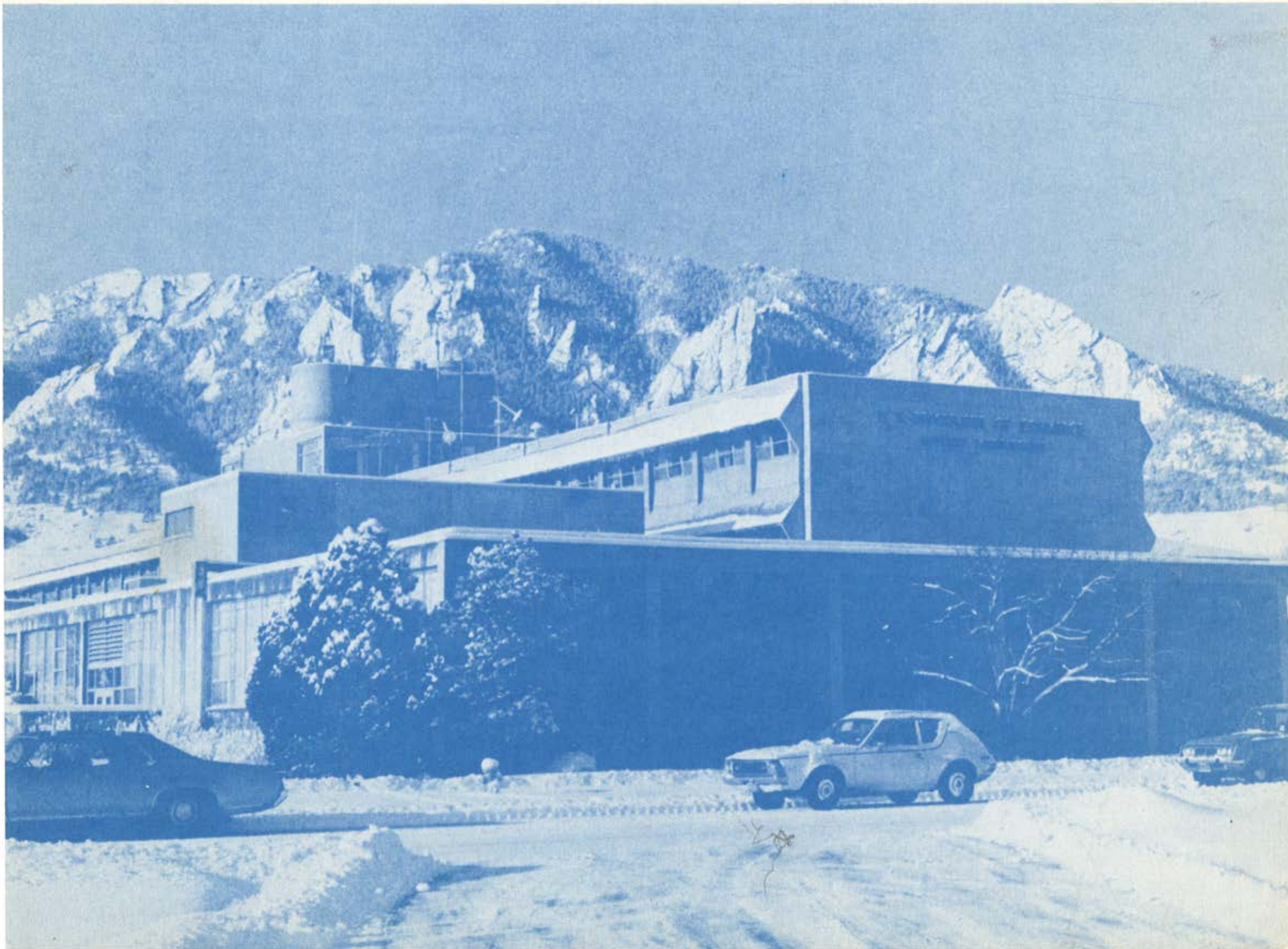
INSTITUTE FOR TELECOMMUNICATION SCIENCES
OF THE
NATIONAL TELECOMMUNICATIONS AND
INFORMATION ADMINISTRATION

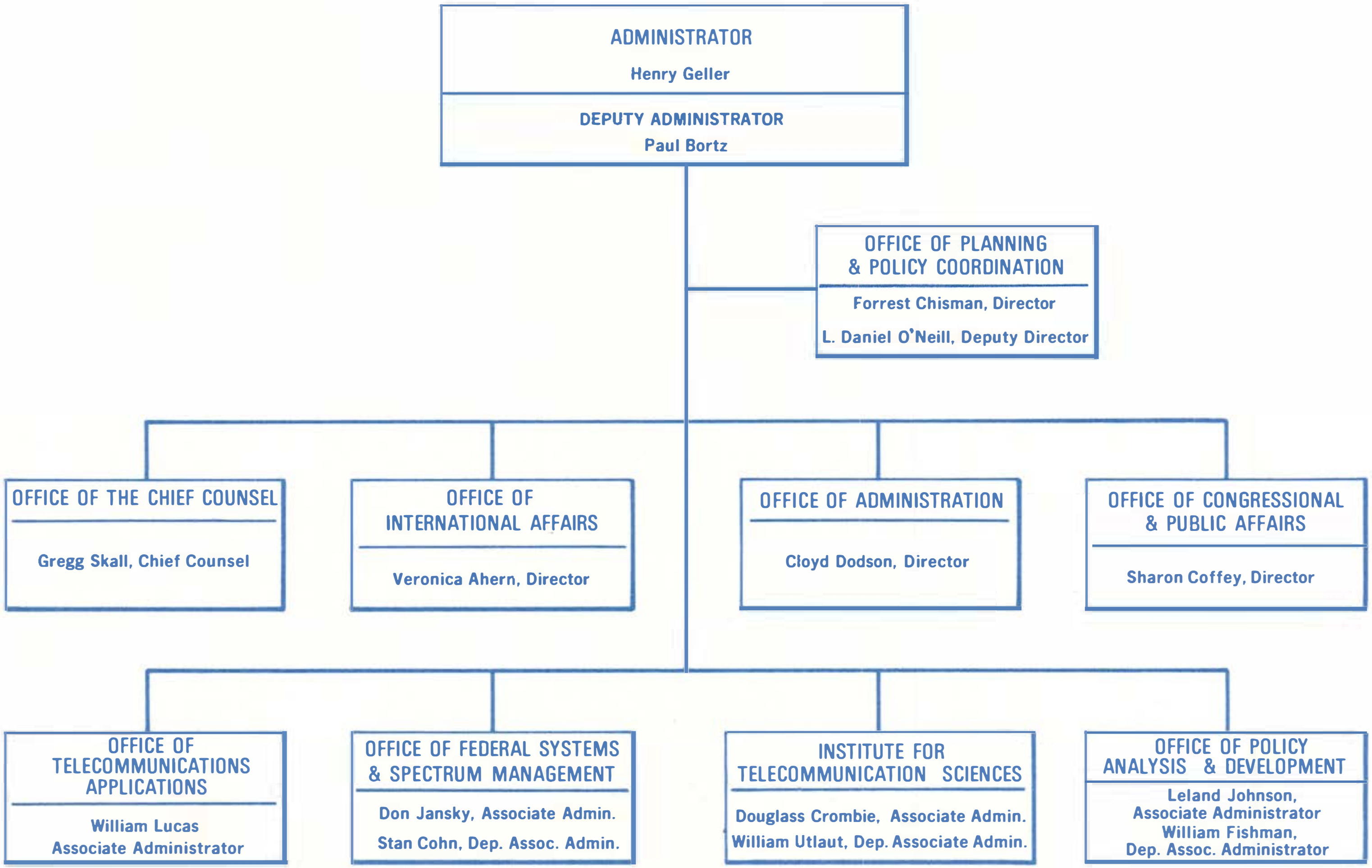
ANNUAL TECHNICAL PROGRESS REPORT 1978

For the period from October 1, 1977 through Sept. 30, 1978



U.S. DEPARTMENT OF COMMERCE

National Telecommunications and Information Administration



ITS

ANNUAL TECHNICAL PROGRESS REPORT 1978

For the period
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U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

Henry Geller, Assistant Secretary
for Communications and Information

FOREWORD

Fiscal year 1978 saw the beginning of the National Telecommunications and Information Administration (NTIA), and a new era for the Institute for Telecommunication Sciences. NTIA was formed, by Presidential Order No. 1, 1977, by combining the former Office of Telecommunications Policy (from the Executive Office of the President) and the Office of Telecommunications (from the Department of Commerce). NTIA is now located in the Department of Commerce under the new Assistant Secretary for Communications and Information.

ITS is one of the Offices of the new organization and is responsible, on behalf of the Administrator of NTIA, for the telecommunications technology research programs of NTIA and for providing technical research support to other elements of NTIA as well as other agencies on a reimbursable basis. To perform these functions it shall, as stated in Departmental Orders:

a. Conduct and coordinate technical analyses of telecommunications and information policy options.

b. Acquire, analyze, synthesize and disseminate data and perform research in general on the description and prediction of electromagnetic wave propagation and the conditions which affect propagation, on the nature of electromagnetic noise and interference, and on methods for improving the use of the spectrum for telecommunications purposes; prepare and issue predictions of electromagnetic wave propagation conditions and warnings of disturbances in those conditions; develop methods of measurement of system performance and standards of practice for telecommunications.

c. Conduct research and analysis of electromagnetic propagation, radio systems characteristics, and operating techniques affecting the utilization of electromagnetic spectrum, in coordination with specialized, related research and analysis performed by other Federal agencies in their areas of responsibility.

d. Conduct research and analysis in the general field of telecommunication sciences in support of assigned functions and in support of other Government agencies and State and local governments.

e. Provide scientific, engineering, and technical expertise, as the central Federal Government laboratories for research on transmission of radio waves.

f. Coordinate or undertake, on behalf of and at the direction of the Administrator, policy programs with major scientific or technical content.

g. In coordination with the Office of Federal Systems and Spectrum Management, provide advice and assistance to the Administrator and the Director of International Affairs in carrying out spectrum management related aspects of NTIA's international policy responsibilities and perform such other duties related to those responsibilities as the Administrator shall designate.

As a result, ITS will continue to be heavily involved in research and engineering for increasing the availability of the spectrum by scientific and engineering techniques, and in overcoming natural, engineering and cost factors limiting the performance of telecommunication systems.

We expect that more of our efforts will be in collaboration with, and support for, our sister offices in NTIA. These offices are those of Policy Analysis and Development, Telecommunications Application, Federal Systems and Spectrum Management, and International Affairs. In addition, NTIA recognizes the national value of our support for other Federal Agencies and encourages such activities, particularly where these can occur at the planning level.

The public will expect more from telecommunications in the future. More quality, more diversity of services, and more value for the costs. It is NTIA's role, on the Government side, to help their expectations be fulfilled. Without research and its applications in economics, in legal issues and in telecommunications engineering, these expectations will not be met. ITS welcomes the opportunity to participate and to assist in the development of soundly based public telecommunications policies, and in sound telecommunication applications by the Federal Government.

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INTRODUCTION

Three divisions in ITS perform the technical work reported here. They, and their directors, are:

- Spectrum Utilization (John P. Murray)
- Systems Technology and Standards (Joseph A. Hull)
- Applied Electromagnetic Science (Donald L. Lucas)

This Division structure correlates closely with the primary program areas of ITS. These program areas are:

- Efficient Use of the Spectrum
- Systems Engineering and Evaluation
- Electromagnetic Wave Transmission

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 joint 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. A major part of the effort is in support of the NTIA Office of Federal Systems and Spectrum Management, which manages the Government portion of the spectrum. In addition, work for other Federal agencies is concerned with electromagnetic compatibility analysis and radio coverage estimation.

Highlights of FY-78 activities include:

- Evaluation of the spectrum efficiency of FM, AM, and SSB modulation for Personal Radio services, and of Spread Spectrum modulation for mobile radios.
- Production of TV coverage maps for the FCC.
- Studies of the sharing of the spectrum by AM broadcast and radionavigation systems.
- Development of spectrum monitoring equipment for use in evaluating the effectiveness of airborne electronic counter-measures systems.

Details of the program are given in Chapter 1.

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 of telecommunication systems, from a user's point of view, 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 of multiplexed signals in the engineering sense, and in real time on message trunks, are badly needed to detect incipient failures. ITS is developing criteria and measurement methods for both voice and data transmission.

In addition, this program element is concerned with channel simulation and evaluation of modem techniques, communications via fiber optics, and improved use of satellites for communications.

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 wave-guides for high data-rate transmission.

The satellite activity is concerned with overcoming the regulatory, economic, and technical barriers to the use of small earth terminal satellite systems.

Significant achievements in FY-78 include:

- Continuation of support to U.S. Postal service in development of electronic message service systems.

- Development of a desk-top calculator program for design of line-of-sight microwave links.

- Production of an Emergency Medical Service Planning guide for use by nontechnical personnel in the procurement of emergency telecommunication services.

- Evaluation of the characteristics of single-mode optical fibers for long distance high capacity communications.

Details of this program are found in Chapter 2.

<u>Electromagnetic Wave Transmission</u>

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 probability of 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 78 continued to be directed mainly at the higher frequency end of the spectrum. Notable achievements include:

- Design and test of buried MF and UHF antenna prototypes for potential use in the MX ballistic missile system.

- Initial evaluation of potential impacts of the Solar Power Satellite high power microwave beam on the atmosphere and on terrestrial communications.

- Data collection on multipath fading on long microwave paths.

- Exploration of the feasibility of recovering radio signals in ionospheric ducts by use of the Platteville high power transmitter.

Details of this program are found in Chapter 3.

<u>ITU Support</u>

ITS continued to provide support to the U.S. and International ITU committees of CCITT and CCIR. Preparation for WARC-79 was a significant part of the CCIR effort. This activity included participation in the IRAC AdHoc 144 Committee and preparation for the CCIR Special Preparatory Meeting to be held late in 1978. ITS leaders in these activities include W. F. Utlaut, J. P. Murray, P. M. McManamon, C. M. Rush, H. T. Dougherty, and D. L. Lucas.

<u>Support for Other Agencies</u>

Much of the work described in this report is in support of, and reimbursed by, other Federal Agencies. This both helps solve technical problems of these Agencies and aids ITS in maintaining broad awareness of national telecommunication problems. It also helps to provide data for use in the development of models which become available to those requiring them and thus helps ITS to fulfill its responsibilities to the public. An important part of this effort, in each of the program areas, is assessing technical requirements; assisting in definition of specifications for telecommunication equipment and systems; and evaluating their performance. This work helps the Agencies in their procurements from industry, and by limiting the range of alternatives makes it easier for industry to respond to the Agencies' needs.

As in previous years, our work in FY-78 for other Federal Agencies was oriented closely towards NTIA's goals. NTIA's criteria for acceptance of work from Other Agencies can be summarized as follows:

1. It 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 ITS).

4. The work contributes to NTIA's goals.

5. The work does not conflict with other ongoing work within NTIA.

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 NTIA and the Department of Commerce.

Acknowledgement

R. B. Stoner was responsible for the preparation of the report, from material provided by the Associate Directors - J.P. Murray, J.A. Hull, and D.L. Lucas. He was ably assisted by other ITS staff.

Douglass D. Crombie
Director, ITS

CHAPTER 1. EFFICIENT USE OF THE SPECTRUM

The radio, or electromagnetic, spectrum has seen dramatic growth 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 National Telecommunications and Information Administration, Institute for Telecommunication Sciences (NTIA/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 the Electromagnetic Wave Transmission chapter of this report. That chapter 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 NTIA/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 TECHNIQUES

Traditionally, such techniques have been developed to evaluate a specific situation, usually with a series of "safe" or "conservative" assumptions. Conservatism allowed for some simplicity in these techniques, but even so they were arcane enough so that relatively few people used them, and even fewer understood them.

Our goals in this part of the program are to develop a family of such techniques that is based on a sound knowledge of the physical characteristics of the problem, the technical properties of equipment involved, the practical way in which that equipment is used, and the influence that Mother Nature brings to bear. If we are successful in developing such techniques, they are necessarily complex and consequently difficult to use and understand. We are aggressively working to overcome these barriers to effective use by careful documentation and by developing computer methods that are easily used and provide results in the user's context.

Conservatism in many cases equates to wasted spectrum. We address this problem by building techniques which incorporate a comprehensive statistical analysis of the many variables (and their complex inter-actions) which affect the results. By so doing, we allow the user to be as liberal or conservative as he chooses.

For over a decade, government, academic, and industrial groups have avocated 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.

The developments reported here are discussed with current applications in mind. But their true value lies in their general character. In most cases, these methods can be readily adapted to meet many new requirements involving a broad range of telecommunications needs and services. The presentation of summary results in graphic form (particularly as maps and map overlays), the development of demographic results, and the design of interactive computer programs that make it easy to ask "what if?" questions are symptomatic of our continuing effort to bridge the gap between technology and the planners and policy makers.

Quantitative analysis of the tradeoffs between equipment specifications, operating procedures, and Government regulations can show how to get maximum communications yield from the radio spectrum resource. This year, in the Tradeoffs for Spectrum Use Project, technical tradeoffs for spectrum efficiency in a personal radio service were studied in cooperation with the Personal

Radio Planning Group (PRPG) of the Federal Communications Commission.

Citizen's band radio channels are already badly congested in metropolitan areas, and the number of licensed sets is increasing several million per year. As a result, the Federal Communications Commission has been studying the possibility of establishing a new Personal Radio Service to supplement CB.

Earlier studies by PRPG had selected the 220-224 MHz and 900 MHz bands as candidates for a new personal radio service. Design parameters that might affect spectrum efficiency and service quality are modulation type, channel width, and radiated power. The different propagation characteristics and ambient noise in the two frequency bands also affect the results.

Modulation types and channel widths considered were as follows: Double-Sideband Amplitude Modulation (DSB-AM) with a channel width of 10 kHz; Single-Sideband AM (SSB-AM) with a channel width of five kHz; and Frequency Modulation (FM) for channel widths of 15, 25, 50 and 100 kHz. Transmitter power was variable, but most calculations assumed five W. The average mobile station was assumed to have a quarter wave whip antenna mounted on the roof of a vehicle, between one and two meters above the ground. An average base station was assumed to have a 5/8 wavelength whip or a two-element Yagi antenna mounted five to ten meters above ground. The variation in installation heights and antenna types was accounted for by assuming that the effective radiated power had a statistical distribution around these average cases.

A statistical propagation model, which depended on the terrain parameter Δh was used. Fairly smooth terrain or suburban development was represented by Δh = 90 m, and rough terrain or urban development was represented by Δh = 200 m.

Transceivers were assumed to be distributed uniformly but randomly over a metropolitan area, and users were assumed to transmit at random times (no courtesy). The density of users was varied to find the maximum number of users per channel for a desired quality of service.

Quality of service was assumed to be given by the signal-to-noise or signal-to-interference ratio at the output of the demodulator. The results here are for an output S/I ratio of 17 dB. Then the operational range (OR_x) is defined to be the range at which this S/I ratio was achieved on 100x % of the attempted contacts.

Calculations were made with a probabilistic model described in the 1977 report.

Figure 1-1 shows the average operational range, $OR_{.5}$, as a function of the number of simultaneous interferers for the conditions shown on the figure. The capacity, or saturation level, of a personal radio band can be determined using such a figure. For example, if the regulatory authority decides that the service should provide a median operational range of three km for mobile-to-mobile commmunications, FM modulation with 25 kHz channel spacing wil support five simultaneous users per channel (four interferers plus the wanted signal) at saturation. The SSB-AM will support only two users per channel, but it is still more spectrally efficient than 25 kHz FM because 25 kHz will hold five SSB-AM channels and hence ten users in the same space.

This idea is used with more extensive data to construct Table 1, which shows the total number of users per megahertz of bandwidth that each kind of modulation will allow for different specified operational ranges. Calculations were made for FM bandwidths greater than 25 kHz, but these bandwidths did not allow as many users/megahertz so the values are not shown.

Table 1-1 shows that SSB-AM is about twice as spectrum efficient as the other contenders. It is important to note that this conclusion is a function of the required output signal-to-noise ratio. If the required ratio were much higher--say 30 dB or more--it is possible that frequency modulation with channel widths greater than 25 kHz would be more efficient.

A project to draw TV Coverage Maps was sponsored by the Federal Communications Commission. Its finished product was a set of computer programs which may be used to draw the maps and to compute associated statistics under various conditions and suppositions. The programs employ the FCC Television Data Base, a file of 1970 population density values, and several "environmental" files that provide values for propagation paramaters. A sample map is shown in Figure 1-2. It displays a small portion of the United States including Washington, Philadelphia, and New York City. The shaded areas indicate where one can expect to find at least Grade A service from one, three and five (or more) television stations on any of the 82 channels.

A principal feature of the final program is that while computing areas and populations of the various categories of coverage, it simultaneously computes an estimate of the probable errors of these

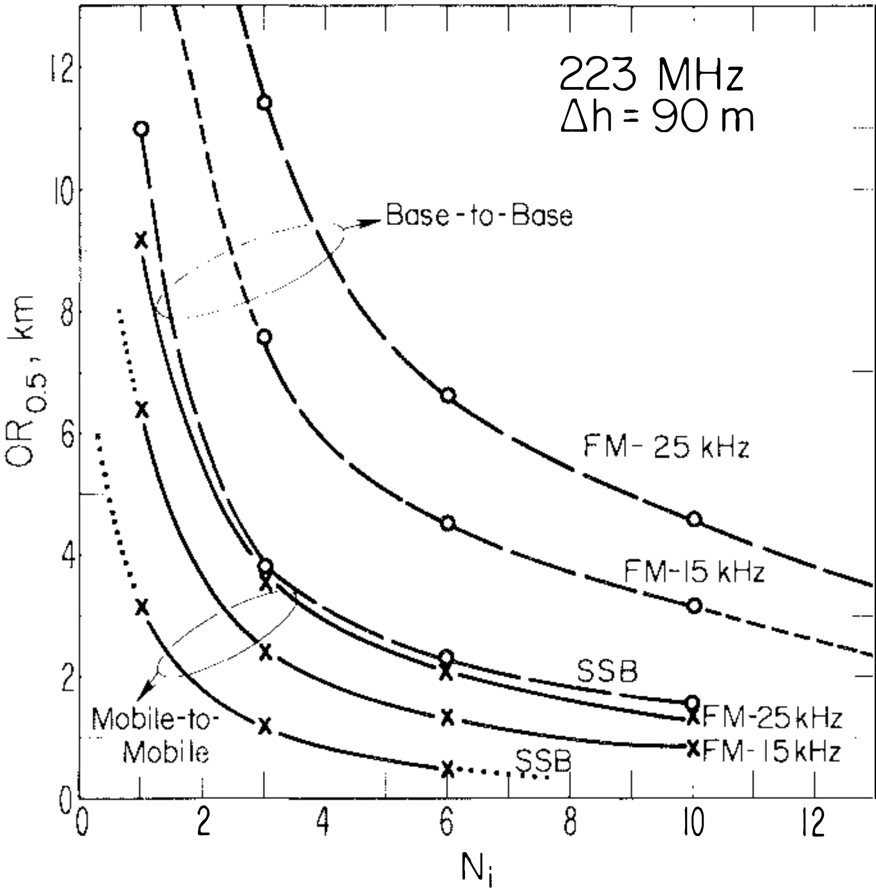


Figure 1-1. Average operational range as constrained by interference for varying levels of usage.

Table 1-1. **Number of Simultaneous Users per MHz Bandwidth when Mobile-to-Mobile Links are Getting Specified Operational Range**

(Assumes equal loading of channels; 17 dB output S/I; interference limited case; 223 MHz; Δh = 90 m. Eighty percent of users are mobile; 20 percent are base stations.)

Specified $OR_{.5}$, km	Channel Width, kHz SSB-AM 5	DSB-AM 10	FM 15	25
2	540	270	320	288
3	420	210	233	192
4	340	170	187	152
5	300	150	160	128
6	260	130	140	112

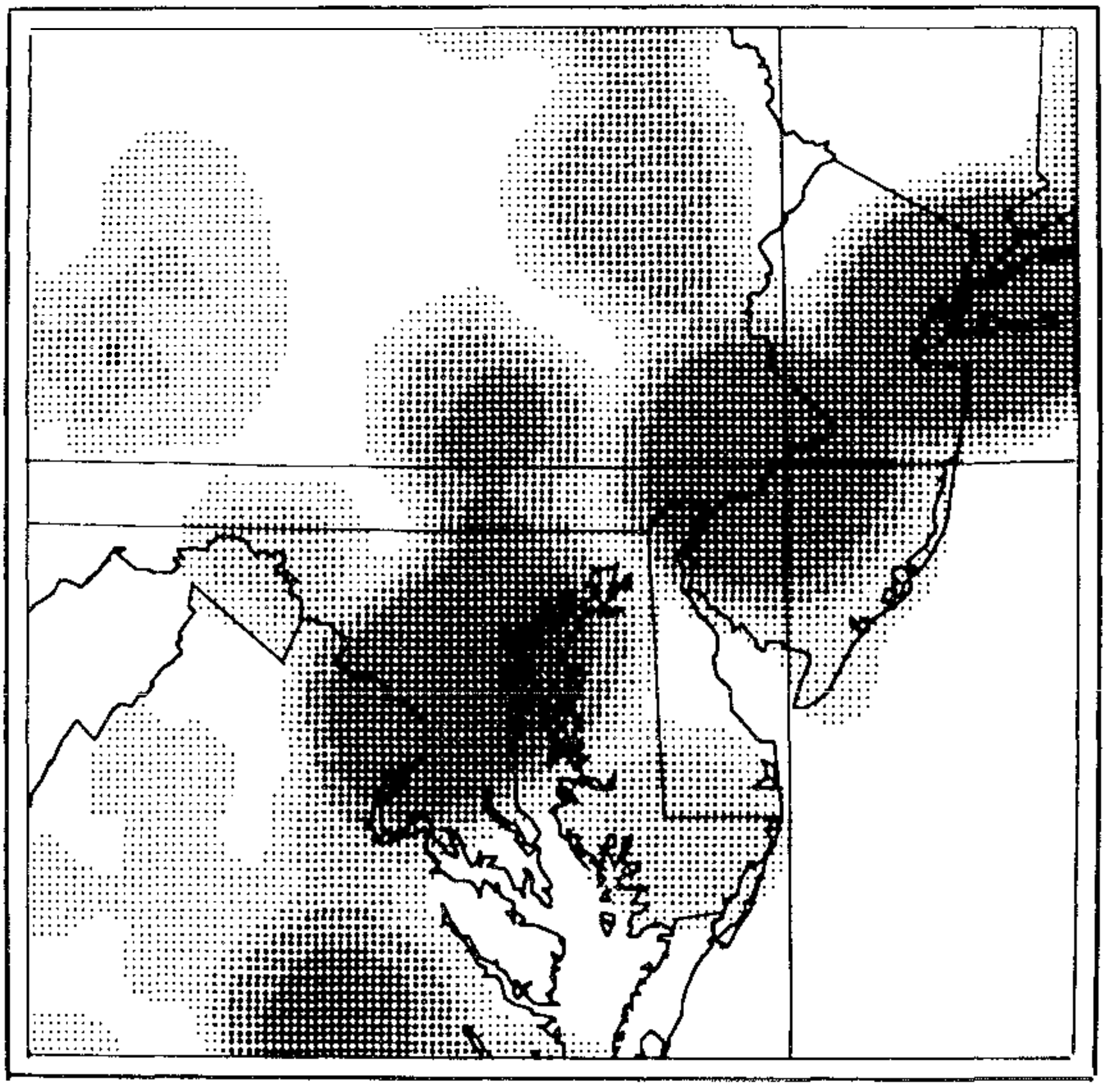


Figure 1-2. Washington. The shaded areas indicate in succession where Grade A service is available from 1, 2, 3, and 5 (or more) television stations.

quantities. This, one should note, is not a trivial task. If for example, no one lives in a particular area then it does not matter how bad the estimates of received field strengths are, the probable error of population there will be zero. Clearly, the probable errors must somehow be related to the magnitude of population densities. Sources of error include not only our ignorance of radio propagation losses, but also the inexactitude of some of the station parameters and suspected errors in our environmental files.

In Figure 1-3 is the output of statistics corresponding to the map in Figure 1-2. Below each computed value is a second value (followed by the letter "X") which is the corresponding probable error. Note that there are over two million people in that region who do not receive Grade A service from even one television station.

This technique has broad future applications in all broadcast situations, with FM as the most obvious example. Estimates of such coverage from satellites alone or in combination with conventional broadcast facilities would be possible.

Spectrum planning techniques rely on some measure of desired system performance as a key factor in determining spectrum-sharing potential. Such a performance measure has been very difficult to find for voice communication.

An objective evaluation of receiver performance in terms of voice intelligibility has long been a difficult problem. In the past, both subjective and objective measurement techniques have been used to assess the intelligibility of voice communication systems. The subjective method involves trained speakers and listeners that directly score the percentage of words that are correctly perceived. Unfortunately, subjective scoring methods are time consuming, difficult and expensive, and as a result, are not used extensively.

One objective method used in the past to measure voice intelligibility has been the Articulation Index (AI) defined as an average of the signal-to-noise ratio in several audio frequency bands. Several automated techniques to obtain AI have been used. The two most well-known automatic techniques are the Speech Communication Index Meter (SCIM) and the Voice Intelligibility Analysis Set (VIAS). Although the AI technique is more practical than the subjective AS technique, AI is not one-to-one correlated with the subjective measurement technique.

Recently a new objective technique has been developed at ITS to measure voice intelligibility. A distortion measure is obtained using Linear Prediction Coding (LPC), a mathematical technique widely known for its application to the analysis and synthesis of speech. The feasibility of using LPC to develop an objective intelligibility measure has been demonstrated.

The objective of this measurement task is to evaluate the potential of using the LPC method to obtain Articulation Scores (AS) scores for different interference situations.

Receiver performance measurements have been made on both a narrow-band AM and FM receiver with interference being noise, a similar type signal (AM or FM), or pulsed co-channel signal. The AS, AI and LPC scores will be measured and compared. The output of the project will be presented in a letter report.

A study (AM Broadcast and Radio-location Sharing) was undertaken at the request of the Federal Communication Commission (FCC) to provide technical data for determining the feasibility of extending the AM broadcast band from 1615 kHz to 1800 kHz, on an equal-status sharing basis with radio-location services. The study was limited to consideration of one specific narrow-band radio-location system, the Decca Hi-Fix System, chosen because of its widespread use in many areas. The basic methodology of the study was to calculate the ratio R of the geographic distances from interfering transmitter to intended-receiver and desired transmitter to intended-receiver. For interference from a radio-location transmitter to a broadcast receiver, calculations were performed for signal-to-interference ratios of 25 dB and 40 dB, and for two types of receivers having different pre-detection bandwidths. The results of these calculations are shown in Table 1-2 and Table 1-3. For interference from a broadcast transmitter to a radio-location receiver, the calculations were based on a 1 dB reduction in effective S/N ratio at the radio-location receiver. For this case, the study also took into account the out-of-band emissions of the broadcast transmitters (i.e., due to harmonic and intermodulation distortion products). The results of these calculations are presented in Table 1-4.

WASHINGTON

USING-
FCC BASE 77/09/20.

LICENSED, PRIMARY STATIONS ONLY

SERVICE THRESHOLD- GRADE A (INTERFERENCE IS IGNORED)
68. 71. 74. DBU

NO. OF SERVICES	FOR POPULATION DENSITIES					TOTALS
		10/SQ MI	50/SQ MI	100/SQ MI	250/SQ MI	
1 OR MORE	2780 POP. 460X 353 SQ MI 147X	378100 POP. 9000X 10890 SQ MI 320X	750700 POP. 14700X 10290 SQ MI 240X	2185000 POP. 29000X 13070 SQ MI 220X	28912000 POP. 34000X 18900 SQ MI 200X	32228000 POP. 48000X 53510 SQ MI 520X
2 OR MORE	1000 POP. 200X 133 SQ MI 108X	159700 POP. 5800X 4560 SQ MI 190X	371000 POP. 12700X 5050 SQ MI 190X	1488000 POP. 31000X 8780 SQ MI 200X	28455000 POP. 50000X 17820 SQ MI 190X	30475000 POP. 60000X 36340 SQ MI 400X
3 OR MORE	657 POP. 129X 90 SQ MI 94X	69700 POP. 4100X 1948 SQ MI 139X	151800 POP. 8200X 2041 SQ MI 127X	917000 POP. 24000X 5260 SQ MI 150X	27785000 POP. 64000X 16340 SQ MI 190X	28924000 POP. 69000X 25680 SQ MI 320X
5 OR MORE	410 POP. 108X 53 SQ MI 69X	12700 POP. 2300X 314 SQ MI 79X	36400 POP. 5400X 454 SQ MI 90X	413000 POP. 19000X 2326 SQ MI 123X	26008000 POP. 77000X 12600 SQ MI 190X	26471000 POP. 79000X 15740 SQ MI 270X
NONE	12870 POP. 460X 2080 SQ MI 410X	493500 POP. 9000X 15860 SQ MI 490X	497500 POP. 14700X 7020 SQ MI 300X	854000 POP. 29000X 5520 SQ MI 290X	590000 POP. 34000X 1490 SQ MI 280X	2448000 POP. 48000X 31980 SQ MI 820X

Figure 1-3. Statistics of television coverage near Washington.

