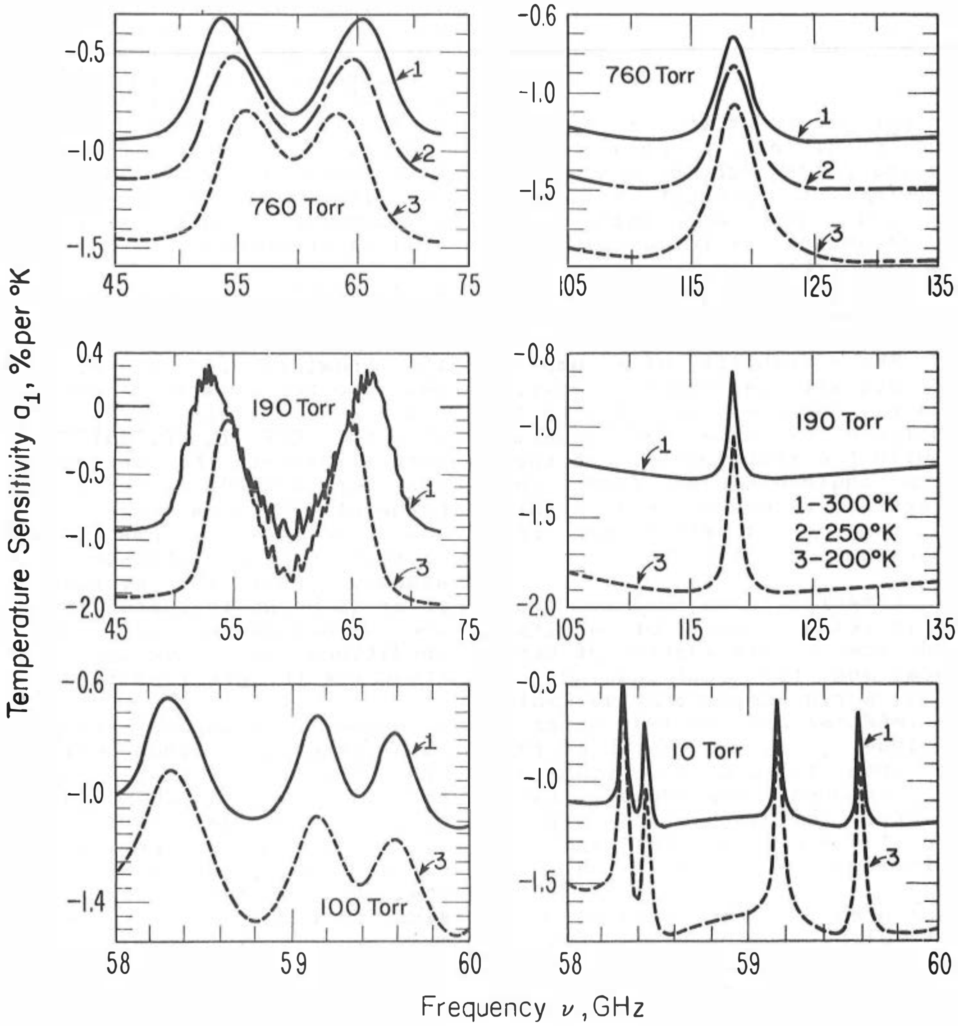


Figure 4-16. The temperature sensitivity of dry air attenuation for different atmospheric conditions representative of altitudes between sea level and 30 km at frequencies in the vicinity of 60 GHz and of 120 GHz.

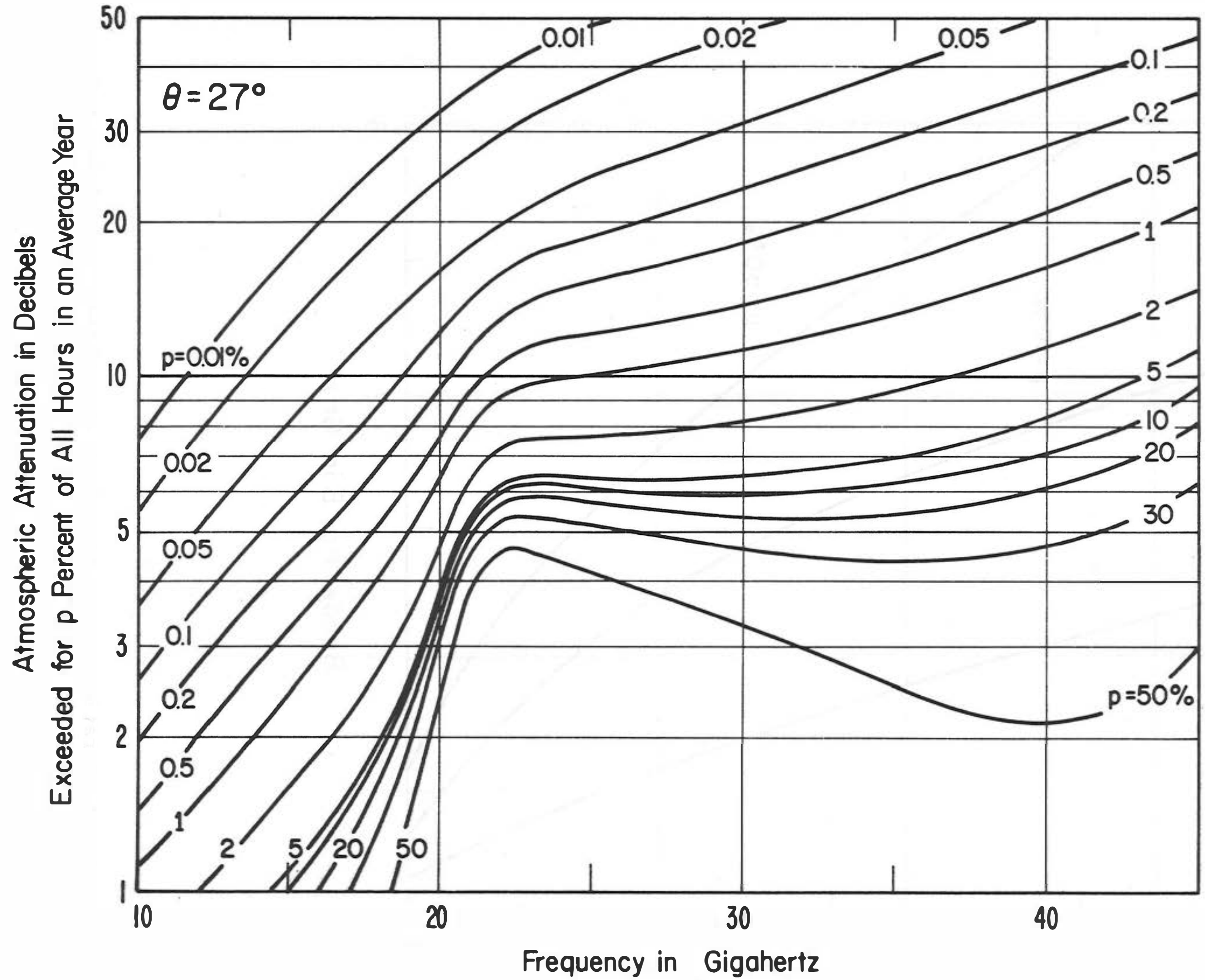


Figure 4-17. Statistical distributions of atmospheric attenuation for an average year between Washington, D.C., and a geostationary satellite seen at an elevation angle of 27°.

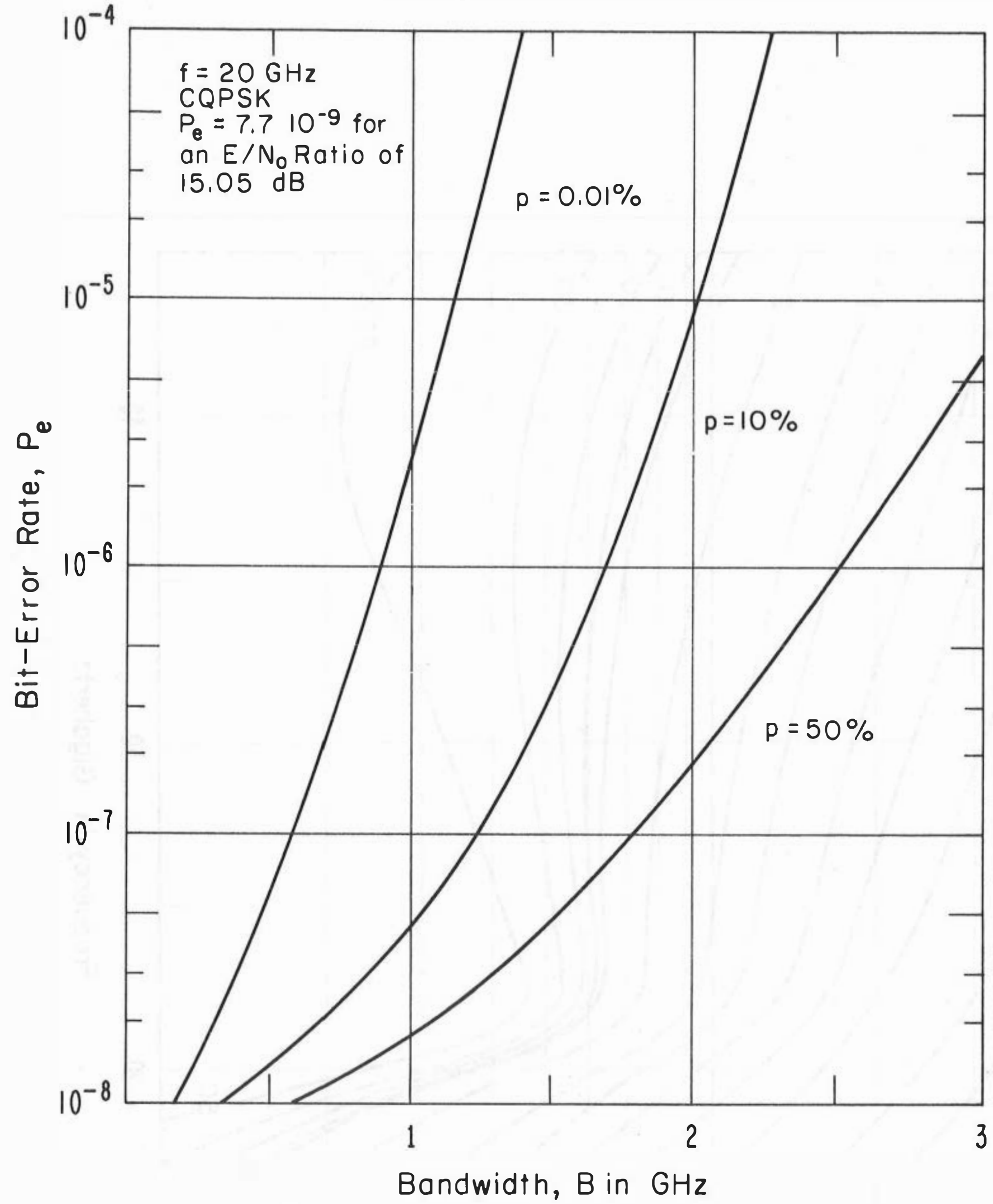


Figure 4-18. An illustration of the effect of atmospheric distortion upon bit-error rates shown as a function of bandwidth for the same circumstances as in figure 4-17.

Time-Variant Channel Limitations. The performance of future telecommunication systems using high bit rates is determined, in part, by both the fading and dispersive characteristics of the medium through which the wave is propagating. Fading dispersive channels are usually best described as random, linear, time-varying filters. The work on this project was directed toward characterizing the time-variant properties of a communications channel for a radio wave propagating in a random turbulent medium.

The deterministic variations in the transfer function associated with long-term atmospheric time variations (i.e., tens to hundreds of seconds) are caused by weather fronts and diurnal and seasonal changes in pressure, temperature, and water vapor pressure. Ott and Thompson (1976) examined the effects of long-term time variations on the transfer function. The random variations in the transfer function associated with short-time variations (i.e., tenths to tens of seconds) were studied by Ott (1976). Both papers are scheduled to be published in the November 1976 issue IEEE Trans. Ant. Prop.

Radio signals from point sources in the microwave spectral region are observed to experience amplitude scintillations even though the propagation medium is non-absorbing at the signal frequency. The effect is a consequence of the random spatial variations in the refractive index of the medium and has been treated at some length in the literature. In contrast, in the millimeter spectral region, an absorption mechanism as well as a scattering mechanism occurs. The dash-dot curve in figure 4-19 shows the shape of the radio amplitude spectra expected for the case of propagation through a turbulent medium having a real refractive index. For radio frequencies near regions of molecular absorption (e.g., 60 GHz), the absorption effect increases the amplitude variability. The absorption is generally a function of atmospheric state and composition. Since one or both of the latter are normally random in both space and time, the path attenuation varies randomly. Based on available information on the expected spectral shapes for pressure and temperature, the amplitude spectrum from the absorption mechanism should have the form $W_A(f) \propto f^{-8/3}$ where f is the fluctuation frequency, as shown by the vertical dashed line in figure 4-19.

The temporal amplitude spectra in figure 4-19 are measures of the Doppler spread or frequency dispersion of a radio wave propagating in a random turbulent medium. The reciprocal of the Doppler spread is an estimate of the time separation beyond which samples of the transmitted wave are independent. The term coherence time is frequently used to describe the reciprocal of Doppler spread. If the Doppler spread, B, satisfies $BT \gg 1$ where T is the duration of the information pulse, severe distortion and pulse spreading may occur.

The objective for FY77 is to predict the performance of telecommunication systems undergoing random time-variant changes in the transfer function.

Refractive Index Measurements. In certain parts of the world, atmospheric conditions often lead to the formation of propagation ducts. At frequencies commonly used in radars, these ducts can severely distort the radar's coverage, resulting in "holes" or regions in which a target could not be detected and/or the appearance of undesired background echoes from sea or land surfaces far beyond the intended range of the system.

In evaluating the performance of a radar and in the determination of optimum locations, these propagation effects are extremely critical. Two such areas were studied by ITS during FY76 at the request of USAF/ESD and RADC.

The ITS Model 5 airborne microwave refractometer was used to measure and record radio refractive index as a function of height. The resulting profiles were used in ray tracing programs to map the radar coverage expected for the particular conditions represented by each profile.

Shown in (a) of figure 4-20 is a typical profile from a sponsor-specified region, while (b) and (c) of the figure illustrate the two types of propagation effects in terms of the paths taken by signals leaving the transmitting antennas over a range of ±10 milliradians in elevation angle. In (b), the transmitted beam is divided into two parts, leaving a region of greatly reduced sensitivity in its coverage. In (c) most of the energy has been trapped and may be propagated over long distances, e.g., hundreds of kilometers, giving returns from low-level and surface targets but with positions corresponding to high elevations. This results in the occasional tanker being tracked at, say, 20 knots and at an apparent altitude of 70,000 feet.

NOAA Radar Support Program. This work was undertaken to assist NOAA's Weather Modification Program Office in the installation and interfacing of radar, navigation, and other instrumentation in the NOAA P-3D aircraft (used in connection with severe storm warnings and weather modification).