TABLE 1-2

Carrier Separation	Output S/I = 25 dB Input S/I	R	Output S/I = 40 dB Input S/I	R
≥ 1.5 kHz	25 dB	1.1	40 dB	6
3	18.5	.5	33.5	3
5	8.5	.15	23.5	1
8	0	.06	15	.36
10	-4	.04	11	.22
12	-7	.03	8	.14

Receiver IF bandwidth: -3 dB 4.5 kHz
-20 dB 14 kHz
-40 dB 40 kHz

$$R = \frac{\text{dist. radioloc. xmtr to broadcast rcvr}}{\text{dist. broadcast xmtr to radioloc. rcvr}}$$

Broadcast transmitter power = 10 kW (carrier)
Radiolocation transmitter power = 10 W (low mode)

Table 1-3

Carrier Separation	Output S/I = 25 dB Input S/I	R	Output S/I = 40 dB Input S/I	R
≥3 kHz	25 dB	1.1	40 dB	6
5	19.5	.6	34.5	3.3
8	11	.22	26	1.2
10	6.5	.13	21.5	.75
12	4	.1	19	.56

Receiver IF bandwidth: -3 dB 8 kHz
-20 dB 22 kHz
-40 dB 65 kHz

$$R = \frac{\text{dist. radioloc. xmtr to broadcast rcvr}}{\text{dist. broadcast xmtr to radioloc. rcvr}}$$

Broadcast transmitter power = 10 kW (carrier)
Radiolocation transmitter power = 10 W (low mode)

TABLE 1-4

Carrier Separation	R
>75 kHz	<0.1
30-75 kHz	0.7
15-30 kHz	2.4
0.5-15 kHz	60
5-15 kHz	2*

*With 40 dB notch filter in the broadcast transmitter audio circuits at a frequency equal to the carrier separation.

$$R = \frac{\text{dist. broadcast xmtr to radioloc rcvr}}{\text{dist. radioloc. xmtr to radioloc. rcvr}}$$

Broadcast transmitter power = 10 kW (carrier)
Radiolocation transmitter power = 10 W (low mode)

SECTION 1.2 SPECTRUM ENGINEERING FOR EFFECTIVE SPECTRUM USE

In addition to the development of new analytical and measurement techniques, ITS applies the results of such work to specific problems of concern to various agencies. One important factor in planning for new developments is our experience with such projects where the practical needs of operational agencies must be recognized.

Two projects sponsored by the Federal Communications Commission examined the potential of spread-spectrum (SS) modulation for the land-mobile radio (LMR) service. The objective of the Spread Spectrum LMR-TV Sharing project was to compare the conditions under which spread-spectrum land-mobile radio and television stations can share spectrum with the conditions under which conventional narrow-band FM land-mobile radio and television statios can share spectrum. This can be done by comparing the protection ratios required against the two types of interference.

The dashed lines in Figure 1-4 show the measured minimum signal-to-interference ratios necessary to achieve acceptable performance with interference from conventional FM land-mobile transmissions with various modulations. (Details are contained in the NTIA Report 78-6, "A Preliminary Estimate of the Effects of Spread Spectrum Interference on TV," by John R. Juroshek.) Also shown on Figure 1-4 is the FCC recommended protection ratio for interference to color TV. It would appear from the figure that the interference mechanism of interest is a simple interaction between an amplitude-modulated picture or chrominance signal and the interfering signal. Because the spectral bandwidths of both the chrominance and picture signals are of the order of 2 MHz, a spread-spectrum signal with a lesser bandwidth would be largely unfiltered in the TV receiver and, therefore, should produce interference similar to a conventional FM land-mobile signal. (While it is true that the spectral shape of an interferer can have an effect on the level of interference, this effect is generally of second order compared to the power ratio.) In other words, the interference produced by a constant envelope, spread-spectrum signal (2 MHz bandwidth or less) should be nearly identical to that produced by a narrow-band FM modulated signal of equal power. For spectrum spreads greater than 2 MHz, some additional advantage can be expected because of filtering by the video and IF circuits.

A limited set of laboratory measurements was made to check this conclusion. In the tests, FM interference from a conventional LMR FM generator was set at a recorded level and added to a TV signal received on a laboratory antenna and viewed on a 19-inch portable color TV. The test subject was then asked to adjust the attenuator of a spread spectrum signal to get a "comparable" level of interference. The subject could switch between the FM and SS interference as often as he desired to compare the interference.

Figure 1-5 shows our theoretical estimate of the potential for interference of SS to TV as a solid line. The shaded area, for bandwidths greater than 2 MHz, shows the uncertainty or variability due to different filtering characteristics of TV receivers. The points on Figure 1-5 show the median value for nine observations by three observers, and the bars through the points are the ranges of measurements with the highest and lowest points removed.

Considering the small sample and the range of values shown in Figure 1-4, the measurements confirm the theoretical estimates. This is a very useful result, because much is known about the interference of conventional FM LMR to TV. This available knowledge can be applied to analysis of interference of spread-spectrum LMR signals of the same total power, as long as the SS bandwidth is less than 2 MHz. If the bandwidth is greater than 2 MHz, Figure 1-5 can be used to estimate the power that is to be compared with FM interference.

The objective of the second Spread-Spectrum Land-Mobile Radio Systems project was to define and establish the conditions under which spread-sprectrum land-mobile radio (SS LMR) systems can operate and determine the spectrum efficiency of such systems relative to conventional FM LMR. A service consisting of multiple independent networks, like the business land-mobile radio service, was analyzed. The systems were assumed to be operating in an urban environment, transmitting voice signals with a modulation bandwidth of 3 kHz. A network consists of a base station with its associated mobiles, and the service contains many networks.

The analysis shows the following:

(1) Because an SS LMR network uses a channel 100 to 1000 times wider than a conventional FM LMR network with 25 kHz spacing, there must be at least 100 to 1000 times as many SS

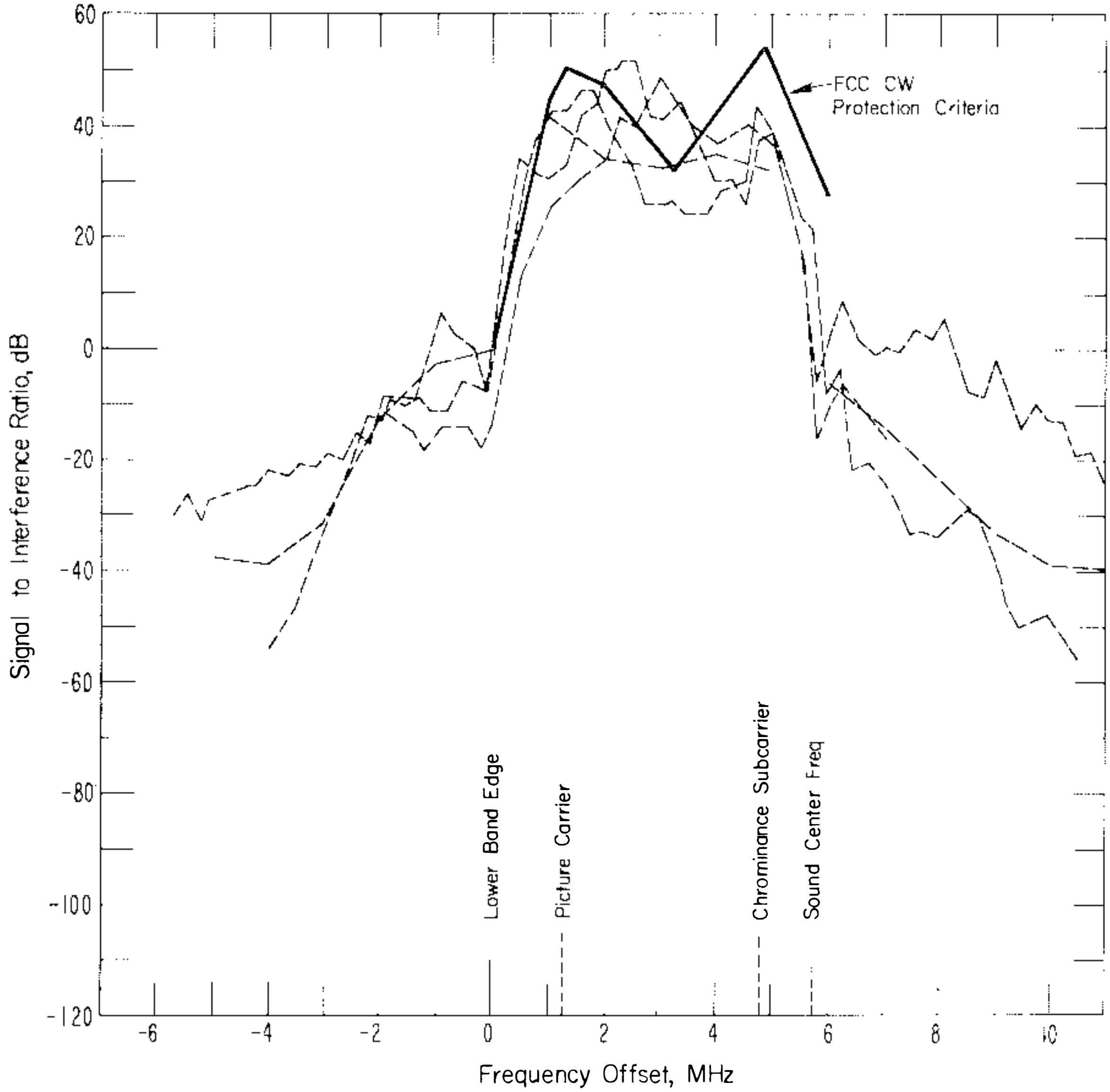


Figure 1-4. Measurements of minimum signal-to-noise ratio required for acceptable performance of TV interfered with by FM interference (dashed lines) and FCC-recommended protection ratio (solid line).

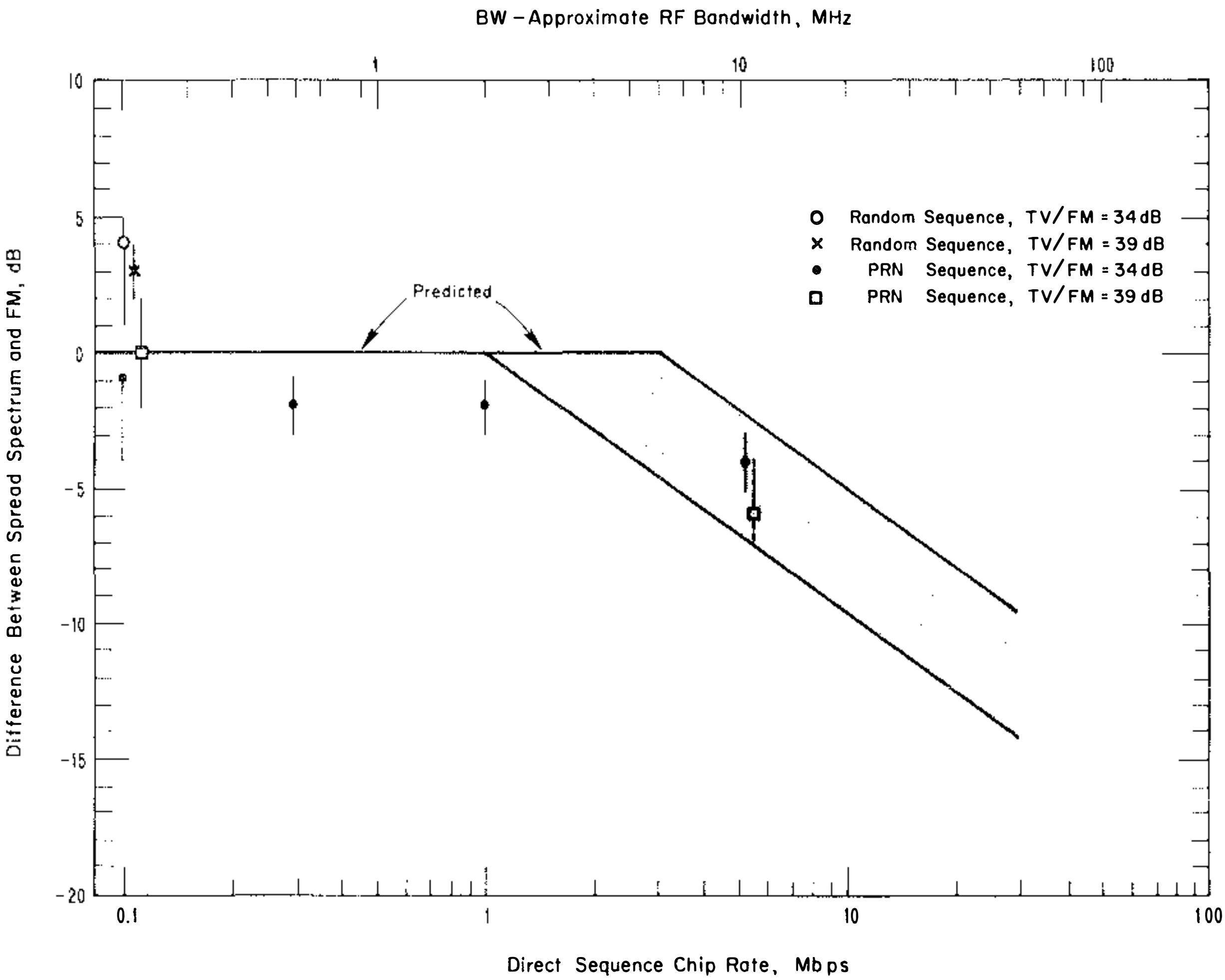


Figure 1-5. Estimates and measurements of interference potential of a spread-spectrum signal compared to a narrowband FM LMR interferer.

networks operating on a channel for comparable spectrum efficiency.

(2) An SS LMR service with multiple independent networks must be duplex; that is, the base stations and mobile stations must operate on different channels. Otherwise, an interfering base station will black out a wanted transmission from a mobile to another base station.

(3) In an area near a base station antenna, mobiles from another network receive unacceptable interference from the base station. The radius of the area is proportional to the separation between the base station antennas. To avoid having many areas blacked out, all base station antennas must be located near each other so that they can share the blacked-out area. It is best if the base station antennas are all located on a single tall building or tower.

Under these conditions, the probability of successful communication of a given quality is given by

$$P(\text{communications}|m,U) = \sum_{k=0}^{m-1} P(S/I \geq R|k)$$

where: P(A|B) means "probability of A given B," m is the total number of networks in the service, U is the total number of message hours per hour for all base stations, R is the required input signal-to-interference ratio, and k is the number of stations transmitting at a given time. The probability, P(k|U), was computed using queueing theory, and $P(S/I \geq R|k)$ was computed using the probabilistic Trade-offs Program described in last year's annual report. Table 1-5 shows the probability of communications as a function of U and R for large m. This table can be used to compute the number of SS LMR networks that could operate successfully in an exclusive SS LMR band.

As an example, assume that we have 3 MHz of bandwidth for the service and want to provide an output S/I = 10 dB with probability 0.97. Suppose that the average network has five mobiles, and they transmit for an average of five minutes per hour. At the normal FM LMR channel spacing of 25 kHz, 24 networks would each have their own exclusive channel with perfect reliability under the assumptions of Table 1-5.

On the other hand, suppose that all 24 networks were assigned to one SS channel. Then U would be 10, using the definition of U in Table 1-5. The maximum processing gain for the SS system would be 10 log (3 MHz/3 kHz) = 30 dB; so R = -20. The reliability from Table 1-5 is only about 0.51. For the spread spectrum system to have a reliability of 0.97, we must cut U to 0.5--a factor of 20. That is, in this case, conventional FM could provide 20 times as many users with the desired reliability as SS LMR in a fixed frequency band and geographic area. Frequency Modulation is therefore much more spectrum-efficient.

An approximate analysis to be included in the final report shows that, under simplifying (but plausible) assumptions, the spectrum efficiency of SS LMR systems is proportional to $(\text{SS bandwidth})^{-a}$, where a is between 1/3 and 1/2. This shows that using a bigger processing gain (larger bandwidth) would make the spread-spectrum LMR system even less spectrum efficient.

We conclude that spread-spectrum modulation is not as spectrum-efficient as FM LMR in a land-mobile radio service containing multiple independent networks.

The compatible SSB/HF Broadcasting study was undertaken at the request of the Federal Communication Commission (FCC) to provide technical advice in preparing for the general World Administrative Radio Conference (WARC) to be held in 1979. In view of the extreme congestion in the HF Broadcasting bands, conversion from the present double sideband (DSB) modulation to single sideband (SSB) modulation would be desirable to achieve increased spectrum efficiency and minimize some kinds of interference and distortion. The ITS was tasked to consider two approaches toward this end: (1) the use of Compatible Single-Sideband (CSSB) techniques as an intermediate step; and (2) spectrum division between DSB and SSB modulation, with the SSB portion gradually expanding until complete conversion to SSB is achieved.

Two systems of CSSB were considered, both of which are based on the principle that a single sideband signal with an undistorted envelope can be formed from a signal with three components as follows:

$$E = \zeta \sin 2\pi ft + a \sin 2\pi (f+F)t + (a^2/4\zeta) \sin 2\pi (f+2F)t$$

Table 1-5. Probability that S/I ≥ R Given that at Least One Transmitter is on. Mobile-to-Base Transmission in Urban Areas

R	.25	.5	1	2	3	4	5	10	20
-30	.995	.991	.981	.959	.937	.910	.886	.784	.64
-27	.993	.987	.973	.941	.908	.874	.843	.711	.55
-24	.990	.981	.961	.916	.871	.827	.786	.633	.46
-21	.987	.973	.945	.886	.814	.773	.723	.544	.37
-18	.982	.964	.926	.849	.776	.710	.652	.456	.29
-15	.976	.951	.902	.805	.717	.640	.574	.372	.21
-12	.968	.937	.875	.758	.654	.567	.496	.294	.15
- 9	.960	.921	.845	.705	.587	.492	.417	.223	.11
- 6	.950	.902	.810	.648	.517	.421	.342	.164	
- 3	.940	.883	.776	.592	.452	.350	.276	.118	
0	.930	.864	.741	.537	.390	.288	.218	.082	

Notes: Assumes that the probability that S/I ≥ R is one if exactly one transmitter is on.

All bases near the center of a circle with radius 30 km.

Mobiles are randomly located in the circle.

Table was computed for radio frequency of 150 MHz, base antenna height = 200 m, mobile antenna height = 1.5 m; but should be correct within a few percent for frequencies between 100 and 1000 MHz; base antenna heights from 50 to 400 m, and mobile antenna heights from 1 to 3 m.

$U = (N\ell/60)\,m$, where N is average number of transmissions per hour by an individual transmitter, ℓ is the average length of a transmission in minutes, and m is the total number of transmitters.

Values in table assume that $U^m/m! \ll 1$. This is true if $m > 3U$.

where

- f = RF carrier frequency
- F = modulation signal frequency
- a = modulation depth
- ζ = a function chosen according to the desired implementation, $0<\zeta<1$.

As can be seen, in the theoretical case the bandwidth of the CSSB signal is the same as for DSB signal (i.e., 2F); however, by a judicious choice of the functions and because the energy content, and thus the modulation depth, for higher frequency components in the normal broadcast material is low, a practical broadcast signal with a bandwidth of less than 5 kHz can be achieved with acceptably low distortion.

Consideration of various aspects of practical application to relieving the congestion in the HF broadcasting band led to the following conclusions:

(1) CSSB would allow some improvement in spectrum efficiency, however, the improvement is less than achievable with SSB, due to the high energy density in the CSSB signal and limitations in present-day receiver designs (the major purpose of using CSSB as an interim step is to avoid obsoleting present-day HF broadcast receivers);

(2) CSSB will not spur development of low-cost receivers with acceptable quality SSB capability, as CSSB does not gain in any way from SSB detection techniques, unlike AM DSB, which can benefit from such techniques in cases of interference on one sideband only;

(3) Acceptability of spectrum (band) division between DSB and SSB is mostly a non-technical issue; the principal and serious objection is the lack of low-cost receivers with acceptable quality SSB capability--thus broadcasters operating in the SSB portion would, at least initially, be faced with a very limited audience.

SECTION 1.3 ADVANCED INSTRUMENTATION AND SPECTRUM MEASUREMENTS

Needs for more realistic estimates of how the spectrum is really used generate requirements for instrumentation that is more accurate, faster, and more economical. In some cases, the requirement is for new types of measurement. In this section, we describe several kinds of instrumentation that share computer control and digital recording as common features. The first group of instruments provide powerful, computer-controlled capabilities mounted in vehicles for a variety of special uses.

The second approach to instrumentation provides a small package that is very portable, operates with a wide range of existing equipment, and is relatively low cost.

Perhaps the spectrum instrumentation development with the longest history at ITS is the Radio Spectrum Measurement System (RSMS).

This year marks the end of the first five years of operation of the RSMS, a system fully dedicated to gathering measurements of the radio environment for frequency management purposes. This computer-controlled system has been used for a wide range of measurements between 30 MHz and 12 GHz. The measurement system has been incorporated into a motorhome-type vehicle (Figure 1-6), providing an air-conditioned laboratory environment which can be driven to a measurement site--complete with antenna tower, electrical generators, and mobile telephone. The measurement system itself (Figure 1-7) contains a very flexible general-purpose system, augmented by specialized hardware for various radio and radar measurements. The hardware is controlled by a minicomputer programmed in BASIC, which has access to interactive graphics, hard copy devices, digital cassette, floppy disc, and magnetic tape input/output devices. During the first five years, a sizeable portion of the effort has been used in developing suitable measurement techniques, measurement and analysis programs, adding supplementary hardware to the measurement system when necessary to gain improved performance, and generally becoming more efficient at deriving the desired data from field measurements.

A standard set of measurements now includes a survey of usage in the following federal government communication bands: 30-50 MHz, 138-150 MHz, 162-174 MHz, 225-400 MHz, and 406-420 MHz. Radar bands are also part of the standard set

Figure 1-6. The Radio Spectrum Measurement System (RSMS) undergoing antenna calibration at the ITS antenna range.

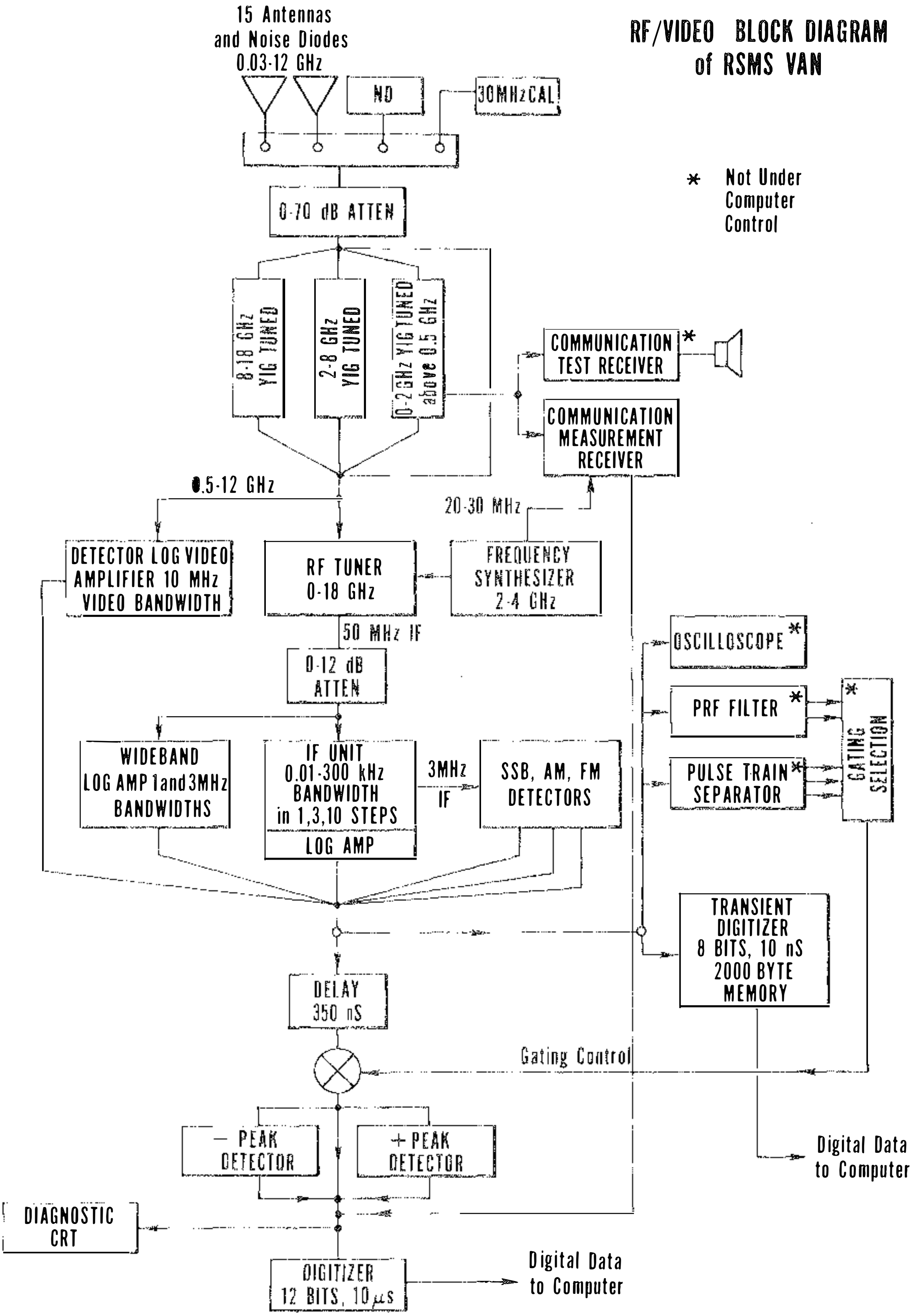


Figure 1-7. Major elements of the Radio Spectrum Measurement System.

of measurements, including the 1030-1090 MHz, 1215-1400 MHz, 2700-3700 MHz, 5250-5925 MHz, and 8.5-10.5 GHz bands. Many or all of the preceding bands have been measured in six large metropolitan areas across the United States. Measurements have been repeated in two of the areas, giving a first look at the growth of usage over a four-year period. In the past year, measurements have been made in ten cities in the eastern half of the U.S., including extensive measurements at Eglin AFB, Florida; Atlanta, Georgia; Norfolk, Virginia; and Washington, D.C.

In addition to the standard usage measurements, the RSMS has often been called upon to help solve particular problems. The following examples will serve to illustrate some of the system's special capabilities. We expect that the RSMS will continue to respond to requests for special assistance, especially when the capabilities of the RSMS can be applied with a marked advantage over less elaborate systems.

- The emission spectra of many different types of radars have been measured as part of an effort to determine trade-offs between various techniques of spectrum conservation in the radar bands. These measurements have taken the RSMS to many parts of the U.S. to observe prototype radars, crowded radar environments, and many older radars in various states of maintenance.

- The RSMS was used in a study of factors causing possible system malfunctions in the very crowded 1030-1090 MHz air traffic control beacon (IFF) band. For this work the RSMS was tied to a large FAA computer which processed air route data from beacon signals, while the RSMS simultaneously measured the signal environment. By correlating the signal environment with computer processing malfunctions, the RSMS was able to provide some data on the causes of some malfunctions, as well as to help estimate the amount of improvement with various fixes.

- NASA asked for help in locating the cause of occasional interference to reception of deep-space signals at its Goldstone communication site. Automatic surveillance programs were devised for the RSMS and operated on a 24-hour/day basis for five weeks. These programs included many features like automatic direction finding to assist in identifying any unknown signals.

Each year has seen some new measurement hardware and software added to the RSMS for the purposes of making better, faster, more accurate measurements. This year improvements were made in two areas, apparently finishing a long chain of evolutionary developments. These areas--antenna system and communication band measurements--will be discussed in the following paragraphs.

LMR Measurement Techniques

Usage surveys are made in several land-mobile radio (LMR) and similar communication bands. In these bands, signals are usually narrow-band voice and the assignments are made according to a formal band channelization plan, with each channel separated from adjacent channels by a fixed amount, typically 25 kHz. In theory, a usage measurement is very simple--one merely has to tune to a frequency and measure how much of the time a signal is there. In practice, it may be fairly difficult to make such a measurement efficiently while assuring that the measured data is accurate. The problems come mainly from the interaction of occasional large signals with the non-ideal characteristics of practical measurement system hardware.

Large signals will cause the hardware to generate spurious responses, called intermodulation products, at frequencies related to the sum and different frequencies of various harmonics of the strong signals. In addition, noise on the measurement system local oscillator will show up as a band of signals adjacent to any strong signal. These spurious responses will be measured by the system as though they were real signals in the environment. Software processing of the measured data to separate the spurious signals from the real signals is often extremely difficult, since the measured data on the large signal population is usually not adequate to reliably calculate quantitative amplitudes for the spurious responses.

Although we attempted to remove spurious signals from recorded data with software processing in some of our early LMR measurements, our philosophy has shifted strongly toward real-time screening and analysis of the data. The cost of taking massive amounts of data with computer-controlled systems is so small that it is often practical to merely throw away the data if there is reason to suspect that it may be contaminated with spurious responses Accordingly, the RSMS measurement techniques now include several precautionary tests which are continually operated on a real-time basis to determine whether data might be contaminated by spurious responses. Fortunately, the most important test is a simple one, since the possibility of spurious responses is directly related to peak power incident on the active components of the receiver.

Figure 1-8 shows many of the precautions which are taken to insure measurement quality. These precautions fall into three main areas: 1. High performance measurement equipment, designed to have few spurious responses; 2. choice of a measurement environment to avoid most strong signals; 3. tests which discard possibly wrong data if 1. or 2. is not sufficient. One should note that all three of these precautions are inter-related compromises. For example if one could build ideal measurement recievers (#1), it would not be necessary to worry about #2 or #3. Similarly, with a sufficiently benign measurement environment (#2), it would not be necessary to employ #1 or# 3.. In the real world, none of the precautions can be made to work sufficiently well to do the job by itself, and all must be used in combination.

Careful selection of a measurement site, avoiding local transmitters, is the first step in assuring a relatively easy measurement environment. Good RF bandpass filters eliminate out-of-band strong signals and notch filters can be used to eliminate a few strong, relatively-continuous, in-band signals. The high performance measurement equipment is a subsystem designed and built by ITS with capabilities in selected LMR bands below 500 MHz (labeled "communications measurement receiver" in Figure 1-7). This specialized system makes accurate measurements over an instantaneous 110 dB dynamic range (-115 dBm to -5 dBm) with an 18 kHz rectangular bandwidth that is down more than 80 dB 25 kHz away. Even in this state-of-the-art system, signals larger than about -40 dBm can cause intermod responses above system noise, which would masquerade as real signals.

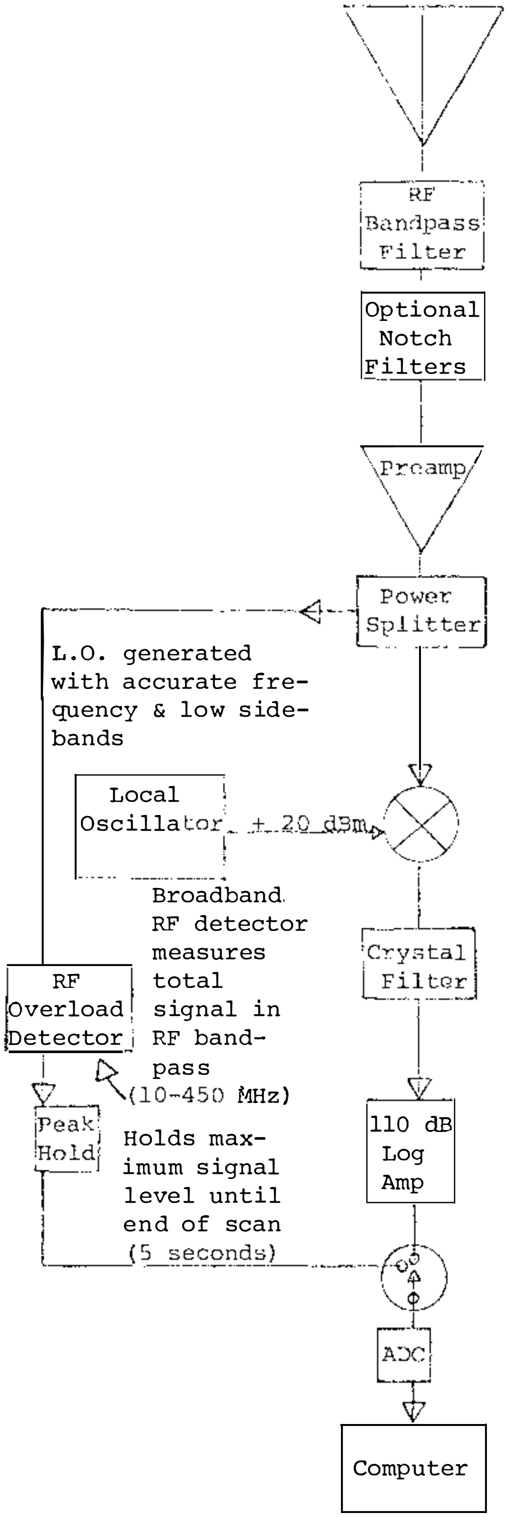
For the occasional signals stronger than -40 dBm, data measured during these periods is simply ignored. Because strong signals might occur on frequencies that are not measured or at times when other frequencies in the band are being measured, one cannot depend on the regular measurement system to provide reliable peak signal power data. We use a separate RF wideband detector, which looks at the entire RF bandpass all the time, assuring that no strong signals will be missed. To simplify the measurement software, the peak value of a signal during a five-second scan is held in a peak detector and measured only at the end of a scan. If a strong signal is seen, all of the data for that scan is deleted.

This combination of hardware and software has allowed us to gather uncontaminated data at many sites which would have been unsuitable for measurements with a less capable system. In a recent series of LMR measurements, for example, almost 25% of the data was deleted because of strong signals, but we believe that the data which was retained is completely free of spurious responses and accurately represents the signal environment.

Antenna Systems

A second area of improvement is the RSMS antenna system, which has been modified to allow considerably more effective direction-of-arrival measurements on unknown signals (Figure 1-9). The RSMS was designed originally with 1-12 GHz cavity-backed-spiral (CBS) antennas and .15-4 GHz conical helix antennas in sets of four (see Figure 1-6). Since these antennas typically have 70-90^o beamwidth, the set of four could be aimed with 90^o between each antenna to give fairly complete coverage for 360^o. Two sets of four were used to get right-hand and left-hand circular polarization. These antennas have served well in our earlier measurements and gave a very primitive direction-of-arrival capability (by noting which antenna received the signal best).

The RSMS also had a roof-mounted El-Az pedestal carrying a 36", 1-12 GHz dish antenna suitable for more precise direction-finding, as well as to isolate a signal for more detailed analysis. The dish was very useful, but clumsy, turning only at one very slow rate (1^o/-second) and turning only $\pm$ 200^o before needing to be stopped and reversed. In addition, its position on the roof of the RSMS was often



Antenna site chosen with care, away from local transmitters, but near electricity, telephone, roads, with good coverage.

Bandpass filters remove all signals outside band of interest, minimizing number of strong signals.

Notch filters used inside bandpass to eliminate a few local signals, if necessary.

Wide-dynamic-range preamplifier increases system sensitivity with minimal decrease in overload levels.

Power-splitter provides signal for RF overload detector.

High level mixer and + 20 dBm L.O. reduce spurious responses.

18 kHz BW crystal filter is more than 80 dB down 25 kHz away, reducing adjacent channel response.

110 dB range log amplifier allows simultaneous measurement of large and small signals.

Samples maximum signal at end of each scan to determine if data is good.

ADC makes 40 measurements on each channel, which are processed to eliminate impulsive noise.

Controls system, analyzing data in real time after determining that data contains no spurious responses.

Figure 1-8. Special design precautions to insure high quality measurements.

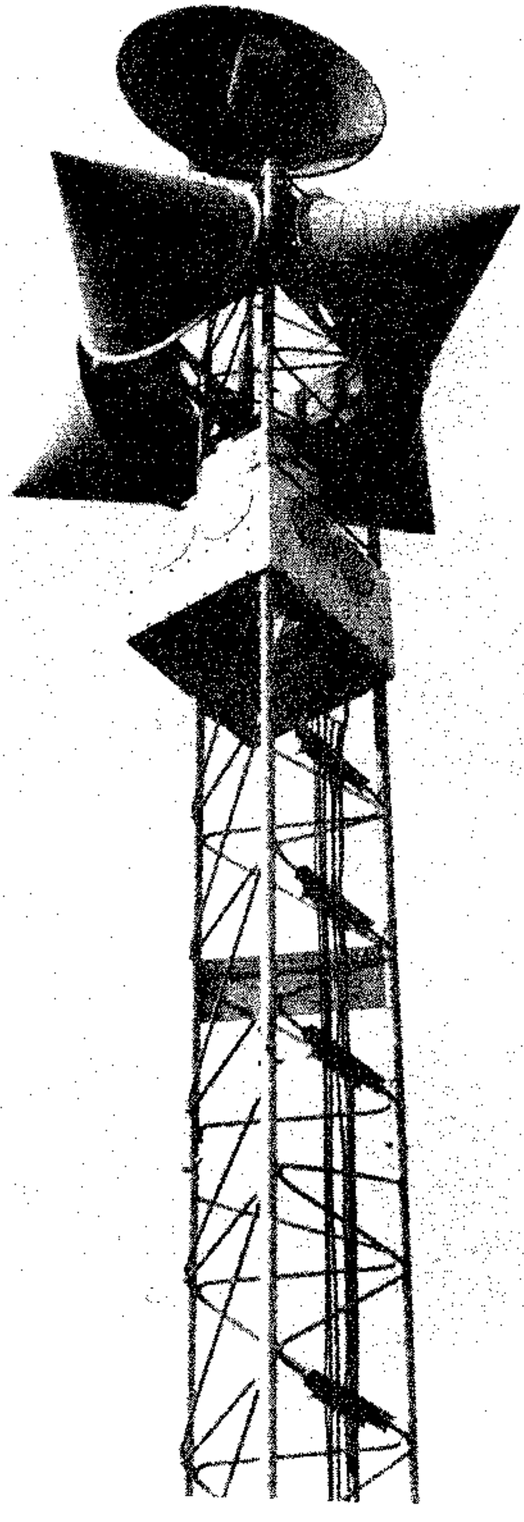


Figure 1-9. RSMS antenna array.

below the height of nearby buildings, trees, etc., which blocked its view in several directions. Many signals disappeared before this slow and uncertain direction-finding process could be made to give an answer.

Recent modifications to the RSMS antenna system use the cavity-backed-spiral antennas for instantaneous direction-finding of moderate precision, supplemented by a fast-moving dish antenna at the top of the tower. Using the CBS antennas to find approximate direction-of-arrival, the operator can rapidly find a more exact bearing using the dish antenna. A PIN-diode switch allows the system to rapidly measure the signal on each of the four CBS antennas in a set. System software controls the switch according to operator-selected parameters, gathering peak and average signal amplitude measured at each of the four antennas. For example, measuring for 10 ms on each antenna before switching to the next and continuing switching for five seconds would reliably measure a radar with a five-second rotation period and any PRF more than 100 pulses/second. The relative amplitude is compared to known receiving antenna patterns, and a direction-of-arrival is immediately calculated. Although the bearing is typically accurate to only 10^{o}, this is often sufficient to identify the source of a signal, and the process is very rapid. An identical procedure could be implemented with the conical helix antennas to extend the fast direction-finding-capability down to 150 MHz. However, the antenna patterns are not as uniform on these antennas, and considerably larger directional errors would be expected to occur.

When greater accuracy is needed, the 1-12 GHz dish antenna can be used. The new antenna positioner allows the dish to be placed at the top of the antenna tower, where it is more free from local obstruction. The dish can be rotated at up to ± 20° per second with a digital readout accurately showing pointing direction. A rotary joint and slip rings allow continous rotation, as well as noise diode calibration through the rotary joint. Though not yet implemented, it is planned to allow the pointing direction to be read into the computer system via an IEEE 488 bus, allowing direct plots of signal amplitude vs. direction-of-arrival.

The RSMS technology has led to the development of a series of related instrumentation systems. One such development is the Air Force Multiple Receiver System (AN/MSR-T1).

This program, under the Air Force Systems Command, involves the development, acquisition, integration, and testing of a first article pre-production multiple-receiver system, designated the AN/MSR-T1. The system is being acquired to meet the electronic warfare (EW) training and testing requirements of the Air Force. The purpose of the AN/MSR-T1 is to provide measurements for evaluating the operational performance of ground-based threat radar systems and the response of automatic and manual airborne electronic counter-measure (ECM) systems.

The EW training exercises are conducted at Air Force ranges equipped with multiple threat systems, which are directed on aircraft that come within operating range. The radar threats emit simultaneous signals at different frequencies in the range 0.5 to 18 GHz. The aircraft, equipped with multiple ECM emitters, responds to each threat emission with a signal containing noise or complex modulation waveforms designed to inhibit/degrade/deceive the target acquisition/tracking capability of the threat radar receiver. Due to cost limitations, the threat radars do not include receivers which could be used to measure and evaluate the airborne ECM responses; therefore, the AN/MSR-T1 is utilized to determine the operational capability of the ECM systems and provide maintenance personnel with reliable and sufficient data to identify malfunctioning equipment.

The program was started in February 1976. The multiple receiver design was completed in May 1977 after extensive testing of new technologies for receivers (wideband 0.5-18 GHz tuners with 500 MHz IF bandwidths) and signal processors (500 MHz bandwidth Bragg cell optical techniques with 1 MHz frequency resolution) which were considered essential requirements for the first article pre-production of AM/MSR-T1. Procurement was initiated and delivery of all hardware was completed in July 1978. Integration was completed in August 1978, and extensive testing is now underway at the USAF/SAC Strategic Training Range (STR) in La Junta, Colorado. Figure 1-10 is an aerial photograph of the SAC/STR site showing the various ground-based threat systems and AN/MSR-T1 in their operational locations.

The operational frequency range of the AN/MSR-T1 is 0.5-18 GHz. The system consists of four 0.5-18 GHz tuners (one with a 500 MHz IF bandwidth and three

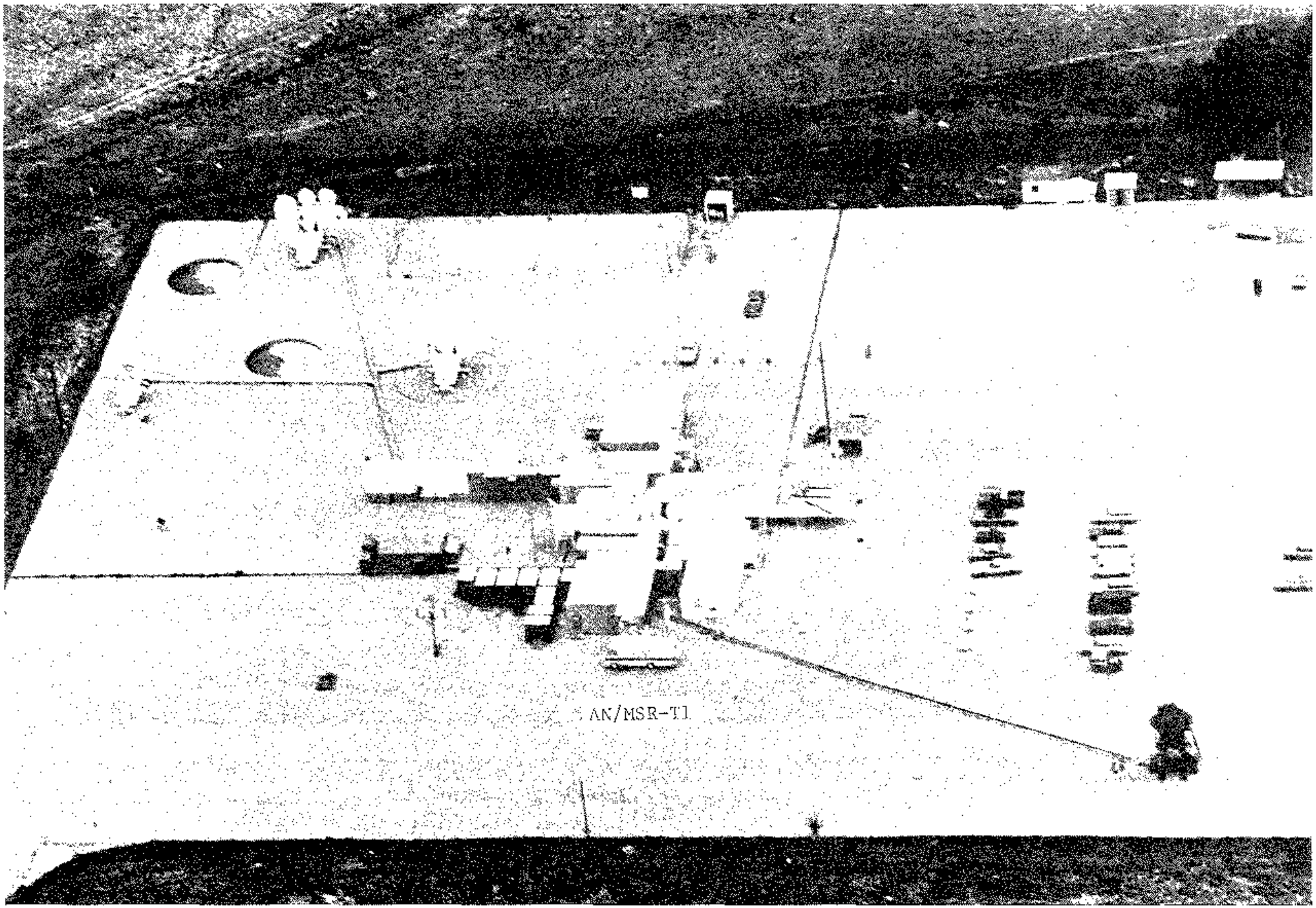


Figure 1-10. SAC Strategic Training Range for Electronic Warfare, La Junta, Colorado.

with a 20 MHz IF bandwidth), a spectrum analyzer receiver (3 MHz bandwidth), appropriate demodulations signal processing units (Instantaneous Fourier Transform optical processor, microprocessors, computers, special function hardwired units) and data/display/storage units. All hardware is configured in a self-propelled vehicle with non-directional and directional antennas mounted on the vehicle roof. The azimuth and elevation position of the directional antennas are computer-controlled using slaved tracking commands from a local threat IFF target tracking system.

The system is fully automated and contains extensive software for command and control of all units and measurement/-analysis routines. The ECM equipped aircraft, upon entry into the range designated airspace, are subjected to various realistic threats which are to be countered by specific signals that are generated to jam or deceive the threat receiver and operator. Since the threats do not have receivers, the AN/MSR-T1 is employed to receive and analyze the airborne response. The ECM signals are evaluated by precise measurements of the time of response, frequency of response, and all signal characteristics. The threat emissions and their effective countermeasure signals are classified, but involve pulsed waveform patterns which produce range gate pull-off and velocity gate pull-off target deception techniques as well as barrage and spot noise jamming modes. Airborne ECM systems are either manual or automatic depending on the aircraft configuration. Data are output to the aircrafts home base for aircrew training proficiency ratings and identification of malfunctioning airborne ECM equipment.

Air Force acceptance testing began in September 1978 and is to be followed by a six-month Air Force user (SAC and TAC) Operational Test and Evaluation (OT&E) period. The purpose of the extensive user OT&E is to identify design problems and finalize specifications for the production of similar units. Emphasis is to be placed on trade-off of capabilities to reduce complexity and cost in production units and still meet the essential use requirements.

A related program is the Air Force Signal Analysis System. This program, under the Tactical Air Command, Tactical Fighter Weapons Center Range Group (TFWCRG), Nellis AFB, Nevada, is to provide an interim electronic warfare (EW) Signal Analysis System (SAS) capability until production units of the AN/MSR-T1 become available in the 1982 time frame. The interim SAS design is based upon portions of the AN/MSR-T1.

Although the TAC/SAS design is similar to the AN/MSR-T1, it will be deployed for different applications in EW test and exercise evaluation. Its primary application is the evaluation of ECM emissions from airborne fighter platforms when stimulted by widely-spaced (several kilomters) ground-based acquisition and tracking radars.

The system is fully automated and is designed to cover the frequency range 500 KHz to 18 GHz and consists of antennas, receivers, computers, signal processors, data display/storage units, and support equipment. It is housed in a self-contained, self-propelled vehicle with internal power sources for remote operation (Figure 1-11). The antenna system includes an electro-optical television tracker system to provide automatic tracking of a target aircraft at a range of 20-25 nautical miles. The receiver sub-system contains two receiver sets. One is a wideband tuner covering the range 500 MHz to 18 GHz with a 500 MHz IF bandwidth, and the second is a spectrum analyzer receiver covering the range 50 KHz to 18 GHz. The wideband tuner works with an IFT optical processor that has a 500 MHz instantaneous bandwidth and frequency resolution of 1 MHz. Its purpose is to scan or monitor all frequency bands of interest to detect onset times of transmissions which are to be measured. A read-out is obtained indicating activity and frequency for hand-off to the spectrum analyzer receiver for detailed signal processing of the detected emissions.

Procurement of all hardware items has been completed and integration is underway. Software routines for command and control are essentially complete, and special software measurement routines for TAC applications are in process. The system is to be compiled by October 1978. Acceptance tests are planned during November 1978 with deployment to the Nellis EW range complex scheduled in December 1978.

Transportable Automated Electromagnetic Measurement System (TAEMS)

TAEMS is a system being developed for the U.S. Army Communications Systems Agency to be used by the Communications Electronics Engineering Installation Agency CEEIA for field measurements to provide a reliable data base for EMC analysis. This includes measurements of radio spectrum usage for the management and engineering of military communication systems and for the evalution of electromagnetic energy levels at various worldwide sites. The emphasis in FY78 has been the operational enhancement of the system including the development of a

Figure 1-11. The TAC/Signal Analysis System (SAS) for electronic warfare (EW) test and exercise evaluation.

remote extension which allows the operation of the down converter/antenna subsystem some 300 feet from the TAEMS.

There are two four-wheel-drive special purpose vans that make up one system. One van is the Data Acquisition Van (DAV) which houses the computer-controlled EMC measurement system. The other van is the Maintenance and Calibration Van (MCV) which houses maintenance, calibration, and other ancilliary equipment. Another FY78 project in the area of application enhancements was to develop the required computer grid interface and operating software to permit automated operation of the equipment in the MCV and DAV. Along with this effort was the development of a voltage tuned tracking filter and saturation detector to augment the basic TAEMS capabilities with respect to preselection and mixer saturation below 500 MHz.

Work has also started on a performance verification test set for the automated receiver system. The test set is to be used to validate key prformance parameters and to periodically calibrate the system. Based on previously established verification limits, a routine will also be configured to indicate to the operator of the system when any of these key performance parameters are out of specification and when corrective calibration or maintenance needs to be initiated.

The data obtained from verification measurements will be a valuable record of system performance and can be compared to subsequent tests to discover trends in overall performance.

Key system performance parameters to be checked are:

1. Tuning accuracy
2. Selectivity
3. Tune/measure time
4. Sensitivity
5. Frequency response
6. Relative amplitude accuracy
7. Intermodulation accuracy
8. Isolation
9. Absolute power calibration

Performance verification test routines will be constructed to verify the performance of various subsystems as well as the overall system. These subsystems include such units as the multimode detector, wideband IF section, power meter and source control.

The instrumentation discussed so far has been large and sophisticated, both in design and operation. A compelling need exists for automation and new technology in spectrum measurements at the other end of the scale - small, lightweight, easy-to-use systems that still provide digital records of the observations and perhaps some degree of automatic control. One such project requires the development of a Manportable EMC Measurement System. This program is in its third year under sponsorship of the U.S. Army, Communications and Electronics Engineering Installation Agency (CEEIA).

During this year, the microprocessor development system was upgraded to include a CRT terminal, a high-speed line printer, and a one-half inch magnetic tape recorder. These improvements allow much easier, faster, and more accurate program development. The industry standard half-inch magnetic tape also will allow compatibility of data between various data analysis systems (computers) such as the CDC 6000.

Current work is being undertaken to improve the field units by providing shock mounted ruggedized chassis. The development system is being improved with the addition of a 1977 ANSI Standard Fortran compiler.

The Automated Field Intensity Measurement System Project is a further effort to provide small, modest-cost spectrum instrumentation. The system will be used to make ordinance and personnel hazards measurements. The field intensity receivers used by the system are automatically calibrated. The operator then specifies frequency scan width, receiver bandwidth, detector, etc. to the system controller. The controller sets the specified parameters, collects the measured data, stores it on magnetic tape, and computes statistics of the collected data. The system has been designed to operate unattended for long time periods (24 hours, one week, etc.), depending upon how often data are to be collected. The major contribution from this project is the development of application software which could be utilized by other agencies having similar ordinance hazards measurement requirements.

The U.S. Army Combat Development Engineering Command (USACDEC) at Fort Hunter-Liggett, California, is increasingly dependent upon radiating telecommunications systems to locate and monitor the locations of participants in mock military exercises. The primary system currently in use is the Range Measurement System (RMS), which utilizes a large number of interrogators and beacons to locate the participants. When an interrogator malfunctions and begins transmitting a continuous tone or when a local or remote source interferes with the RMS operation, the position data can be lost.

To avoid costly losses due to interference, a Spectrum Monitoring Unit is being designed and built which meets the following requirements:

a) capable of observing radio signals over the air at frequencies betwen 30 MHz and 18 GHz with emphasis on the RMS frequencies near 918 MHz;

b) capable of direction-finding for rapidly and accurately locating interfering sources, especially those around 918 MHz;

c) capable of full operation with minimal training by field personnel;

d) capable of remote area operation in a four-wheel drive vehicle by a single operator/-driver; and

e) capable of self-calibration and digitally-controlled operation.

The Spectrum Monitoring Unit will utilize a microprocessor-controlled spectrum analyzer with directional, omnidirectional, and steerable antennas to detect and locate signals or interference. Because the communications and displays are remoted from the operational area of the vehicle to the driver's position, one person will be able to drive the vehicle plus direction find and locate an interfering source.

The Spectrum Monitoring Unit will upgrade the USACDEC spectrum management capabilities for making spectrum occupancy surveys, for improving spectrum utilization, and for insuring that local equipments are operating within specifications and allocations for frequency, bandwidth, etc.

Along with the development of new instrumentation, NTIA/ITS applies this equipment in the measurement of various spectrum properties. A series of laboratory measurements were made in support of a number of other projects, most particularly one to define Spread Spectrum Interference Characteristics.

The purpose of this project has been to study spread-spectrum techniques to determine if they can be efficiently and effectively applied to communications, specifically land-mobile radio; spread spectrum has its origins in radar, navigation, radio location, and deep space communications. An NTIA Special Publication entitled, "Spread Spectrum: An Annotated Bibliography", NTIA SP 78-1, was published to alert interested readers about spread-spectrum reports which pertained to one of the folowing groupings:

1) tutorial
2) applications
3) interference rejection
4) spread spectrum system studies
5) multipath propagation
6) direct sequence/frequency-hopping/chirp techniques
7) modulation/demodulation
8) synchronization/tracking
9) codes for spread spectrum.

One task of the present project is to make measurements of the interference effects of spread spectrum signals on narrow-band FM. The spread spectrum signals are generated by passive surface-acoustic-wave devices and by active pseudorandom noise generators. One concern is whether spread spectrum system can share frequency bands with the channelized FM system.

One of the most comprehensive instrumentation development and measurement projects deals with assessment of the Interference Potential Between CATV and Air Traffic Control Systems operating in the 108-136 MHz bands.

Leakage from a coaxial cable system carrying CATV signals at frequencies used for air navigation and control poses an interference potential studied by ITS for the FCC. A series of flight tests were performed to measure the signal levels radiating from operating CATV systems to aircraft instrumented to probe the airspace for RF signals above the CATV systems.

Figure 1-12 shows an FAA aircraft used in the measurements and Figure 1-13 shows the ITS instrumentation mounted in the aircraft for the measurements.

The signals at 108.05 MHz or 118.0 MHz were introduced at the head end of the CATV system while the aircraft flew a grid pattern over the CATV system and recorded the RF signal leakage with a very sensitive, narrow-band receiver. At the same time, FCC ground crews measured the leakage at ground-level over a grid pattern along the CATV system.

This project has been a joint program in cooperation with the FAA, several CATV operating companies, and the FCC. Ground measurements were made by the FCC Field Operations Bureau. The FAA National Aeronautical Facilities Experiment Center provided flight test aircraft and other support.

The measurement results will be used by the FAA, the CATV industry, and the FCC.

Figure 1-12. Aircraft used for measuring CATV radiated signals.

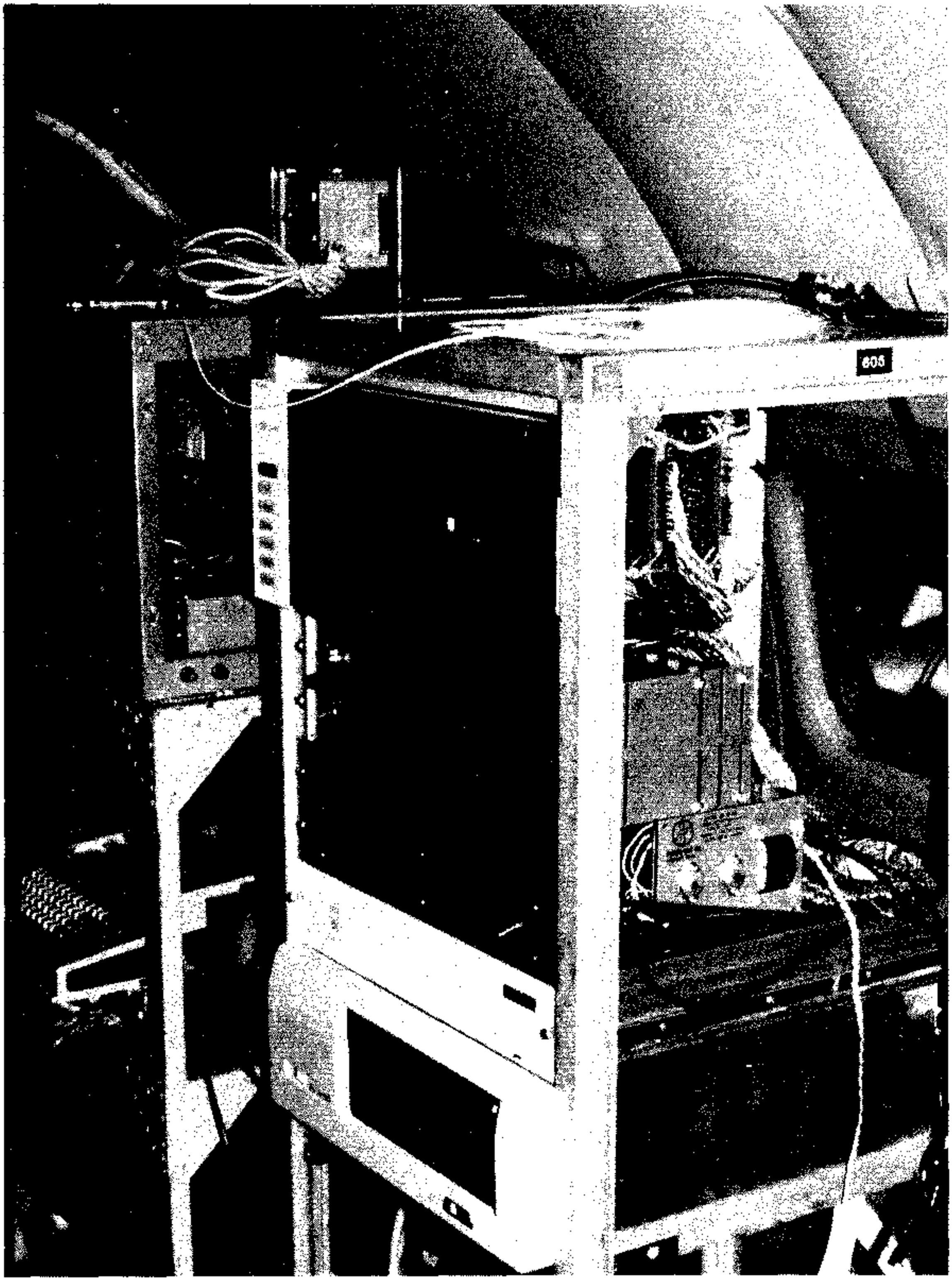


Figure 1-13. ITS developed instrumentation, as installed in flight test aircraft for acquiring data measured as part of the CATV interference evaluation project.

CHAPTER 2. SYSTEMS ENGINEERING AND EVALUATION

The objective of this program subelement is to provide telecommunication system definition, designs, and consulting services to meet users' requirements through measurements, analyses, and evaluations and to develop and disseminate performance criteria. The resultant 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. Section 2.1 addresses work relating to communication services engineering. Section 2.2 presents 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. COMMUNICATION SERVICES ENGINEERING

Some of the systems technology projects relate to established or planned communication services. The services are either offered or leased by mission agencies, and the engineering described here relates to the evaluation, performance criteria, or new technology required for efficient, cost-effective procurement, offering, or establishing these services. Five projects are described; namely: Data Communications, Electronic Message Services, Access Area Digital Switching Systems, AM Stereo Broadcasting, and Maritime Administration Assistance.

Data Communications. There is a growing need within the Federal Government for uniform means of specifying and measuring the performance of data communication systems from the point of view of the digital services delivered to the end user. NTIA's Data Communications project has been undertaken to meet that need through the development of Federal Standards specifying universally applicable, user-oriented performance parameters and measurement methods. The project is being conducted in cooperation with the Federal Telecommunication Standards Committee (FTSC), an interdepartmental standards group organized by the National Communication System under the auspices of the General Services Administration (GSA). After approval, the standards developed under the project will be promulgated by GSA, and will be mandatory for use by all Federal agencies in specifying the end-to-end performance of data communication systems and services. Project outputs are also being coordinated with the American National Standards Institute, which is involved in the development of industry standards for data communication performance; with the National Bureau of Standards, which is responsible for the Federal Information Processing Standards (FIPS) program; and with the Federal Communications Commission, which is considering the establishment of performance standards for common carrier services under its Quality and Reliability Inquiry (Docket 18920).

Figure 2-1 illustrates the overall organization of the Data Communications project. Major project outputs will consist of three related Federal Standards:

> Federal Standard 1033 - defines user-oriented, universally applicable performance parameters for specifying data communication system performance.
>
> Federal Standard "1033A" - will define standard measurement methods to be used in conjunction with the standard parameters in assessing delivered performance.
>
> Federal Standard "1033B" - will define standard performance classes and requirements for interconnection of dissimilar networks.

The Data Communications project is comprised of three major project activities: Technology Applications (consisting of three consecutive phases), Statistical Analysis, and ARPA Network measurements. The Technology Applications activity serves as a focal point for development of each standard. Final results of Technology Applications Phase 1 have been presented in a 2-volume NTIA Report (Seitz and McManamon, 1978; Kimmett and Seitz, 1978). Interim results of this activity have also been presented in two articles published earlier in FY 78 (Seitz and McManamon, 1977a; Seitz and McManamon, 1977b).

The second major Data Communications project activity, Statistical Analysis, is aimed at developing confidence limits and sample size requirements to standardize measurement of the selected performance parameters. Prior work in this area has addressed the measurement of bit error probability, and has produced definitive new methods of assessing the statistical precision of such measurements. FY 78 efforts have extended these results to the block-oriented accuracy parameters (Crow, 1978); and have laid the foundation for the development of confidence limits for the time delay parameters.

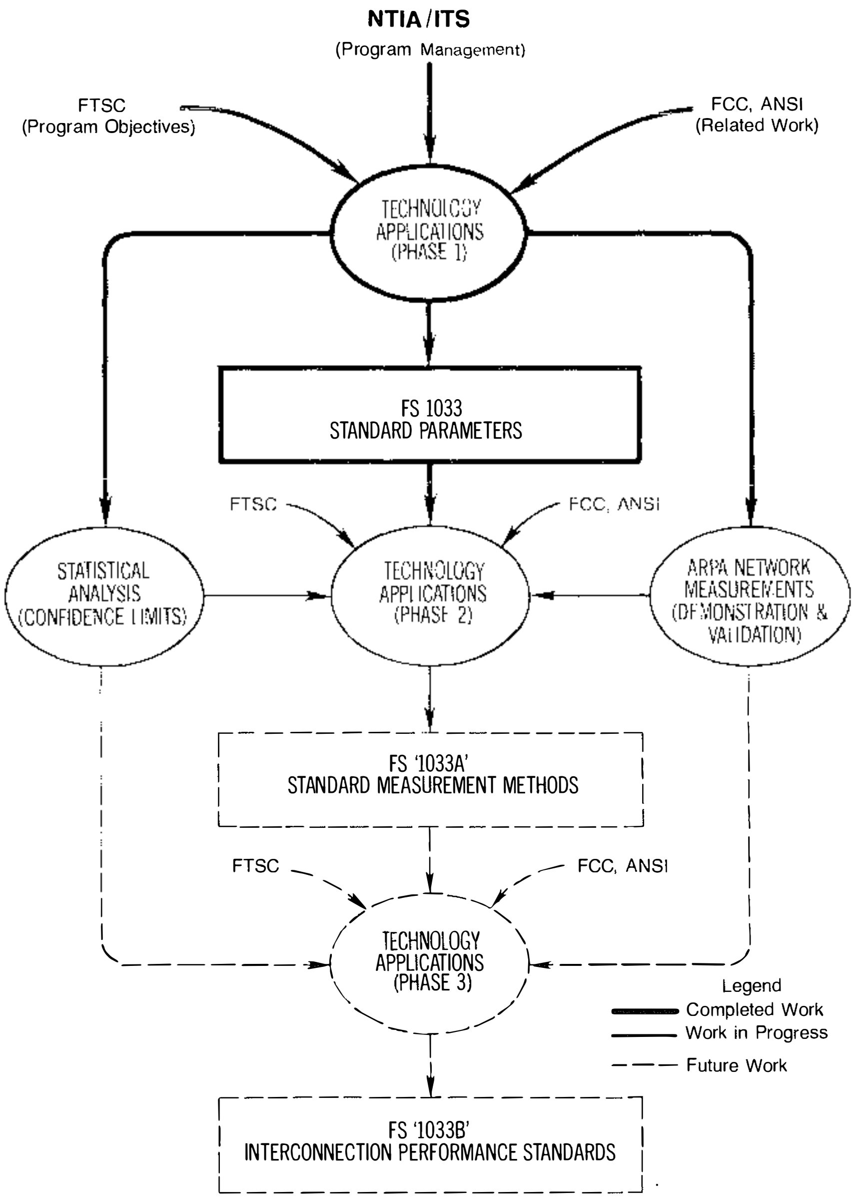


Figure 2-1. Data communications project overview.

The third major Data Communications project activity, ARPA Network Measurements, has been undertaken to substantiate the theoretical results of the first two activities by means of actual network performance measurements. Values for five of the selected performance parameters were measured during this fiscal year (Payne, 1978).

Figure 2-2 illustrates the specific parameters selected for inclusion in proposed Federal Standard 1033. The parameters are organized in a matrix form, to associate each parameter with a corresponding communication function and user concern (or "performance criterion"); as an example, the parameter Access Time expresses performance of the access function relative to the user's concern with efficiency or "speed."

A total of 26 parameters are specified in the standard, including 19 "primary" parameters, 3 "secondary" parameters, and 4 "ancillary" parameters. The primary parameters provide a detailed description of performance by focusing on a relatively short observation period; as an example, the parameter Block Transfer Time expresses the end-to-end delay expected during the transfer of an individual user information block. The secondary parameters provide a more macroscopic view of performance, closely associated with the traditional concept of availability; as an example, the parameter Service Time Between Outages is essentially a sampled measure of the availability parameter Mean Time Between Failures. The ancillary parameters provide a quantitative means of expressing the influence of user performance delay on the primary parameter values; as an example, the ancillary parameter User Access Time Fraction expresses the average proportion of total Access Time that is attributable to user access delay.