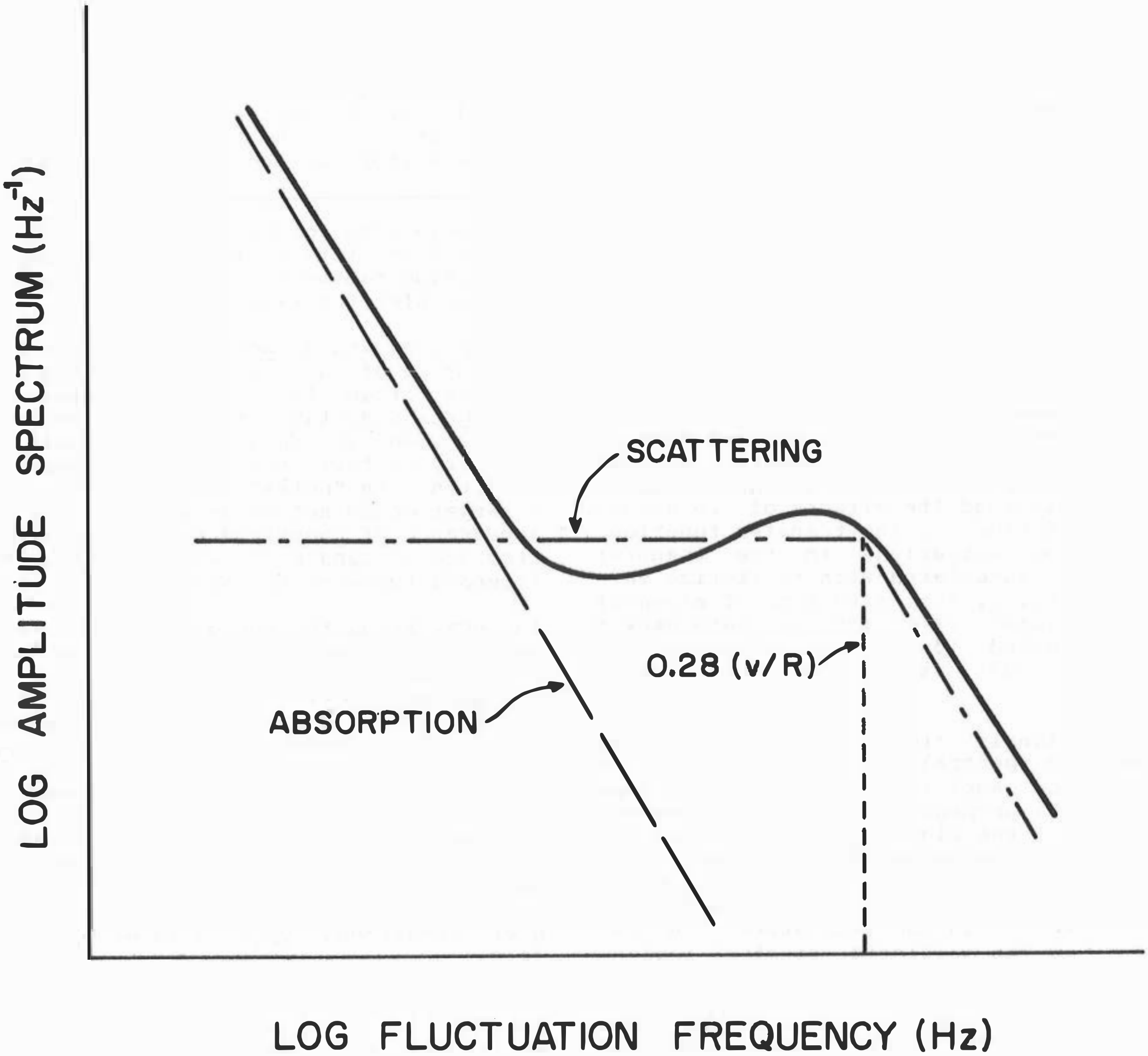


Figure 4-19. Expected shape of the radio amplitude spectra for a wave propagating in a turbulent atmosphere with a complex refractive index. Solid line is resultant spectrum; v is the velocity of the eddies transverse to the radio path; R is the radius of the first Fresnel ellipsoid with foci at transmitter and receiver; 0.28 (V/R) differentiates the two regimes.

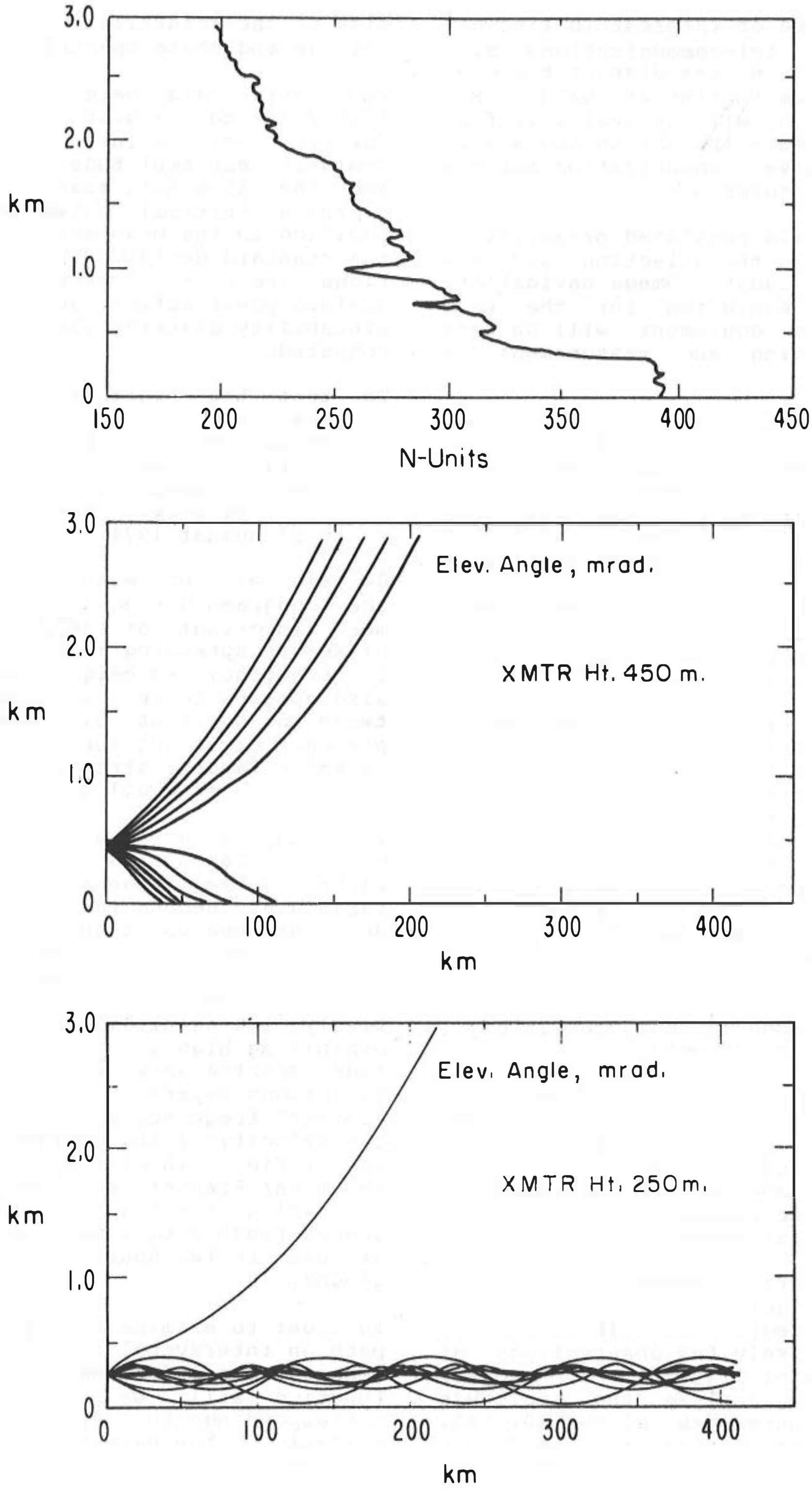


Figure 4-20. Effect of propagation ducts on radar returns in the Persian Gulf: a) refractivity profile, b) ray paths for radar at 250 m elevation, c) ray paths for radar at 450 m.

Severe storms are of interest in line-of-sight microwave telecommunications systems in that the storms disrupt the communication system in time of need. Future data which will be available from NOAA will lend some insight to the severity of microwave communication outages caused by such storms.

The effort in FY76 consisted primarily of assisting NOAA in the selection and installation of radar, Omega navigation, and other instrumentation for the P-3D aircraft. This equipment will be used during the tracking and measurement of severe storms.

The radar is an AVQ-30C airborne weather radar with 70 kW peak power, 6 μs pulse length at 200 pps, a 30 dB antenna, and which operates at a frequency of 5.85 GHz. For analysis purposes, raw video will be recorded and digital video in 1.0 dB increments will be recorded on magnetic tape. These data can then be played back through the data processing system and be displayed on video monitors. Selected portions of the data can then be analyzed in detail.

Many of the observations are expected to be obtained from severe storms at sea. The majority of the predictions now made for microwave transmission characteristics through the atmosphere are dependent upon the mass of data available from land-based weather stations. There is considerable need for data taken at sea for use in ship-to-satellite transmission predictions. It is not expected the measurement results will be available before January 1977.

4.2.2. Ionospheric Characteristics and Effects

Ionospheric Effects on Transionospheric Radio Signals. Scintillations sufficient to degrade the performance of satellite communication systems have been detected up to the UHF band at high latitudes, up to 4-6 GHz in the equatorial regions, and at least to VHF at temperate latitudes.

Although considerable knowledge is available concerning scintillation effects in the equatorial region and high latitudes, there are relatively few observations of mid-latitude scintillations. The project objective was to analyze the amplitude and phase measurements of the 40, 140, and 360 MHz transmissions from the ATS-6 radio beacon, taken by the Space Environment Laboratory, NOAA, Boulder, Colorado.

During FY76, appropriate statistical models and software were developed for determining the amplitude and phase distributions of the excursions from the undisturbed signal, the S indices or intensity of the scintillations, and the amplitude and phase spectra.

The basic data were taken at 1-second intervals and the statistics are computed for each 5-minute interval using both the 5-minute mean amplitude and mean power and the 15-minute means centered on the 5-minute interval being analyzed. In addition to the mean amplitude and power, the standard deviation of the distributions about the means, the minimum and maximum power ratios, and the cumulative probability distribution of the power are computed.

To test the hypothesis that the time-varying irregular structure in the ionosphere is the cause of signal degradation in satellite communications, the vertical incidence ionograms taken at Boulder, Colorado, were examined in detail for the month of August 1974.

Certain salient features are observed on the ionograms during scintillations. The most important of these is the presence of severe spreading in the F layer both in frequency and height. However, there also appears to be a high correlation between the onset of scintillations and the presence of height spreading in both the Es and F layers, strongly blanketing sporadic E and many oblique echoes.

The temporal amplitude and phase spectra have been calculated using an FFT algorithm from amplitude and phase recordings taken every second for the 40, 140, and 360 MHz beacon signals. Spectra are presented over a seven-hour time period for two days exhibiting relatively high scintillation and one day showing relatively low scintillation. On those days exhibiting high scintillation, the amplitude spectra show two distinct power-law variations separated by a scintillation "corner" frequency approximately equal to the velocity of the medium transverse to the radio path divided by the radius of the first Fresnel ellipsoid. The time for which spectra are presented corresponds roughly to sunset in the F region, or one to two hours after sunset on the ground.

In order to examine the effects of multipath on intersymbol interference, a mathematical model for the channel scattering function will be derived in FY77 corresponding to periods of high scintillation. The parameters characterizing the scintillating medium that are needed in the mathematical model for the scattering function will be identified. Also in FY77, the radio frequency dependence of scintillation will be examined.

Ionospheric Data Analysis. Ionospheric parameters are critically important to the long-distance propagation of radio waves with frequencies less than 40 MHz. These parameters are highly variable with time and location, so their measurement and prediction have been studied at ITS and its predecessor organizations for many years.

Ionospheric data analysis is sponsored by the Air Force Geophysical Laboratory. The objective of the project is to retrieve basic data from appropriate data sources, such as NOAA's World Data Center, to provide digitized values of specified ionospheric parameters, and to analyze these data to determine their latitudinal, longitudinal, diurnal, and seasonal variations.

In FY76, the digitization of the specified ionospheric data has been completed and a draft report on the analysis on the ionospheric data has been supplied to the sponsor. The purpose of the study was to evaluate the probability of sporadic-E (Es) occurrence in the area of the northeast United States, Canada, and Greenland, and to provide quantitative estimates of the likelihood of simultaneous Es occurrence at several pairs of vertical-incidence ionosondes in this area. The sporadic E observations used in this study were measured at Wallops Island, Virginia; Ottawa, St. Johns, and Goosebay, Canada; and Godhavn and Narssarssuaq, Greenland for the years 1969-1972.

The conclusions of this analysis are (as expected) that sporadic E occurs predominantly in the summer season and daytime hours for temperate latitudes (Wallops). However, this trend tends to disappear in the auroral zone. There is some tendency for sporadic E to occur simultaneously at widely separated locations in the sub-auroral area, but this tendency is greatly weakened in the auroral oval region.

LF Data Analysis. In order to estimate the performance of the Minimum Essential Emergency Communications Network (MEECN), it is necessary to determine the time-availability of each individual link. Some links in MEECN are LF-VLF radio links whose time-availability depends on the temporal variation of the signal-to-noise ratio. Models developed to predict this ratio require models of the ionosphere as input, but no ionospheric model which varies with the relevant geophysical parameters was available.

This project made use of measured D-region profiles from the literature to develop such a model.

The parameters of an "exponential model" of the ionosphere were scaled from over 500 profiles culled from the available literature, and analysed using multiparameter linear regression.

The resulting model is given by the expression in figure 4-21.

The model was validated by comparing theoretical field strengths, computed using it, with measured field strengths.

Lower Ionospheric Research. This project combined results of the ITS partial-reflection sounder data from the Alaskan Ice-Cap program with other ionospheric measurements from New Mexico to determine the high-latitude lower ionospheric behavior during normal and aurorally-disturbed periods.

In FY76 the detailed analysis of partial reflection sounder data acquired in Alaska during the DNA sponsored ICECAP 73-74 programs concerned with aurorally disturbed and normal ionospheres was completed along with analysis of measurements from White Sands, New Mexico.

A report has been written, and is under review, which includes a composite analysis of the impact of strongly perturbing ionospheric events on long-path propagation modes of communications systems which operate at LF, VLF, and ELF frequencies.

A complementary program titled Joint Ionospheric Studies is sponsored by the U.S. Army Electronics Command and concerns the completion of ionospheric data reduction and analysis of the support data taken during a rocket measurement program at the White Sands Missile Range. The data reduction and analysis have been completed and a report to the sponsor is in preparation.

SECTION 4.3. DEVELOPMENT AND IMPLEMENTATION OF EM WAVE TRANSMISSION MODELS

Information about EM Wave Transmission Characteristics, and the characteristics of the transmission media are incorporated into engineering models. These models are being developed for users within and outside government. As in section 4.2, we first discuss the non-ionized media cases and then those primarily influenced by the ionosphere.

4.3.1. Atmospheric Transmission Models

A Communication System Performance Model is one example of the type of development effort being carried out by the Institute for other government agencies.

The sponsor of this project, the U.S. Army Communications-Electronics Engineering and Installation Agency (USACEEIA),

$$N(h) = N_o \exp(\alpha(h-h_w)),$$

where: $N(h)$ is the D-region electron density at height h(km);

$$N_o = 1.43\,(10^7) \exp(-0.15\, h_w);$$

$$h_w = 71.96 - 7.78\, x_1 + 7.79\, x_2 - 1.20\, x_3 - 0.0372\, x_4 - 7.06\, x_5;$$

and

$$\alpha = 0.281 - 0.134\, x_1 + 0.108\, x_2 - 0.0762\, x_3 + 0.191\, x_5;$$

and

$x_1 = \cos(\chi)$, where χ is the sun's zenith angle;

$x_2 = \cos(\theta)$, where θ is the latitude;

$x_3 = \cos\varphi$, where $\varphi = \frac{m-0.5}{12}(2\pi)$, and m is the month number;

x_4 = the Zurich smoothed relative sunspot number;

$x_5 = 0$ for quiet conditions; $x_5 = 1$ for disturbed conditions.

Figure 4-21. Ionospheric model for use with MEECN 20-60 kHz circuits. Model is for all hours and all latitudes. Disturbed in X_5 is defined as $K_p > 4$, riometer absorption > 0.5 dB or SID condition.

has world-wide responsibilities for planning and installing Army line-of-sight and troposcatter communication systems.

A communication system performance model is being developed which will provide a variety of user-selectable forms of output information. At the heart of the model is the ITS point-to-point reference model for predicting basic transmission loss. That model requires as input certain data describing the physical characteristics of the propagation path between the transmitter and receiver. These path data are obtained by automatically accessing digital files of topographic data, extracting the necessary topographic information, and calculating the required path parameters.

The types of output data which may be selected by the model user will include simple path terrain information obtained from the digital topographic files, basic transmission loss, and utilizations of the basic transmission loss to compute power density and received signal level. All output data will be available in tabular and plotted forms at the choice of the model user. The ultimate form of output data will be equal-value contours, about the transmitter location, of basic transmission loss, power density, or received signal level imposed upon a geographical map not to exceed 2° longitude by 2° latitude, also generated by the model. A final type of output data will be predictions of "quality of service" determined by predicting the probability that received signal level will equal or exceed a specified threshold.

This project extends into FY77. There is a need for improved antenna models for use in this model and other Army models, and a need for capabilities for handling and utilizing topographic data which are considerably more detailed than the data presently being used.

Another example of model development for the Army was European Wideband Communication System Performance at SHF. The U.S. Army Communications Command at Ft. Huachuca, Arizona, has a need for a FORTRAN IV computer prediction model for their CDC 6500 computer for making performance predictions for LOS (8 to 30 GHz) systems in Europe.

From the available experimental data and theoretical formulations for rainstorm structure and cell size, rainfall predictions, and the impacts of rainfall, a performance prediction procedure for the EWCS at 8 to 30 GHz was formulated and computer programed. The procedure will accommodate the inputs of path length, operating frequency, and appropriate rainfall statistics. The outputs will be: the rainfall path loss and its variation for a given path.

During FY76 most subprograms for the final software package have been prepared, and the methodology for the determination of the variances of station convective storm activity have been obtained. From these, then, the mathematical procedure for calculating the rain rate variance, and, thence, path loss prediction variance have been established. Further, from the available historical data, the temporal (year-to-year) variance of rainfall has been determined for the meteorological stations of Europe and has been used as the basis of predicting (at the 90% level) the range of rainfall distributions for an average year.

Figure 4-22 represents the comparison of the prediction of the average annual distribution of rainfall rates, obtained via the modified Rice-Holmberg model (Dutton, Dougherty, and Martin, 1974, USACC Tech. Report No. ACC-ACO-16-74), with purported "long-term" data taken by the Weather Bureau of the Federal Republic of Germany. These particular results are for Hamburg in the FRG, and are representative of several meteorological stations that are available. Happily, the data are still within prediction confidence limits. Dashed lines represent the prediction of the confidence level of the prediction based on an assumed normal distribution about the mean. These dashed lines enclose a 90% confidence interval.

The prediction of variance and standard deviation of rainfall rates, and, hence, path loss, represent an advanced and pioneering effort in this regard, so far as we are aware, to attach a quantitative value to this highly unpredictable meteorological quantity.

Because very little was known regarding propagation at VHF and UHF with antennas near the ground, an extended measurement program was planned and carried out in 1973 and 1974. The objective was to show that a sensor communication system may operate with antennas placed virtually at ground level. Data were obtained at 172 and 410 MHz at various times of day, and seasons, over several types of terrain.

We carefully evaluated, summarized, and analyzed these data, and compared the results with values predicted using several models of radio propagation over irregular terrain. The data, especially at the lower frequency, clearly show that the power received over these relatively short paths (less than 7 km long) tends to remain practically constant from one hour to the next for periods of 16 hours

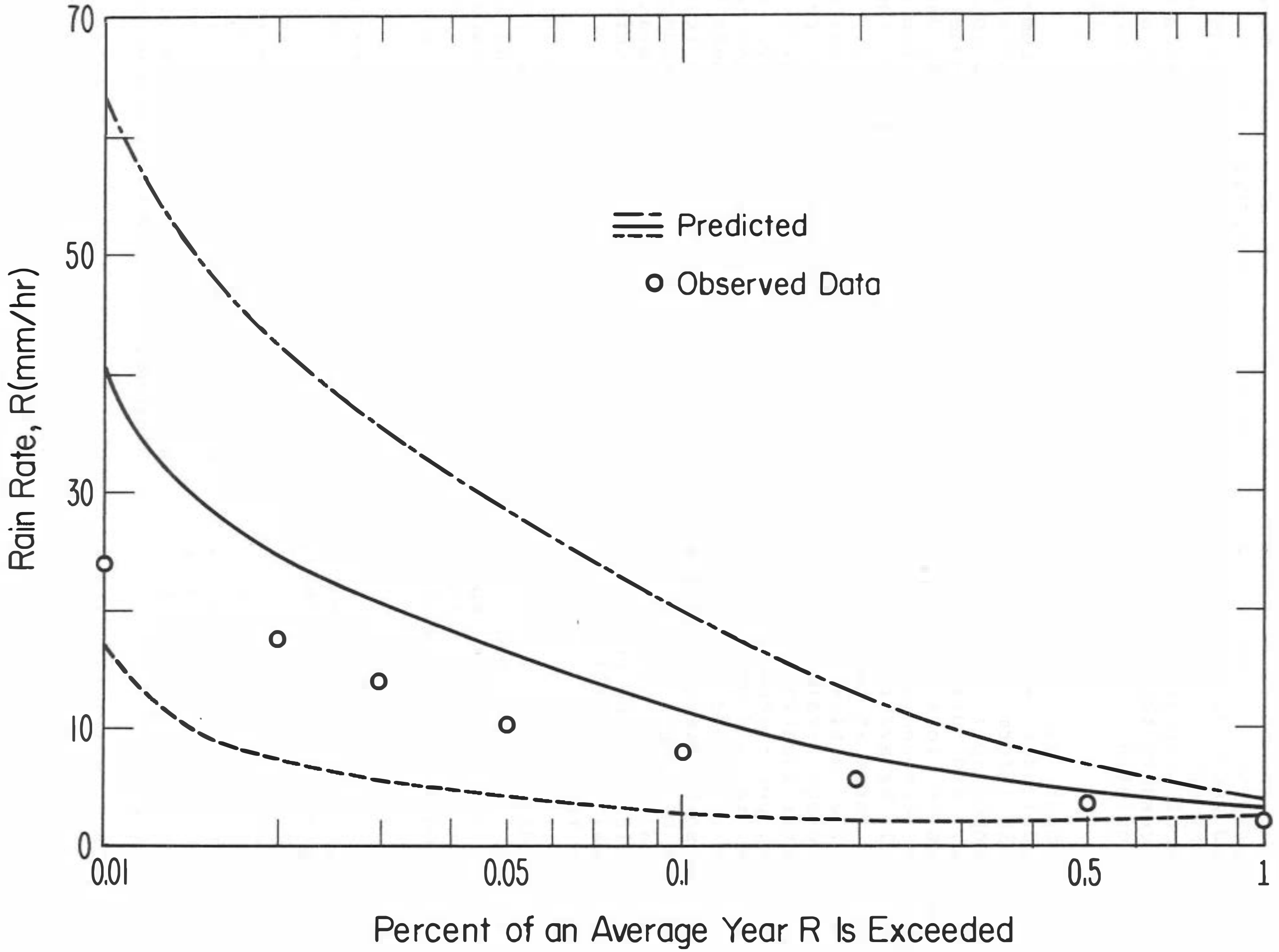


Figure 4-22. Comparison of predicted versus observed rainfall rates for Hamburg, F.R.G. The solid line is best guess prediction, the other two curves define the 90% confidence limits.

or more, and that the change from one day to another rarely exceeds 5 or 6 dB. The short-term or within-the-hour variability is small, also, with a variance that is usually much less than 1 dB. Somewhat more variability in received power was observed at UHF.

Although the variability with time is small, large path-to-path differences of 40 to 45 dB were common. This large location variability is associated with the very low antenna heights, where small obstacles in the immediate foreground partially block the signal.

Measured transmission losses were compared with values predicted using several models of radio propagation over irregular terrain. The Longley-Rice (ESSA Technical Report ERL-79, ITS 67) area prediction model proved useful for this type of communication, except that this model makes no specific allowance for the effects of trees. In a heavily forested area, additional losses occur, especially at the higher frequencies. In an area where many of the terminals were located close to thick stands of evergreen trees, the additional loss was about 5 and 13 dB at 172 and 410 MHz, respectively. The additional attenuation also depends on the density and height of the forest and how close it is to the path terminals.

The attached figures show comparisons between measured and predicted values. Figure 4-23 shows median values of basic transmission loss at 172 and 410 MHz, with both antennas 0.35 m above ground level, compared with area prediction curves. Figure 4-24 shows the differences between measured and predicted losses for individual paths using path parameters with an allowance for trees.

In FY76 we completed and published the final report on this project (OT Report 75-74).

4.3.2. Ionospheric Transmission Models

Computer programs developed by ITS for predicting ionospheric transmission and the performance of HF radio systems are used by government agencies and commercial firms in the U.S. and other nations. A continuous program is carried on to upgrade and expand prediction services to fit user needs.

One of the FY76 projects in this area was the HF Broadcast Compatibility study, conducted for the Voice of America (VOA).

Evaluation of HF sky-wave predictions (as used for VOA scheduling) with emphasis on the evaluation of the broadcast compatibility program developed in FY75, was carried out.

Important parts of the HF predictions, e.g., day-to-day variations of HF signal levels, were compared with actual observations on long circuits to check the accuracy of HF models. Predicted day-to-day variations show acceptable agreement with observations. Overall agreement between predicted and observed values is as yet uncertain due to lack of observational data.

The overall comparison of the model and the observations was made available to VOA on a time-share computer. Future comparisons can now be made by VOA directly by time-share access to the model.

Along with the above program was the Development of Improved Models for Multihop Propagation, also sponsored by VOA.

The performance of HF communication systems is strongly dependent on the reflection properties of the ionosphere, which vary systematically with hour, season, solar cycle, and geographic location. The Voice of America has relied entirely on the competence of OT/ITS for developing global ionospheric models for predicting ionization levels in the various regions of the ionosphere. It has also been our responsibility to apply these ionospheric models to the development of propagation models for estimating system performance criteria such as reliability, field strength, and compatibility for long-distance, high-frequency radio systems. Improved models for estimating HF system performance enable the United States Information Agency to more effectively determine optimum assignments of facilities and frequencies for VOA broadcast circuits.

A complete program for the prediction of radio system performance has been written. This includes the standard output format as used in HFMUFES (reliability, percent of days, etc.). While any two locations in the world can be used, the models in this program are not intended for long paths. The program was written in such a way that all subsections are modular, and modifications may be made without involving a major recoding of the entire program.

A model for very long paths which does not depend on finding the precise model structure has been developed and programed. This is the first computerized version of these prediction methods, which have a history back into the 1940's. Verification of the combined program will be carried on in the next fiscal year.

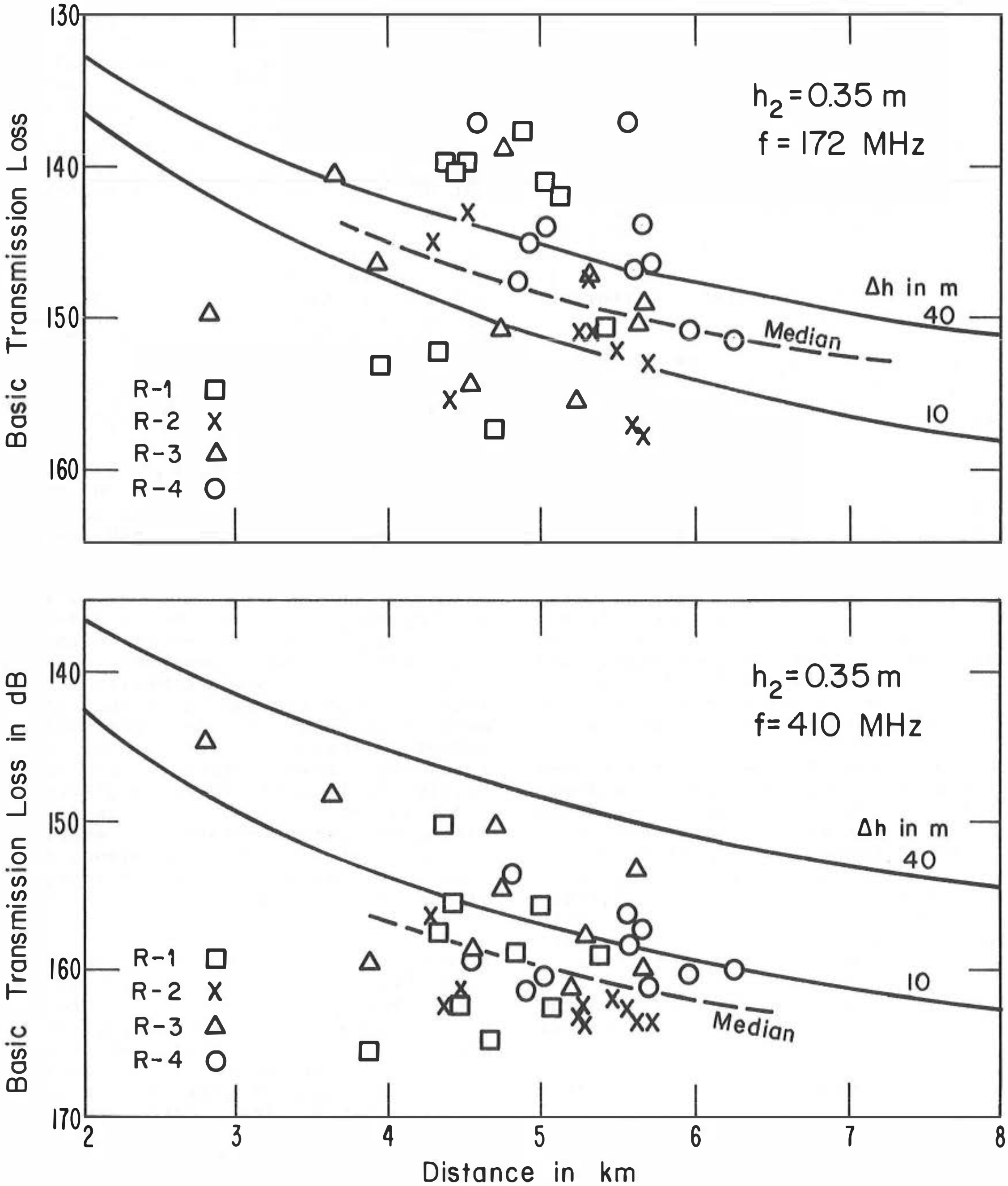


Figure 4-23. Comparison of measured transmission loss at 172 GHz (upper graph) and 410 MHz (lower graph) for both antennas 0.35 m above the ground compared to standard area prediction curves (solid lines).

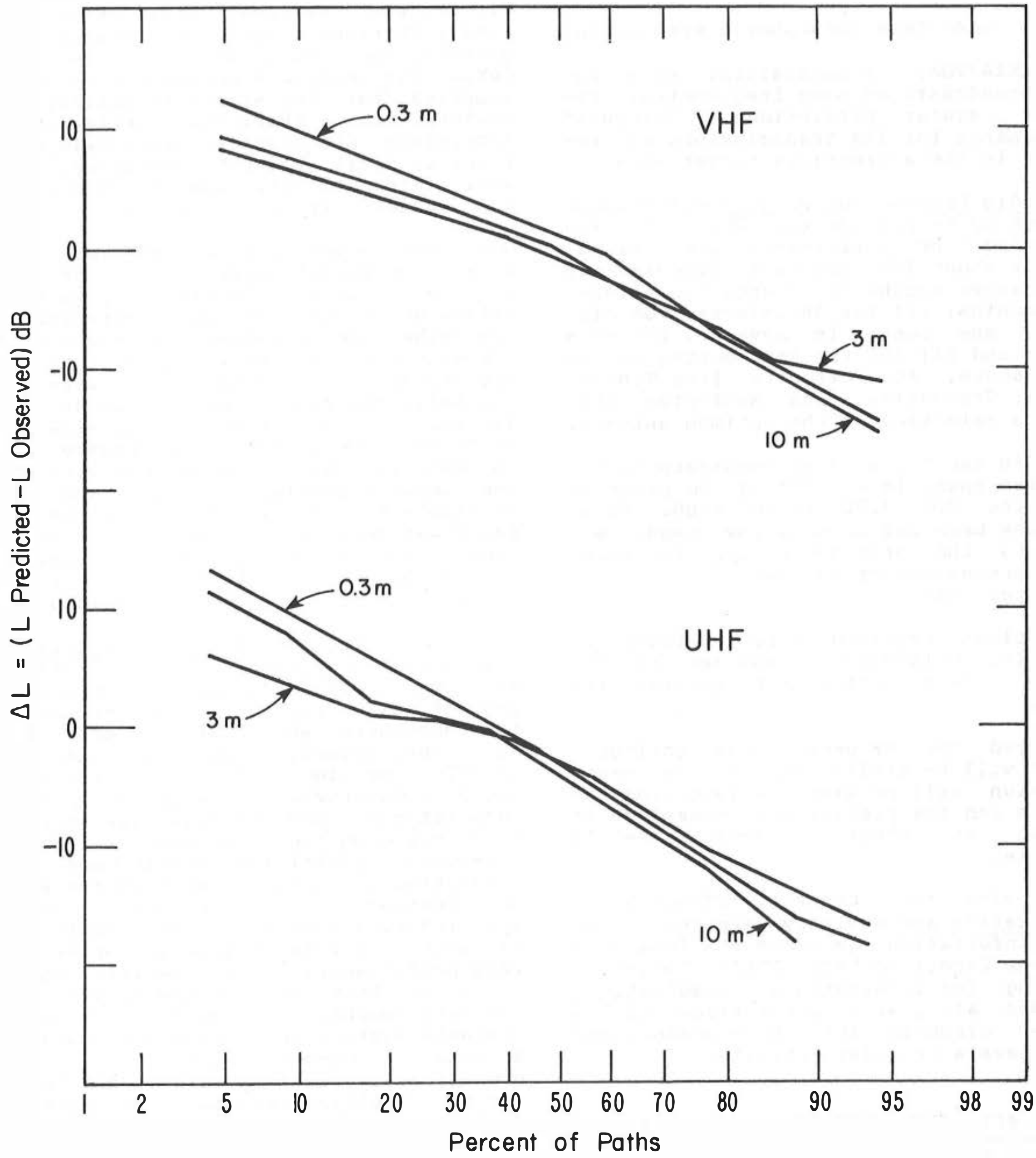


Figure 4-24. Difference between predicted and measured transmission loss for 172 GHz and 410 MHz. Curves are parametric in receiver antenna heights.