To eliminate the possibility of misinterpretation, each selected parameter is defined in two ways:

1. Axiomatically, by reference to a "pie" diagram or sample space representing the possible outcomes of an individual "trial performance" of the associated communication function.
2. Mathematically, by reference to parameter definition flowcharts and equations.

The parameter definition flowcharts and equations provide a detailed procedure for calculating performance parameter values, given a measured sample population of performance trials.

Figure 2-3 is a histogram of individual access time values measured on the ARPA network (Payne, 1978). The abscissa represents total access time in seconds, and the ordinate indicates the total number of access attempts encountering each particular delay. Each measured value represents the total elapsed time between operator typing of a CONNECT TO request (initiating the transaction) and transfer of the first byte of information from user storage to the Network Control Program (initiating user information transfer). This histogram is typical of the results being produced in the ARPA network measurements activity; collectively, these results are demonstrating that the performance parameters specified in proposed Federal Standard 1033 can be measured in a complex, multi-user teleprocessing network.

The real importance of the Data Communications project lies in its substantial cost savings potential. An independent National Research Council committee formed to advise the Office of Telecommunications on program priorities has estimated that a 20% reduction in total Federal data communications costs could be realized through the promulgation of an efficient method of selecting the right system or service for a given user need - a potential savings in excess of $400 million per year by the mid 1980's. The Federal Standards being developed under this project will provide the essence of such a method.

USPS Electronic Message Service System. During FY '78 the ITS has continued with on-going tasks, completed work started during the past fiscal year and undertaken new efforts in the development of an Electronic Message Service System (EMSS) for the U.S. Postal Service (USPS). This project now constitutes Phase VI of the NTIA/ITS continuing support of technical studies for the USPS. The effort continues to provide technical support, analysis, documentation, and review for the EMSS Definition and Evaluation (D&E) program.

The ITS support again provides 1) analysis reviews and recommendations concerning reports and documents developed by a USPS contractor and 2) technical consultation to the USPS regarding telecommunications problems. Attendance and participation at reviews and briefings continues as part of ITS support to the USPS.

In tasking initiated during a previous ITS/USPS agreement, three final EMSS candidates were selected from fifty-two system alternatives that had been identified. Twenty-eight of these candidates were developed by the ITS in cooperation with the USPS. The three candidates will be studied in more detail using a network costing and parametric analysis

FUNCTION	PERFORMANCE CRITERION: EFFICIENCY	PERFORMANCE CRITERION: ACCURACY	PERFORMANCE CRITERION: RELIABILITY	
ACCESS	• ACCESS TIME	• INCORRECT ACCESS PROBABILITY	• ACCESS DENIAL PROBABILITY	USER ACCESS TIME FRACTION
BIT TRANSFER	• BIT TRANSFER TIME	• BIT MISDELIVERY PROBABILITY • BIT ERROR PROBABILITY • EXTRA BIT PROBABILITY	• BIT LOSS PROBABILITY	USER BLOCK TRANSFER TIME FRACTION
BLOCK TRANSFER	• BLOCK TRANSFER TIME	• BLOCK MISDELIVERY PROBABILITY • BLOCK ERROR PROBABILITY • EXTRA BLOCK PROBABILITY	• BLOCK LOSS PROBABILITY	
MESSAGE TRANSFER	• BIT TRANSFER RATE • BIT RATE EFFICIENCY • BLOCK TRANSFER RATE • BLOCK RATE EFFICIENCY	• OUTAGE PROBABILITY		USER MESSAGE TRANSFER TIME FRACTION
DISENGAGEMENT	• DISENGAGEMENT TIME	DISENGAGEMENT DENIAL PROBABILITY		USER DISENGAGEMENT TIME FRACTION
SERVICE CONTINUATION	• SERVICE TIME BETWEEN OUTAGES			
SERVICE RESTORAL	• OUTAGE DURATION			

Legend

- Primary Parameters
- Secondary Parameters
- Ancillary Parameters

Figure 2-2. Summary of selected performance parameters.

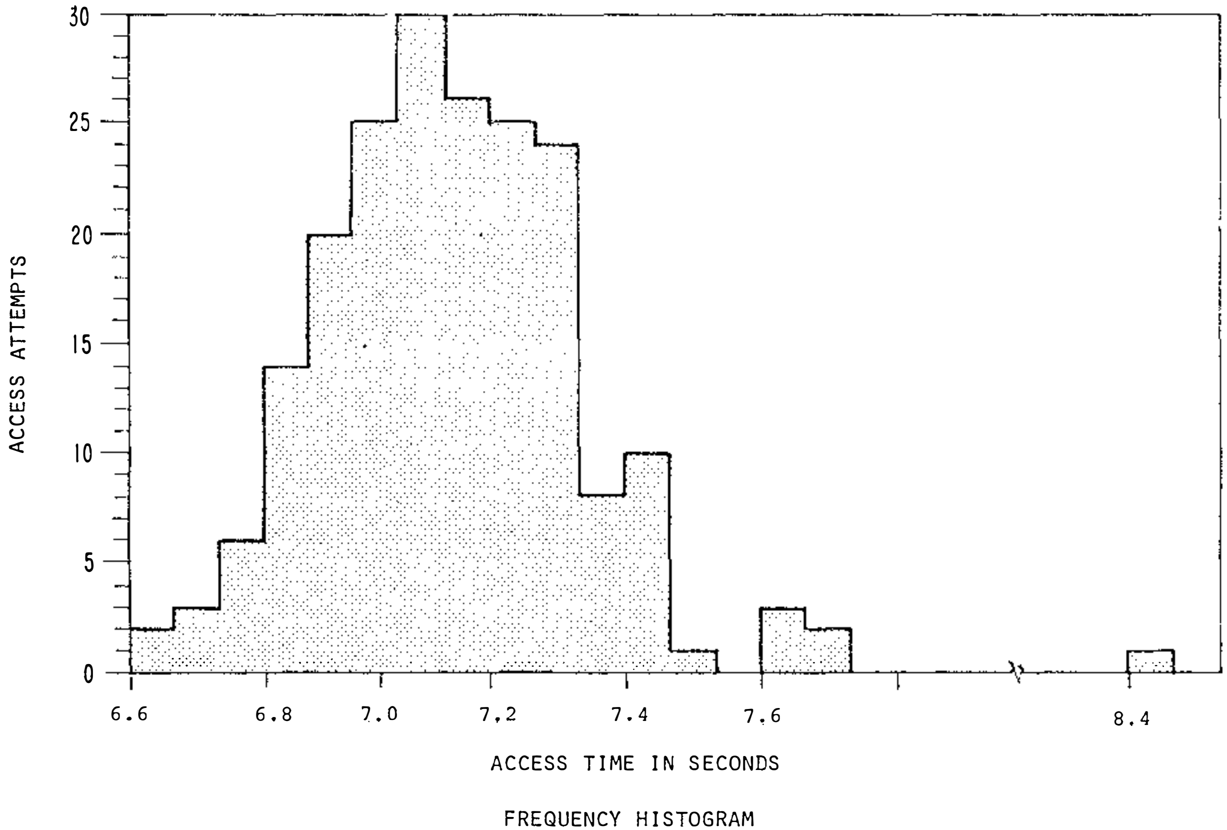


Figure 2-3. Access time histogram.

computer model. Eventual selection of a final EMSS candidate will be based in part on these analyses.

The characteristics of the three candidates that were selected are summarized in Table 2-1a and 2-1b. Start, intermediate, and mature levels of development are shown for candidates A and B, while only the mature level is shown for candidate C. Three of over 90 input parameters to the parametric analysis computer model are shown across the top of the tables while the other headings are for some of the results of the analysis. The three input parameters are Annual Volume (Billions), Number of Stations, and Number of Public Terminals (Table 2-1a). Average Letter Size (Bits) and Size of EMS Staff (Table 2-1a) are computed in the course of the algorithm. Stations are defined as facilities which provide for customer access as well as input, output, and processing capability. Stations may have different input and output conversion capability for magnetic and paper media, and telecommunications.

Public terminals are defined as owned or leased by the USPS and are intended for access to the EMSS by the general public. They are distributed for easy access in post office lobbies, public buildings, shopping centers, and so forth. However, public terminals would only have an input message capability using facsimile and address entry by keyboard. The service would be limited compared to EMSS stations.

The annual message volume along with the number of EMSS stations and public terminals show the growth of EMSS for Start, Intermediate, and Mature candidates. A time frame for this growth is the subject of future work.

Two of the important results are Cost/1000 Messages and Cost/Megabit, both dollar figures (Table 2-1b). In parentheses in those columns we also show the telecommunication costs which are a fraction of the message cost. The message cost computed in candidate A is 2.5¢ per message, while the cost of transmitting that message is approximately 0.4¢. Note that in candidate A message size increases dramatically (more than doubles), the number of stations and public terminals that serve the customer also increase, but the cost per message remains constant during intermediate and mature phases.

The message cost in candidate B ranges from 1.5¢ to double that as message volume goes from 6.5 billion to 35 billion pieces. The telecommunication costs increase from .23¢ to .46¢ per message. Also the investment costs start at $194 million and escalate to over $2 billion. One might pause in considering this candidate. However, the issue of public service enters the picture here. The number of stations increased from 25 to 1500. These stations offer a variety of services such as customer service and faster speed of message delivery. The EMSS then becomes a trade-off between costs (hidden and apparent) and customer service and convenience.

Other work concerned itself with an accuracy-cost study of the EMSS which must begin with the message as it leaves the sender and ends with the message as it reaches the recipient. Sources of inaccuracy for digital data such as telecommunications and magnetic media, as well as paper media were taken into account. The sources included message error at input, output, and as the message proceeded through the system. Accuracy, cost equations and a computer program that implements cost-accuracy trade-offs are reported in OT Technical Memorandum 78-248, "Accuracy-Cost Study for the USPS Electronic Message Service System" by M.J. Miles.

Another contribution was the resolution of message size conversion factors used in the EMSS parametric analysis computer model. The number of bits per message is determined by factors such as the message origination and destination (e.g., business-government, household), message function (e.g., transaction, correspondence), address, and alphanumeric and graphic characteristics.

Under current contracts with the USPS, the ITS is involved in 1) Development of EMSS Planning Factors and 2) EMSS Network Planning Support. These are described here.

The development of EMSS planning factors involves systems and service planning as follows.

1) Development of System Planning Factors. Necessary plans, planning factors, and support data for the EMSS study are being provided. Assistance is being given to the USPS in the development of a system plan that will lead to a work statement for the EMSS at inception of capability (IOC). An example of systems planning factors involved are the interfaces existing between EMSS stations, existing USPS stations, and USPS customers (Figure 2-4). A viable EMSS requires that these interfaces are compatible. Another planning factor implied in this figure is the terrestrial satellite or hybrid networks

Table 2-1a. 3 EMSS CANDIDATES

CANDIDATE	ANNUAL VOLUME (BILLIONS)	AVERAGE LETTER SIZE (BITS)	NUMBER OF STATIONS	SIZE OF EMSS STAFF	NUMBER OF PUBLIC TERMINALS
A - START	9.9	31,950	76	4,021	917
A - INTER-MEDIATE	19.8	31,960	150	9,177	1,986
A - MATURE	41.6	66,820	360	19,816	3,480
B - START	6.5	29,360	25	1,062	0
B - INTER-MEDIATE	17.6	21,900	360	5,666	795
B - MATURE	35.0	54,500	1,500	22,901	2,427
C - MATURE	24.1	35,750	99	4,142	7,100

Table 2-1b. 3 EMSS CANDIDATES

CANDIDATE	COST/1000 MESSAGES (DOLLARS)	COST/MEGABIT (DOLLARS)	TOTAL INVESTMENT ($ MILLIONS)	TOTAL OPERATING COSTS ($ MILLIONS	PRODUCTIVITY MILLION MESSAGES PER PERSON-YEAR
A - START	25(4)	0.78(0.12)	665	180	2.46
A - INTER-MEDIATE	26(3.35)	0.82(0.10)	1,375	381	2.16
A - MATURE	26(3.52)	0.38(0.05)	2,615	801	2.10
B - START	15(2.36)	0.49(0.08)	194	77	6.12
B - INTER-MEDIATE	26(3.07)	1.20(0.14)	1,335	333	3.11
B - MATURE	29(4.62)	0.52(0.09)	2,260	787	1.53
C - MATURE	21(6.96)	0.59(0.19)	1,580	348	5.82

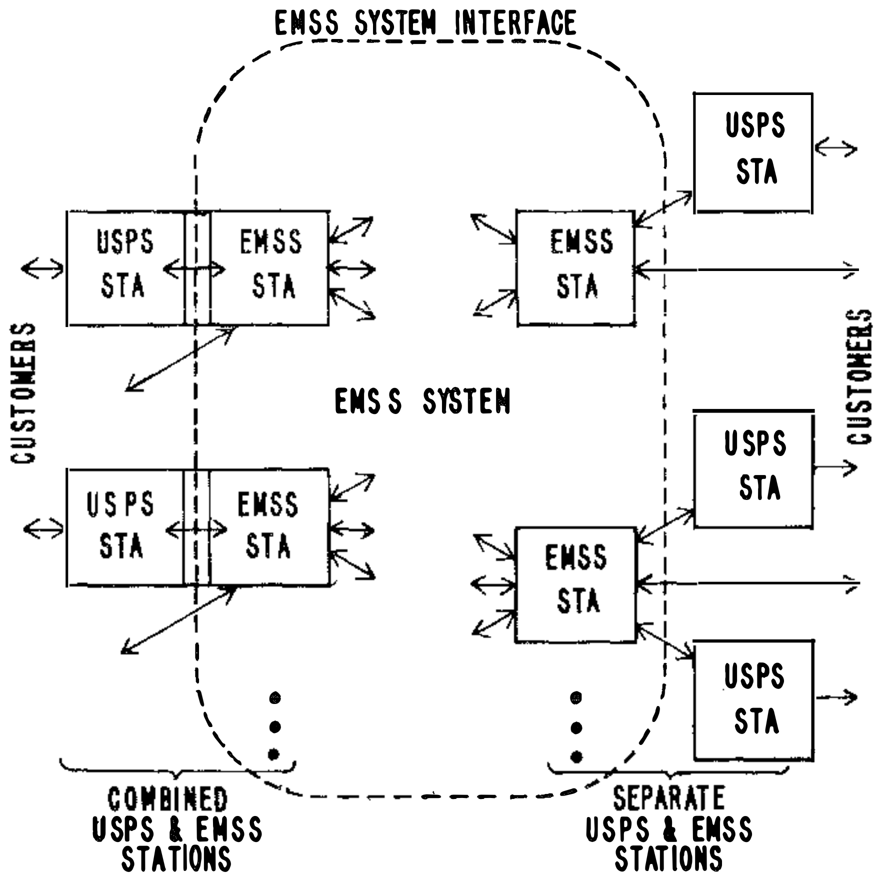


Figure 2-4. EMSS stations as part of EMSS system as an example of planning factors.

required between EMSS stations. That is another project area for the ITS.

2) Development of Service Planning Factors. Extensive definition of services to be provided to the U.S. public by EMSS is taking place. The definition includes applications (e.g., billings, general messages), media characteristics for input and output, speed of message delivery, customer access to EMSS facilities, message quality, enveloping, customer billing, EMSS pricing, prices of services competitive to the EMSS, and customer costs to use the EMSS.

The EMSS network planning support entails the following tasks.

1) Computer Program and Data Base Adaptation. In this task the ITS is undertaking a modification of a contractor-developed network costing and parametric analysis computer model for the EMSS. Implementation will be on the Boulder Laboratories CDC 6600. Involved are the update of the network costing data base as tariffs change for common carriers and domestic satellites, update of equipment costs in the program file, adaptation of the network costing model to calculate costs and channel miles for a minimum distance network, fully interconnected networks, and modification of the computer model to reflect recent requirements.

2) Development of Local/Trunk Network Planning Factors. This task is divided into the technical areas described below.

   a) Attenuation Assessment of 12/14 GHz Bands. This work is near completion with a report entitled "Earth-Satellite Links in the U.S.A." by E.J. Dutton. In this report attenuation modeling predictions for earth-space links are compared with data from the Communications Technology Satellite (CTS) and from radiometric measurements. Then predictions are made at 12.2 and 14.5 GHz for 75 possible U.S.A.-based earth stations pointing to several potential geostationary satellite locations.

   b) TDMA-FDMA Tradeoff and Hierarchy Satellite Network Study. The purpose of this task area is to develop planning factors for EMSS trunk and local communication networks. Work has been started to investigate a two-level hierarchy TDMA-FDMA satellite network using the 4/6 GHz and 12/14 GHz bands. This work will be achieved through a tradeoff study to be developed in this task that permits a quantitative evaluation and choice of the four combinations of multiple access and frequency bands.

   c) Remote Siting Assessment for the 4/6 GHz Bands. The purpose of this study is to develop planning factors for the location and remote siting of EMSS earth stations in the 4/6 GHZ frequency bands. A review is to be made of existing and planned terrestrial microwave locations, satellite earth station locations, frequencies, modulation, and interference coordination distances for the same 75 cities as (a) above, to determine preferred frequency bands for an EMSS satellite network.

Access Area Digital Switching System (AADSS). The U.S. Army Communications Systems Agency (USACSA) at Ft. Monmouth, NJ, continued its sponsorship of ITS work on military local and access area communications. Previously reported ITS efforts have dealt with parametric distribution system studies for the near future. The substance of this background study was reported earlier in OT Report 76-95.

In 1977 the program was extended to include Access Area Digital Switching, a task that has continued through FY 78. Initially, and to some extent even now, there appeared to be considerable uncertainty about the criteria to be used in assessing switching hubs for military bases and access areas. Various features, some service-oriented, some technically-oriented, and yet others identified as performance critera, were described in a October, 1977 Special Report to the sponsor, entitled "Preliminary Evaluation of Hub Alternatives for Access Area Digital Switching." The same Special Report also reviewed currently available switching equipment, including stored program PABX's, store-and-forward message and packet switches, as well as real-time message switching systems. The review paid particular attention to seven implementation alternatives based on PABX technology. The more promising options were singled out for later scrutiny.

NTIA Report 78-2, "Access Area Switching and Signaling: Concepts, Issues, and Alternatives" reflects two topics of work. First, it describes and analyzes an attractive example of a stored program-controlled digital switch. Endowed with interchangeable, analog/digital, line/trunk cards, as well as with remotable concentration modules, the prototype switch shows many advantages for the future access area.

The second half of Report 78-2 deals with signaling functions and methods that are currently in common use for the remote control of circuit switches. Figure 2-5 shows some of the interoffice signaling concepts. Part (a) depicts conventional associated signaling, where individual signaling units are assigned to individual trunks. Part (b) illustrates a more recent, and more economical development, called common-channel associated signaling. Here a signaling line parallels a group of trunks. All signaling lines end in one or two signaling terminals, thus reducing signaling hardware and cost. Part (c) of Figure 2-5 shows the nonassociated version of common channel interoffice signaling (CCIS). This final version appears to be the signaling system of the future for North American telephony.

With the advent of integrated data/voice systems, control signaling and network management involves a complex interplay between all the network elements (terminals, links, mode switches, and separate autonomous subnetworks). New advanced signaling techniques and multi-level protocols are being developed to exercise automatic remote control of processes that in turn control the traffic flows. New service features and system functions involve large commitments in software and associated hardware development. ITS work during the summer of 1978 was concerned with such advanced signaling aspects. Figure 2-6 illustrates the more significant AADSS system interfaces. These interfaces have a variety of transparency requirements for control signaling in the foreseen, 1980-1990, analog-to-digital transition period.

This ITS work on advanced signaling is summarized in a draft report, "Control Signaling in the Military Switching Environment." As of August 1978, the draft was still in review. It is scheduled to be available in October, 1978. Various data communication protocols, such as the bit oriented SDLC, the byte oriented DDCMP, the character oriented BISYNC, plus such packet protocols as CCITT's X.25 (or its equivalent, SNAP) have been considered and assessed in light of AADSS unique requirements.

AM Stereophonic Broadcasting. On July 6, 1977, the Federal Communications Division released a Noticy of Inquiry (No. 9) regarding AM sterophonic broadcasting as a result of two petitions requesting adoption of rules to permit stereophonic broadcasting by AM broadcast stations.

Eventually, five competitive systems were proposed, respectively by Belar, Harris, Kahn, Magnavox, and Motorola. The ITS study focused on aspects which were not thought likely to be adequately treated by others, i.e., the sponsors of the various systems or the National AM Stereophonic Radio Committee (NAMSRC).

In particular, ITS conducted analysis of spectral occupancy, effect on coverage range (both monophonic and stereophonic), and distortion as a result of restricted receiver pre-detection bandwidth and as a result of the effects of skywave and ground wave interference (fading) under nighttime propagation conditions. Spectral occupancy is of importance as it influences the possibility of achieving maximum spectrum utilization of the available broadcast band. Adoption of stereophonic AM broadcasting would stimulate the production of AM receivers with synthesized tuning and more widespread inclusion of, for example, adjacent channel whistle suppression filters, which would de facto preclude any future change of channel spacing. Coverage range (i.e., monophonic and stereophonic S/N ratios as compared to straight monophonic transmission) and distortion resulting from restricted receiver pre-detection bandwidths are, of course, of importance in providing the best consumer service and are also of major importance to the broadcaster. Finally, performance under conditions of nighttime propagation is of importance to many rural listeners who after sundown may be fully dependent on skywave reception. The results of the ITS studies were submitted to the FCC in Initial Comments on Docket No. 21313 in January 1978, and in further Reply Comments in March 1978. At the time of writing, a decision had not yet been taken by the FCC.

MARAD Assistance. Since 1973, ITS has provided a range of technical services to the U.S. Maritime Administration (MARAD), including test facilities and assistance, technical representation in connection with advanced communications projects, communication systems studies, and inputs to the CCIR. Some of the specific efforts in FY78 are described in the following paragraphs.

1) ITS provided the technical input, and was the U.S. Spokesman, at the CCIR Study Group (Mobile

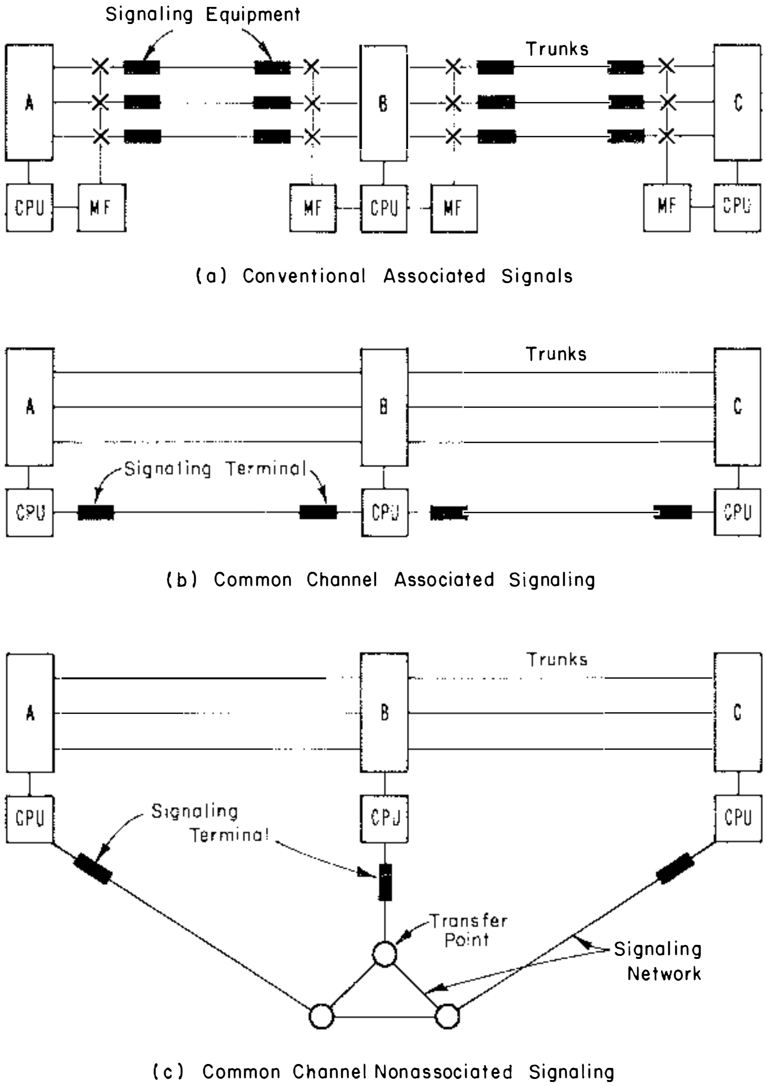


Figure 2-5. Interoffice signaling concepts.

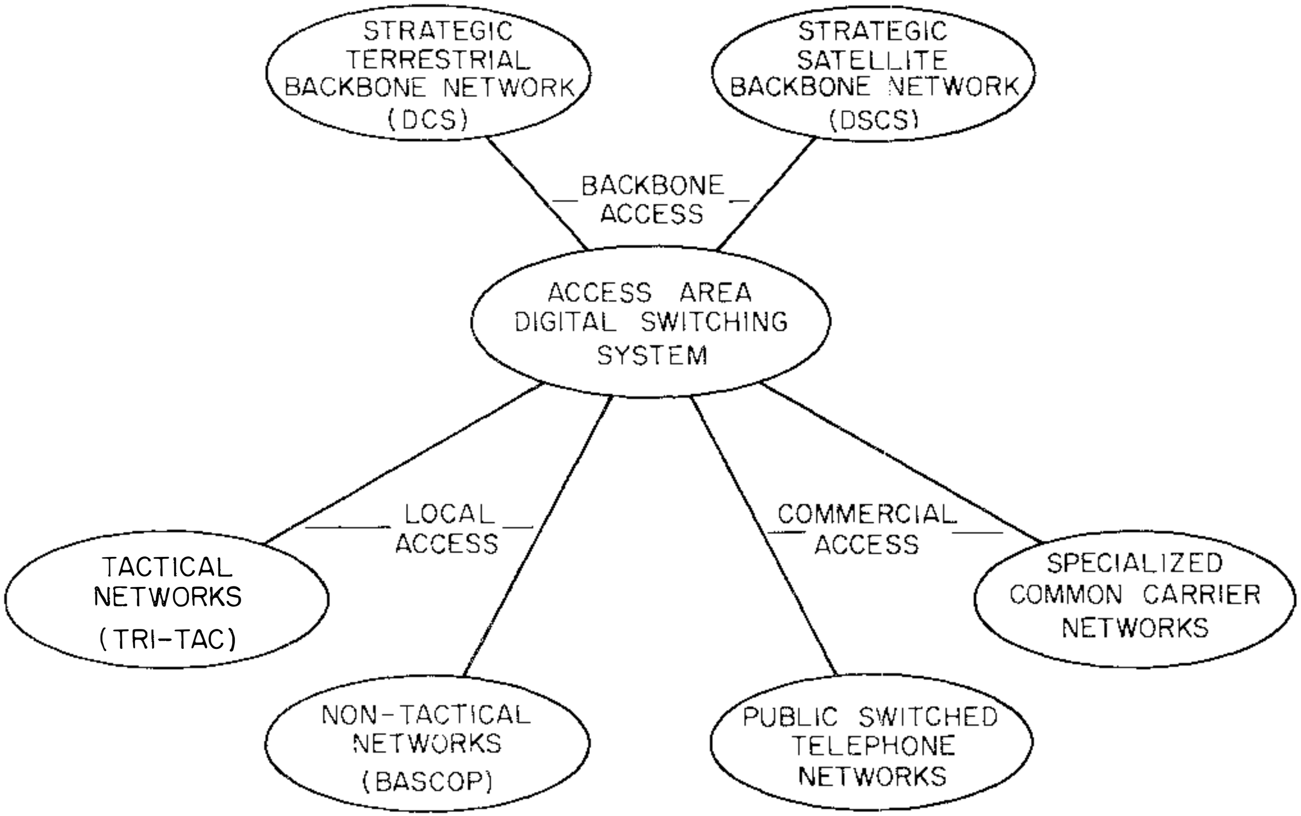


Figure 2-6. Main interfaces in the access area.

Services) Final Meeting in January 1978 on Digital Selective Calling (SELCALL) and Direct Printing for the mobile maritime services. These efforts culminated in the revised Recommendations 493-1 (SELCALL) and 476-2 (Direct Printing) which were approved by the XIVth Plenary Assembly of the CCIR in June 1978. In addition, ITS provided technical consulting to several manufacturers relating to Recommendation 476-2.

2) ITS, as technical representative for MarAd, participates in the work of the Radio Technical Commission for Marine Service (RTCM), Subcommittee for Automated VHF Maritime Mobile Telephone Systems (SC-71) and has been a U.S. member to the CCIR Interim Working Party 8/5 on the same subject. Some of the results of the work accomplished during FY78 is published in NTIA Technical Report 78-4, "Interfacing the Automated Maritime Mobile Telephone System with the U.S. Public Switched Telephone Network". This report details the unique difficulties in the U.S. marine communications field, such as the heterogeneous makeup of communications' providers (i.e., telephone company owned and independent coast stations), regulatory restrictions, insufficient spectrum resources, and economic considerations. It further discusses some of the characteristics of the U.S. telephone network as it affects the automation of maritime mobile public correspondence services and presents concepts for interfacing the radio portion of such services with the public telephone network.

SECTION 2.2. SATELLITE COMMUNICATIONS

The main effort in the satellite communications program area during FY 78 has been on the direct funded project which was initiated in FY 77. On this project, the regulatory, economic, and technological barriers to the development of small-antenna earth-station systems have been studied. Work has continued at a low level on satellite communication related work sponsored by other Federal Agencies. For example, the GOES ground terminal Equipment Certification has continued.

Direct Satellite Communications. The long-term objective of the Direct Satellite Communications project is to contribute toward the goal of increasing the likelihood of satisfactory systems performance as affected by natural, engineering, and economic factors and to accelerate the use of direct communication satellites by lowering barriers to the use of small earth stations and by identifying and consolidating public service sector needs.

The objectives for FY 78 were:

a. through studies and participation in WARC 79 preparations concerning future needs and uses of the 12 GHz frequency allocation, assist in the resolution of regulatory, technical, and economic barriers to the use of small earth stations in cooperation with NASA, other Federal agencies, and U.S. industry;
b. monitor the progress of NASA, PSSC, and other agencies in developing public service sector satellite communication requirements to determine the possible need for a pilot program of high-powered direct satellite communication systems with associated small earth stations; and
c. complete the analysis of technical barriers limiting the earth station antenna size requirements in the interference-free situation.

A study was conducted which addressed some of the past, current, and planned activities relating to the U.S. domestic satellite communications services, both fixed-satellite services and broadcasting-satellite services. Since there is not yet a domestic U.S. broadcasting-satellite service, the primary emphasis was on the fixed-satellite service. The results of this study are reported in NTIA Report 78-9.

The development of the U.S. domestic satellite common-carrier systems was traced and the current status was presented. The general technical characteristics of the current-generation communication satellites were included.

The technical design of these satellite communication systems requires the use of relatively large earth station antennas. Typical minimum earth station antenna diameter for transmitting is in the range of 10 to 15 meters. While for a receive-only TV application, the earth station antenna diameter is typically 4.5 to 10 meters, depending on geographical location and the required TV picture quality.

An important aspect in considering the potential for growth of small antenna earth-station systems is the regulatory and frequency allocation climate in which such systems can develop. The frequency band having the greatest potential for accommodating small-antenna earth-station systems is the 12/14 GHz band. However, if this band develops (as it appears to be developing) in the same manner as the 4/6 GHz band has developed, the small-antenna, earth-station system development will be foreclosed in the 12/14 GHz band also. The future growth potential for satellite communication systems is one of the very important problems that needs serious consideration during preparation for the 1979 WARC.

Some tariff information on the cost of private-line service offered by terrestrial and satellite common carriers was studied. The capital equipment investment requirements for satellite communications is not dependent on the distance between the earth locations being served. However, the tariff rates on file with the FCC are distance-dependent. This distance-dependence of the tariff rates appears to be based on a competitive pricing strategy, rather than on the cost of providing the service.

The study for determining minimum dimensions of earth-station antennas, carried over from FY 77, was completed for various cases of single carrier per transponder. The results of this study were reported in OT Report 78-145.

Covered in this study are FM TV, FDM-FM telephony, multiplexed PCM-PSK telephony, and PSK digital-data transmission. Any other type of signal can be added without difficulty if the need exists for the signal.

Although we have tried to determine actual values of minimum antenna diameters for given types of signals, we have not been able to eliminate all uncertainties in this study. For the reception of a TV signal, we have determined a range of values for the minimum antenna diameter. For telephony signals and digital-data signals, we have calculated sample values that correspond to assumed sizes of the system and assumed values of the satellite EIRP. If more specific values of these system parameters are known, we can narrow the uncertainties.

Actual values of minimum antenna diameter are of the order of 1 m for the reception of FM-TV broadcasts in most places in the contiguous 48 states of the United States, if the broadcasts are done in the 12-GHz band in accordance with the 1977 WARC decision. For multiplexed telephony carrying 60 telephone channels or less, the minimum antenna diameter is about 5 m or less, if the satellite EIRP's of 30 dBW and 40 dBW are available for the 4-GHz and 12-GHz bands, respectively. The same is true for digital-data-signal transmission of 3 Mb/s or less. Except for the FM-TV case, however, the RF bandwidth is only a small fraction of the nominal 36-MHz or 40-MHz bandwidth of commercial-satellite transponders. If a currently available commercial-satellite transponder is to be used, effective methods of its sharing by a number of users must be assumed and the effects on the minimum antenna dimension determined.

In order that more direct users can be accommodated in satellite communications, it is essential that one can estimate costs associated with both earth station and satellites for various services. The results of this study are expected to be useful for such cost estimation.