SECTION 4.4. PREDICTION OF TRANSMISSION PARAMETERS AND SYSTEM PERFORMANCE

Completed engineering models for EM wave transmission calculations are delivered to sponsoring and requesting agencies for their use. Following are representative uses of these services.

4.4.1. Long-Term Ionospheric Predictions

The USIA/VOA, in maintaining its worldwide broadcasts on high frequencies, requires regular predictions of "circuit" performance for its transmissions as received in the appropriate target areas.

The Radio Propagation Predictions project was set up to provide the VOA with the following HF performance predictions: (1) for about 150 broadcast circuits at least seven months in advance for alternate months; (2) for 30 selected VOA circuits, one month in advance, for each month; and (3) for the same months as in (1), above, for circuits from Tinang, Kavala, Greenville, and Wooferton that make a selection of the optimum antenna.

Early in the fiscal year considerable effort was spent in converting the programs from the CDC 3800 to the 6600. Files have now been set up to allow ready access to the program either for local batch processing or for use of a remote Telex terminal.

Predictions required were delivered on schedule. USIA/VOA has made use of the remote access option for special circuits.

VOA need for HF predictions continues, and it will be filled as in the past. Attention will be given to improving the service and the predictions themselves as success in other projects make it possible.

Along with this project, ITS provided Consultative and Advisory Services to the U.S. Information Agency in the form of a 3-volume report to help VOA's long-term planning for international broadcasting. Included, also, were predictions of 75 special circuits for three seasons and three levels of solar activity.

There are many government agencies and industries which use the Numerical Prediction Services. This project provides numerical coefficients, HF radio propagation predictions, computer programs, and other materials, e.g., maps and reports, as requested, on a cost reimbursable basis.

ITS provided monthly prediction numerical coefficients for foF2 and M(3000)F2 to approximately 14 yearly subscribers. HF Radio Propagation Predictions were provided routinely to ITT World Communications, Associated Press, Voice of the Gospel, and NOAA/SEL. In addition, HF Radio Propagation Predictions were supplied to: Texas Gas Transmission, Martin Marietta, Canadian Marconi Company, Environmental Devices Corp., E-Systems, Family Stations, Page Communication Engineers, Inc., Radio Nederland, and Exxon Corp. The HFMUFES 4 computer program was supplied to: Los Alamos Scientific Laboratory, Family Stations, Harris Corp., Interstate Electronics Corp., Main Electronics, Naval Research Laboratory, Rockwell International, Sanders Associates, and Standard Oil of California.

Over the years ITS has provided Johns Hopkins University with special HF prediction services. In FY76 a project entitled HF Fleet Sub was initiated to determine the coverage of groups of HF transmitters in order to evaluate an operational communication network. A specially modified version of an HF prediction program is used to provide predictions of HF systems performance data on magnetic tapes compatible with both the computer available to ITS and that available to JHU. The format of the data tapes was modified so that they could be used directly as input to JHU's systems evaluation program. Predictions for all areas requested by JHU were provided.

Prediction Techniques for Marginal HF Communication Systems. The analysis of HF communication systems is strongly dependent on the reflection properties of the ionosphere, which vary systematically with hour, season, solar cycle, and geographic location. Various agencies of the U.S. Government, as well as private corporations and foreign governments, have relied on the competence of ITS for developing global ionospheric models for predicting ionization levels in the various regions of the ionosphere, and for applying such models to the development of methods for the evaluation of HF systems performance. The specific objectives of this project are to develop a complete computer program to be used to evaluate systems which have only marginal success in communication (e.g., voice communication barely possible) and to apply the resulting program to an existing system, the U.S. Army's AN/TSC-38B. Emphasis is to be given to determining the range capability of the existing transportable radio system and to determine the feasibility of incorporating signal processing equipment into the system.

The programing phase is part of a continuing effort by ITS, and, based upon these studies, improved ionospheric prediction and analysis models have been developed.

These models have been programed for use in the real time analysis of over-the-horizon radar systems and for predicting the area coverage of HF radio transmitters. Because of the extremely sophisticated processing of the radar data, various improvements in the analysis model have been realized. This information was largely short distance data; i.e., one and two hop paths. It was felt that these models should now be included in a general point-to-point HF radio systems prediction program.

The preliminary programing for both the long distance and short distance modules has been completed. Quite extensive model verification both against alternative programed models (to check computer coding) and measured data (to check model accuracy) will be carried out in the next fiscal year.

A feasibility study incorporating signal processing equipment into the AN/TSC-38B has been completed and recommendations delivered to the sponsor. Only commercially available equipment was considered. Even with a near optimum operating frequency, an HF circuit often experiences short term variations in received signal level, noise, and interference that can seriously affect system error rate. An improvement of only a few dB gained from better antennas and larger transmitters removes only those errors which occur when the signal-to-noise ratio is in a marginal range of only a few dB, a situation which occurs infrequently with HF signal-to-noise variability. Therefore, signal processing techniques which can achieve more effective error rate reductions were recommended for use with the AN/TSC-38B High Frequency Communications Center.

It is anticipated that additional funds will be available to us during the next fiscal year to obtain the signal processing equipment and to set up a field experiment utilizing said equipment with the AN/TSC-38B. The results of the test phase will then determine the actual performance of the modified system.

4.4.2. Ionospheric Warning Service and Short-Term Predictions

In addition to the long-term predictions which are useful for system planning and design, ITS provides short-term forecasts and warnings that are useful for day-to-day operations. Some of these were described under VOA Time-Share above.

Ionospheric Warning Services, provides forecasts of conditions which are likely to affect ionospheric radio propagation conditions in the high frequency range from about 3 to 30 MHz to communication agencies and certain research groups. Of primary concern are those transmission paths at high latitudes, which are more likely to be adversely affected by significant disturbances in the earth's magnetic field; upon special requests, however, forecasts for propagation paths at other latitudes can be made available. Objectives also include the maintenance of various computer programs and data files by which remote users may acquire ionospheric predictions through access of a time-share computer. Users of these forecast services include U.S. Government, private business (domestic and foreign) groups, amateur radio operators and shortwave listeners, and schools, elementary through college levels.

During this fiscal year, project personnel continued to issue routine forecasts of telecommunication conditions on weekly, daily, and six-hourly schedules. Distribution of these forecasts was accomplished by mail, teletype, and telephone, and were made available in time-share computer files and on a telephone answering service. The six-hourly forecasts were also broadcast by NBS radio station WWV; in addition to the propagation forecasts, the WWV transmissions also included solar radio flux data and geomagnetic indices, supplied by personnel of this project.

At approximately two-week intervals, project personnel prepared Ionospheric Prediction Revision factors for inclusion in the Weekly Telecommunication Forecast reports. These revision factors are to be applied to semi-permanent frequency predictions (maximum usable and optimum traffic frequency). Monthly summaries of radio propagation quality figures and geomagnetic activity indices were prepared for publication in NOAA's Environmental Data Service's publications, Solar-Geophysical Data.

Project personnel also provided the mechanism for preparation and distribution of the AMVER charts, in support of the U.S. Coast Guard, and for retrieval and distribution of certain computer runs (such as terrain profiles) submitted via the time-share computer by internal and outside groups.

There was a special project set up for VOA Time Share of computer models. The object here is to provide VOA's Master Control with a means to acquire prediction of high-frequency radio performance characteristics by remote access to time-share computer programs, and to alert Master Control to any existing or impending solar and geophysical events considered capable of affecting high-frequency broadcast services. Of particular importance to Master Control are those disturbances which might necessitate their acquisition of cable services, in lieu of ionospheric propagation circuits, for relay of their programs to overseas broadcast stations.

The bulk of project funds for this project goes to actual computer time for the sponsor's use of the ionospheric prediction programs; only 10% is available for labor costs. Project personnel continued to maintain solar and geophysical files necessary for access by the computer program, as well as other files which contain the latest forecast issued by the Telecommunication Services Center (files maintained as a regular TSC service).

A special service performed for the USIA/VOA Frequency Division was a daily (Monday through Friday) message which contained a summary of solar and geophysical conditions during the preceding 24 hours (through the weekend in the case of the Monday messages) and a forecast of geomagnetic/ionospheric conditions for the following days (or for the ensuing weekend on the Friday report). These messages were transmitted by direct-dial TWX.

Radio Warning Communications. During the United States space program, the protection of space flight personnel from solar radiation of high energy particles became important. With the advent of programs for the development of supersonic aircraft to operate at high altitudes for civilian air transportation, it was recognized that exposure of aircraft occupants to galactic and solar cosmic radiation needed investigation. Further study revealed that subsonic jets operating in the polar regions were also subject to hazards during periods of high solar activity.

The Federal Aviation Administration, Office of Aviation Medicine, contracted with the Space Environment Laboratory, NOAA, to study and devise a radiation prediction and warning system for solar activity. As a part of this effort, ITS is investigating methods of disseminating the forecasts and warnings. The predictions need to be available at pre-flight centers so they can be considered in the preparation of flight plans as well as being broadcast to aircraft in flight so that remedial actions can be instituted during periods of hazardous radiation conditions. The work on the project has consisted of a survey of existing communication systems in the polar regions and recommendations for implementing a forecast and warning dissemination system which would make maximum use of these facilities. Recommendations for the implementation of future more sophisticated systems are a part of the report. This work will be completed in FY76 and a continuation of the project is not contemplated.

SECTION 4.5. APPLICATIONS

The constant study of EM Wave Transmission Characteristics, the development of up-to-date theoretical and empirical models, and the study of real-world telecommunication problems lead to state-of-the-art applications for telecommunication uses. This section deals with a variety of programs which show the broad spectrum of applied electromagnetic sciences.

4.5.1. Remote Sensing with Over-the-Horizon Radar

NOAA Sea Scatter and Project NONESUCH. A joint effort involving sea-scatter radar between the Office of Telecommunications, National Oceanic and Atmospheric Administration, and the Naval Research Laboratory has continued at San Clemente Island off the coast of California. Some years ago it was recognized that a need existed in the area of environmental sensing and monitoring for a technique and system for monitoring the principal wave height, period, and direction of sea waves over a wide area at a given time. The design and construction of the San Clemente Sea Echo Radar has enabled the development and testing of various techniques to perform these tasks. The two principal sponsors this year were NOAA and NRL.

The FY76 objective of this work was to design and build a high frequency ionospheric radar system especially optimized for the generation and detection of sea scatter over a wide area with good resolution and capability to process and handle large quantities of data.

Activity this year consisted in checking out and shaking down the newly redesigned radar system at San Clemente Island. Assistance was provided to the sponsoring agencies in performing some data runs and in training their personnel in operation and maintenance of the system.

A "black box" was designed and built which allows the system to switch rapidly from the ordinary data taking mode to an ionospheric sounding mode for the interspersal of ionospheric diagnostics during data runs. This allows real-time knowledge of the ionosphere to be used to determine the parameters of the experiment.

Most of the "bugs" were worked out of the system and operation and maintenance were transferred to the sponsoring agencies for their area of system use.

The San Clemente Radar System remains under the joint control of OT, NOAA, and the NRL. It is anticipated that the level of activity by OT during the next fiscal year will be low and consist primarily of assistance with difficult maintenance problems or in the incorporation of modifications or additions to the system.

4.5.2. Radio Navigation and Radio Position Determination

FAA Polariscope. An experimental antenna-receiving system was designed to measure the ratio of the vertically to horizontally polarized electromagnetic fields transmitted by VOR/ILS facilities. This ratio is particularly important because course bearing errors can be caused by modulation carried by some components of the vertically polarized field from VOR facilities. This work resulted in the development and testing of a field polarization meter, called a Polariscope by the FAA, to be used for measuring this field ratio.

A special discone-dipole antenna (figure 4-25) capable of receiving both vertically and horizontally polarized fields was developed and used with existing receivers to measure the VP/HP field ratio from a portable VOR at our Table Mountain test range. This antenna and a commercial battery-operated VOR receiver were capable of measuring VP/HP field ratios as small as -46 dB, corresponding to a 0.3° bearing error.

The results of this work can be used by the FAA to aid in minimizing VOR bearing errors by adjusting various parameters in the VOR antenna.

Another effort in this area was carried out for the FAA entitled Airport Multipath Environment Measurements.

This project was originally established to study the potential multipath effects at sea-land transition areas relative to over-water approaches using Microwave Landing Systems (MLS). However, early in the program, the emphasis was changed (by amendment from the FAA) to investigate the multipath environment in operating airports that could be detrimental to MLS systems. The project was described in last year's annual report, so will only be briefly reviewed here.

The ITS Channel Probe equipment was used in two locales to measure the multipath structure and level at the MLS operating frequency of 5.1 GHz. A series of measurements was performed at the National Aviation Facilities Evaluation Center (NAFEC) at Atlantic City, N.J., and at Logan International Airport, Boston, Massachusetts (figure 4-26).

During FY76 a related project was developed to expand the measurements program to other major airports and to study more comprehensively the complex multipath structure.

A draft report (to be published by the FAA) was completed on this project and submitted to MIT Lincoln Laboratories. Data analyses for the project were also completed in FY76.

Central Europe Loran D Predictions. ITS was asked by the U.S. Air Force Electronic Systems Division to develop an automatic prediction/calibration computer package for the Central European Loran C/D chain. The required accuracy of the prediction program is 50 nanoseconds (one sigma) along each LORAN propagation path for distances up to 1000 km. This integrated program (i.e., terrain retrieval, impedance retrieval, propagation simulation and automatic integral equation package) with data base was to be modified as necessary for compatibility with the CDC-6600, the IBM 360/50, and the UNIVAC 1108 computers.

The objectives of the program were fourfold:

1. Develop lithology digitization procedure. Geologic maps were to be studied to determine the extent of the information to be digitized. The desired form of the final lithologic data was then to be defined, and computer algorithms developed to transform the digitized data into the desired form, including any necessary compaction.

2. Terrain data processing. Computer algorithms were to be developed to read and decode existing tapes, decreasing the volume by reducing detail, the result to be in a form usable as an elevation data base.

3. Propagation simulation research. The need for including such factors as overburden, ground water, permafrost, ice, etc. in propagation simulation was to be investigated. A complete algorithm was to be developed and tested for converting lithology and overburden into electrical impedance values for use in propagation simulation. The impedance conversion algorithms would be incorporated into a single subroutine package to automatically retrieve the impedance along any propagation path. A similar path retrieval algorithm was to be developed for terrain elevation data.

4. Computer program integration. The several computer programs were to be integrated into a single computer program to translate receiver position into true propagation times from each transmitter

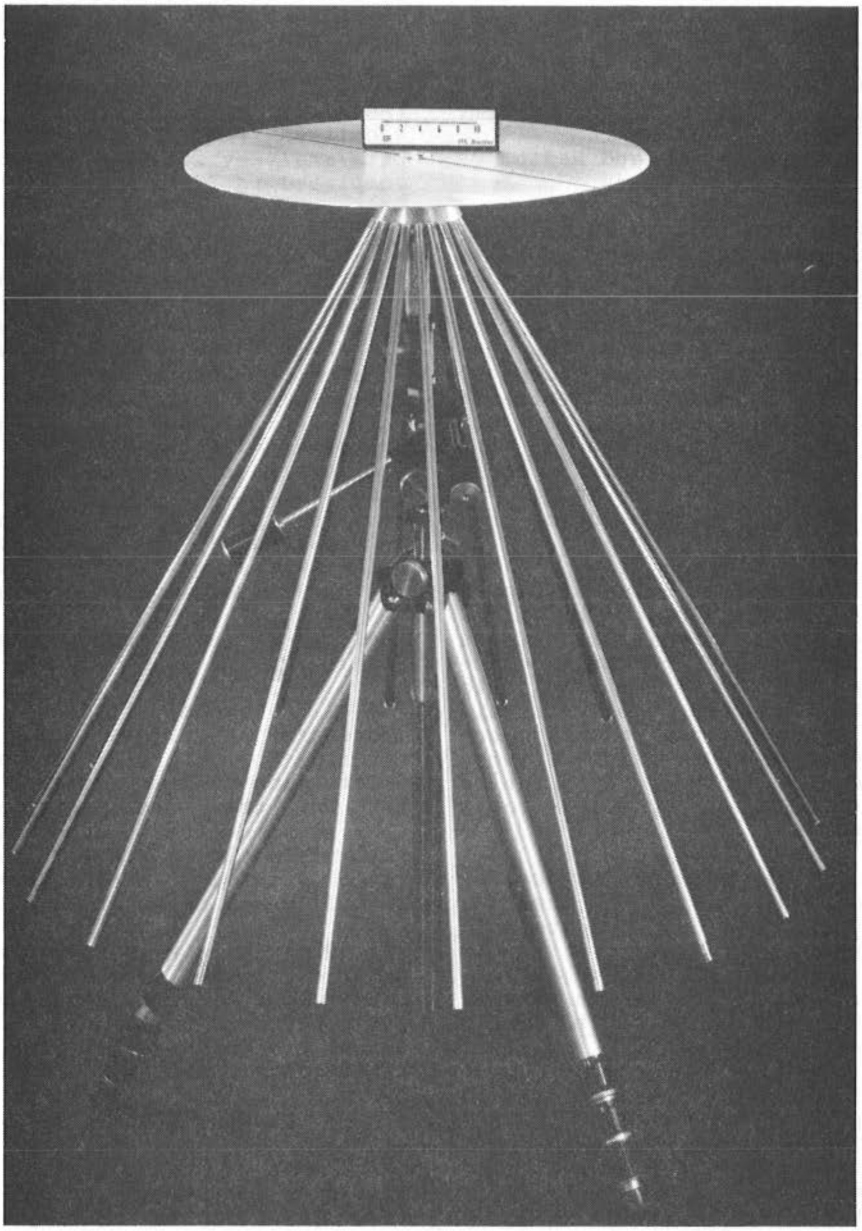


Figure 4-25. Discone-dipole antenna capable of receiving both vertical and horizontal polarizations.

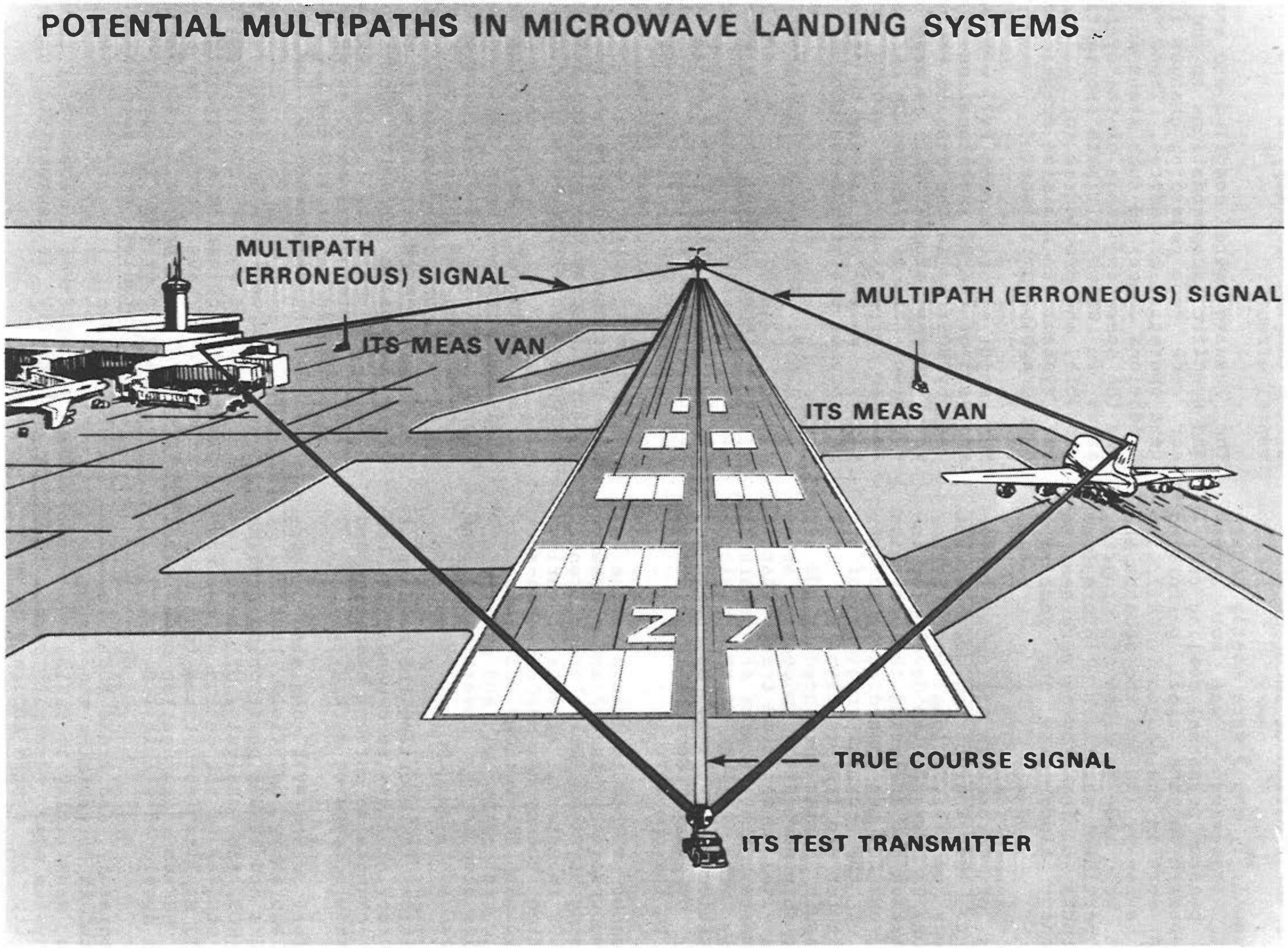


Figure 4-26. Multipath configuration at Logan Airport, Boston, measured by ITS channel probe.

to the receiver, which would then be automatically converted to time-difference readings. Following debugging and testing of the program the final results were to be compared to measurements for verification of accuracy.

Objectives 1, 2, and 3 were mostly accomplished. Objective 4 was not accomplished because personnel ceiling reductions impacted on the staff performing the major work on the project. Following a joint review by ITS and the sponsor the decision was made to close the program. All the pertinent materials (information and output) of the program were sent to the sponsor along with the remaining funds.

Analysis of Errors in Radiopositioning Equipment. The Engineering Development Laboratory of the National Ocean Survey (NOAA/NOS) is charged with developing instrumentation and analyzing the operation of equipment for use in hydrographic surveying of the coastal regions of the United States and its territories. The hydrographic charts produced by NOS are used for ship navigation in coastal areas and are vital to maritime transportation and commerce. These charts are generated primarily with the use of HF and microwave positioning systems, so that the accuracy of these devices is of utmost concern to the sponsor.

The sponsor wished to determine the inherent accuracies of the HF and microwave positioning systems which are currently in the NOS inventory. Effects of various propagation phenomena, such as sea-surface multipath for various sea state, atmospheric refractivity, and ducting effects, are also to be investigated and reported.

In addition to reporting the results of the accuracy studies, recommendations regarding changes to current operating and maintenance procedures were given.

The effort during FY76 consisted primarily of laboratory and field testing of the 5 GHz and 10 GHz positioning systems used by NOS, the analysis of test results, studies of the design of the systems, and applications of the test result to the UHF-SHF propagation model which has been developed within ITS.

The laboratory and field tests included such tasks as determining the respective system's sensitivity to fading, accuracy of the system over surveyed paths, and sensitivity of system accuracy to environmental parameters.

The fading tests performed on each system defined the useful dynamic range of each device, and this information was used in the ITS propagation model to determine the expected maximum operating range of each system. Effects of multipath propagation arising from reflections at the sea surface were determined in terms of system ranging accuracy, as were environmental effects.

The results were compiled and analyzed and specific recommendations to the sponsor were made regarding changes in current operating procedures. These recommendations concerned such items as limiting the operating range of the systems in areas in which multipath propagation is probable, and procedures for calibrating the systems to maximize accuracy during hydrographic operations.

The major effort during FY77 will be the analysis of the HF radiolocation systems used by NOS; as in the case of the microwave systems, studies will be made of the equipment and of propagation parameters, such as refractivity and ground conductivity, which are likely to affect the accuracy of position measurements.

4.5.3. Antennas and Radiation

Buried Antenna Studies for this year consisted primarily of measuring the received signal level from a military satellite at the terminals of an existing UHF antenna, and an ITS model of the antenna, at a Minuteman Launch Facility near Minot, North Dakota. These tests were undertaken to determine the feasibility of using the existing antenna for a proposed satellite communication link.

As a result of the tests, we began a study with TRW to help SAMSO determine the probability of developing a higher-gain hardened UHF antenna. Our contribution was the design of an encapsulated cavity helix antenna mounted in the face of a truncated pyramid monument. The mean power gain of this circularly polarized antenna was about 44 dB between model frequencies of 1.0 and 1.6 GHz at elevation angles between 10° and 60°.

A modest expenditure by recognized senior theoreticians on EM theory applied to practical problems is a cornerstone to an effective EM Wave Transmission program. Three current projects, EM Theory, EM Wave Analysis of BOM Problems, and EMP Simulator Studies are good examples of this program.

Work accomplished in support of this program activity is summarized under two headings.

INTERFERENCE FROM COAXIAL CABLES AND RELATED ANTENNA PROBLEMS. A rather basic problem in communication technology is to calculate the effect of breaks in the outer conductors of cables that are used for transmission of information. This is a particularly important question if the bandwidth of the signal (in the coaxial cable) encompasses frequencies that are being utilized for other purposes in the region exterior to the cable. While it is possible to measure some of these effects for a particular situation, it is still desirable to have an adequate theory if the relative importance of the many physical parameters are to be understood. The general problem is akin to much of the earlier work on radiation from slot antennas. Unfortunately, the available results from such studies cannot be directly applied since the aperture fields were usually assumed to be known. In the present case, we do not wish to assume the voltage across the opening or gap in the cable shield. Instead, it is one of the desired quantities. A boundary value treatment was used to derive field expressions for a dielectric coated coaxial cable with a gap in the shield. Specific results were given for an incident TEM mode in the interior coaxial region. For example, it was shown that, for the VHF region, as much as 18% of the incident power was radiated into the external region via a single circumferential gap in the shield. We also found that comparable amounts of power are transferred to a reflected TEM mode in the cable and into surface waves in the dielectric jacket. Another approach to the boundary-value problem was also considered. Previously the internal and external fields were matched, in an average sense, across the gap. Here a quasi-static analysis was employed that does not require an assumption about the field distribution in the gap. However, the method appears to be useful only for small gaps. Using either method, it was shown that typically 15% of the incident power in the cable is converted to external radiation and typically 20% is transferred into surface waves in the dielectric jacket. Such power calculations were exhibited for frequencies of 20, 50, 100, and 300 MHz and for two coaxial cables that are typical of those being used in present day CATV systems.

The foregoing theory has also been extended to treat scattering from a break in the shield of a braided coaxial cable.

SHIELDING BY WIRE GRIDS AND MESH STRUCTURES. Wire-mesh screens are often used in place of solid metal sheets in the shielding of electromagnetic waves because such screens are light and relatively inexpensive. However, the electromagnetic properties of such screens are not well-known, particularly when the incident electromagnetic wave has arbitrary polarization and angle of arrival. The goal of this theoretical study is to determine the reflection and transmission coefficients of a rectangular wire mesh as a function of the mesh dimensions and wire radius for an arbitrary incident plane wave. Since wire meshes are often used over an imperfectly conducting earth, the effectiveness of this "ground screen" application is also of interest.

Electromagnetic scattering by a single planar array of parallel wires has been considered in the past for a variety of assumed conditions. Such grids are used in many technical applications such as shielding enclosures and in ground systems for antennas. However, when the incident wave has arbitrary polarization, the use of two planar arrays of perpendicular wires may be desirable. Earlier analytical work by the Soviets was carried out for square meshes and for rectangular meshes employing ingenious techniques based on averaging the fields over one cell of the mesh before applying the boundary conditions. As such, the results would seem to be restricted to relatively small spacings of the grid wires in terms of wavelength. Thus we derived a general solution for the crossed wire grid, with no restrictions on polarization, incidence angle, or wire conductivity. The separation between the two grids could become arbitrarily small, but should not become zero. Thus we did not consider the bonded rectangular mesh limit. The solution for the wire currents involved a doubly infinite set of linear equations which were solved by either perturbation or matrix inversion. The calculation of the transmission coefficient, including the cross-polarized component, was straight-forward once the currents are known, and numerical results were presented to illustrate dependence on various parameters.

In a further analysis, we considered the tricky problem of bonded junctions. The appropriate doubly infinite set of linear equations for the currents were found to be valid for a wire mesh with bonded junctions without imposing any junction conditions. However, the convergence of the solution was greatly improved by building junction discontinuity conditions into the current representation. Using such a modified solution, numerical results were generated to illustrate the dependence of reflection and transmission coefficients on various parameters. The same method is now being applied to treat the penetration of EM waves through the loosely braided shields of coaxial cables that have relatively small optical cover. As mentioned before, they are finding much use in leaky feeder communication systems, so a proper analysis is badly needed if reliable engineering designs are to be made.

Computer programs have been written to solve for the desired reflection and transmission coefficients, and numerical results have been published to aid in the selection of the mesh size and wire radius. These results make it possible to design an effective wire mesh screen without using an excessive amount of metal. The same information can be applied either to shielding of undesired signals with wire meshes or to the formation of a desired antenna pattern through the use of a wire mesh ground screen. A computer program has also been written to calculate the far-field radiation pattern of a dipole antenna over a wire mesh ground screen.

The work during this fiscal year has also extended our knowledge of the use of braided coaxial cable and of the trolley wire for communication in mine tunnels.

Propagation of electromagnetic waves in a coal seam (highly resistive material) bounded by more conducting rock is found to be quite attractive as a means of communication.

In FY77 the work on loosely braided coax will be continued. An analytic study will be undertaken of the magnetic vector of the field of a dipole located in a homogeneous and also a layered overburden in order to better answer the question as to whether helicopter measurements can be profitably utilized.

A technique for the reduction of fading on line-of-sight paths by the use of Antenna Tilting was carried out for the FAA.

On line-of-sight paths, multipath components which originate below the direct path are usually present, even though their magnitude may be small. When the direct path is attenuated (e.g., by atmospheric induced diffraction effects), the magnitudes of the off-path components relative to the direct path may become large enough to produce deep fading. The reduction of the multipath component by antenna tilting reduces the depth of fades. It is clear that tilting the antenna will have little or no effect on the diffraction type fading. Thus, for paths which exhibit the characteristic described above (i.e., power fading of the direct signal to a level which induces multipath fading), tilting the antennas upward should provide some protection against the deeper multipath fading.

An experiment was conducted to examine techniques for improving communications on microwave links which experience periods of deep fading. The experiment was performed for the Federal Aviation Administration over one of their radar microwave links (RML) in southeastern Colorado between Fowler and Boone (figures 4-27 and 4-28). The path from Fowler to Boone is approximately 50 km long, and the operating frequency was 8110 MHz.

The experiment showed that, when antennas were tilted up to obtain 2 dB decrease over maximum gain during steady signal conditions, the fading was reduced over the system utilizing untilted antennas. The tilting technique should also work on other paths where sufficient angular separation between the direct and reflected rays exist, and where antennas with sufficiently "sharp" main beams are used.

This technique will reduce fading whenever the fading is caused by the interference between the direct path component and one or more components which are reflected (scattered) from below the direct path, and an antenna with an appropriate pattern is used.

4.5.4. Transmission Through the Atmosphere: Applications

A five-year program planned for the study of information transmission problems in radio links, and the laboratory simulation of time-variant transmission channels, was started in FY75. There was a recognized need to develop new standards and techniques for greater information transfer efficiency in assigned radio channels, and to provide the laboratory tools needed to facilitate future studies.

In FY76 the Channel Simulation and Evaluation project summarized and reported on the operation and application of the ITS Channel Probe in evaluating the time-variant characteristics of radio transmission channels. The probe technique is based on the correlation detection and processing of a wideband pseudo-random noise (PN) signal, transmitted over a path in binary format. The receiver output is a measure of the impulse response of the transmission channel. The system has the resolution of a nanosecond pulse technique, but through time-bandwidth trade-offs, it is capable of data rates that are recordable on standard analog magnetic tape systems.

Activity on this project in FY76 has included the publication of a report (OT Report 76-96) which completely describes the channel probe system and its capabilities.