Preparation in the United States for the 1979 General World Administrative Radio Conference (1979 GWARC) has been in progress since early 1975. These preparations are being conducted by two entities: (1) the Interdepartment Radio Advisory Committee (IRAC) Ad Hoc Committee 144 for the Government sector and (2) the Federal Communications Commission (FCC), by internal planning and solicitation of public comment through the notice-of-inquiry, for the non-Government sector. The ITS studied some technical and economic aspects related to the fixed-satellite and broadcasting-satellite services operating in the frequency range from 2.5 GHz to 14.5 GHz. These services operate in portions of this segment of the spectrum designated for non-Government use in the United States.

This study focused on the technical and economic issues associated with spectrum- and orbit-use planning for broadcasting-satellite and fixed-satellite services in the 2.5 to 2.69 GHz frequency band and in the frequency bands between 11.7 to 14.5 GHz. The key questions addressed are:

- o How should flexibility for the 1982 Broadcasting-Satellite Regional Administrative Radio Conference (RARC) for Region 2 be developed and taken into account in planning for the 1979 GWARC?
- o What new spectrum resources should be planned for the broadcasting-satellite and fixed-satellite services in the 11.7 to 14.5 GHz bands?
- o How can small earth terminals be accommodated?
- o How can hybrid satellites introduce greater flexibility in planning for the 1979 GWARC and 1982 RARC?
- o Why do orbit-division and spectrum-division policies developed in preparation for the 1977 WARC-BS need reexamination prior to the 1979 GWARC?
- o What planning could be done to encourage utilization of the 2.5 to 2.69 GHz band?

- How can high EIRP (effective isotropic radiated power), multiple beam satellites be accommodated below 15 GHz?

These and other questions were reviewed, and recommendations for planning were given to the extent possible.

The results of this study were submitted to the FCC in an informal report and will be published as an NTIA Special Report.

Proposed changes of the ITU Table of Frequency Allocations, based on the above comments, were submitted to the IRAC Ad Hoc Committee 144-I for consideration for inclusion in the U.S. proposals for the 1979 GWARC.

Late in FY 77 a contract was negotiated with TransCommunications Corporation, Greenwich, Connecticut, for a study on the current status of the domestic satellite communications industry. This study includes development of an information data base on domestic satellite, earth-terminal systems. This data base includes a listing of earth terminals, equipment technical characteristics, type of use application, and their interface to terrestrial systems. The contractor final report was completed this fiscal year.

Certification of GOES Data Collection Platform Radios. The GOES satellites are in earth-synchronous orbit for the purpose of monitoring the earth environment. A part of the monitoring is accomplished by relaying information from remote data collection platforms on the earth.

The ITS has an on-going program for certification of the data collection platform radios. During FY 78, performance tests by three manufacturers were witnessed by the ITS certification officer. Results of the tests were submitted to NOAA/NESS.

SECTION 2.3. TERRESTRIAL RADIO SYSTEM PERFORMANCE

This activity is directed toward the design, evaluation, acceptance, operation, and upgrade of existing or proposed systems operated by the Federal Government. The projects generally result in recommendations for system design and/or upgrading as requested by the other Federal agencies. Five tasks are reported, namely: Automated Digital Systems Engineering Model, EFAS/PEP II Program, Aircraft Interference Effects, Lightning Protection Evaluation of Spanish Territorial Command Network (TCN), and Nontactical Radio Networks.

Automated Digital System Engineering Model. The purpose of this project is to develop programs to be used in a desk top computer system which will permit the line-of-sight microwave system engineer to evaluate many design configurations with immediate feedback in terms of system performance and cost trade-offs. The concept of this engineering model is based in a large part on the information and methodology contained in MIL-HDBK-416, which was prepared by ITS under an Air Force contract. The handbook was written several years ago; consequently, emphasis was placed on analog systems (FM/FDM) with little information on digital systems. With the passage of time, many of the original models used to predict path-loss variability and other factors affecting performance have been improved. Much emphasis on this program (sponsored by USACC EED-PED) is placed on adding needed models and updating ones which have been improved.

Seven programs have been developed. These programs make key calculations in the design of line-of-sight microwave systems. The models have the following ranges: bit rates up to 50 Mbits/sec, carrier frequencies from 1 to 40 GHz, and path distances up to 150 km. The programs calculate, tabulate, and plot information about earth geometry, path profiles and ray paths, median basic transmission loss, path-loss variability, equipment gain, link performance, and system performance. Models were chosen based on their wideness of acceptance and the size and type of data base substantiating the model. In order that the design engineer might have immediate access to the calculated results of changing various design parameters, the programs are written for use in an interactive mode by people with no experience in programming.

An example of one of the outputs of Program No. 2 (Path Profiles and Ray Paths) is shown in Figure 2-7.

EFAS/PEP II Program. This program addresses the technical performance characteristics of the Digital European Backbone (DEB) communication system shown in Figure 2-8. The DEB program is directed at the conversion of wideband analog systems to secure digital telecommunication systems. As a portion of the change-over and upgrade, many links are being reengineered. Of particular concern is a 160 km link that is being changed to operate at 8 GHz. A portion of this program was to collect the path variability data to substantiate the engineering predictions.

Data were collected during the period between October 1977 and January 1978. The European fall is punctuated with extensive stationary high pressure zones that cause stable stratification of the atmosphere and thus encourage excessive

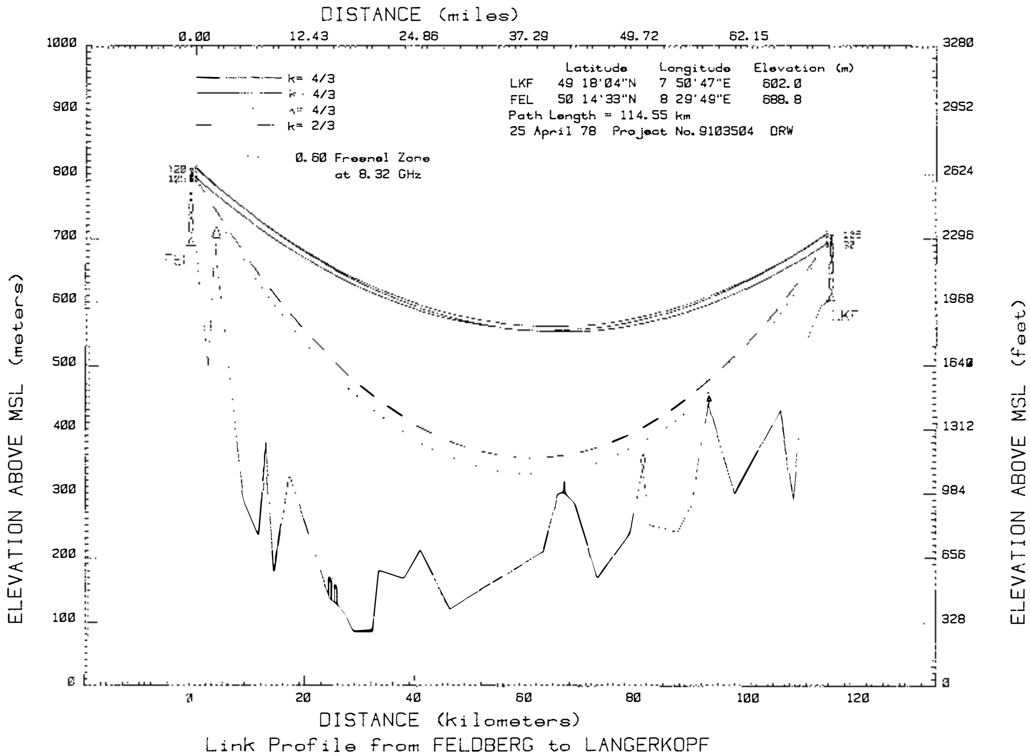


Figure 2-7. Profile plot and ray trace.

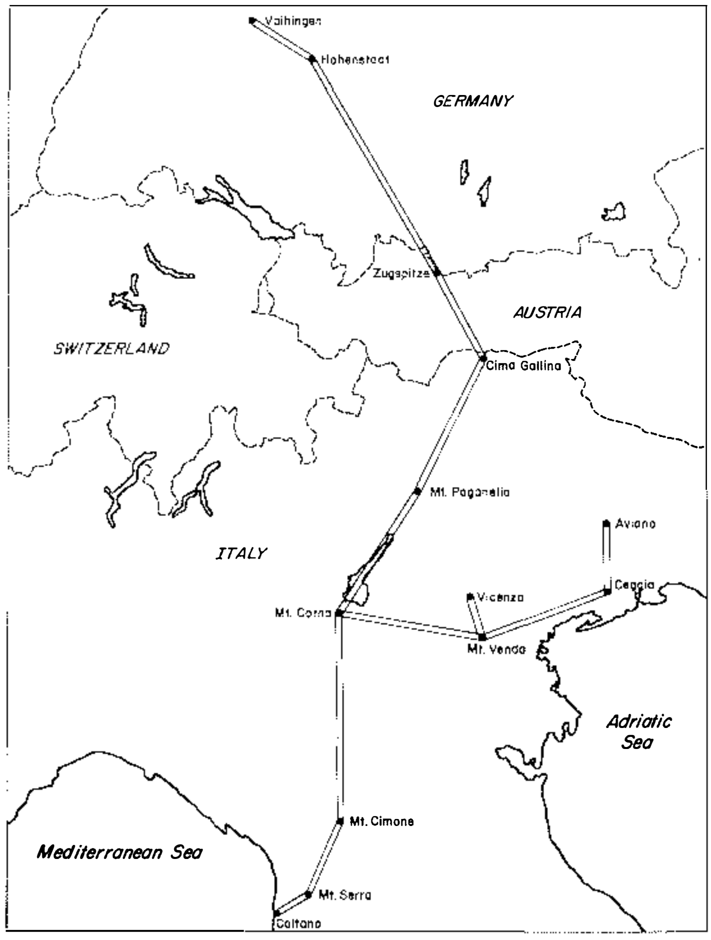


Figure 2-8. Digital European Backbone System, Phase I.

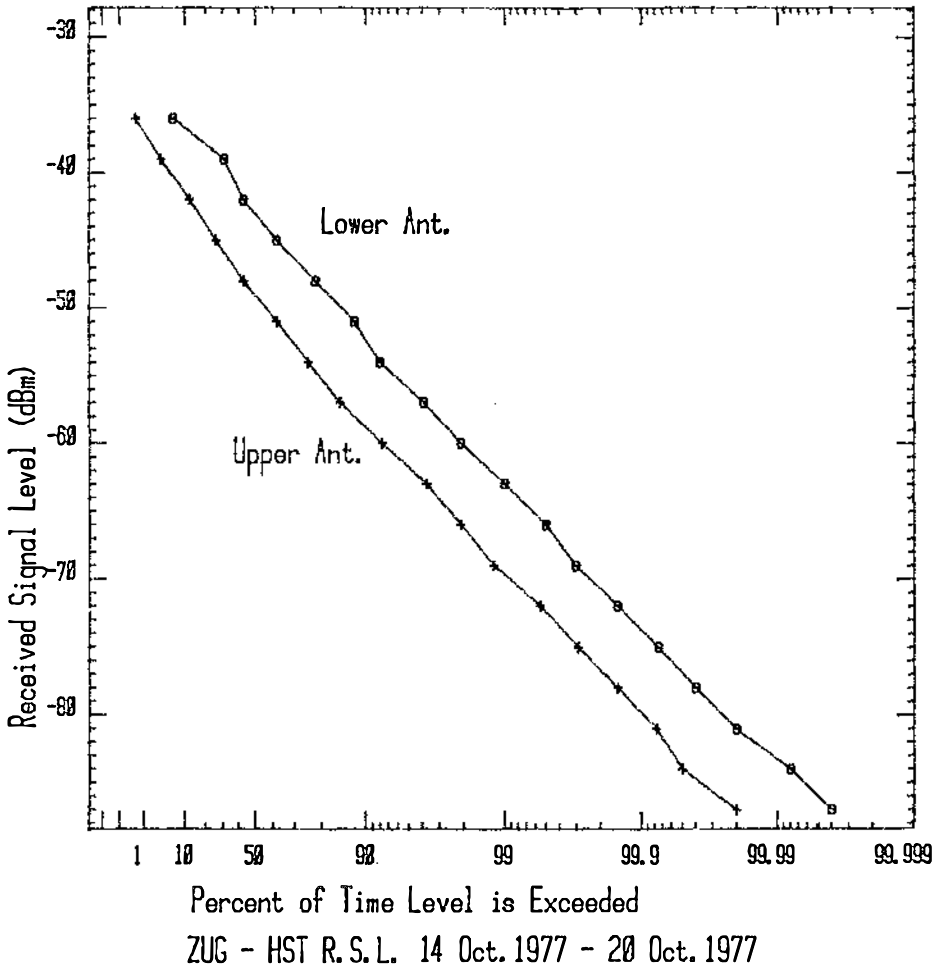


Figure 2-9. Received signal level distribution for 160 km link.

```
212/04:43:45          ***Total  System  Status***          Master:Aviano

     No                               Equipment      Site
   Answer                           Major Minor Major Minor  Parameter

      ** VHN Vaihingen
         HST Hohenstadt                   0            0      RSLB
      ** ZUG Zugspitze
      ** CIM Cima Gallina
      ** PAG Paganella
      ** MCA Mt. Corna
      ** MTC Mt. Cimone
      ** MSA Mt. Serra
      ** CLO Coltano
         MTE Mt. Venda                          0             RSLB
      ** VCA Vicenza
      ** CEG Ceggia
      ** AVO Aviano
      ** FZM Friolzheim

 Enter Command:                                               SYS
```

```
212/04:43:32          HST - Hohenstadt   Alarm / Status       Master:Aviano

Site        -MINOR- Digroup HST-2:CLO-2                     212/0422
            -STATUS-Tower Light Disable                     212/0422
            -STATUS-Rectifier Sharing Load                  212/0422
            -STATUS-Expansion  1                            212/0422
            -STATUS-FAS Test                                212/0422
            -STATUS-Generator Number 1  On                  212/0422
            -STATUS-Tower Light On                          212/0422
            -STATUS-Fuel  Pump  Number 2  On                212/0422
M0175.1-ZUG-MINOR- Standby Mux Fault                        212/0422
            -STATUS-Receiver  A Select                      212/0422
            -STATUS-Transceiver B Disable                   212/0422
M0559.2-VHN-MINOR- B TWT Failure                            212/0422
            -MINOR- Expansion  9                            212/0422
            -STATUS-Receiver  B Select                      212/0422
            -STATUS-Transceiver A Disable                   212/0422

 Enter Command:                                               ALM,HST
```

Figure 2-10. Sample enhanced fault alarm system displays.

microwave multipath fading. The effects of this phenomenon are illustrated in Figure 2-9, detailing the distribution of the received signal level.

Another effort undertaken with the new communication system is the inclusion of an extensive alarm and status remoting system. ITS is preparing a multi-minicomputer system that is intended to control and poll the remote sites to present system conditions in a form most useful to the operator as well as to record all system changes for later analysis. Two of the displays to be used in the system are shown in Figure 2-10.

Another task to be undertaken is the collection of information from other parameters not associated with the alarm system. Among these will be detailed received signal-level data, power system reliability, and subscriber channel block error rate and availability.

Aircraft Interference Effects. Conversion to digital transmission has renewed the concerns about what effects aircraft obstruction of microwave links have on user quality. This is of particular concern where it is necessary to install a telecommunication system that crosses runways and taxiways where the frequency of obstruction may be great.

A limited measurement program was undertaken to determine if a condition existed that could cause excessive error rates on digital systems. Measurements were made at Atlanta and Chicago International Airports where 8 GHz links that crossed runways were already established. Received signal level measurements were made along with monitoring baseband noise on the operating system. A parallel measurement was made using ITS developed equipment to determine the continuous impulse response of the transmission medium.

Measurement results indicate that, during takeoff and landing, aircraft can be the cause of signal level fades to 20 dB, but the baseband noise did not increase significantly. Modern system margin is sufficient to cope with such fades. A typical fade is shown in Figure 2-11 and an obstructing aircraft in Figure 2-12. In Figure 2-12, the transmitting antenna is identified by the arrow.

The impulse response measurements at Atlanta did not reveal any delayed pulses that would indicate excessive multipath nor any pulse distortion which would imply frequency-selective fading. However, slight distortion from taxiing aircraft at Chicago was observed. The implication of this detected distortion is reflected in the possibility of a distorted frequency response within the 15 - 20 MHz passband of a microwave digital receiver. Stated another way, the received spectrum contains some slope in response that could potentially cause distortion in the received data. Little has been done however to correlate this phenomena with system performance.

Lightning Protection Evaluation of Spanish Territorial Command Network (TCN). This project had as its objective the analysis of specific problem areas impacting the performance of the Spanish Territorial Command Network (TCN).

The Territorial Command Network (TCN) is a complex network which utilizes line-of-sight, diffraction, and tropospheric scatter microwave radio links to provide voice, teletype, and high-speed data communications between Army and Navy installations throughout the mainland of Spain and the islands of Mallorca and Menorca. The specific problem areas to be investigated by ITS related to the adequacy of protection against lightning strikes, various electrical transients, and longer term power fluctuations.

After a review of the TCN specifications (U.S. Army Communications Electronics Engineering Installation Agency, SCCC-73003), it was necessary for ITS to measure the ground resistance of several selected sites, to inspect several sites for conformance to the specification, and to measure power fluctuations.

There are 40 fixed sites in the TCN, with most of the sites being in the categories of tactical, terminal, active repeater, and passive repeater. Tactical sites are located on mountain tops and have a high vulnerability to lightning strikes, lightning induced transients, and significant voltage fluctuations since they are at the end of the commercial power distribution system.

A group of 6 TCN sites were selected for detailed study after consultation with the TCN Deputy Project Manager in Spain. Each of the selected sites was visited and a measurement taken of the ground resistance of the site grounding system and, where practical, a typical measurement of earth resistivity for each site was taken. Discussions were held with site personnel regarding lightning- or transient-induced equipment failures. Observations were made concerning air terminal (lightning rod) installation, down conductor (grounding conductor) type, and routing, and whether or not these conformed to good engineering practice as well as the specific codes covering these types of installations. Recordings were taken at each site of the 220/380 3-phase power for periods of 1 to 3 days. These recordings were taken with a commercial power-line disturbance

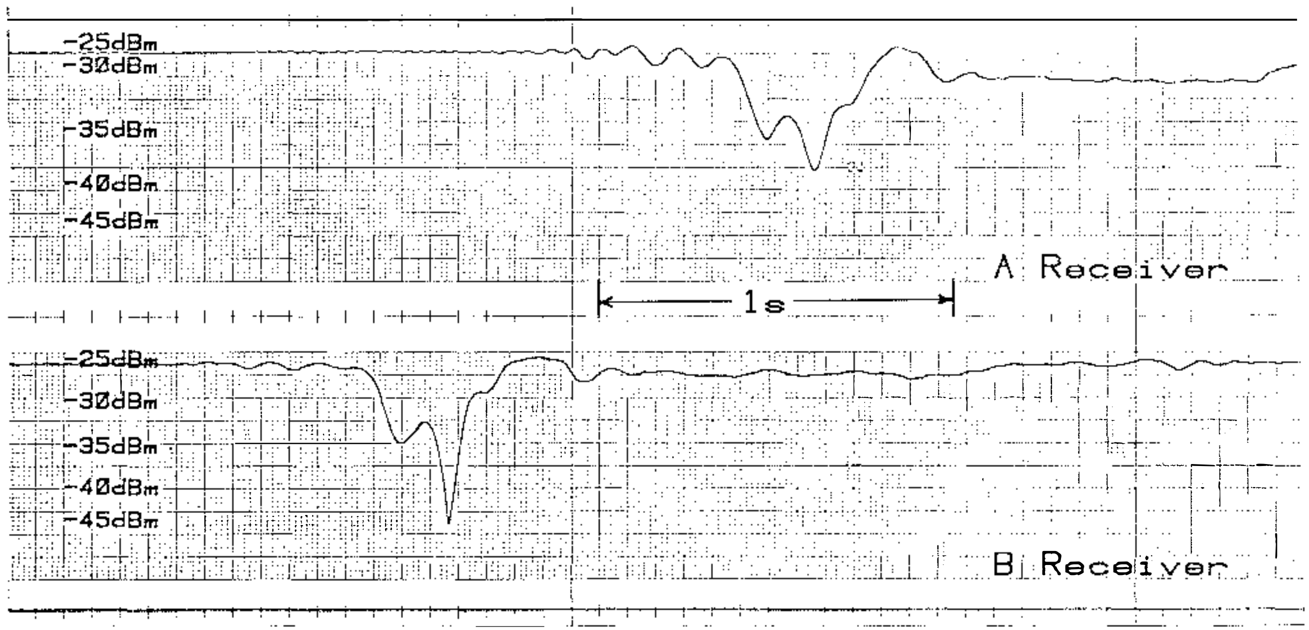


Figure 2-11. Sample fade caused by aircraft.

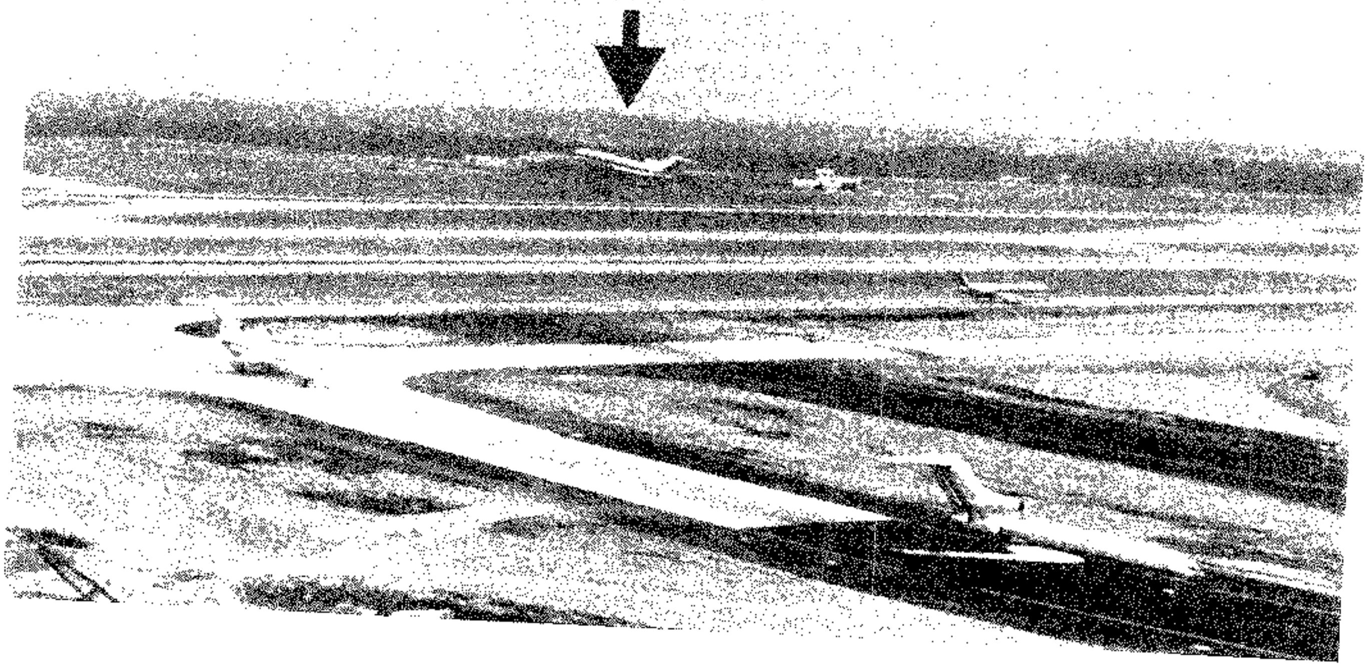


Figure 2-12. Aircraft obstruction.

analyzer that recorded slow average voltage (10 second moving average), Sag/Surge (transients having a duration from 1 cycle to 10 seconds), impulses (spikes having a duration between 0.5 and 800 microseconds), and frequency variations (measured over a 1 second sampling period).

A report was submitted detailing the measurements taken, the conclusions reached, and the recommendations made for improving the system reliability.

Non-tactical Radio Survey. The United States Army, as well as other branches of the military services, uses non-tactical radios for a great variety of communication services on their posts and bases. These uses range from the networks common to each post that serve the security and military police systems to the highly specialized need to communicate from the floor to an overhead crane operator in a large assembly facility and the control necessary on a gunnery range.

The radio networks vary significantly in size and complexity. Most of the systems operate in the VHF frequency range, using FM (16F3) voice modulation. A few operate in the UHF band, however, generally for applications where the higher frequencies provide improved performance.

As a result of an earlier study performed by a special committee, the U.S. Army Communications Command (ACOM) at Fort Huachuca, AZ, planned for an in-depth survey of the applications, service concepts, and procurement procedures used by the Army in this non-tactical communications field. The Institute for Telecommunication Sciences (ITS) conducted this survey under the guidance and sponsorship of the Army. In order to provide a good statistical sample that would be representative of the entire Army, a total of eight installations in the U.S. were selected for the survey. Two locations in each of the following classifications were selected:

1. Headquarters
2. Training Bases
3. Depots
4. Proving Grounds.

A team of two ITS engineers visited each of these installations. The local ACOM detachment served as hosts and coordinators for the visiting team. Interview sessions were scheduled and conducted with cognizant personnel for each network operating at the particular base. The latter were identified by the local ACOM staff, and from frequency assignment records furnished by the Army. These survey interviews were conducted with those in a management role, individual users, dispatchers (where appropriate), and operating and maintenance personnel. The objective of these interviews was to collect data in the following areas:

1. Configuration of the network
2. Equipment used
3. Operational procedures and requirements
4. Service objective and scope
5. Coverage required and experienced
6. Internet requirements
7. Grade of service
8. Maintenance procedures.

The responses and data collected in these interviews have been compiled into a final report for the project sponsor. The results will be used in developing plans and techniques for new integrated communication networks on Army posts in the future. To further assist in this endeavor, the project also included a survey of the non-tactical radio equipment commercially available today and in the near future.

SECTION 2.4. SIMULATION AND STANDARDS

Simulation and standards (including handbooks and glossaries) are combined in this program element. Simulation provides a realistic and repeatable method for evaluating and comparing the performance of different subsystem elements (e.g. modems) on an objective basis. Three tasks are described; namely: MEECN Simulation, Radio System Glossary Update, -and EMS Technical Planning Guide.

MEECN Simulation. The objectives of this project are:

1) To perform synchronization tests on the U.S. Air Force 616A and U.S. Navy Verdin VLF-LF digital radio communication systems.
2) To develop and evaluate an experimental adaptive filter that can be used in digital spread-spectrum receivers to suppress interference (unwanted signals).

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 Minimum Essential Emergency Communication Network (MEECN) of the Department of Defense. Near the end of FY 77, laboratory tests were performed on the 616A and Verdin systems under ideal channel conditions to determine the intra-system and inter-system synchronization characteristics. The results of the synchronization tests are described in a classified report that was prepared during the first quarter of FY 78 (Watterson, C.C., 616A and Verdin Back-to-Back Compatibility Tests, Sets 1-3 (U), OT Tech. Memo. 78-246C, January 1978, pp. 1-75 (Secret) U.S. Dept. of Commerce, Boulder, CO 80303).

The design and construction of an experimental adaptive filter for the suppression of unwanted-signal interference in spread-spectrum receivers was undertaken and completed two years ago, in FY 76. Laboratory experiments on the adaptive filter, planned for FY 77, were postponed because of other project commitments. During the last three quarters of FY 78, the experimental work with the adaptive filter was resumed and essentially completed.

The performance of any digital receiving system with respect to interference can generally be improved by incorporating a suitable filter that automatically adapts or adjusts its response, according to the characteristics of the interference, to increase the signal-to-interference ratio. Adaptive filters can be particularly effective in spread-spectrum receivers, where the performance improvement they provide is an addition to, and in some cases much greater than, the usual chip-processing gain. The improvement in receiver performance that an adaptive filter can provide depends on the ratio of the bandwidth of the modulation on the interference to the bandwidth of the spread-spectrum signal. With CW interference, the bandwidth ratio is zero, and the improvement is ideally infinite. For other types of interference, the improvement decreases as the bandwidth ratio increases, with relatively little or no improvement remaining when the bandwidth ratio approaches one. To obtain the best performance, a practical adaptive filter must utilize digital processing. For small bandwidth radios, the improvement in receiver performance is consequently limited by quantizing noise. It was shown that the theoretical improvement in the signal-to-interference power ratio in a digital spread-spectrum receiver with CW interference when limited by quantizing noise is

$$\overline{\gamma}_i = \frac{8}{\pi^2} 2^{2b} \tau_c f_s ,$$

where b is the number of bits/sample in the analog-to-digital conversion, τ_c is the reciprocal of the chip rate, and f_s is the sampling rate. The equation is illustrated in Figure 2-13.

The experimental adaptive filter was based on a relatively simple delay-line model. Basically, it is a filter which is automatically tuned to maximize the signal-to-interference ratio at its output. During FY 78, comprehensive bench tests were performed on the adaptive filter under simulated-signal and interference conditions to determine the optimum values of a number of adjustable parameters. Following the completion of the bench measurements, the adaptive filter was incorporated in the 616A receiving system, and a set of channel-simulator experiments were made to determine the improvement in receiving-system performance provided by the adaptive filter with CW and FSK interference. The tests confirmed expectations that dynamic nonlinear operation of the adaptive filter can provide greater improvement than quasi-static linear operation. A classified NTIA Report entitled, "An Adaptive Receiver Filter for Interference Suppression in Digital Spread-Spectrum Radio Systems" (U) is being prepared on the design and characteristics of the adaptive filter and the improvement observed in the 616A receiver performance. The report will be printed early in FY 79.

FED-STD-1037, Vocabulary on Telecommunications. This is the first Federal Standard to provide a mutually agreed-upon telecommunication vocabulary for use by both the DoD and non-military Federal communities. The terms and definitions in this standard are compatible with usage in Federal systems performance standards currently under review and will form the nucleus of a commonly understood language for future standards within the FED-STD-1000 series. This standard is also to be adopted by the DoD to replace MIL-STD-188-120, Military Communication Standard: Terms and Definitions, which formed the initial data base for this FED-STD. Thus, FED-STD-1037 will also provide the definitive language for subsequent revisions of and additions to the MIL-STD-188 series of systems performance standards. Continuous updating of the glossary is anticipated in order to keep abreast of new technology developments and applications. This reference list of terms and definitions will not only provide a common terminology for writing and interpreting communications standards, specifications, and contracts, but will also aid in designing, developing, operating, and maintaining of operational systems.

This work has been funded by the National Communications System (NCS), coordinated via the Standards Branch of the U.S. Army Communications-Electronics Engineering Installation Agency (USACC/CEEIA). Utilizing the computer-stored text of MIL-STD-188-120 as the initial data base, ITS has employed an existing word-processing/text-editing computer software program to add more than 700 new terms and definitions to the initial 1300-term data base. These new entries represent inputs from the non-DoD Federal Government, coordinated through the NCS. The resultant enlarged draft was distributed, in early 1978, to 75 reviewers, within DoD and non-military Federal Agencies, for critical comment. All reviewer comments were considered and resolved during two 2-week resolution committee meetings of a Federal Telecommunications Standards Committee (FTSC) subcommittee, in which ITS was a participant, in July and August,

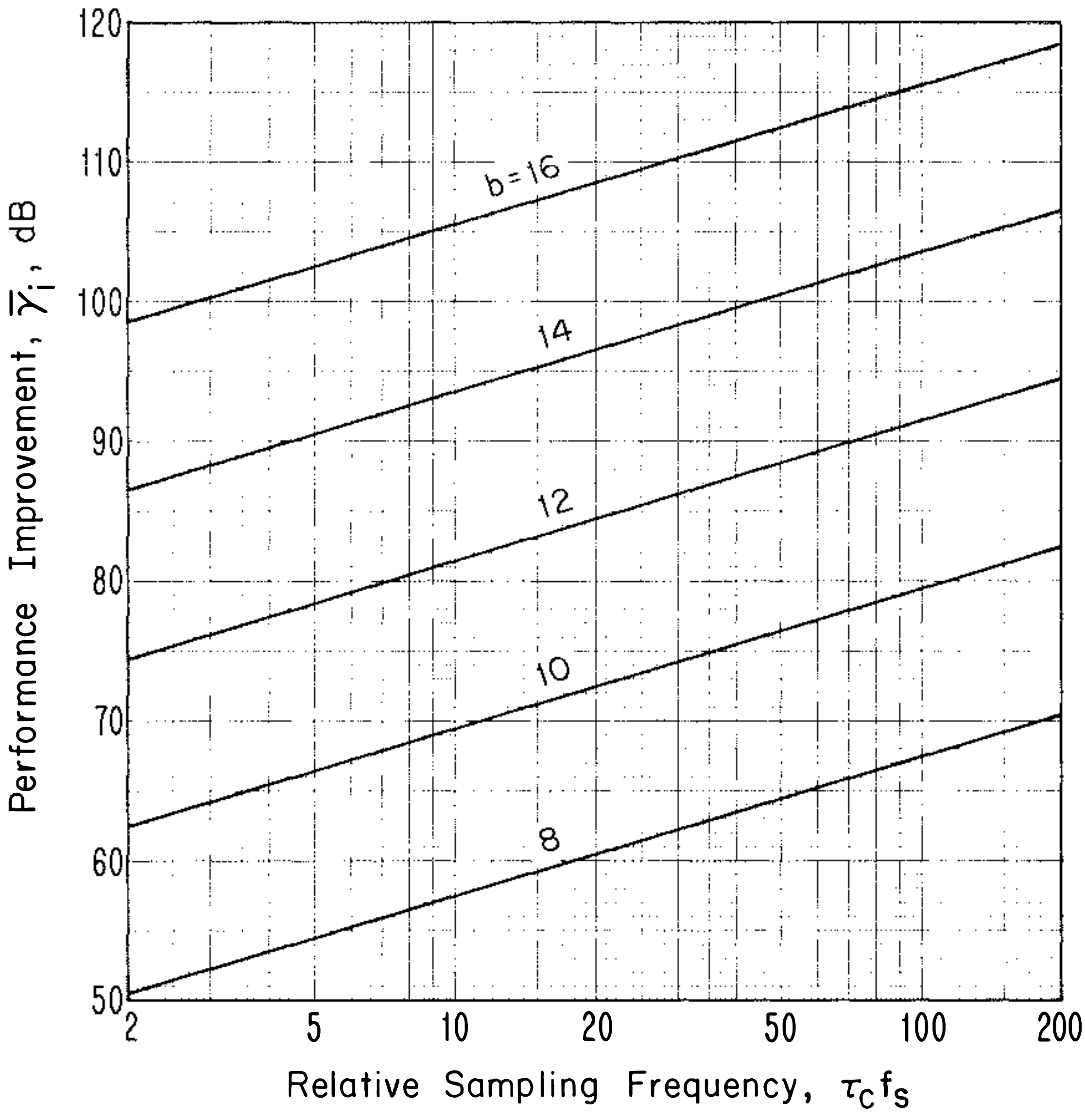


Figure 2-13. Theoretical improvement in digital spread-spectrum receiver performance provided by adaptive filter with CW interference.