In addition, a second report was completed which presents a summary and analysis of various measurements that have been performed with the system. The

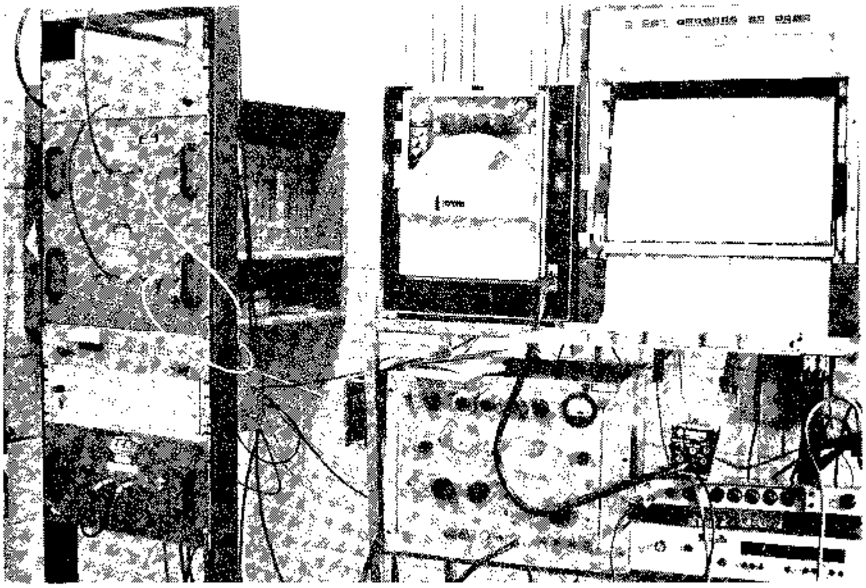


Figure 4-27. Recording equipment at Boone, Colorado.

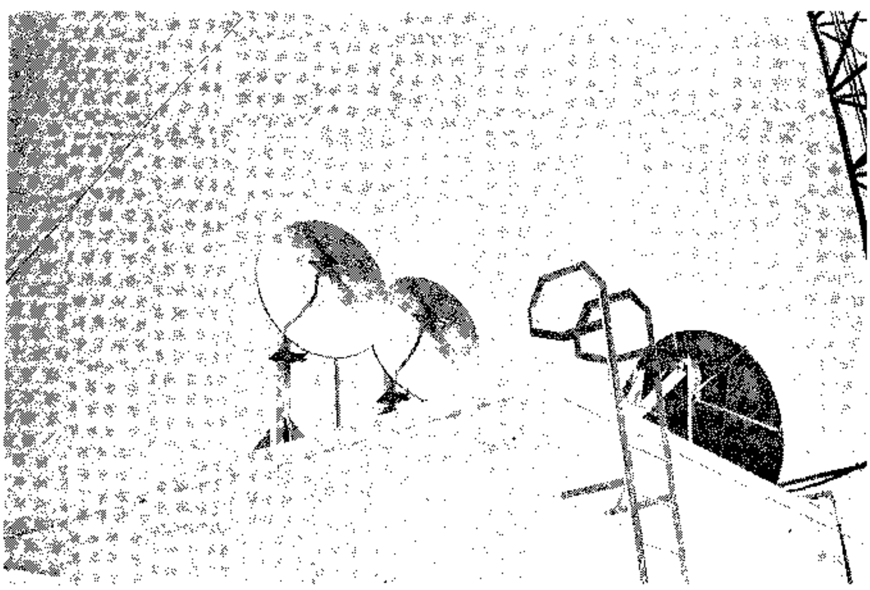


Figure 4-28. Receive antennas at the Boone Site used in the tilting experiment.

latter include impulse response measurements over time-variant microwave transmission circuits, and the results from a comprehensive set of measurements applicable to link engineering problems such as path clearance and reflections. These measurements were performed under contract for the U.S. Air Force, and the results have been used directly to specify system operating parameters and link installations for high-speed digital communication.

ERDA Support Program. The Energy Research and Development Administration inherited from AEC the responsibility of transporting nuclear weapons from station sites to silos and other military installations. This responsibility includes the development and operation of a communications network for location, tracking of mobile systems by headquarters, and normal command/control capabilities between mobile systems and headquarters. A network employing HF communication techniques was developed by a contractor during the 1968 to 1970 period. This network originally accommodated only analog voice mode. A recent enhancement to maximize security and reduce undesired message traffic converted the network to a digital mode of operation. Conversion problems and general difficulties in operational management resulted in ERDA requesting assistance in improving various functional capabilities of the existing network and providing a computer management system for planning convoy routes and the general control of status communications.

This program was initiated by ERDA with four tasks:

1. To measure emission characteristics of the Albuquerque site transmitter to determine compliance with OTP standards.

2. To measure the pattern and efficiency of the antenna for the portable communication system for all frequencies of network operation.

3. To complete a design for a physically small configuration of an antenna having the efficiency of at least 6 dB advantage over the current "rooftop antenna," with a physical configuration that would minimize detection and identification of convoy vehicles.

4. The development of the management support program to assist route planning and the development of reporting regulations for convoy communications personnel.

Subsequent paragraphs discuss progress on the individual tasks during FY76.

An instrumented van was utilized to measure the total emission at all operational frequencies of the Albuquerque transceiver site. R. G. FitzGerrell and staff completed all primary, harmonic, and spurious emission measurements and reported various violations, primarily in the harmonic and spurious spectral regions. This was not unexpected, since various filters had been removed from the commercial equipment to accommodate site constraints. A report detailing the emission characteristics and the area of violation was provided to the systems manager.

A communications van with complete communication system components was transported to Boulder and the antenna measurements completed at the Table Mountain site by FitzGerrell and staff. Two antennas were employed on the van: a whip, originally developed by the SANDIA Corporation, but subsequently abandoned because of communications problems; and a single loop "luggage rack" configuration that represented the most recent SANDIA recommendation for the mobile requirement. With the site instrumentation and a helicopter mounted source, complete pattern measurements to all operational frequencies for vertical and horizontal polarization were completed. Significant differences were noted from the design predictions, particularly in reduced gain. These data will form the basis for redesign of the antenna system. This information, with the reduced degradation, provides the basic justification for ERDA to redesign the antenna system to improve efficiency and reduce the physical profile.

The antenna redesign effort will be initiated in early FY77 upon submission of the final measurement report to ERDA. This antenna will employ some form of large periodic structure with the necessary low physical profile to enhance security of the convoy.

The initial design of a computer model to assist in route and control planning has been completed. This model employs the basic HF prediction routine previously developed by ITS, with differences in data presentation and plotting to accommodate planning design. Ionospheric and temporal data are reported in the manner identical to the existing HF management support model. Plots are provided of signal magnitude and fluctuation at any desired location, with uncertainties quantified to support the preparation of communications operation instructions for convoy personnel. This model will also be employed for "quick look" assistance in determining problems in communicating with operating systems. This latter operation is necessary where voids in communications must be quickly evaluated before emergency conditions are assumed.

For this program, the activity in FY77 will primarily concern the detailed design of the mobile antenna system and the completion and installation of the management support model. For the antenna system, ERDA will receive design data and performance predictions, and a detailed test plan. Fabrication of the antenna will presumably be accomplished by an industrial group.

The completion of the design of the management support model concerns the preparation of data bases, and the integration of plotting and display routines appropriate to the previously sited planning requirements. This program will be installed on a computer at AFWL or SANDIA with the assistance of ERDA Albuquerque personnel.

FRA Communication Study. This program was initiated by the Federal Railroad Administration to provide detailed operational support requirements, usage, investment, and cost of ownership information for railroad communications systems. This investigation is being carried out to support VHF spectrum allocation in response to the consideration by the Federal Communications Commission of transfer of all or part of the current Railroad Industry assignments to maritime operations.

The objectives have been set out as follows:

1. Collection of data regarding railroad communications operating procedures, equipment characteristics and investment, usage, deployments, operational support relationships (safety aspects, command/control enroute and in yard operations, police, etc.), and maritime communications operations in port areas.

2. Develop time-line descriptions and support capability analyses for existing RR communications and advanced configurations, and cases of reduced allocations on partial or total reassignment to alternate frequency regions.

3. Prepare cost of ownership and investment information in relation to communications system usage and RR system operations categories.

4. Perform capability analyses for reduced allocation and reallocation options; develop appropriate system configurations, implementation schedules, and investment and cost of ownership estimates.

5. Analyze shared allocations between railroad and maritime operations in port areas. Detailed interference potentials and the possibilities for a form of integrated control process.

6. Design and implement a yard frequency-usage measurements program. Two or three yards will be included, the number dependent primarily on the operational variabilities and competing environment differences indicated by the RR system produced data.

7. Complete a final technical report having detailed requirements, usage, planning, and cost information and supporting analyses to justify recommendations to spectrum regulating agencies.

Consideration of the time required to formulate a composite U.S. position for the 1979 World General Administrative Radio Conference necessitates the completion of this DoT study within a 6 to 9 month period.

Various meetings with the Superintendents over Communications for the U.S. railroad companies have taken place. Collection of data regarding railroad communications for all areas and maritime communications in port areas have been completed. The development of time-line descriptions of train movements and use of supporting telecommunications have been started for selected railroad yards.

The major effort of this program will be accomplished during the transition quarter and in FY77.

This program will continue into FY77 and upon the completion of the presently assigned tasks as listed above under objectives will lead to a follow-on study. The follow-on study will include the use of high data rate digital communication to enhance railroad operations particularly in the urban areas.

Hydro-Quebec is planning an extensive modernization of its land mobile radio system. Under this project, entitled Mobile Aids, Hydro-Quebec, ITS will devise computer aids to help the design of the new system and will supply these aids in the form of computer programs able to operate at the sponsor's facility.

In FY76 we have supplied Hydro-Quebec with programs to reduce digital topographic data, to interface with executive routines, and to utilize these data in several ways. Combined with radio propagation models, the data can be used to estimate received signals and so be of direct use in the siting of base stations and the choice of antenna structures.

Calibrated Range. In 1971, ITS established a calibrated baseline between Upolu Point and Mt. Haleakala in Hawaii. The path is 65 km long and extends from near sea level to 3000 m in elevation simulating aircraft to ground geometries. In the present project, this calibrated line was used as a reference for comparing two methods of making range corrections in high accuracy tracking systems. During the test period, a 3 cm microwave ranging instrument was operated simultaneously with measurements of atmospheric index structure by radiosondes and by an airborne microwave refractometer. The data from each of the latter are being used to correct the observed range data, and the corrected data will be compared with the calibrated length to evaluate both the precision and accuracy achieved by each method. The analysis of the refractometer data has been completed and shows a correlation of 0.993 with the microwave range data. Using the former as the correction for the latter, the estimated standard deviation for the mean corrected range is 1.6 cm.

FM Coverage. The purpose of this interesting project was to plot maps such as those in figure 4-29 showing how the totality of standard FM broadcast stations cover the coterminous United States. It was done for the Federal Communications Commission (FCC) to provide some small amount of help towards deciding policy questions concerning aural radio, both FM and AM.

The maps were constructed by computer using the FCC data base of 4235 broadcast stations and the OT collection of environmental data including average terrain elevations and the terrain irregularity parameters Δh. The shading in these maps consists of a large number of "spots" whose darkness is controlled by how much of each spot is blackened, just as in the usual photogravure process. The degrees of shading show where there is no coverage (white), where there is coverage by a single station (lightly dotted), where there is coverage by two or more stations (heavily dotted), and where coverage consists solely of one or more 10 watt (class D) stations (very dark). In figure 4-29(a) is shown the case where $F(50, 50) \geq 1 mV/m$ (i.e., where 50% or more of the locations receive a signal of at least one millivolt per meter for at least 50% of the time), while figure 4-29(b) illustrates the case where $F(50, 50) \geq 50 \mu V/m$. By simply counting the spots we find that 84% of the land area of the U.S. is served by at least one FM signal having a field strength of $50 \mu V/m$ or more. An analysis of the errors involved seems to show that while the representation of coverage by individual stations may sometimes be quite erroneous, the percentage quoted above should be accurate to within a percent.

4.5.5. Special Applied Electromagnetic Sciences

Automotive Radar Research. The Office of Telecommunications has been assisting the National Highway Traffic Safety Administration for the past three years in a study of the feasibility of the application of radar systems as sensors for automatic vehicular braking devices. The third phase of this investigation was completed in November 1975.

Problems addressed in this most recent phase were identified during the Phase I and II studies as areas requiring further investigation. These areas include the degradation of the performance of realistic automotive radar systems by rainfall, the investigation of the encounter probabilities for the situation in which three or more vehicular radars mutually interfere, and the effects of realistic antenna radiation patterns in the detection of non-hazardous targets located on the peripheries of typical horizontal highway curves.

In addition to these tasks, a prototype baseband radar system was evaluated for its ability to detect automotive targets. A baseband radar is a system which uses extremely narrow baseband pulses for target illumination, obviating the need for a radio-frequency carrier and hence much of the complexity of conventional radars.

Results of the Phase III tasks indicate that cw radars operating above 20 GHz (which is the lowest frequency at which automotive radars are expected to be allowed to operate) will suffer severely reduced range performance in the presence of light rain. Pulsed systems, however, are expected to provide acceptable maximum range performance (≈ 100 m) even at rainfall rates exceeding 50 mm/hr.

The multiple-vehicle interference study showed that mutual interference among three or more automotive radars is highly unlikely, and that the most likely situation in which interference could occur is the case in which two vehicles approach each other in a head-on configuration along a straight, narrow roadway. Potential solutions for this type of encounter were discussed in the Phase II investigation.

The study of antenna patterns and the illumination of roadside targets indicated that sidelobe levels must be kept at least 20 dB below the main lobe peak in order to minimize the detection of these non-hazardous targets. Significant false

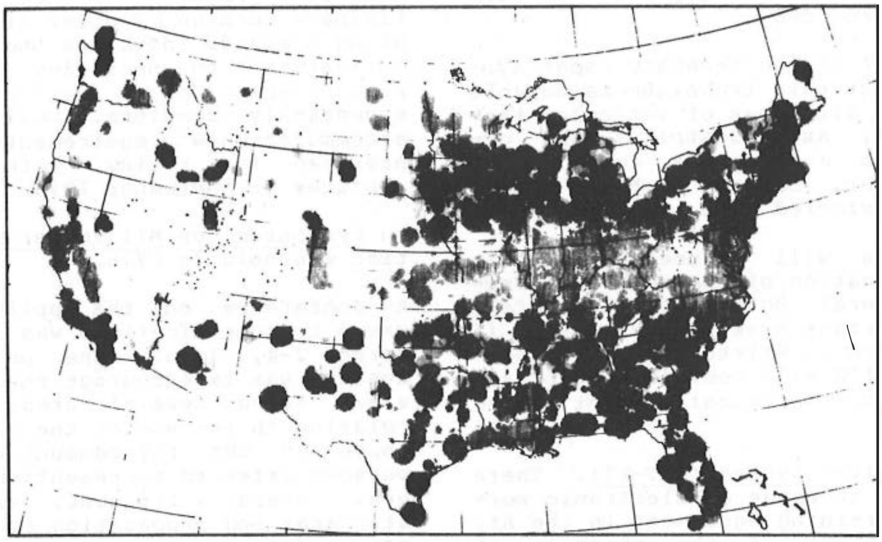


Figure 4-29a. Estimated coverage of the U.S. by FM stations for F(50, 50) $\geq$ 1mV/m.

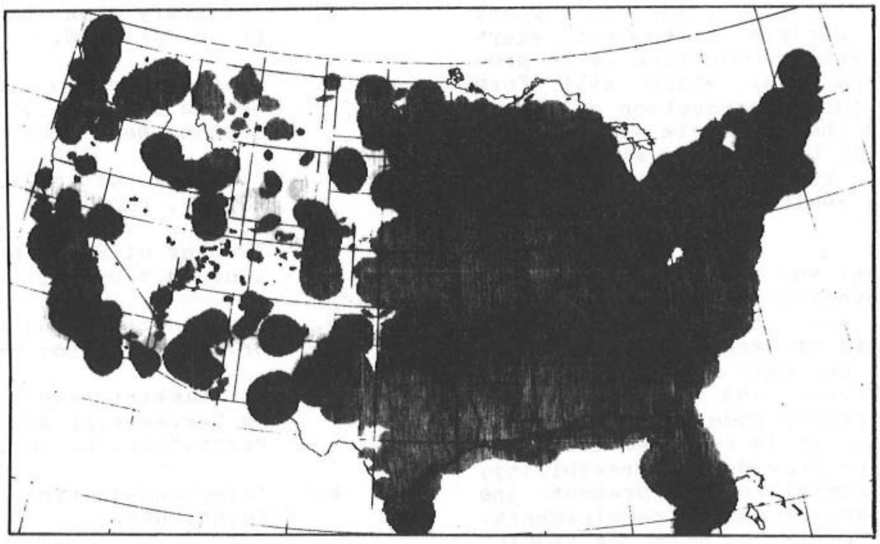


Figure 4-29b. Estimated coverage of the U.S. by FM stations for F(50, 50) $\geq$ 50 μV/m.

alarm problems will develop if proper discrimination against this class of targets is not provided.

The evaluation of the baseband radar system showed that this technique is capable of detecting all types of vehicular targets, as well as pedestrians and cyclists. Much development work is required, however, before such a system could be considered as a braking sensor.

These results will be used by NHTSA in their determination of the need to formulate a Federal Motor Vehicle Safety Standard for radar braking systems. If such a standard is written, the work performed by OT/ITS will contribute substantially to the technical content of the standard.

Multiple Receiver System (MST-TI). There is a critical shortage of Electronic Warfare (EW) training equipment in the Air Force. The impact of the shortage of this equipment has a direct effect on our Operational Forces combat capability. There is an immediate need for adequate and realistic simulated enemy-threat systems as well as appropriate receiving/analysis systems to evaluate the effectiveness of electronic counter measures (ECM) employed against these systems.

The project objective is the development, design, and procurement of a multiple receiver system for deployment by the Air Force Security Service, Electronic Warfare Center, Kelly AFB, Texas, in support of electronic warfare tests and exercises. The design objective is to provide a prototype model which will form the basis for future production models to be deployed by the Strategic Air Command and Tactical Air Command for similar missions related to operational testing, training, and evaluation during EW tests and exercises.

The development and design of the prototype system involves automation of hardware command and control functions as well as analysis of measurements during the conduct of EW tests and exercises for evaluating aircrew and ground forces training efficiency under simulated combat conditions. It is required that the prototype system provide for flexibility, and growth potential to meet present and future Air Forces user requirements. Initially, the prototype multiple receiver system will be divided to provide independent capabilities for application to communication EW tests and exercises in the frequency range 500 kHz to 500 MHz and radar EW tests and exercises in the frequency range 100 MHz to 18 GHz.

The project was initiated in February 1976, and a detailed statement of work and specifications for the prototype systems were prepared. Review of the preliminary design by other Air Force operating commands indicates the need for modifications to meet new requirements. Procurement of major hardware items is essentially complete. Design changes to accommodate new requirements are being prepared for review, with final design expected in September 1976.

A Symposium on Millimeter-Wave Utilization was held in FY76.

A conference on the applications of mm waves to communications was held during March 2-4, 1976. The purpose of the meeting was to encourage the exchange of views among several areas of activity relating to the use of the radio spectrum above 10 GHz for communication. Forty persons attended representing manufacturers, users, frequency managers, and standards and propagation research workers. The organizations represented included private industries, universities, and both military and civilian government agencies. In the first plenary sessions, eight speakers presented reports on various aspects of the conference topic generally emphasizing the problems which appear to be limiting greater use of the radio spectrum above 10 GHz.

1. "A New Approach to MM Waves," Mr. N.E. Feldman and Dr. S.J. Dudzinsky, RAND Corp.
2. "Military Plans for MM Waves," Dr. P. Jain, D. C. A.
3. "Some Aspects of MM-Wave Research at B.T.L.," Dr. L. Tillotson, Bell Labs.
4. "The Role of the FCC," Mr. A. Reiner, FCC.
5. "Survey of Solid State MM Waves Sources," Dr. B. Fank, Varian.
6. "Communication Satellites," Dr. L. Ippolito, NASA.
7. "Millimeter Wave Propagation on Terrestrial and Earth-Space Paths," Dr. D. Hogg, Bell Labs.
8. "Electromagnetics," Dr. H. Boyne, NBS.

A report on the proceedings, with recommendations, is currently in preparation and should be published in September 1976.

ANNEX I
SUBSTANTIAL ITS PROJECTS FOR FY76
ORGANIZED BY DEPARTMENT AND AGENCY

COMMERCE, DEPARTMENT OF (DOC)

Direct Support

Page	Project	Title	Leader
75	9106201	Broadband Transmission in the 10 to 100 GHz Band	Thompson
89	9106202	Atmospheric Effects, 10 to 40 GHz	Dougherty
93	9106203	Time-Variant Channel Limitations	Ott
96	9106205	Ionospheric Effects on Transionospheric Radio Signals	Leftin
110	9106206	EM Theory	Wait
84& 46	9106207	Radio Systems Performance Studies, 10-30 GHz	Barsis
105	9106208	Ionospheric Warning Services	Boggs
77	9106209	Optical Availability Measurements	Chandler
73	9106210	CCIR/Consult & Advise	Lucas
33	9106221	Data Communications	McManamon
67	9106222	Fiber Optic Communications	Bloom
112	9106224	Channel Simulation and Evaluation	Hubbard
73	9106225	CCIR/Consult & Advise	Hull
10	9106232	Tradeoffs for Optimum Spectrum Use	Berry
10	9106233	Digital Interference Evaluation	Juroshek
73	9106235	CCIR Activities	Murray
118	9106240	Symposium on Millimeter-Wave Utilization	Thompson
71	9106241	Telecommunications Trade Questions	Crombie
71	9106292	International Telecommunications and Trade	Crombie

Maritime Administration (MARAD)

Page	Project	Title	Leader
49	9102419	SELCAL	deHaas

National Bureau of Standards (NBS)

Page	Project	Title	Leader
67	9103439	Law Enforcement Standards Laboratory (LESL) Standards	Blair

National Oceanic & Atmospheric Administration (NOAA)

Page	Project	Title	Leader
87	9101410	Millimeter Wave Transmission Spectroscopy, 40 to 140 GHz	Liebe
60	9102376	NDBP - Shore Station	Stewart
106	9102440	NOAA Sea Scatter	Tveten
110	9103412	Analysis of Errors in Radiopositioning Equipment	Chandler
41	9103414	Spin Modulation Statistics of GOES Data Collection Systems	Bolton
5	9103417	RFI Surveys for WSR-74C Radar Installations	Tary
93	9103445	NOAA Radar Support Program	Warner
106	9103448	Radio Warning Communications	Stewart
93	9103449	NOAA Radar Support Program	Warner
43	9103454	Improvement of the GOES Interrogation Link	Glen

DEFENSE, DEPARTMENT OF (DOD)

Air Force Communication Systems (AFCS)

Page	Project	Title	Leader
48	9101515	Test and Acceptance Upgrade	Wortendyke
65	9103418	Line-of-Sight (LOS) Handbook Additions	Barsis
48	9103426	AFCS Digital Data Systems	Wortendyke

Air Force Systems Command (ESD)

Page	Project	Title	Leader
107	9101440	Central Europe Loran D Predictions	Johler
96	9102407	Ionospheric Data Analysis	Leftin
93	9103423	Refractive Index Measurements	Thompson
55	9103424	Digital European Backbone (DEB) Link Tests	Hubbard

Air Force Systems Command (RADC)

Page	Project	Title	Leader
77	9102400	Signal Fading on Line-of-Sight Microwave Paths	Thompson
49	9103388	RADC Automatic Data Acquisition and Analysis System Instrumentation	Wortendyke
87	9103389	Long Path Polarization	Wood
64	9103407	RADC Noise Simulator	Bolton
116	9103431	Calibrated Range	Thompson
93	9103461	Refractive Index Measurements	Thompson

Air Force Space & Missile Command (SAMSO)

Page	Project	Title	Leader
110	9101463	Buried Antenna Studies	FitzGerrell

Air Force Miscellaneous

Page	Project	Title	Leader
110	9103421	EMP Simulator Studies	Hill
118	9103441	Multiple Receiver System (MST-TI)	Barghausen

Naval Research Laboratory (NRL)

Page	Project	Title	Leader
106	9102370	Project NONESUCH	Tveten

Naval Electronics Systems Command (NESC)

Page	Project	Title	Leader
35	9103419	Modulation Studies for an Undersea Acoustic Coupler and Data Collection Network	Akima
70	9103429	Communication Systems Consultation	Bloom

Army Communications Command (USA/CC)

Page	Project	Title	Leader
48	9102385	Radio Systems Applications Consulting	Barsis
70	9102465	Optical Fiber Communications Handbook	Gallawa
32	9103382	Army Automatic Receiver System	Wood
51	9103387	FKV Pilot Digital System Evaluation	W.E.Johnson
51	9103404	FKV Data Measurement System Development	Wortendyke
51	9103405	FKV Pilot Digital System Evaluation	Skerjanec
51	9103406	FKV Pilot Digital System Evaluation	Farrow
32	9103427	Army Automatic Receiver System	Wood
35	9103434	Local Digital Distribution Subsystem Concepts	Nesenbergs

Page	Project	Title	Leader
DEFENSE, DEPARTMENT OF (continued)			
		Army Communications Command (USA/CC) (cont.)	
32	9103437	EMC Training Course	Barghausen
104	9103440	Prediction Techniques for Marginal HF Communication Systems	Haydon
99	9103442	European Wideband Communication Systems Performance at SHF	Dougherty
97	9103444	Communication System Performance Model	Jennings
		Army Electronics Proving Ground (AEPG)	
99	9102389	Sensor Communication System	Longley
		Army Satellite Communications Agency (USA/SCA)	
12	9103420	EMC of Small Earth Terminals	Adams
22	9103430	Small Earth Terminal Antenna Measurements	FitzGerrell
		Army Communications-Electronics Engineering Installation Agency (USA/CEEIA)	
66	9103400	Telecommunications Glossary	Samson
32	9103446	Software Applications	Barghausen
27	9103452	EMC Data Recording System	Harr
		Army Miscellaneous	
64	9103402	Simulation Methodology	Morrison
97	9103415	Joint Ionospheric Studies	Carroll
		Defense Communications Agency (DCA)	
60	9101534	Minimum Essential Emergency Communications Network (MEECN) Simulation	Watterson
97	9102431	LF Data Analysis	Berry
		Defense Nuclear Agency (DNA)	
97	9101443	Lower Ionospheric Research	Carroll
		Miscellaneous DOD	
66	9103422	Federal Communications Glossary	Samson
U.S. ENERGY RESEARCH & DEVELOPMENT ADMINISTRATION (ERDA)			
114	9103450	ERDA Support Program	Morrison
FEDERAL COMMUNICATIONS COMMISSION (FCC)			
37	9103425	Circuit Status for Multiple-Satellite-Hop User Reaction Tests	Glen
116	9103438	FM Coverage	Hufford
INTERIOR, DEPARTMENT OF (DOI)			
110	9101453	EM Wave Analysis of BOM	Wait
NATIONAL AERONAUTICS & SPACE ADMINISTRATION (NASA)			
44	9103390	Building Attenuation of Satellite Signals	Wells
1	9103397	Interference to Geostationary Orbit	Adams
46	9103453	Alternative Reception Techniques for Direct Satellite Communication	Wells
OFFICE OF TELECOMMUNICATIONS POLICY (OTP)			
22& 27	9106520 9106521	Measurement Van Operations	Matheson
2	9106522	Support to Spectrum Analysis	Haakinson
16	9106523	Probabilistic EMC Model	Jennings
66	9106524	IRAC-TSC Standards Working Group Support	Murray
12	9106525	Model Development	Adams
2	9106526	Man-Made Noise	Spaulding
32	9106527	Software for Irregular Terrain	Hufford
TRANSPORTATION, DEPARTMENT OF (DOT)			
		Federal Aviation Agency (FAA)	
16	9101477	Air Navigational Aids	M.E.Johnson
1	9102390	Compatibility of Collision Avoidance Systems	Stewart
22	9102460	Emission Spectrum Simulation	Spaulding
112	9102463	Antenna Tilting	Hartman
64	9103376	Time Domain Objective Measurements	Hartman
107	9103383	FAA Polariscope	FitzGerrell
107	9103394	Airport Multipath Environment Measurements	Hubbard
54	9103411	Radar Microwave Link Upgrade	D.Smith
		Transportation Systems Center (TSC)	
84	9102450	Data Link Tests for VHF Air Traffic Communications	Juroshek
		U.S. Coast Guard (USCG)	
60	9101532	U.S. Coast Guard Consulting	Adams
		Miscellaneous DOT	
116	9102410	Automotive Radar Research	Chandler
5	9103416	Automotive EMI Research	Espeland
115	9103459	FRA Communication Study	Morrison
U.S. INFORMATION AGENCY (USIA)			
		Voice of America (VOA)	
105	9101498	VOA Time Share	Boggs
104	9101499	Radio Propagation Predictions	Agy
101	9101501	Development of Improved Models for Multihop Propagation	Lloyd
104	9101503	Consultative and Advisory Services	Leftin
101	9102444	HF Broadcast Compatibility	Haydon

Page	Project	Title	Leader
U.S. POSTAL SERVICE			
43	9103409	System Definition Study for the U.S. Postal Service Electronic Message Service System	McManamon
44	9103432	Electronic Message Service System Definition	McManamon
OTHER			
104	9101561	HF Fleet Sub	Lloyd
104	9101587	Numerical Prediction Services	Leftin
115	9102378	Mobile Aids, Hydro-Quebec	Hufford
58	9103435	Los Alamos Scientific Laboratory (LASL) Systems Program Study	Morrison

ANNEX II
ORGANIZATIONAL DIRECTORY
INSTITUTE FOR TELECOMMUNICATION SCIENCES
OFFICE OF TELECOMMUNICATIONS, DEPARTMENT OF COMMERCE

325 Broadway, Boulder, Colorado 80302
(303) 499-1000 (FTS dial 323, 499 + extension)

NAME	EXT.	ROOM
DIRECTOR' OFFICE (O/D)		
CROMBIE, Douglass D. (Director)	4215	3020
UTLAUT, William F. (Deputy Director)	3500	3020
WALTERS, William D. (Budget and Accounting Officer)	4414	3019
SMITH, Ernest K. (Consultant)	3177	3007
WAIT, James R. (Consultant, also with NOAA and CIRES)	6471	227 (RB 1)
WIEDER, Bernard (Assistant to the Director for Program Development)	3484	3014
DIVISION 1 - SPECTRUM UTILIZATION		
MURRAY, John P. (Associate Director)	4162	4533
1.1 Radio Spectrum Occupancy MATHESON, Robert J.	3293	2221
1.2 Antenna Performance FitzGERRELL, Richard G.	3737	4524D
1.3 EMC Analysis & Development ADAMS, Jean E.	4301	4517
1.4 VHF/UHF Models & Mobile Systems HUFFORD, George A.	3457	4523
DIVISION 2 - SYSTEMS TECHNOLOGY & STANDARDS		
HULL, Joseph A. (Associate Director)	4136	2034
2.1 Channel Characterization HUBBARD, Robert W.	3414	2243
2.2 New Technology Development BLOOM, Louis R.	3485	2245A
2.3 Systems Engineering & Analysis BARSIS, Albrecht P.	3589	2213
2.4 Systems Technology deHAAS, Thijs	3728	2246
2.5 Systems Assessment McMANAMON, Peter M.	3570	2237
DIVISION 3 - APPLIED ELECTROMAGNETIC SCIENCE		
LUCAS, Donald L. (Associate Director)	3821	3421
3.1 Navigation and D-Region Sciences* JOHLER, J. Ralph	3601	3459
3.2 Ionospheric Transmission Technology CARROLL, John C. (Acting)	4111	3411
3.3 Advanced Analysis & Spectrum Extension WOOD, Lockett E.	3729	3447
3.4 Advanced Communications Technology THOMPSON, Moody C.	3508	3442A
3.5 Microwave Theory & Predictions DOUGHERTY, Harold T.	3913	3453
3.6 Methodology & Operations Research MORRISON, Ernest L.	4473	3415

*This group was abolished as of 6/30/76.