1978. ITS is currently correcting the computer-stored draft to reflect these extensive modifications, and will have photocomposed text ready for publication in early FY 79.

Technical Planning Guide for Emergency Medical Services (EMS). The Emergency Medical Services Act of 1973 (Amended 1976) has made provisions for the establishment of emergency medical service systems in some 300 regions of the U.S. The concept is to provide border-to-border emergency medical services to reduce morbidity and trauma for all citizens. These systems cooperate with the National Highway Safety Act (1966) provisions which were designed to provide similar services for highway accidents.

A simple, practical communications planning guide has been prepared at the request of the Interagency EMS Communications Working Group, Chaired by NTIA. The guide is intended to provide the basic information needed by a non-technical planner (e.g. hospital administrator or registered nurse) who has responsibility as part of a regional EMS council or committee for planning, procuring and evaluating appropriate communication equipment and facilities to support a regional EMS system.

The guide has been prepared from materials recommended by the DHEW EMS Regional Consultant Team and from recommendations received at the three DHEW Tri-regional Workshops of 1977. Guidance was also given by the Interagency Working Group.

For the purposes of this guide, the function of the communications system are citizen access, dispatch and medical supervision during patient care and stabilization at the scene (providing medical supervision for paramedic personnel), and continued medical supervision during transport and delivery of patients to an emergency receiving room at an appropriate hospital. A diagram showing the communication system is shown in Figure 2-14.

The guide stresses the need for defining the EMS system and the required communication paths and surveying, understanding and securing cooperation from related public safety communication resources (e.g. police, fire, civil defense. . .) of the region prior to the design and procurement of an EMS communication system. The rudiments of system planning, procurement, and evaluation are presented. Alternative system approaches are discussed. The guide is not intended to replace the consulting services needed for system planning, but is intended to make the interface between planner, consultants and suppliers (manufacturers) more effective.

SECTION 2.5. FIBER OPTIC COMMUNICATIONS

ITS has had an active role in the rapidly growing field of fiber optics communications. This role has included such activities as publishing a fiber optics handbook, organizing and chairing an Ad Hoc Optical Communications Task Force, providing consulting services in fiber optics to the Department of Defense, developing a data base for an optical communications glossary, and sending a Chief U.S. Delegate to the International Electrotechnical Commission Subcommittee on Fiber Optics. These activities are discussed in detail below.

Optical Communications Task Force. In Fiscal Year 1975, an Ad Hoc Optical Communications Task Force (OCTF) was formed. The creation of the Task Force was inspired by the OT mission to "assist 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." The Task Force work is carried on today under NTIA's mission of serving as a national focus for Federal policy and decision-making in those areas vital to the new Age of Information.

ITS has assumed a role as a catalyst in assisting other Government agencies to more rapidly develop and apply advancing communication technologies such as the emerging fiber optics communication technology. The OCTF was developed to provide a forum for government and industry technical workers, potential users, and policy makers to explore the applications, advantages ,and potential problems in adopting and using optical communication technologies.

The Task Force work has been well received with the meetings well attended by representatives from industry, universities, and government. Frequently, the Task Force participants have benefited from the introduction of topics earlier than they would have been introduced in a formal societal meeting. One such topic introduced in this year's meeting of the Applications and User's Working Group was the topic of using fiber optics communications in the hospital environment. Medical care costs in the U.S. exceed $180 Billion annually, and hospital costs are about 40% of this total. Cost effectiveness to promote quality health care in hospitals is understandably a large concern. The wide variety of communications, data processing, and wideband telemetry needs in a hospital makes it an important arena for the introduction of broadband communication services. Fiber optical

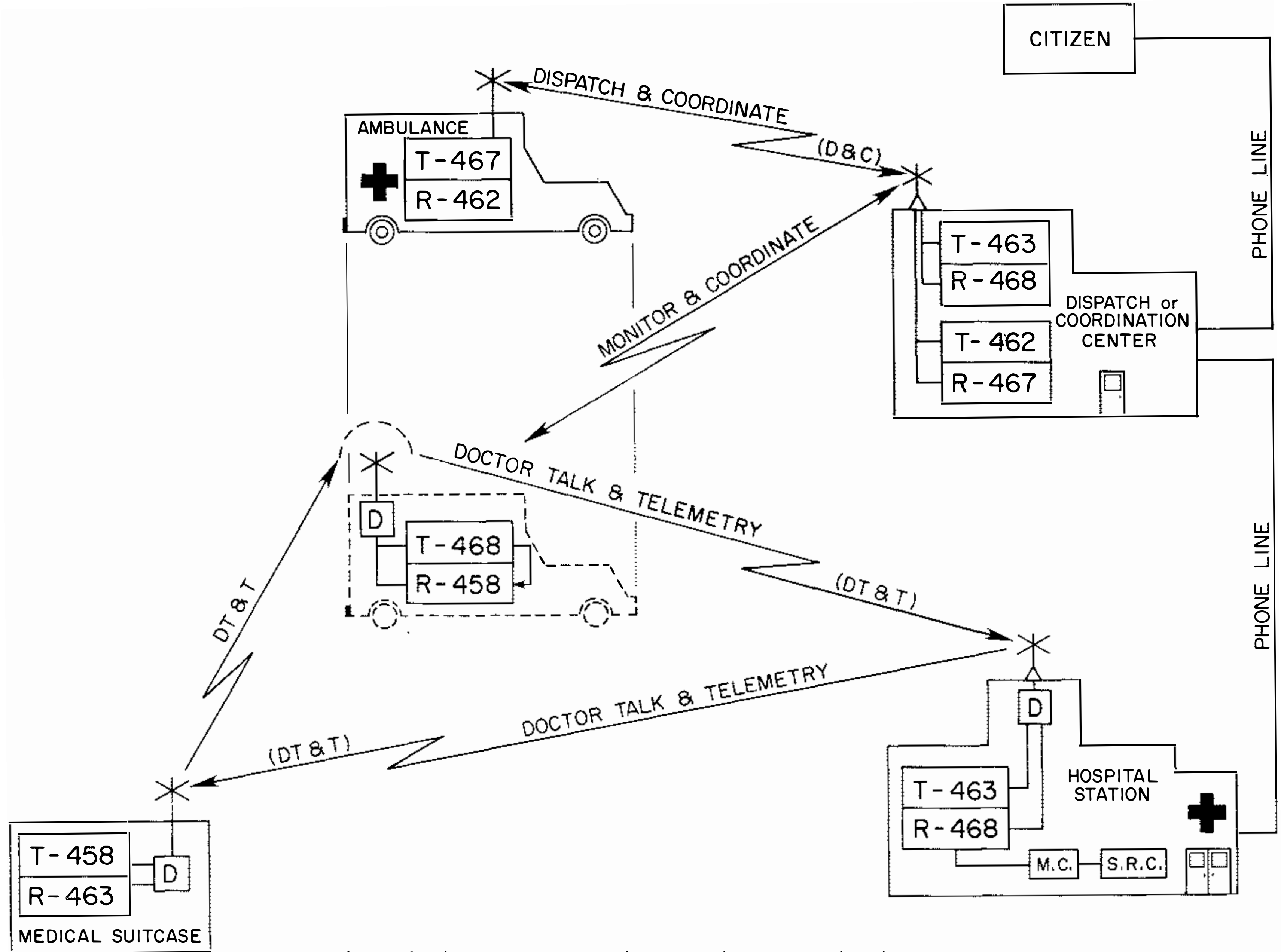


Figure 2-14. Emergency medical services communications.

cables could be quite beneficial in providing the necessary bandwidth, electromagnetic compatibility, smaller size, and non-electrical interfaces with patients.

The most recent meeting emphasized the rapid progress of fiber optics into applications. Fiber optics has moved from the proof-of-technology stage to system-definition and economic-evaluation stages. The next several years have been forecast as years of rapid commercialization. Problems foreseen have shifted from the problems of feasibility to problems of reliability and to difficulties associated with the development of performance criteria and standards.

As Chairman of the Applications and User's Working Group, the ITS representative assists the committee in acquiring, analyzing, synthesizing, and disseminating fiber optics information concerning the efficient use of the nation's telecommunication resources. Summary Reports of the meetings are prepared and supplied to attendees.

Dispersion Characteristics for Optical Fibers at Longer Wavelengths. A series of studies were made to determine the upper limits on bit rate for fiber optical systems. The constant push toward higher transmission rates and longer path lengths for fiber optical cable has required close attention to those fiber structures and material properties which relate to lower attenuation, greater coupling efficiency of light into a fiber, and lower dispersion properties. As attenuation has steadily been driven to lower values, 2 or 3 dB/km, attention has recently turned to those properties of the optical waveguide which define the ultimate limit of the data-handling capabilities of the fibers or the dispersion characteristics of the optical guide. A series of theoretical studies was made at ITS offering methods for determining optimum refractive index profiles for multimode and monomode fibers. Also, a method was obtained for finding the optimum operating wavelength for monomode graded-index fibers. These studies have been prepared for various publications and for presentation at several technical meetings. A brief review of the more significant results is presented as follows.

Optical waveguide attenuation due to Raleigh scattering reduces rapidly as wavelengths increase. Scattering losses at $\lambda = 1.3\mu m$ is less than 20% of the scattering losses at $\lambda = 0.85\mu m$. Taking into account the material, waveguiding, and modal properties of an optical waveguide, it can be shown that pulse spread can be minimized for a variety of glass materials as operating wavelengths are increased from $\lambda = 0.85\mu m$ to $\lambda = 1.2$ or $\lambda = 1.3\mu m$. Since both dispersion and attenuation characteristics improve at $\lambda > 1\mu m$, there is a strong reason for development of sources, detectors, and optical fibers for optimization at these longer wavelengths. An added benefit is the slightly larger dimension of components which should affect strength and reliability. Sources and detectors still require major improvements in efficiency and speed to match component capabilities at the present wavelengths of interest. Progress along these lines has been encouraging.

International Electrotechnical Commission Subcommittee on Fiber Optics. A member of the NTIA/ITS technical staff was appointed as the Chief U.S. Delegate to the meeting of the International Electrotechnical Commission (IEC), Subcommittee on Fibre Optics. The IEC deals with components and telecommunication systems in contrast to the CCITT, which is a treaty-related telecommunications committee; i.e., the CCITT is sponsored by the State Department and deals with telecommunications; the IEC is sponsored by industry and deals with telecommunication hardware and systems. The flow of goods to domestic and non-domestic markets is influenced directly by the U.S. position in the IEC. A strong U.S. market position can best be acquired by working within the framework of the IEC. The subcommittee met in Florence in June, 1978.

The U.S. introduced two key proposals in an attempt to get an early start on the standardization of terminal devices for optical systems. The proposal that succeeded in gaining initial approval was the one which would elevate the fiber optics work to full Committee status. It is as yet a subcommittee under the aegis of the Committee on Cables, Wires, and Waveguides for Telecommunication Equipment. If accepted at all levels of the IEC, the proposal would allow the new committee to determine which terminal components (now forming sub-assemblies of fiber systems) would be subject to standardization.

The commercial availability of modules acting as interfaces between the electronic and the optical worlds has made the standardization of these modules a high priority item.

Fiber Optics Communications Glossary. Fiber optics communications (FOC) technology has evolved extremely rapidly, and Government procurement of systems for operational deployment is on the increase. Numerous standards working groups, in both government and the private sector, are actively engaged in creation of performance standards covering components and systems. Decades of experience in other telecommunications areas have empirically demonstrated that the absence of a standardized vocabulary common to closely related standards inevitably results in ambiguities among such standards. These ambituities may result not only in confusion for the systems designers and users, but also in increased and unnecessary costs to the Government as the result of inadequately-defined procurement specifications. MIL-STD-188-120, Military Communication System Standard: Terms and Definitions and FED-STD-1037, Vocabulary for Telecommunications, both coordinated by ITS, have been directed toward alleviating these problems in a broad spectrum of telecommunications areas. FOC terms and definitions have not as yet been included in these standards.

Many technical terms, unique to this new telecommunications field, have been introduced from the discliplines of optics and physics, are new to practical communications, and are used with various meanings by manufacturers, researchers, and procurement agencies. In recognition of this problem and the need to at least begin standardization of language during early formulation of performance standards, ITS has compiled a preliminary vocabulary data base during FY 78. This limited effort has been conducted, using DoC funds, with the goal of producing, within FY 79, an Addendum to FED-STD-1037. The plan is to prepare a computer-stored draft of the initial data base, to facilitate revision, and to circulate this draft among key workers in the field, including chairmen of all performance stand-ards working groups for review and additional inputs. A revised and enlarged draft will then be submitted to a subcommittee of the Federal Telecommunications Standards Committee (FTSC) for final review prior to publication as a Federal Standard.

Fiber Optics Handbook. During FY 77, a design handbook for optical fiber communication systems was prepared by ITS for the U.S. Army, Communication Electronics Engineering Installation Agency (CEEIA), Fort Huachuca, Arizona. The draft of this handbook was delivered to the sponsor for review and revision at the end of FY 77. During FY 78, this handbook was revised, and completed for publication.

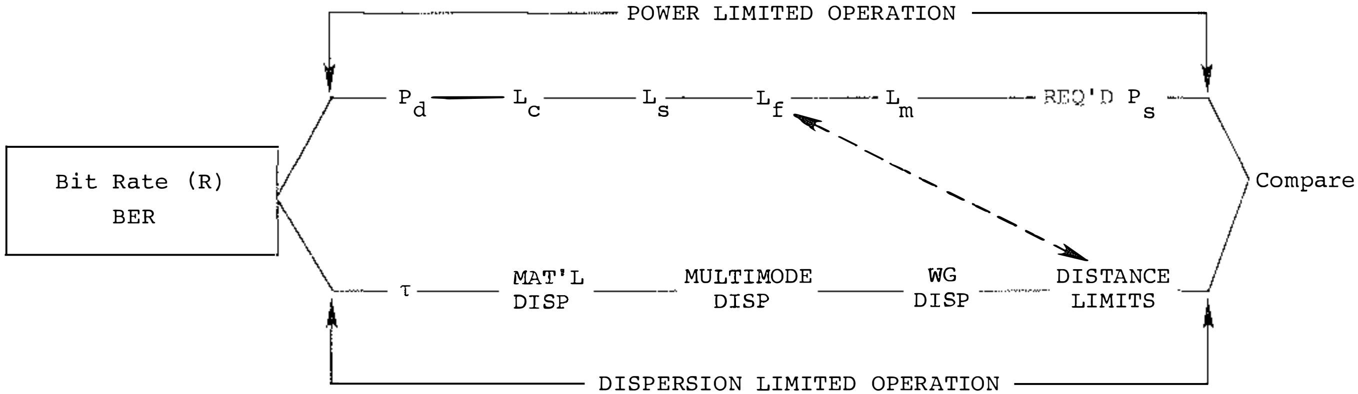
The emphasis in the handbook is toward the microwave engineer and system; i.e., it presents the design aspects of a fiberoptic transmission channel that might be used to replace an existing microwave link, or be considered as an alternative to a new link. The interface requirements with existing communications equipment is discussed.

The handbook is entitled "Design Handbook for Optical Fiber Systems". It is written primarily for the communications engineer that has had little or no prior experience with fiber-optic technology. Fundamental, (yet practical) design and performance data are presented for all of the components required of a transmission system. The design procedures are also presented in a systematic fashion, pointing out those to be followed for both a power limited design and a dispersion limited design. These procedures are summarized in the accompanying tables as an example. The actual design process is iterative in nature (between the two regimes). This aspect is illustrated in three appendices to the handbook, where actual design examples are presented.

The handbook will be published by the U.S. Army, and should be available sometime early in FY 79.

Table 2-2.

Flowchart for System Analysis



τ = PULSE WIDTH

P_d = REQ'D POWER INTO DETECTOR

L_c = CONNECTOR AND COUPLING LOSS

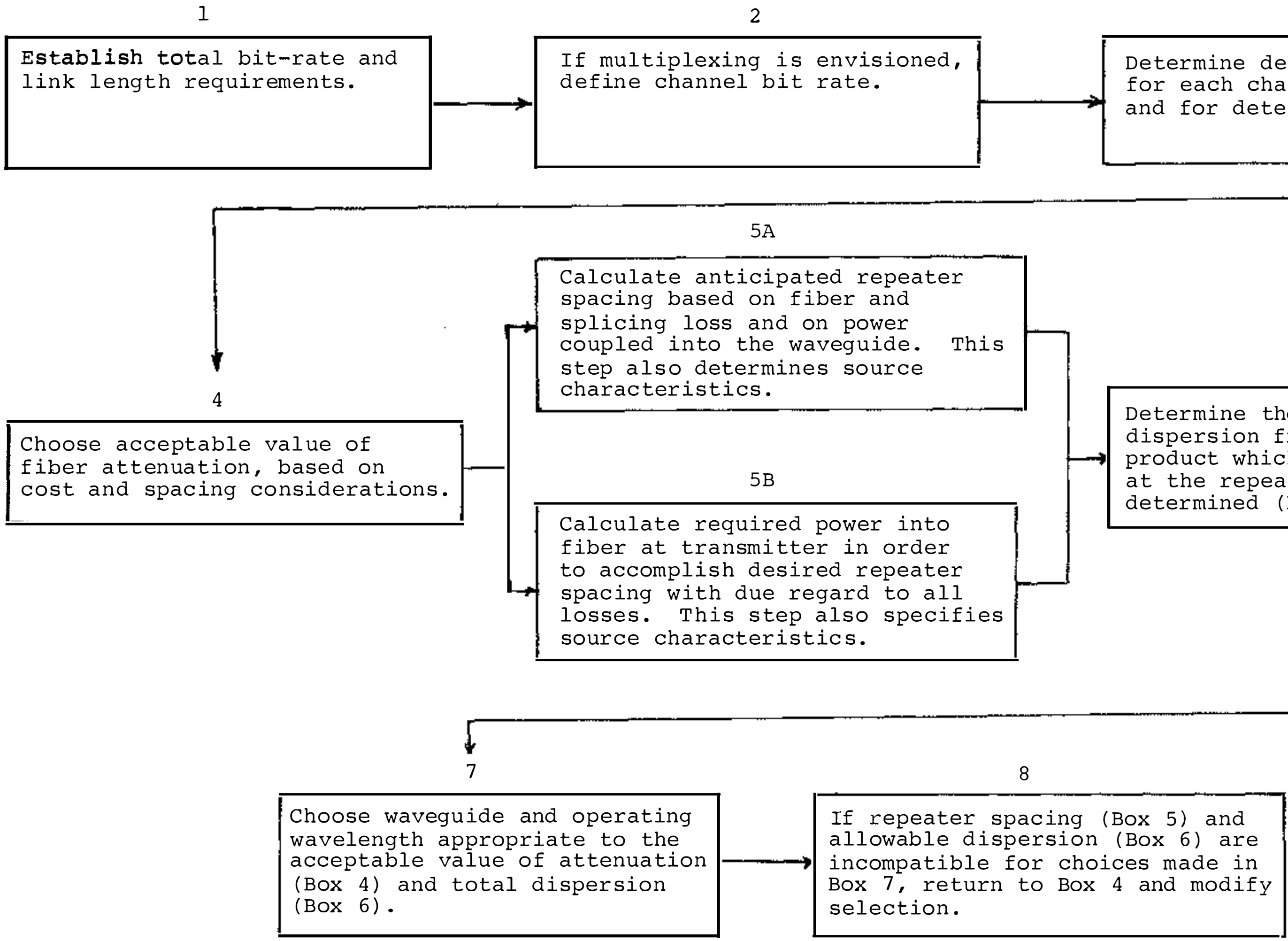
L_s = SPLICING LOSS

L_f = FIBER LOSS

P_s = SOURCE POWER

L_m = DEGRADATION MARGIN

Table 2-3. Optical Communications Design Flow Chart



*Descriptive supplement to this Flow Chart is given on the next two pages.

CHAPTER 3. 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 their decisions for better spectrum use.

Experimental or theoretical determinations of radio wave transmission characteristics, or the channel transfer function, are reported in Section 3.1. Measurements of transmission media properties and analyses of collections of such data are included in Section 3.2. Section 3.3 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 3.4. Section 3.5 reports on applications of the knowledge and tools to specific problems of other government agencies, such as mine and forest service communications.

SECTION 3.1. WAVE TRANSMISSION CHARACTERISTICS

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

Broadband Transmission in the 10-100 GHz Range. 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 wideband, high-data-rate systems. Progress made on the experimental phase is reported below.

Frequency Extension Research. Simultaneous measurements of signal variability were made at 9.6, 28.8, and 57.6 GHz over paths of 200 and 740 m. Although the 57.6 GHz signal showed some correlation with ambient temperature as would be expected, in general, the lower frequency signals showed greater variability. Digital data were transmitted at a 1 Gb/s rate using 30.3 or 59.1 GHz as the carrier. In both cases, bit-error rates were consistently less than 1 in 10^8 except for times (such as intense rain) where the receiver synchronization became erratic.

A model for the effect of multipath on bit-error rate was developed which gives good agreement with direct measurements of this effect (Figure 3-1). A paper entitled "Experimental and Theoretical Assessment of Multipath Effects on QPSK," describing this development is scheduled for publication in IEEE Transactions on Communications, October, 1978. Instrumentation for obtaining correlgrams (using a 1 Gb/s QPSK modem) was developed. This will permit resolving multipath signal components to less than 1 ns and calculating channel transfer characteristics over a band of about 1 GHz.

A paper on deep signal fading (> 20 dB) entitled "Fading at 9.6 GHz on an Experimental Simulated Aircraft-to-Ground Path," by H. B. Janes and M. C. Thompson was published in IEEE AP, September, 1978.

SECTION 3.2. CHARACTERISTICS OF THE TRANSMISSION MEDIA

This section is concerned with the study

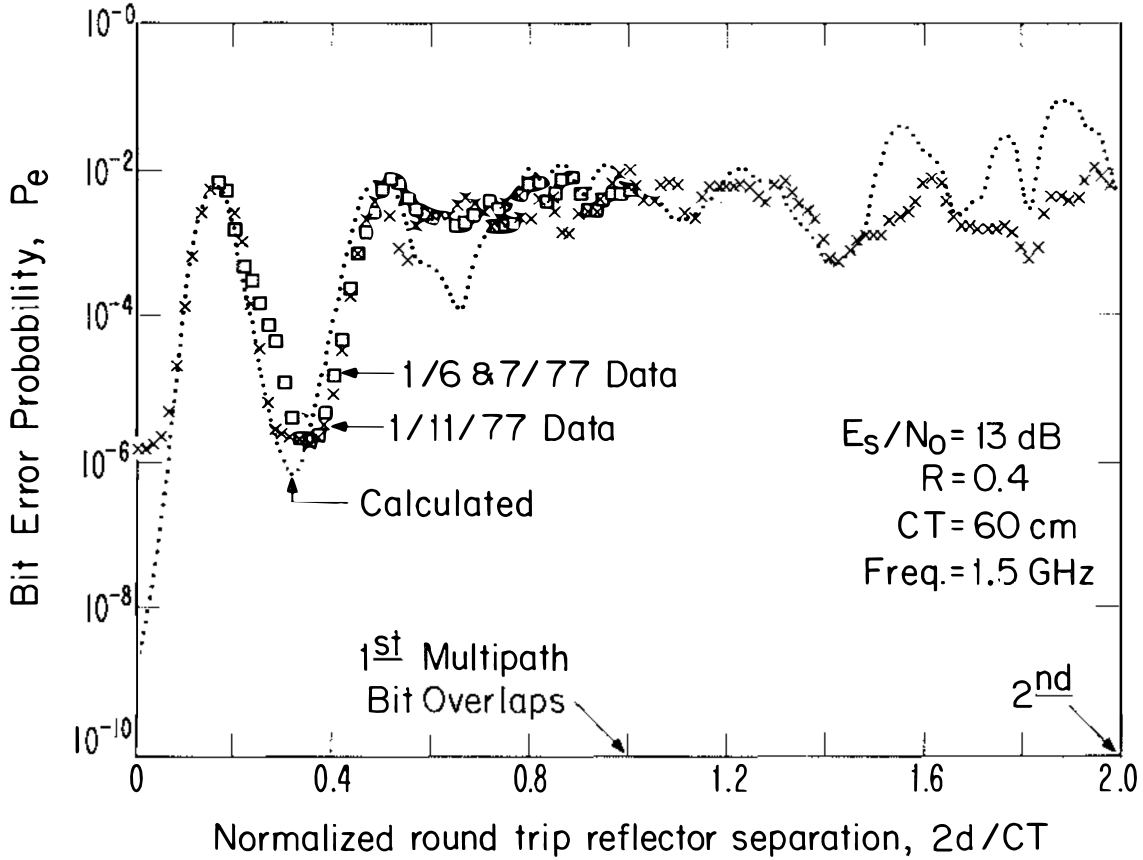


Figure 3-1. Observed and predicted bit-error probability versus round trip delay for 1.5 GHz indoor multipath experiment.

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 nonionized atmosphere and then the ionosphere.

3.2.1. Atmospheric Characteristics

An extensive measurement series on the oxygen microwave spectrum in air has been completed. Out of 228 spectroscopic parameters, the most significant 132 have been measured with accuracies in the 0.5 to 3 percent range.

The improved spectroscopic data base characterizing the EHF properties of air was integrated into a radio path modeling scheme that predicts various propagation behaviors.

Atmospheric Medium Characterization and Modeling of EHF Propagation in Air. It is possible to predict the behavior of an EHF (frequencies up to 300 GHz) radio wave transversing an assumed clear, inhomogeneous, nonturbulent atmosphere at various slant path angles θ. Molecular absorption spectra of major (O_2, H_2O) and minor (e.g., O_3, CO, N_2O) air constituents cause frequency dependent signal attenuation, phase delay, ray bending, and medium noise. The interaction between radiation and air is expressed through a complex refractivity N, which is a function of frequency ν, total pressure p, partial water vapor pressure p_w, temperature T, earth magnetic field strength H (O_2-Zeeman effect), and trace gas number densities. The N-calculation takes into account 36 O_2 lines, 6 H_2O lines plus a nonresonant spectrum, and, if needed, includes trace gas spectra (> 100 O_3, 2 CO, 64 N_2O lines), which are generally weak.

The oxygen microwave lines split into many components under the influence of the earth's magnetic field. The components are spread max. $\pm$ 2 MHz around the unperturbed line centers, which become noticeable at altitudes, h > 40 km (see Figure 3-2). A consequence of the Zeeman splitting is an anisotropic, polarization-dependent, complex refractivity N. Radio path modeling in the frequency bands ν = 50 to 70 and 118.8 $\pm$ 0.1 GHz requires the correct refractivity N(ν, H, h) of air for the height range, h 40 to 110 km. A straightforward, consistent, calculation scheme was developed.

Assuming a distribution of the gas variables for neutral air as a function of height and the radio path geometry (ground-to-ground, aircraft, satellite, etc. link) provides the basis for calculating the various propagation effects. Figure 3-3 gives an example of height contours for constant attenuation rates as, for example, needed in the assessment of atmospheric shielding capabilities. In the window ranges (30-50, 70-110, 125-150 GHz), molecular attenuation is mainly due to water vapor and confined to the first five kilometers.

A tractable propagation model for the air mass employs a spherically stratified atmosphere ("onion-shell" model of thin quasi-homogenious layers) to be amenable to computer calculations of five integrals: cumulative attenuation (i.e., transmittance), radio range, curved path length, and noise temperature due to upwelling and downwelling radiation. These integrals are evaluated by numerical integration. Results of this kind were published in AGARD CP 238, 44/1-18 (1978). Figure 3-4 shows the excellent agreement of the computer simulation with reported values for clear air zenith attenuation.

Orbiting Standards Platform (OSP) Preliminaries. In the continuing cooperative program by the Communications Satellite Corporation (COMSAT), NASA's Goddard Space Flight Center (NASA/GSFC), the National Bureau of Standards (NBS) and NTIA's Institute for Telecommunication Sciences (NTIA/ITS), a preliminary definition of the OSP has been accomplished. Briefly, the proposed Orbiting Standards Platform (OSP) is the equivalent of a combined field-strength meter and signal generator to be placed in orbit to meet the need for a readily accessible, relatively economical, calibration facility for earth stations, large aperture antennas, and satellites.

A preliminary description of this OSP was distributed with a questionnaire to a sampling of the private, commercial, and government organizations that might constitute an OSP user community. The responses to this OSP survey verified the assumption that the manufacturers and operators of satellite system elements, scientific research organizations, and the radio wave regulatory agencies would, in fact, constitute an OSP user community. Further, this sampling suggests the community is strongly supportive (89% of the respondees) of the OSP concept and has specific needs for the proposed OSP capabilities. Further, the user community identified specific scientific studies that should be carried out by an OSP. They also identified the need to fit the OSP into the present frequency allocation schedule on a noninterfering basis (OT Tech. Memorandum 78-249, February 1978).

The OSP definition to date includes the specification of transmitting and receiving antennas of calibrated selectable gains and polarization, generated signals with known stable amplitude and phase characteristics, calibrated circuits for the analysis of received signals, and is highly

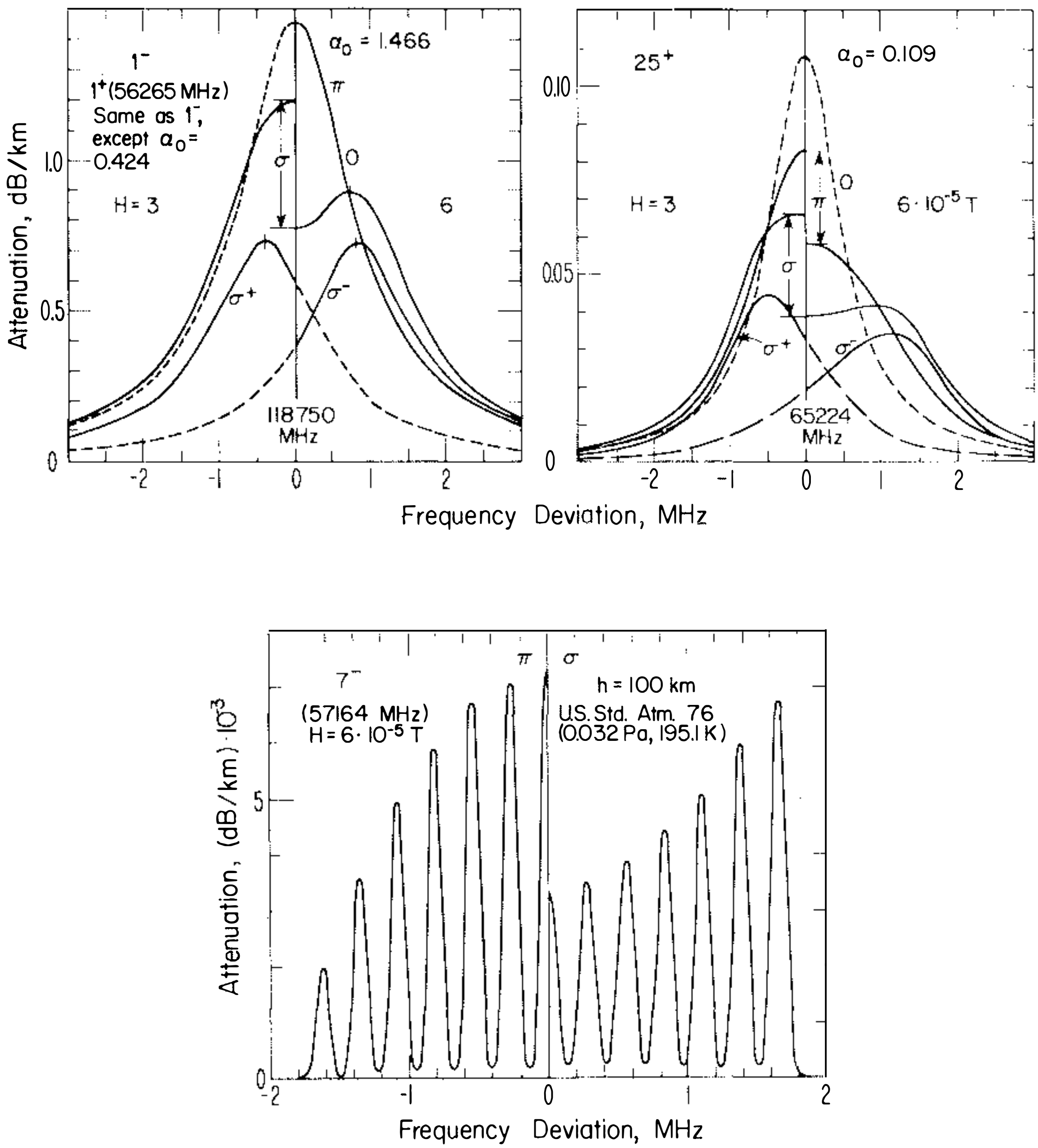


Figure 3-2. Examples of O_2-MS Zeeman patterns for 1^- and 25^+ lines at h = 55 km (p = 42.5 Pa and T = 260.8 K; U.S. Std. Atm. 76) for two magnetic field strengths, H = 3 (left half), H = 6 (right half) x 10^{-5} T, and the unsplit line, H = 0. Zeeman patterns π and $\sigma = \sigma^+ + \sigma^-$ for the 7^- line at an altitude, h = 100 km.