ANNEX III

INSTITUTE FOR TELECOMMUNICATION SCIENCES
OFFICE OF TELECOMMUNICATIONS
DEPARTMENT OF COMMERCE
Alphabetical Listing of ITS Employees
June 30, 1976

Name	Ext.	Room
ACTIS, Donna J.	3291	2219
ADAMS, Jean E.	4301	4517
ADAMS, Steven W.	3513	3442
AGY, Vaughn L.	3659	3441
AKIMA, Hiroshi	3392	2214B
ALLEN, Kenneth C.	3513	3442B
BALLARD, Marie G.	3823	3423M
BARGHAUSEN, Alfred F.	3384	3443
BARSIS, Albrecht P.	3589	2213
BEASLEY, Keith R.	3731	4528C
BEERY, Wesley M.	3677	3430B
BERGMAN, Ralph R.	3627	3409M
BERRY, Leslie A.	4474	3420E
BLAIR, James C.	3478	2218
BLOOM, Louis R.	3485	2245A
BOGGS, Kent D.	3396	4524
BOLTON, Earl C.	3104	2236M
BROOKS, Ferminia	3929	3451
BURCH, Lloyd B.	4179	3422M
CAMERON, Donald C.	4125	4520A
CANADAY, Lois S.	3513	3442C
CARROLL, John C.	4111	3411
CHANDLER, Richard A.	3262	3450A
CHAVEZ, Richard	3584	3430
CHILDS, Gregg E.	3211	2222M
CHILTON, Charles J.	3815	3420
CHRISTENSEN, Deborah H.	3786	4515
CROMBIE, Douglass D.	4215	3020
CROW, Edwin L.	3452	2210E
CURRY, John L.	4124	4518P
DAVIS, Robert M., Jr.	3419	3450
DENTON, Michael J.	4275	4516B
DETMER, Maureen J.	4215	3020
deHAAS, Thijs	3728	2246
DIEDE, Arthur H.	3195	3424
DOUGHERTY, Harold T.	3913	3453
DUTTON, Evan J.	3646	3454C
EHRET, Richard L.	3175	2230
ESPELAND, Richard H.	3882	3410M
FALCON, Glenn D.	4361	2222C
FARROW, Joseph E.	3607	2230
FITZGERRELL, Richard G.	3737	4524D
FRITZ, Olive M.	3589	2213
GALLAWA, Robert L.	3761	2217
GEORGE, Raymond L.	4179	3418M
GIBSON, Beverle J.	4215	3020
GIERHART, Gary D.	3292	2222M
GLEN, Donald V.	3893	2236M
GRANT, William B.	3998	3419
GRAY, Evelyn M.	3307	2210B
HAAKINSON, Eldon J.	4304	4511
HAIDLE, Leroy L.	3233	4524C
HAINES, Bruce F.	3103	3458B
HANSEN, Ruth B.	3708	3455
HANSON, A. Glenn	4449	2223
HARMAN, John M.	3655	2030
HARR, Thomas A., Jr.	4191	4518B
HARTMAN, William J.	3606	2210D
HASKIN, Lawrence J.	4162	4527
HAUSE, Laurance G.	3945	2230B

Name	Ext.	Room
HAYDON, George W.	3583	3420C
HEMP, Thomas H.	4403	3410M
HIEBERT, Jorgeann	3562	3413
HILDEBRANDT, Sarah C.	4258	4528A
HILL, David A.	3472	2209
HOPPONEN, Jerry D.	3880	3426
HOROWITZ, Renee B.	4162	4529
HOWARD, Allen Q.	3635	2236M
HUBBARD, Robert W.	3414	2243
HUEFTLE, Robert A.	4202	2222A
HUFFORD, George A.	3457	4523
HULL, Joseph A.	4136	2034
HYOVALTI, Duane C.	3447	3458A
JANES, Harris B.	3513	3450
JEFFREYS, Charlene E.	4414	3021
JENNINGS, Raymond D.	4303	4513
JOHNSON, Mary Ellen	3587	4522C
JOHNSON, Walter E.	3501	2030
JUNEAU, Robert I.	3512	2238
JUROSHEK, John R.	4362	4518C
KIMMETT, F. George	3945	2230B
KISSICK, William A.	4258	4520C
LANDERS, Mary R.	3821	3421
LAWRENCE, Vincent S.	4202	2222A
LAYTON, Donald H.	3584	3430
LIEBE, Hans J.	3310	3426
LINFIELD, Robert F.	3506	2246
LLOYD, John L.	3701	3419M
LONGAN, Marilyn K.	3634	3417
LONGLEY, Anita G.	3470	4521
LUBEN, Robert A.	3396	4524A
LUCAS, Donald L.	3821	3425
MARLER, F. Gene	3412	3446B
MARQUEZ, Patricia A.	4168	2237
MARTIN, William L.	3195	3424
MATHESON, Robert J.	3293	2221
MAYEDA, Kathy E.	3815	3420
MA, Mark T.	3800	3409
McCOY, Elizabeth L.	4281	2245
McLEAN, Robert A.	3880	3426
McMANAMON, Peter M.	3570	2237
McQUATE, Paul L.	3589	2233
MELLECKER, Carlene M.	3330	3458A
MILES, Martin J.	3506	2246
MILLER, Anne F.	4388	4518A
MILLER, Charles M.	4496	3454A
MINISTER, Carl M.	3805	2242
MIRANDA, Beverly J.	3588	4523
MITZ, Albert R.	3584	3430
MOLLARD, Jean R.	4414	3015
MONTROSE, James K.	4122	4520B
MORRISON, Ernest L.	4473	3415
MURAHATA, Sueki	3513	3442
MURRAY, John P.	4162	4533
NESENBERGS, Martin	3337	2214A
OTT, Randolph H.	3353	3467
PAULSON, Sara J.	3874	4519
PAVLICH, David C.	3513	3446B
PAYNE, Judd A.	3200	2210M
PHILLIPS, Robert E.	4125	4520A
POKEMPNER, Margo	3825	3424M

Name	Ext.	Room
POST, Sharron A.	3864	4530
PRATT, Lauren E.	3826	2234B
PYATT, Kurt W.	3945	2230
RANDELL, Holly L.	3655	2030
REASONER, Rita K.	3184	4522A
REBOL, David N.	4122	4520B
ROSICH, Rayner K.	3109	3415M
RUSSELL, Jane L.	3387	4524B
SAMSON, Charles A.	3778	2213B
SEITZ, Neal B.	3106	2214E
SENSIBAUGH, Carol S.	4215	3020
SEXTON, Alma B.	3883	3449
SHELTON, Lenora J.	3572	3011
SKERJANEC, Richard E.	3157	2230
SKINNER, David F.	3834	4516C
SMILLEY, John D.	4218	2222M
SMITH, Dean	3661	2223
SMITH, Ernest K.	3177	3007
SPAULDING, Arthur D.	4201	2222C
SPIES, Kenneth P.	4275	4516B
STANSEN, Linda M.	4129	4518A
STEELE, Francis K.	3815	3420
STEWART, Arthur C.	3364	4528B
STEWART, Frank G.	3336	3450C
STONEHOCKER, Garth H.	3756	4516D
STONER, Russell B.	3572	3009
SWISHER, Stephen A. IV	4458	3458
TARY, John J.	3702	3450
TELFER, Thelma L.	4162	4529
TETERS, Larry R.	4410	3410M
THACKER, David C.	3875	4520
THOMAS, Donald K.	4302	4515
THOMPSON, Moody C., Jr.	3508	3442A
TVETEN, Lowell H.	3621	3445
UTLAUT, William F.	3500	3020
VanSTORY Carol B.	3267	3017
VIOLETTE, Edmond J.	3702	3446A
VOGLER, Lewis F.	3668	3450
WALLER, Freda L.	3618	2246
WALTERS, William D.	4414	3019
WARNER, Billie D.	4496	3454B
WASHBURN, James S.	3798	3413M
WASSON, Gene F.	3584	3430
WATTERSON, Clark C.	3536	2241
WAYLAND, Susan C.	3175	2230
WELCH, William M., III	4321	3450
WELLS, Paul I.	4368	2235
WHITTEN, Kent D.	3389	2230
WIEDER, Bernard	3484	3014
WOOD, John B.	3512	2238
WOOD, Lockett E.	3729	3447
WOOD, Marylyn N.	4136	2030
WORTENDYKE, David R.	4241	2234B

ANNEX IV
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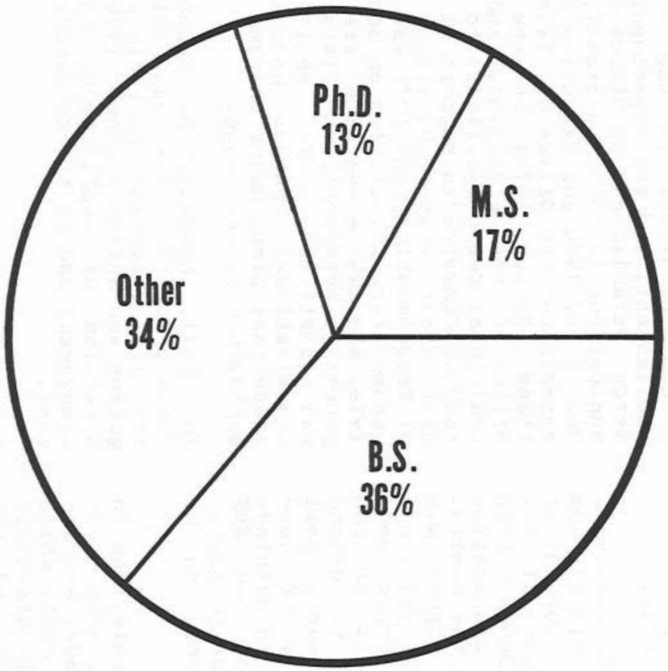
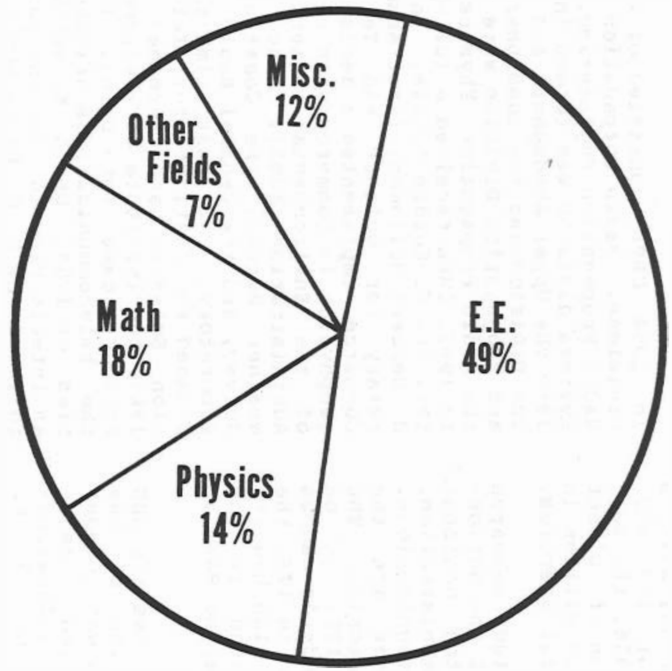
PERSONNEL STATISTICS



By Highest Degree



Discipline of Degrees of Professionals

Full-time Permanent Staff as of June 30, 1976	112
Part-time, W.A.E., and F.T.T.	57

ANNEX VI
GENERAL AND HISTORICAL INFORMATION OF ITS

The Institute for Telecommunication Sciences, largest component of the Office of Telecommunications, is located at the Boulder Laboratories of the Department of Commerce, and has (as of June 30, 1976) a full-time permanent staff of 112 and other staff of 57. In FY 1976, its support consisted of $1.1 million of direct funding from Commerce and $8.0 million in work sponsored by other Federal agencies.

The Boulder Laboratories include research and engineering components of the National Bureau of Standards, the National Oceanic and Atmospheric Administration, and the Office of Telecommunications. Common administrative services are the rule in the Boulder Laboratories. The Radio Building, which houses ITS, is on the National Bureau of Standards campus at 325 Broadway. In addition to ITS, the Office of Telecommunications also has its Policy Research Division located in the 30th Street Building off Baseline Road in Boulder.

The following brief history shows its NBS beginnings. The Radio Section of the National Bureau of Standards was founded prior to World War I, and played a major role in the evolution of our understanding of radio propagation. Dr. J. H. Dellinger, its director for most of the period up until World War II, was strongly convinced of the importance of research and gave it practical application as first Chairman of the Study Group on Ionosphere Propagation in the CCIR.

During World War II, the Interservice Radio Propagation Laboratory (IRPL) was organized at the National Bureau of Standards, under the direction of Dr. Dellinger. His group provided a common focus for military needs in propagation during the war. In 1946, the Central Radio Propagation Laboratory (CRPL) was established, and in its early years had direct ties with the Defense Department; for example, senior officials of DoD would appear before Congress to defend the CRPL budget. In 1949, Congressional concern for the vulnerability of government laboratories located in Washington, D.C., and the crowding of the NBS Connecticut Avenue campus made it advisable for the radio research work to be taken elsewhere.

Three sites, one in California, one in Colorado, and one in Illinois, were considered, and Boulder, Colorado, was selected. The first group from CRPL, which at that time included radio standards work, moved to Colorado in 1951, and the move was completed in 1954, during which year President Eisenhower dedicated the NBS Radio Building. The Radio Standards program left CRPL at the time of the move to Boulder, and has pursued a parallel existence at Boulder in NBS since that time.

In 1954 CRPL consisted of two research Divisions: Radio Porpagation Physics and Radio Propagation Engineering. The Radio Systems division was formed in 1959. In 1960 the Upper Atmosphere and Space Physics Division and the Ionosphere Research and Propagation Division were formed from the Radio Propagation Physics Division. In 1962, CRPL received a full-time Director, Dr. C. Gordon Little. In 1965, Dr. H. Herbert Holloman, first Assistant Secretary for Science and Technology in Commerce, implemented a decision to unify geophysics in Commerce with the creation of the Environmental Science Services Administration (ESSA), made up of the Weather Bureau, the Coast and Geodetic Survey, and the Central Radio Propagation Laboratory. At that time the CRPL was renamed the Institute for Telecommunication Sciences and Aeronomy (ITSA). In 1967, the Institute for Telecommunication Sciences came into being. It contained the telecommunications-oriented activities of ITSA. Dr. E. K. Smith served as an interim Director for one year and was followed by R. C. Kirby who was Director for the ensuing three years.

Meanwhile, in Washington, major attention was being given to the organization of telecommunications in the Federal establishment, and the Department of Commerce established an Office of Telecommunications in 1967. Reorganization Plan No. 1 of 1970 and Executive Order 11556 established the Office of Telecommunications Policy (OTP) in the Executive Office of the President, and assigned additional responsibilities to the Secretary of Commerce in support of OTP. To meet these responsibilities, the Office of Telecommunications (OT) was given expanded responsibilities on September 20, 1970, and ITS, along with its programs, property, personnel, and fiscal resources was transferred to OT. While no major organizational changes have transpired since that time, major changes in program emphasis have been made.

In 1971, Douglass D. Crombie became Director of ITS. ITS has shifted from its strong emphasis on radio wave propagation and antennas since 1970, in the direction of applications in spectrum management and in telecommunication systems.

ITS and its predecessor organizations have always played a strong role in pertinent scientific (URSI), professional (IEEE), national (IRAC), and international (CCIR) governmental activities. The chairmanship of Study Group 6 (Ionospheric Propagation) of the CCIR has always resided in ITS or its predecessor organizations. The Director of CCIR from 1966 to 1974 was Jack W. Herbstreit, a former Deputy Director of CRPL and ITSA, and the current CCIR Director is Richard C. Kirby, formerly Director of ITS. At the present time, the U.S. preparatory work for four of the eleven study groups of CCIR is directed by members of ITS (U.S. Study Groups 1, 3, 5, and 6), and staff members of ITS participate in many of the other Study Groups. ITS actively supports the Interagency Radio Advisory Committee (IRAC), and the Chairmen of its Standards Working Group (J. A. Hull) and the Propagation Working Group (W. F. Utlaut) of the Technical Subcommittee are members of ITS management.

The work which ITS does for other agencies in the government derives its legal authorities from 15 U.S.C. 272(e) "Advisory Services to Government Agencies on Scientific and Technical Problems" and 15 U.S.C. 272 (f) "Invention and Development of Devices to Serve Special Needs of Government." As a matter of Federal policy, the Office of Telecommunications does not accept work more appropriately done by other non-government or government organizations. It is also a matter of policy that all sponsored work reinforce OT's overall program and that it be clear that other agencies, industries, or universities could not serve equally well or better.

Within these policy guides, ITS aspires to being <u>the</u> Federal laboratory for research in telecommunications. It is clear that the government has a responsibility to pursue long-range studies in telecommunications which are not economically profitable for industry. It is also clear that the government must have its own, independent laboratories to assess the significance of research conducted elsewhere. Towards these ends, ITS strives to maintain a knowledgeable staff that is working on the frontiers of technology and is in touch with the telecommunications problems of the Federal Government. Its programs and future directions are succinctly given in the Foreword of this report by ITS Director D. D. Crombie.

The Department of Defense has long been the primary source of advanced technology. At the present time, the largest part of the other agency sponsorship of ITS comes from needs of the Department of Defense. However, there is also a clear need for relevance to national goals on the civilian side of the Federal establishment. ITS is therefore moving to increase its work with the civil side of the Federal government. The agencies in the civilian sector are frequently also in the high technology area, for example the FAA and NASA, for which ITS has done, and continues, very important work in navigation, collision avoidance, satellite communications, and related work.

It is appropriate in conclusion to reemphasize the environment in which ITS exists in the Department of Commerce Boulder Laboratories. The components of NBS, NOAA, and OT which make up the Boulder Laboratories are portrayed on the chart on the inside of the back cover. It is readily seen that ITS reaps many advantages from the common service structure of these Laboratories which are normally only available to an organization many times the size of ITS.

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COMPONENTS OF THE DEPARTMENT OF COMMERCE: BOULDER LABORATORIES