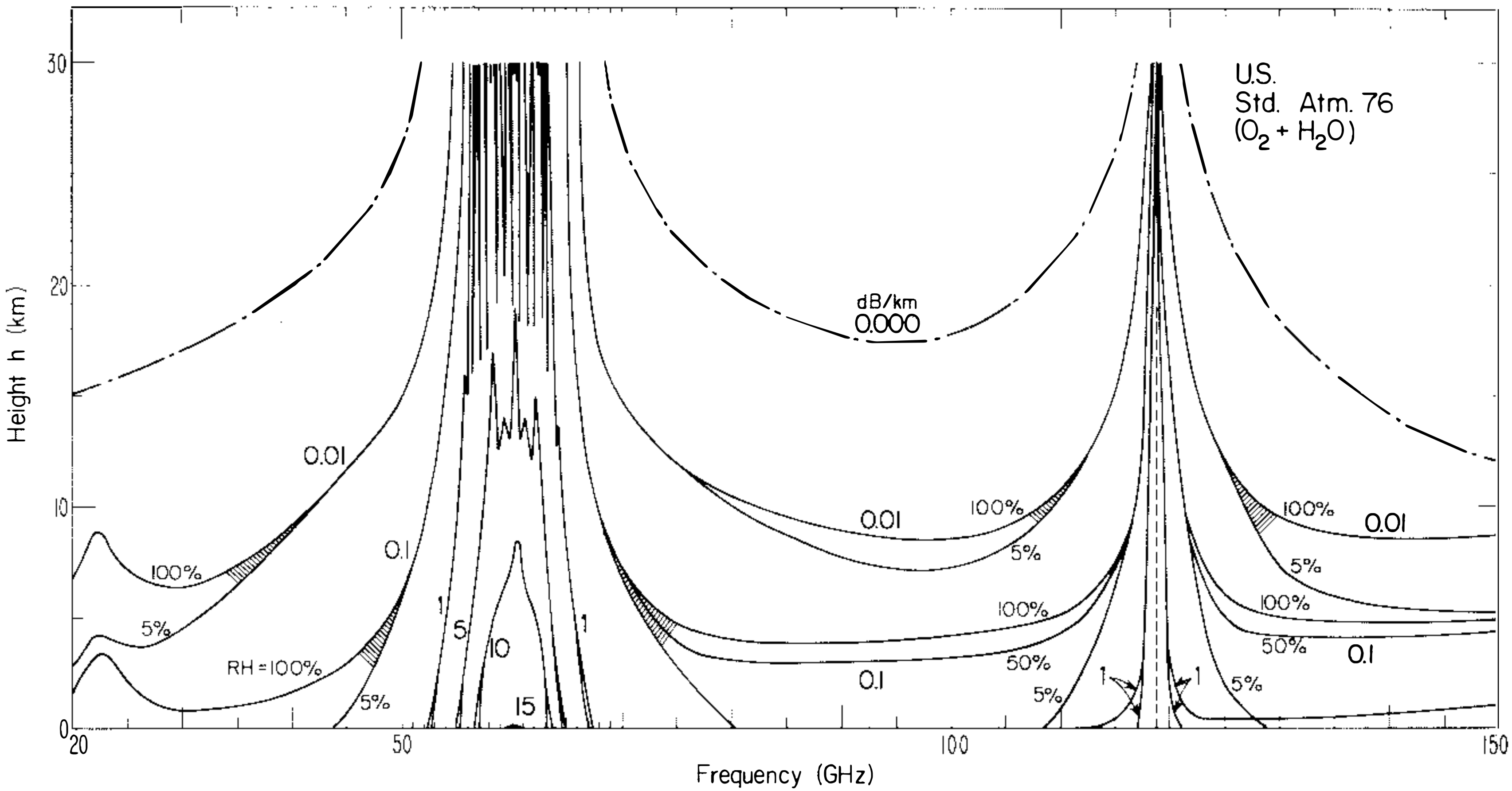


Figure 3-3. Height profiles of constant attenuation rates (0 - 10 dB/km) for clear air.

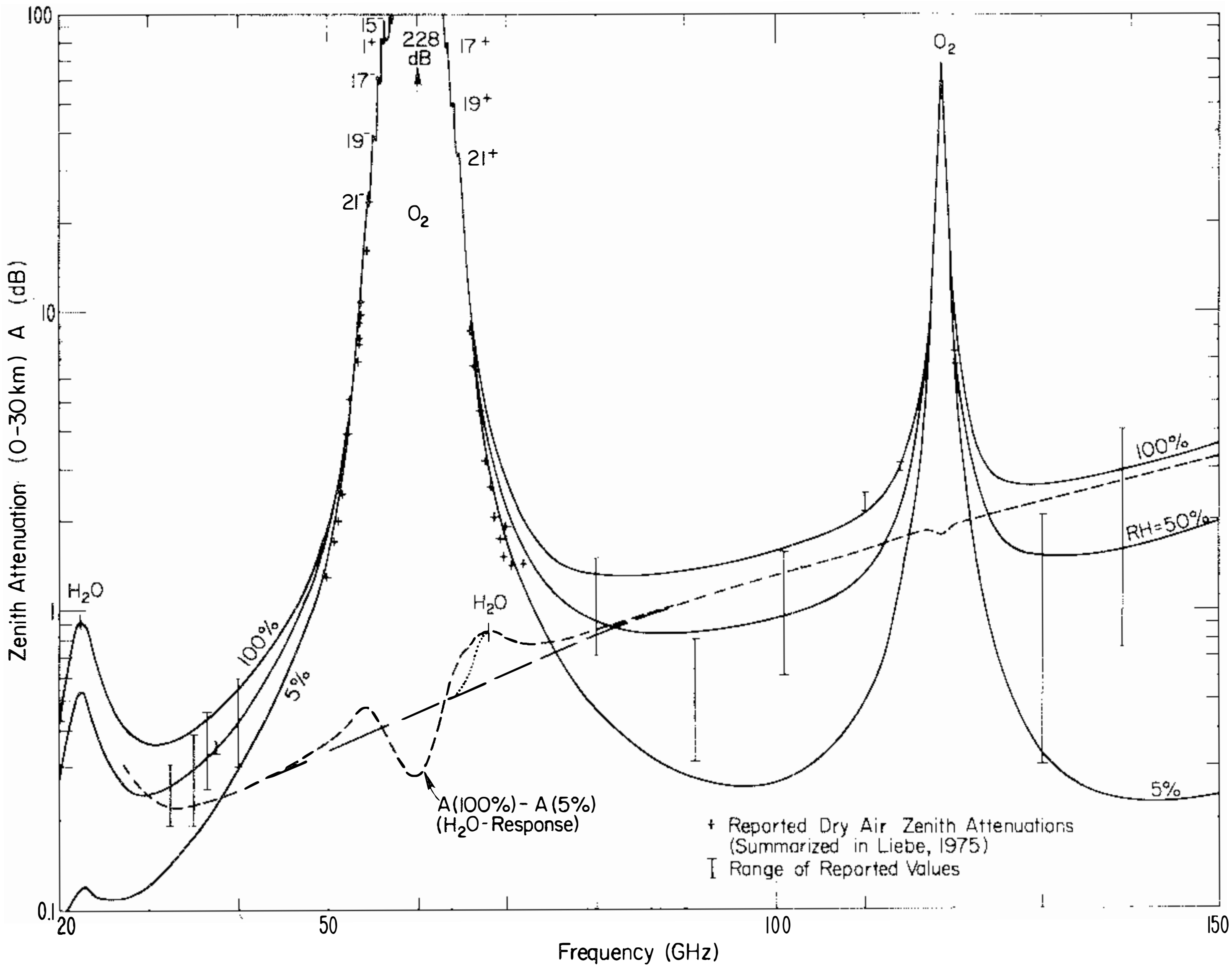


Figure 3-4. Clear air zenith attenuation for 3 humidity models (5, 50, 100% RH at h = 0).

redundant self-calibrating and self-monitoring [Proc. Symposium On Antenna Applications, September 1978]. The OSP would traverse the geostationary orbit and be capable of measuring up- and down-link earth station signals, internally verifying the measurements, and telemetering the results, Figure 3-5. Parameters which are to be measured are primarily related to the radiators of the communications system and include effective isotropic radiated power (EIRP), gain-to-temperature ratio (G/T), gain, pattern, cross polarization, transmission path properties, and sidelobe structure, the latter including both amplitude and polarization characteristics.

A companion earth station serves to perform approximately the same function with up- and down-link satellite signals and also to provide means for periodic re-calibration of OSP. It should be emphasized that OSP does not act as a relay station in the sense of a communications satellite (which receives, amplifies, and re-transmits a signal containing certain information), but rather is a remote standards laboratory which receives or generates a signal and telemeters relevant data about that signal. Processing would be done by a designated government agency such as NBS or by the user himself, as appropriate.

Satellite Propagation Observations at 19 and 28 GHz. Future domestic satellite communication systems carrying high density traffic will use frequencies up to 30 GHz because of the presently greater bandwidth available and because these frequencies are not currently being heavily used.

Beacons at 19 and 28 GHz on several domestic geostationary satellites have been launched. The objectives of this ITS program are to monitor these beacons and collect attenuation and phase information. The data will help to determine minimum power and other performance margins needed for future satellite communication systems operating up to 30 GHz.

Colorado is an excellent location for data collection from the 19 and 28 GHz satellite signals since currently there is no other site planned west of the Mississippi, and the Colorado site should provide optimum reliability from elevation angle considerations.

The satellite beacon transmissions will originate from three satellites, each with a 19 and 28 GHz beacon. The 19.04 GHz beacon signal will be switched between two orthogonal linearly polarized (i.e., vertical and horizontal) antennas at a 1 kHz rate. The 28.56 GHz signal will be transmitted continuously from a linearly polarized antenna (vertical only). The 19 and 28 GHz signals will be coherent since they are derived from the same fundamental source.

The 19 and 28 GHz beacon transmissions from COMSTAR beacons D1, D2, and D3 are being analyzed to learn the useful channel bandwidth at microwave and millimeter-wave carrier frequencies. Government, commercial, and scientific interest in transmission through the atmosphere at frequencies above 10 GHz derives from the potential for employing this portion of the spectrum for satellite communications and the promise for frequency extension. Figure 3-6 shows the 10 foot receiving dish with the receiver front-end at the prime focus used in the experiment. Figure 3-7 shows the one major source of signal impairment; i.e., a rain event on the performance of an earth-satellite communications link. The correlation between received signal strength and rain rate provides information on the temporal variability of attenuation.

In most satellite communication systems, the signal received by an earth terminal is redistributed to various terminals on the earth. A terrestrial link operating at 28.8 GHz has its transmitting antennas located about 30 m from the 10 foot dish used in the 19/28 GHz COMSTAR satellite beacon experiment. This terrestrial link provides information on amplitude and delay distortion signal impairments caused by the same meteorlogical events, and nearly the same frequency, that effect the earth-satellite link. Figure 3-7 also shows the received signal strength on the 28.8 GHz carrier used in the terrestrial link for the same rain event observed on the 28.5 GHz carrier on the earth-satellite link.

Depolarization and Frequency Re-use. Frequency re-use by introducing dual orthogonal linear polarizations or opposite-sense circular polarization has the potential for nearly doubling the available assignments in the radio spectrum. This raises the possibility of an increased number of assignments, such as additional TV stations within a given geographical region. That could have a strong economical and social impact in the U. S.

Of course, a full doubling of the available assignments by frequency re-use could not be accomplished because there can be technical advantages of one polarization over another in some frequency bands. Further, in some frequency bands, there are propagation mechanisms which change a transmitted signal's polarization. This depolarization can arise from the scattering, reflection, and diffraction of radio waves by: irregular terrain, rainfall, clouds, and fog as well as the ionized layers, turbulence, and refractivity stratification of the atmosphere. The basic requirement for assessing the impact of

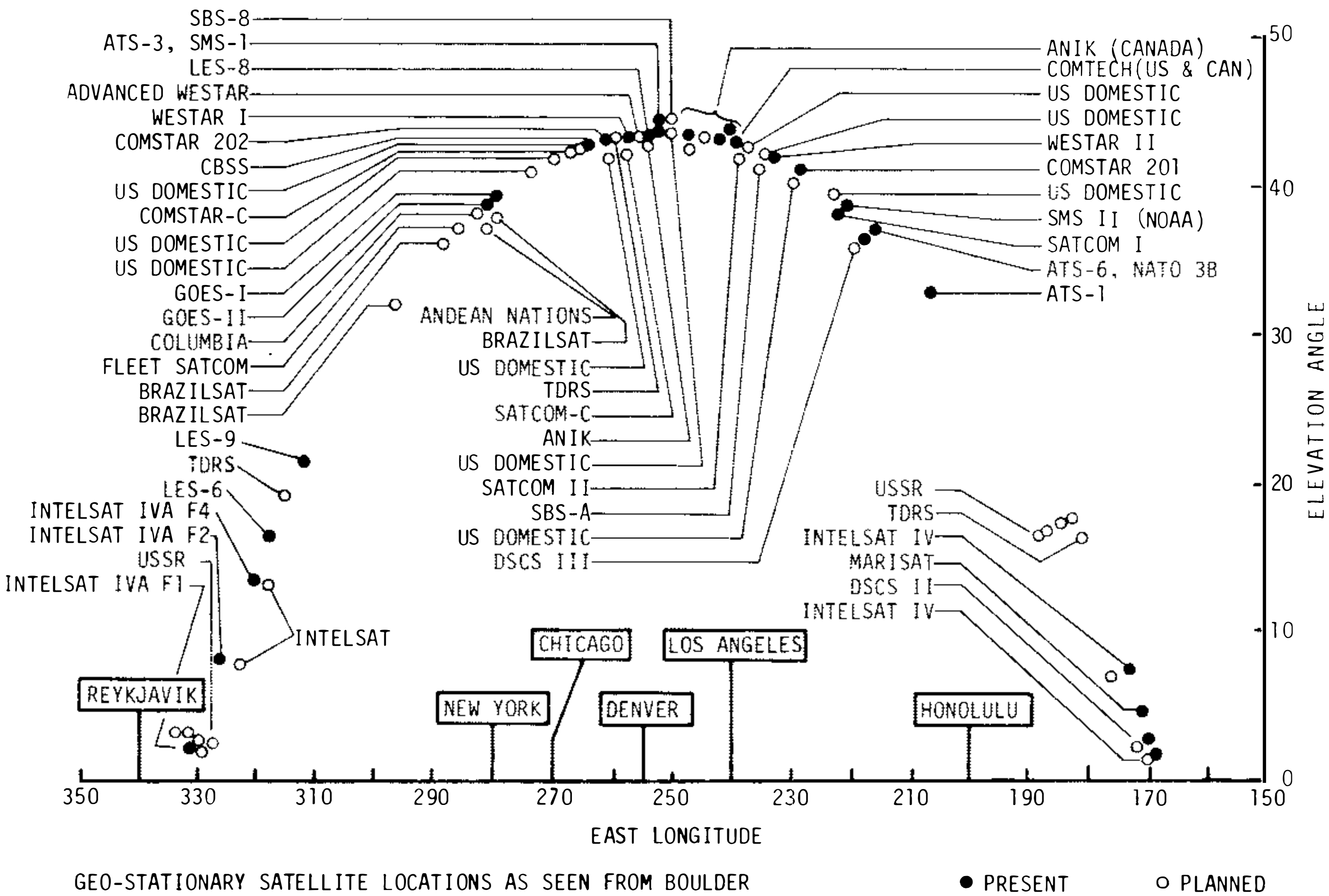


Figure 3-5. Orbiting standards platform illustration.

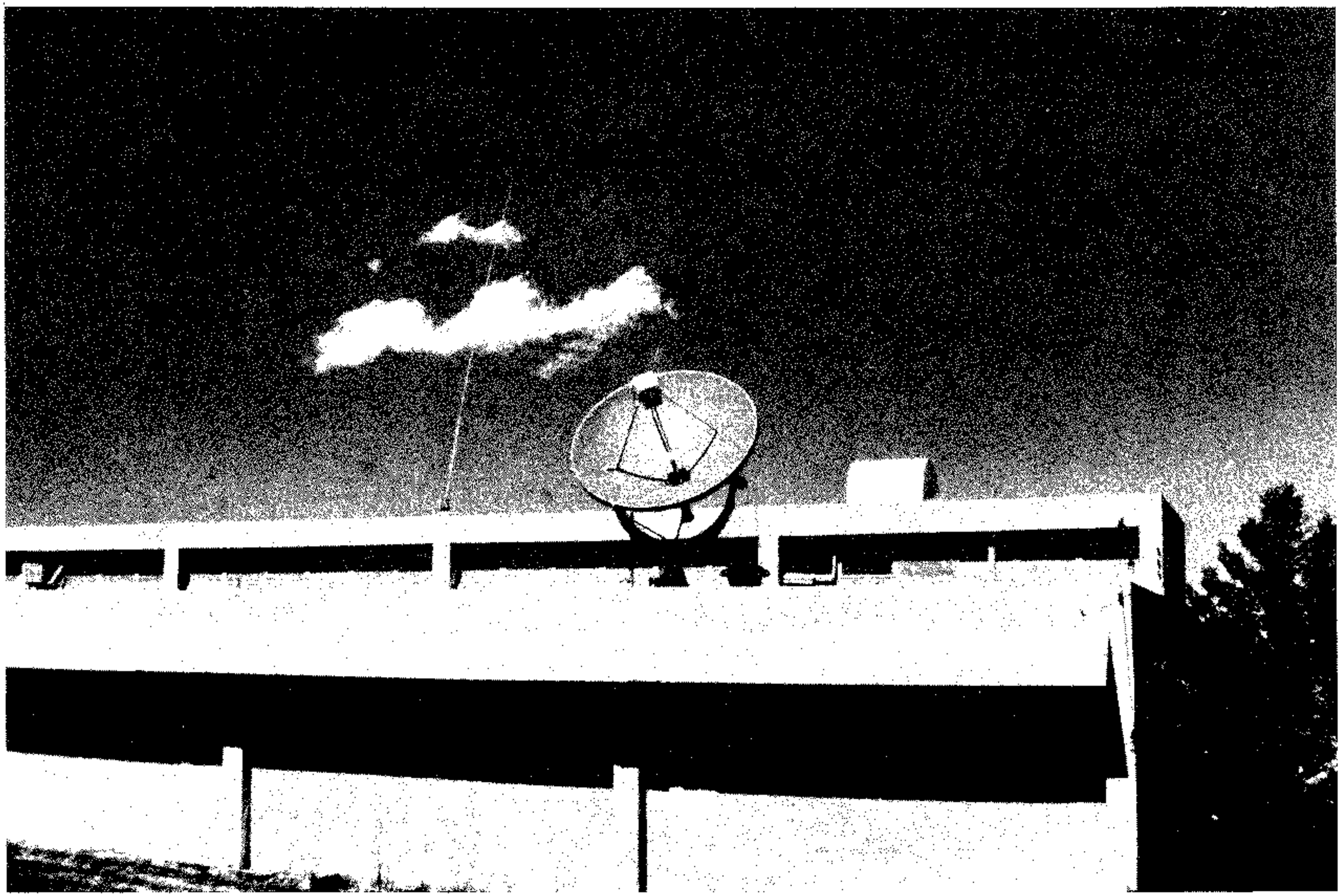


Figure 3-6. Ten foot receiving dish with receiver front end at prime focus.

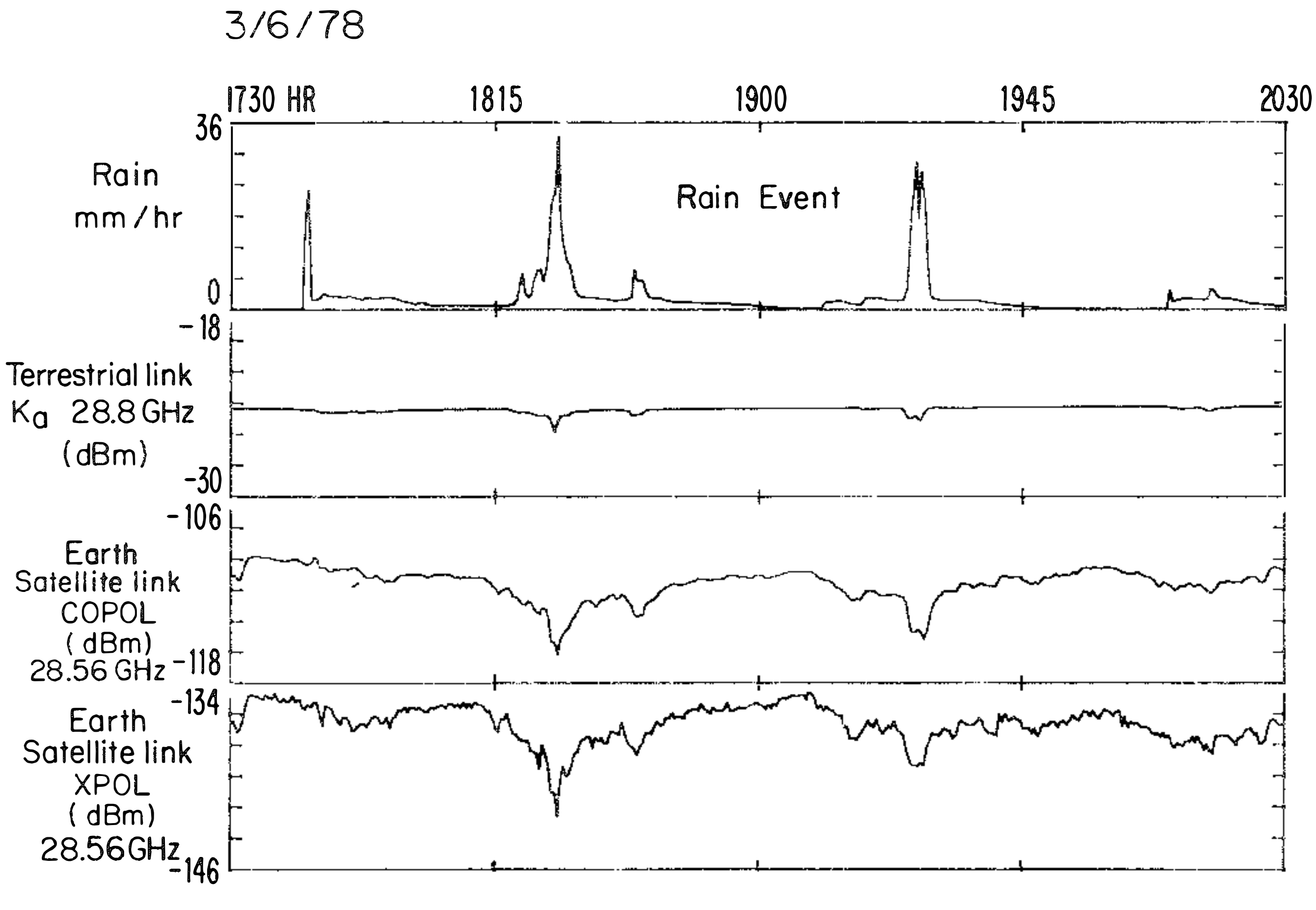


Figure 3-7. Received signal on terrestrial and earth satellite link versus time during a rain event. Satellite beacon signal received from COMSTAR D1 beacon at 128° west longitude.

depolarization upon frequency assignments is our ability to predict both the amount of depolarization and its likelihood of occurrence.

The likelihood of occurrence is directly related to the occurrence of: terrain irregularity, rainfall, clouds, turbulence, and stratification. Descriptors of terrain are widely available, at least for the U. S., and this project's efforts have advanced the prediction of rainfall attenuation due to rainfall (E. J. Dutton and H. T. Dougherty, "Estimates of the Atmospheric Transfer Function at SHF and EHF," NTIA Report 78-8, 1978; H. T. Dougherty and E. J. Dutton, "Estimating Year-to-Year Variability of Rainfall for Microwave Applications," IEEE Trans. Comm., August, 1978; E. J. Dutton and H. T. Dougherty, "Year-to-Year Variability of Rainfall for Microwave Applications in the U. S. A.," submitted to IEEE Trans. Comm.) and of stratification (H. T. Dougherty and B. A. Hart, "Tropospheric Stratification and Anomalous Propagation," AGARD Symposium Proceedings on Aspects of Electromagnetic Scattering in Radio Communications, Cambridge, MA, October 3-7, 1977; and H. T. Dougherty and B. A. Hart, "Recent Progress in Duct Propagation Predictions," submitted to IEEE Trans. Ant. and Prop. 1978).

The prediction of the amount of depolarization is directly related to both observed depolarization data and depolarization theory. Almost all of the observed depolarization data due to terrain effects was obtained in the 1930's and 1940's when the question of polarization (vertical, horizontal, or both) for TV broadcast was being settled. This is now clearly in need of summarization and correlation with theory, and will be the subject of continuing project efforts. Most of the depolarization data due to atmospheric conditions (rainfall, clouds, turbulence, stratification) is limited to forward and back scatter ($\theta = 0°$ or $180°$). Faraday rotation data has been long available and well correlated with theory, particularly at VHF and lower frequencies at which it is a dominant depolarization mechanism.

With the exception of the Faraday rotation or depolarization by ionized layers, the available theory for depolarization is very limited. The most advanced, that for terrain effects, lacks accurate correlation with data. The more currently interesting theory (depolarization by atmospheric conditions such as rainfall, clouds and turbulence) is restricted to forward and back scatter ($\theta = 0°$ or $180°$). Continuing project activity will be concerned with extending the theory for depolarization by atmospheric conditions to that for arbitrary scattering angles ($0° < \theta < 360°$) required for application to frequency assignments. The most promising approach appears to be extending the techniques (that were successfully applied to terrain) to the atmospheric situation.

Calibration of Water Vapor Measurements. During June 1978, an ITS model 7 refractometer system was operated in support of lidar measurements of atmospheric water vapor. Simultaneous measurements of refractivity, temperature, and pressure were recorded on magnetic tape in flight. From these data, water vapor profiles will be calculated to provide calibration of the lidar instrumentation. Twelve flight periods were conducted near Langley Field, Virginia, to altitudes up to about 4000 meters using a single engine aircraft (Figure 3-8).

Microwave Intervisibility Propagation Loss Measurements. An experimental program is being planned to examine feasibility of a millimeter wave system for determining intervisibility of players in simulated combat exercises. Frequencies in the 10 to 40 GHz band will be used to observe variability and predictability of path loss for distances from tens of meters to several kilometers, over different types of terrain, and as a function of position below optical line of sight. Mobile terminals will be used, first in Colorado and later at Ft. Hunter-Liggett, California.

3.2.2. Ionospheric Characteristics and Effects

Recovery of Ionospheric Ducted Signals from an Artificially Induced Scatterer. An artificially induced scatterer at ionospheric heights can be generated by the very high-powered HF transmitter at Platteville, Colorado. Rome Air Development Center (ETEI), Hanscom AFB is sponsoring a program to reactivate the ionospheric modification program and to perform a series of experiments to determine if ionospherically ducted signals can be reliably reflected from the field-aligned scatters generated when a very high rf field excites the plasma. These experiments were described in a special issue of Radio Science, November 1974, which was devoted to Ionospheric Modification. By mid-July 1978, the Platteville two megawatt transmitter facility had been renovated after almost five years of inactivity. As in earlier modification experiments, the diagnostic ionosonde is located about 26 km west of the Platteville transmitter and also guides the modifier in frequency to interact with the plasma at the appropriate heights.

Since the irregularities generated in the plasma by the HF energy are aligned with the earth's magnetic field, the signal reflection from the modified region will intercept the earth at a loci of points south of the region determined by the height of reflection. The most likely propagation path for ducted signals is believed to be

Figure 3-8. Single engine aircraft equipped to make simultaneous measurements of refractivity, temperature, and pressure.

the lower boundary of the F-layer, which varies in height from about 180 to 220 km over a diurnal cycle.

Figure 3-9 shows a sample of a long delayed signal at approximately 140 ms time delay. The Platteville transmitter generated the signals which consisted of two, 1 ms pulses separated by 5 ms at a repetition frequency of 5 per second. The receiver was located at the Erie site. Strong backscatter signals are apparent out to about 80 ms in delay with discrete echoes showing at about 38 and 53 ms. Because long delayed signals are difficult to detect and appear usually for only short periods it is hoped that the scatterers produced by the high powered transmitter will permit much longer periods for observations. If true, these observations will provide a better understanding of the propagation mode and launching technique to achieve the long delayed signals and determine if they are induced elevated modes.

The initial receiving location selected was at Los Alamos, New Mexico. Other locations will be tried to study the effects of path geometry on signal parameters. In order to establish a transportable receiving terminal, the equipment is housed in a 19-foot trailer. An 8-element array of a long-wire traveling wave (Beverage) antenna is used. This long-wire array provides adequate performance over a wide bandwidth (5 to 32 MHz) and is easy to transport and install since elements are only one meter above the terrain.

Although around the world (RTW) signals are often seen, and are presumed transported via an ionospheric duct, little is known about their propagation characteristics, particularly the mechanism for launching a RTW mode. For the first test series, two FM/CW transmitters capable of sweeping over a frequency range of 6 to 30 MHz were in operation, one at Ava, New York, by the Air Force and a second at Lost Hills, California, by Stanford Research Institute (SRI). In addition to the Los Alamos receiving site, SRI used a receiving station located a few miles from the transmitter to initially measure direct backscatter signals from the modified region. The data collected from the swept-frequency sounders during the series of experiments in mid-July supplements the earlier data providing information on scattering cross section versus height and time of day. From this, some knowledge of the amplitude of the recovered signals can be obtained so that propagation losses of the ducted signal can be calculated. Later tests are planned using pulse transmitters. If the injection and recovery efficiencies are sufficiently high to enable detection of multiple RTWs, then propagation losses in the duct can be directly reduced.

Also during the mid-July experiment, time and frequency transmissions at 5, 10, and 15 MHz were monitored and recorded to determine if conditions may permit one of these signals to be launched in an RTW mode. Transmitters geographically to the south of Platteville on these frequencies are located at Hawaii, India, China, Japan, Argentina, and South Africa. At Los Alamos, one or more of the frequencies from WWV at Fort Collins, Colorado, can be observed at anytime, which provides the reference time to measure delays of any other received signal. Of the few hours available when the modifier and the standard frequency signals were appropriate for possible ducting, there were real time observations of signals with delay times corresponding to WWVH in Hawaii and JJY in Japan. Magnetic tapes must be reduced on the computer in order to know the degree of correlation and to identify all stations.

During the next series of experiments scheduled for late September 1978, the FM/CW transmitters will attempt to launch ducted modes to be ejected and detected at the receiving sites.

Efforts on this program will continue in FY 79 with other transmitter and receiving stations employed. The degree of success and predictably of establishing ionospheric ducting channels will determine if long range radar for detecting ballistic missile launching as well as a communication network could result.

SECTION 3.3. 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 3.2, we first discuss the non-ionized media cases, and then those primarily influenced by the ionosphere.

3.3.1. Atmospheric Transmission Models

Propagation Models and Data Bases. Over the years, NTIA has developed many propagation models for a variety of telecommunication problems. This year, a project was continued to provide a unified data base for propagation models to support a wide range of anticipated communication concept, design, and evaluation situations based on current and previous works. This is a data and techniques bank which will consolidate the results of telecommunication research into an overall data base, including both atmospheric structure from models and measurements, and algorithms for translating these into performance predictions for specific system applications.

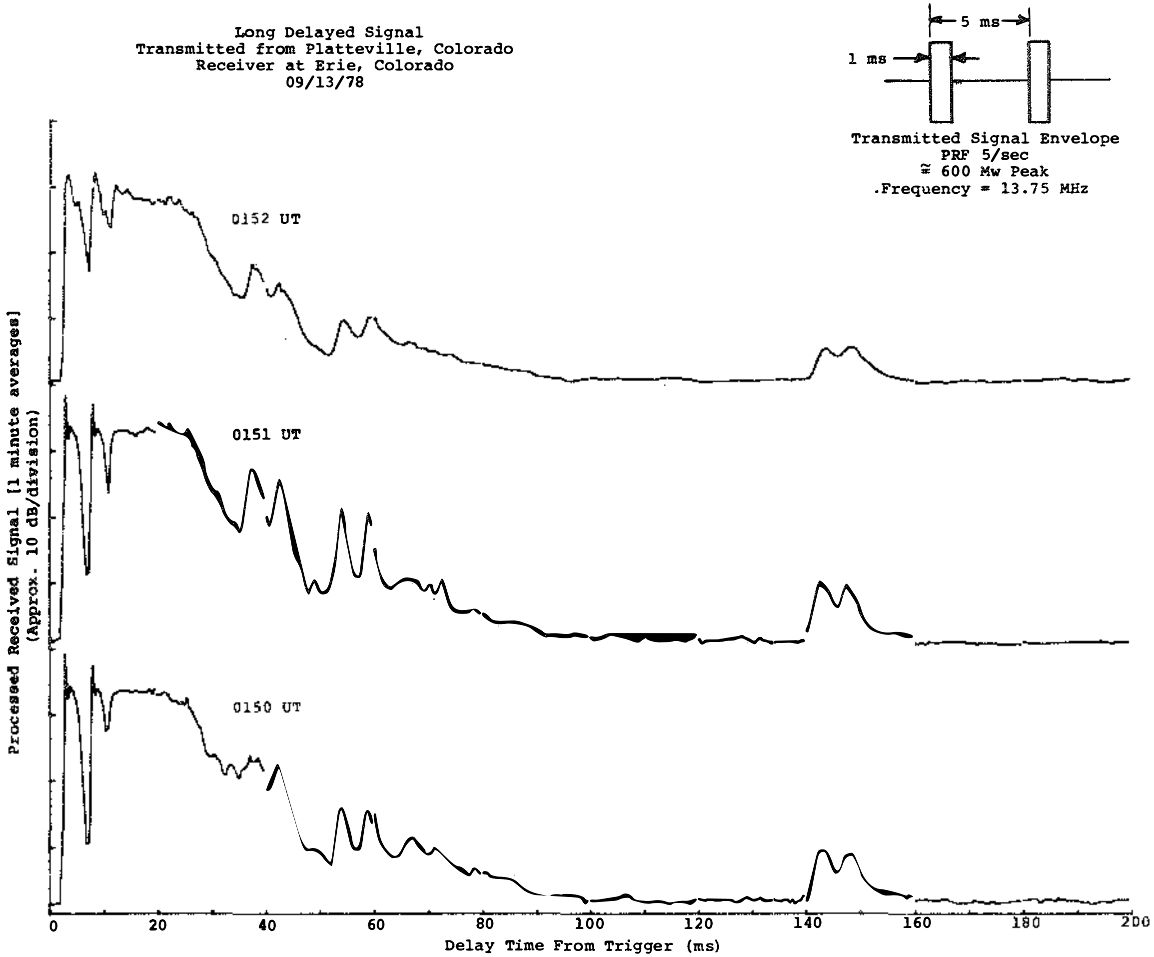


Figure 3-9. Sample of long delayed signal (137.5 ms).

In FY 77, concentration was on the frequencies between 10 and 100 GHz. In FY 78, efforts to expand the data base down to 100 MHz have been undertaken. The various models and algorithms are intended to be upgraded as new and/or better information becomes available. In succeeding fiscal years, it is anticipated that a comprehensive library of information will exist which will cover frequencies from VLF through optical.

A report entitled "A Preliminary Catalog of Programs and Data for 10-100 GHz Radio System Predictions," has been published as OT Report 78-141. An example of what is presently available in the beginning catalog is shown in Figure 3-10.

Computer programs and data bases under the following four categories now exist in the data bank:

Category 1. Computations of Transmission Loss and Radar Returned Power.

Category 2. Computations of Desired/ Undesired Signal.

Category 3. Computations of Atmospheric and Precipitation Parameters.

Category 4. Data Bases and Associated Programs.

Surface Wave Radio Propagation Measurements in the 100 to 2000 kHz Band. Measurements of surface wave propagation path loss and local ground conductivity were made over four paths in the 100 to 2000 kHz band. The paths were of lengths up to 52 km and were chosen to represent both extreme and typical topography and conductivity conditions for short communication paths within the U. S. The sites selected for the measurements were:

1. Canyonlands, Utah -- large variations in topography with wet river bottoms having sheer canyon walls to high, flat plateaus;

2. San Francisco, California -- large variations in ground conductivity with rather level topography;

3. Santa Rita Range, Arizona -- a long ridge with little change in topography along lines parallel to the ridge line; and

4. Highland Range and Dry Lake Valley, Nevada -- another ridge with large junipers, cedars, and similar vegetation.

The first objective of the measurements project was to obtain propagation loss data, over various types of terrain, which could be used to determine the suitability of a propagation prediction program for estimating the performance of a communication link over the same paths. The measurements were made during the daytime in order to restrict the measurements to the surface wave mode of propagation. A companion project compares the measurement results to propagation predictions made by program WAGNER, a theoretical prediction program (R. H. Ott, "An Alternative Integral Equation for Propagation Over Irregular Terrain," Radio Science, Volume 6, No. 4, April 1971).

The second objective was to describe propagation loss measurement techniques which could be used by others to make similar measurements in the LF-MF (low frequency-medium frequency) bands. Thus if program WAGNER is unable to predict the propagation loss values with sufficient accuracy, then these techniques could be used to make field measurements of propagation loss and/or signal strength instead of making loss predictions with program WAGNER.

The third objective was to develop a procedure for making ground conductivity measurements and measure the conductivity along the path that the propagation measurements were made. In order to make propagation loss predictions, program WAGNER requires frequency, ground conductivity, and path profile data for input. Two-dimensional path profiles are available from topographic maps of the areas where measurements are made. Ground conductivity data can be estimated from geological maps and from FCC ground conductivity maps (Fine, 1953); however, it was reasoned that if the ground conductivity could be measured along the path rather than estimated, then the influence of uncertain ground conductivity values could be removed from the prediction process. Eliminating conductivity as a variable parameter allows the prediction program to be tested for its sensitivity to the two-dimensional path profile data and compared with the propagation loss measurements; the measured losses are influenced by the three-dimensional terrain and not just the two-dimensional path profile used in the predictions. The requirements for making ground conductivity measurements were that they be made in situ without destroying the local ecology and that they be made at each of the propagation loss measurement frequencies.

Each site required approval from both the local Federal officials having land jurisdiction and the regional Federal Frequency Managers (in addition to IRAC approval) to transmit on noninterfering test frequencies.

Once the site was selected and the transmitter location and the receiver measurement points were approved by local officials at the sites, the path loss and conductivity measurements were made. The

Title: DEGP 76

Computes: Distribution of annual attenuation due to rain, clouds, atmospheric gases.

PHIRAP = partial phase delay due to rain only to height H, in radians

REVATUP = partial atmospheric attenuation to height H, in decibels

ETADB = reflectivity in DB relative to 1 KM(-1) at height H

PHIRA = total link pahse delay due to rain, oxygen and water vapor dispersion, in radians.

REVTAU = total atmospheric attenuation on link, in decibels.

Input:

NS - number of data stations.

NF = number of frequencies desired.

IF NCLD = 0, the program performs computations with a built-in nonprecipitating cloud distribution (subroutine cldbank). If NCLD not = 0, a cloud attenuation distribution must be provided as subroutine CLDDIS.

NA = number of elevation angles desired.

NH = number of heights desired. If it is not = 2, get attenuation coefficient at surface only. Otherwise, do the whole program as usual.

F = frequency in GHz.

STAT = station identification, not to exceed 40 letters and numbers in length.

P - station average annual pressure in millibars.

T = station average annual temperature in degrees centigrade.

RH = station average annual relative humidity as a decimal fraction.

BETA - ratio of thunderstorm rain to non thunderstorm rain, see RICE, P.L. and N.R. Holmberg (1973), cumulative time statistics of surface point-rainfall rates, trans. IEEE com. soc, 10, Oct.

R = rainfall rate in MM/HR, corresponding to a give percent of an average year (RELI).

HTOP = cloud top height in kilometers corresponding to a given percent of an average year (RELI).

RELI (CURRENTLY IN DATA STATEMENT) = percent of an average year of interest (time availability per year).

THETA = elevation angle of earth station antenna, in degrees.

H = height above surface in kilometers.

Limitations: Not valid for satellite/earth trojectaries where the elevation angle to the satellite is less than 5°.

Current Status: Does not yield smooth output; i.e, the output distribution is not smooth, and should also be graphically displayed, to be of maximum usability.

References: Dutton, E. J., Earth-Space Attenuation Prediction Precedures at 4 to 16 GHz (soon to be OTR).

For more information contact: E. J. Dutton

Figure 3-10. Sample information page from catalog.

transmitter was fixed at one end of the path and measurement points accessible by 4-wheel drive vehicles were selected along a radial from the transmitter over the terrain of interest. The receiver system was transportable to each measurement point and was tuned to sequentially receive CW transmissions on each of the five or six test frequencies. Following the propagation loss measurements along the entire path, ground conductivity measurements were made at each of the test frequencies at each measurement point.

The raw data were digitally stored on magnetic tape for data reduction on a batch computer facility at Boulder. The reduced propagation loss data will be analyzed by a companion project to determine the differences between the WAGNER predictions and the measurements at each site and frequency.

As an example from the measurement program, Figure 3-11 shows the transmitter site for the Canyonlands measurements and Figure 3-12 shows the topography of the Canyonlands. The path profile of the radial along which measurements were made is shown in Figure 3-13. The measured signal and noise levels at 2 MHz along the path are shown in Figure 3-14. The corresponding predicted signal levels are shown in Figure 3-15. The measurement procedure and results are to be published in an NTIA Report entitled "Surface Wave Propagation Measurements in the 100 to 2000 kHz Band."

Multipath Fading on Long 15 GHz Paths. This project is designed to acquire data, analyze it, and develop empirical parametric relationships for designing long (greater than 50 km) line-of-sight microwave links. The largest part of the data base for models now being used was obtained on short paths, for relatively short periods, and at frequencies between 4 and 6 GHz. Although there is some data at 11 and 15 GHz, much of these data were obtained using recording techniques which did not provide adequate time resolution for obtaining short term statistics.

Data acquired on this project will be obtained using carrier frequencies of 8 and 15 GHz. If possible, the data will be acquired on three long paths (90 km, 93 km, and 132 km) which converge at Mt. Corna, Italy (see Figure 3-16). The 93 km path is primarily over water. The data acquisition period will be one year beginning in September 1978, if possible. Recording of data will be done using digital magnetic tape after the data are first preprocessed by computer in one hour blocks. The data will also be recorded on strip chart to aid in categorizing fading mechanisms. This categorization will be done in an attempt to separate signal level variations into incidence of Rayleigh fading, rain attenuation, other forms of power fading, and equipment malfunction. To be comparable with prediction methods now in use, the data will be analyzed to predict Rayleigh fading incidence occurring during the worst 30-day period.

The project is sponsored by the U. S. Army Communication Command in view of increased pressure to change military radio systems to operate in the 15-GHz band within areas of high microwave spectrum usage.

Air Navigation Aids. A knowledge of service and interference ranges associated with existing and future air navigation aids is an important part of the FAA's spectrum planning effort. Propagation prediction capabilities developed by NTIA as part of the Air Navigation Aids project are utilized to provide much of this information.

During 1971-1973, an air/ground propagation model applicable to irregular terrain was developed by ITS for the FAA and was documented in detail. This IF-73 (ITS-FAA-1973) propagation model has evolved into the IF-77 model, which is applicable to air/ground, air/air, ground/satellite, and air/satellite paths. It can also be used for ground/ground paths that are line-of-sight, smooth earth, or have a common horizon. During 1978, documentation for IF-77 was published in the form of two reports. One is an "Application Guide" which details the plotting capabilities of the ten computer programs which utilize the IF-77 model. Two sample plots are shown in Figures 3-17 and 3-18. The other report documents the "Extensions" to the IF-73 model to develop the IF-77 model.

The work currently underway on the project is in two directions: (1) Production of computer generated propagation or interference predictions for the FAA is on an as-requested basis. Part of this work is being used by the FAA to develop new standards and to publish new handbooks. (2) The comparison of predictions with experimental data and with other models is constantly going on. During 1978, a report was begun which compares over 300 predictions made with the IF-77 model with data and with other models. An example of one of these comparisons is shown in Figure 3-19. The report should be published next year.

Propagation prediction capabilities developed as a part of the Air Navigation Aids project are frequently utilized to provide predictions for other projects. One such project is the Ground/Air Propagation Prediction project in which service coverage predictions for a missile command/destruct transmitter were developed for the Pacific Missile Test Center (PMTC). These predictions were made with a program

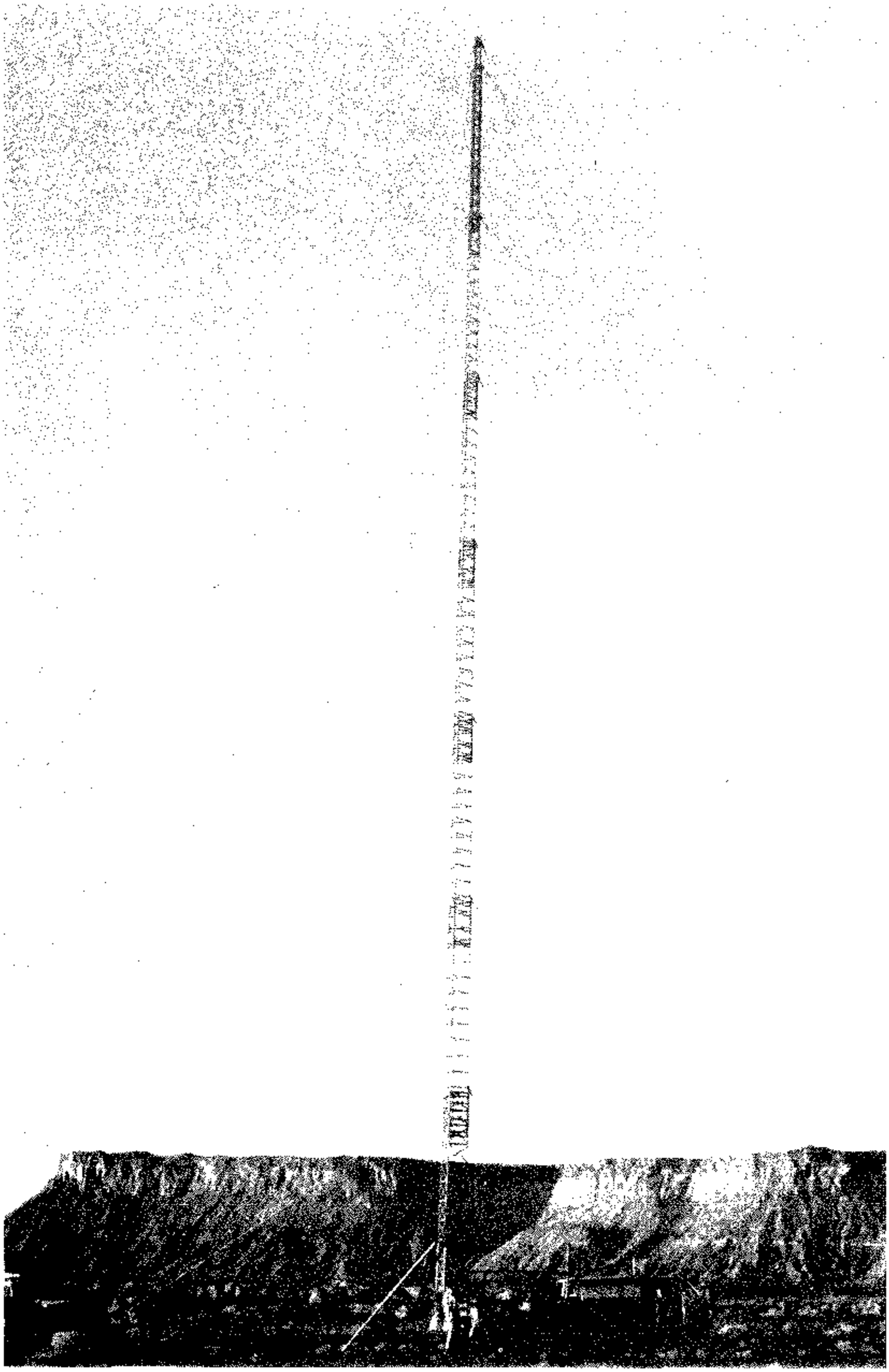


Figure 3-11. Canyonlands transmitter site looking along the measurement radial.

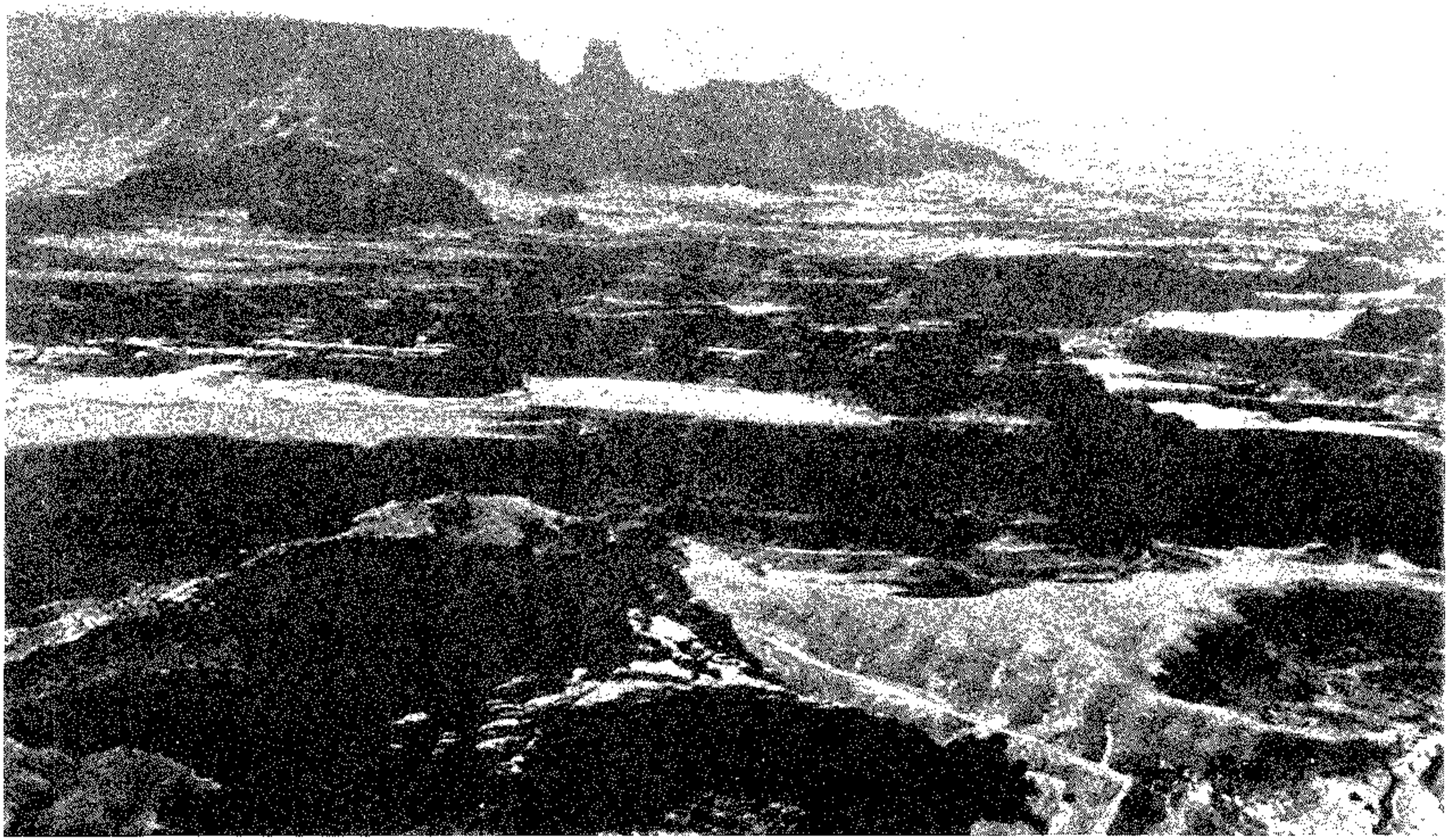


Figure 3-12. The Canyonlands site as viewed from Dead Horse Point. The radial crosses the three plateaus on the left.

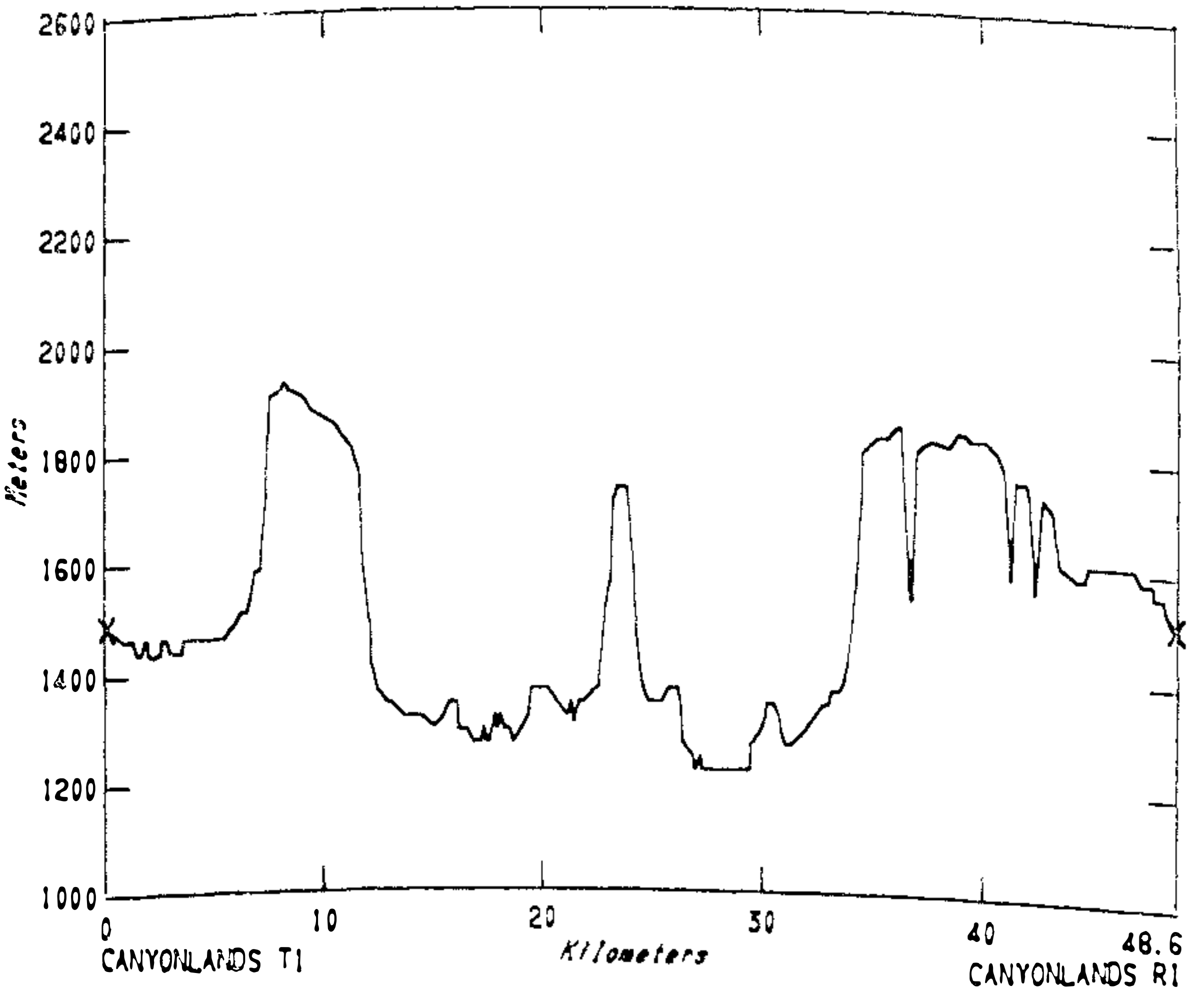


Figure 3-13. Path profile plot for Canyonlands, Utah.

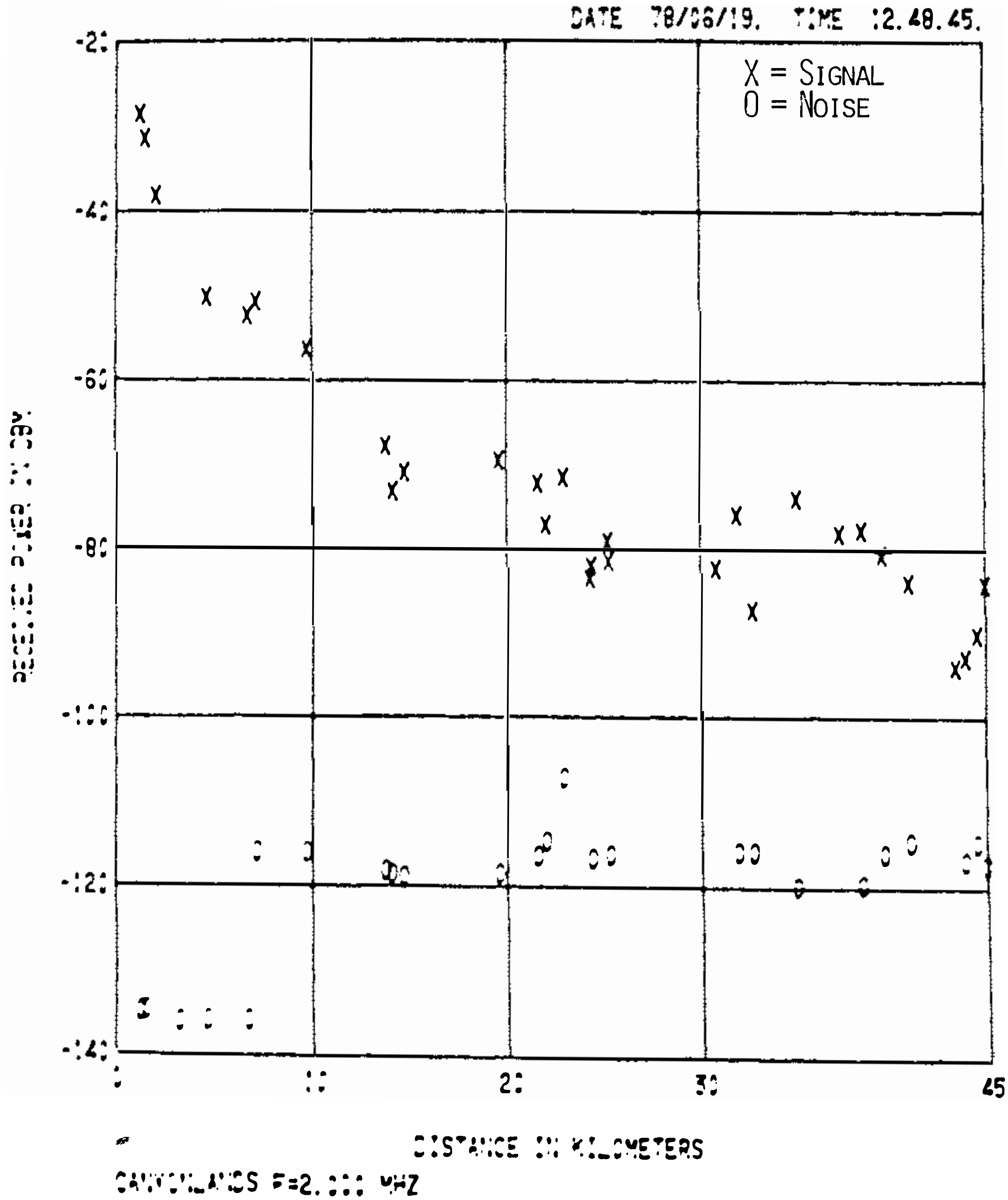


Figure 3-14. Measured received signal and noise levels, Canyonlands path, 2.0 MHz.

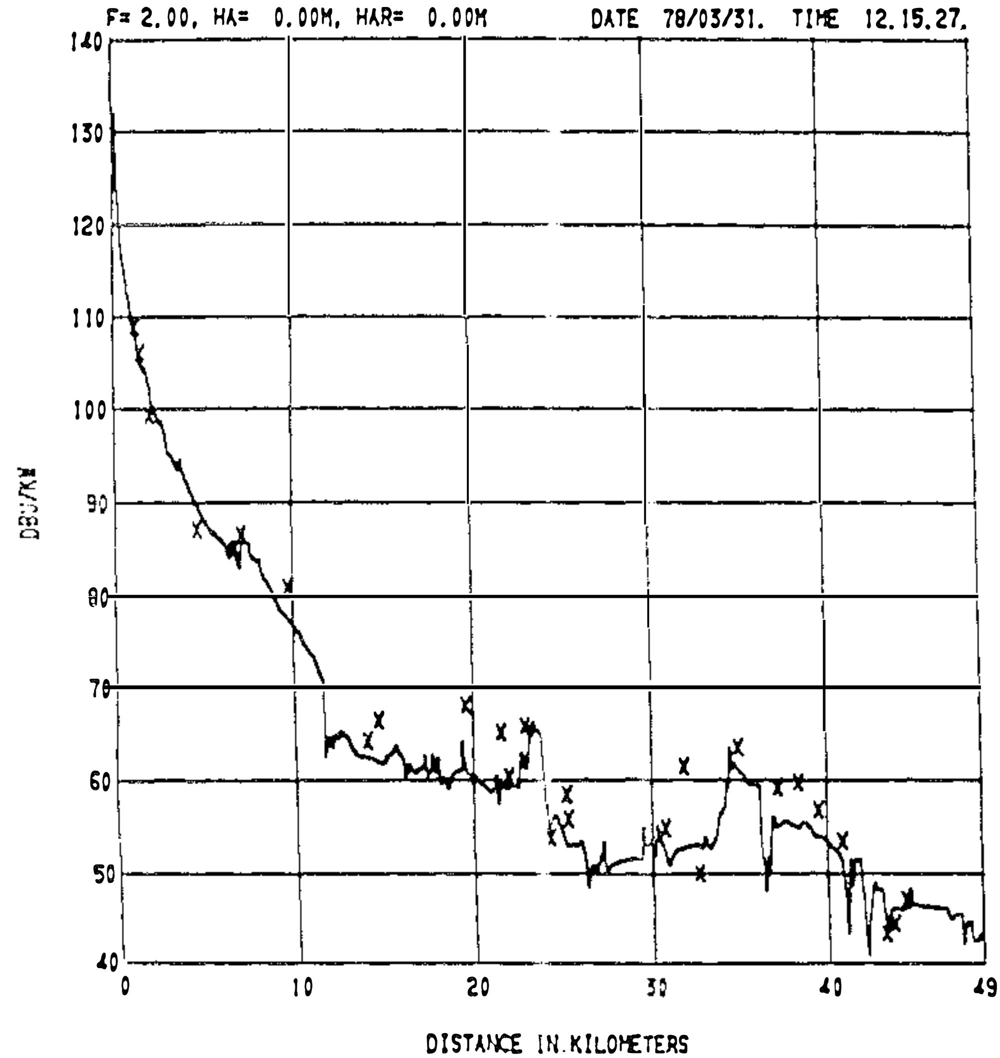


Figure 3-15. Preliminary plot of propagation loss measurements made at Canyonlands, Utah, site (X) and the predictions of loss from WAGNER (solid line) for 2 MHz.

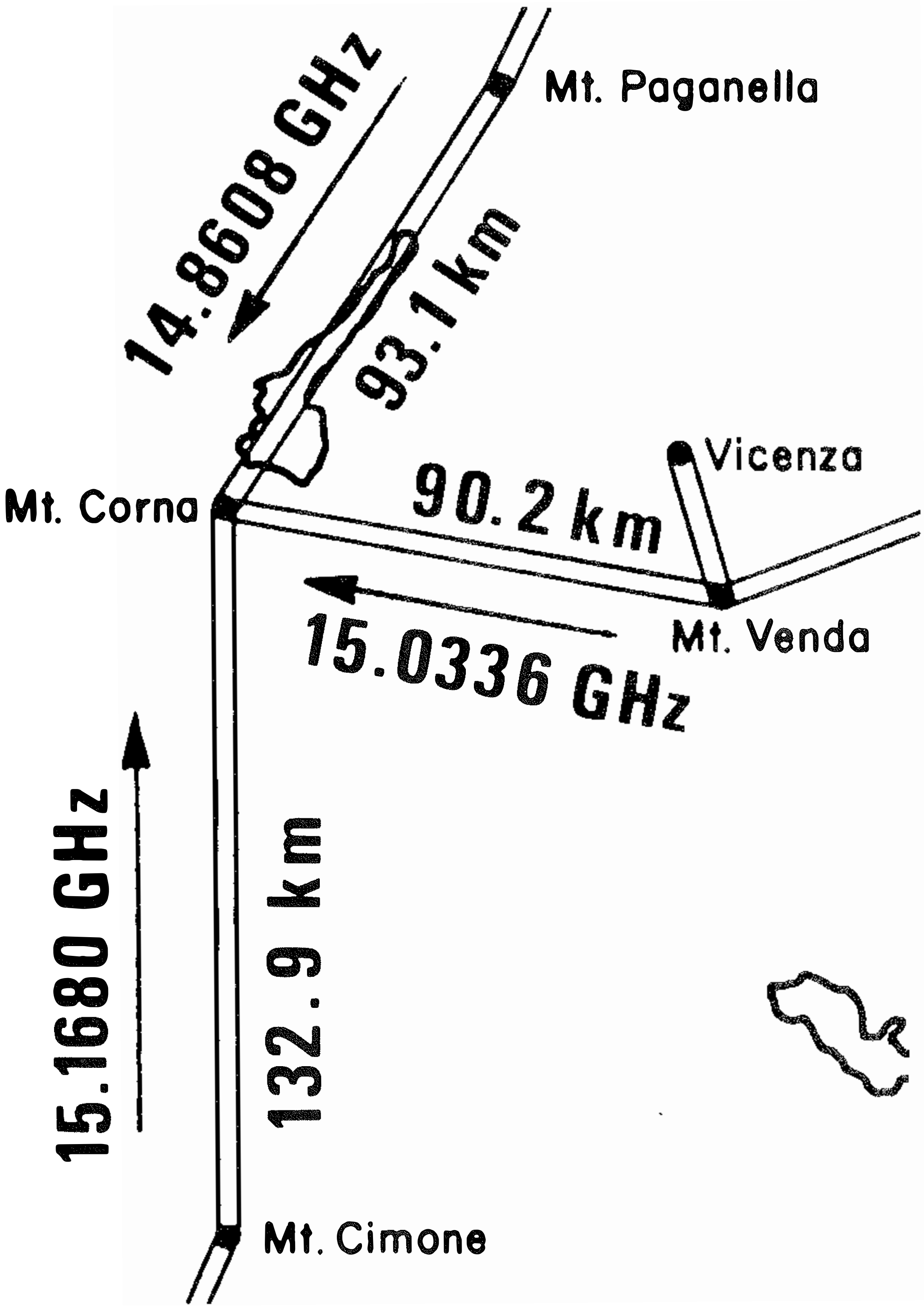


Figure 3-16. Path locations for the long path 15 GHz multipath fading tests.

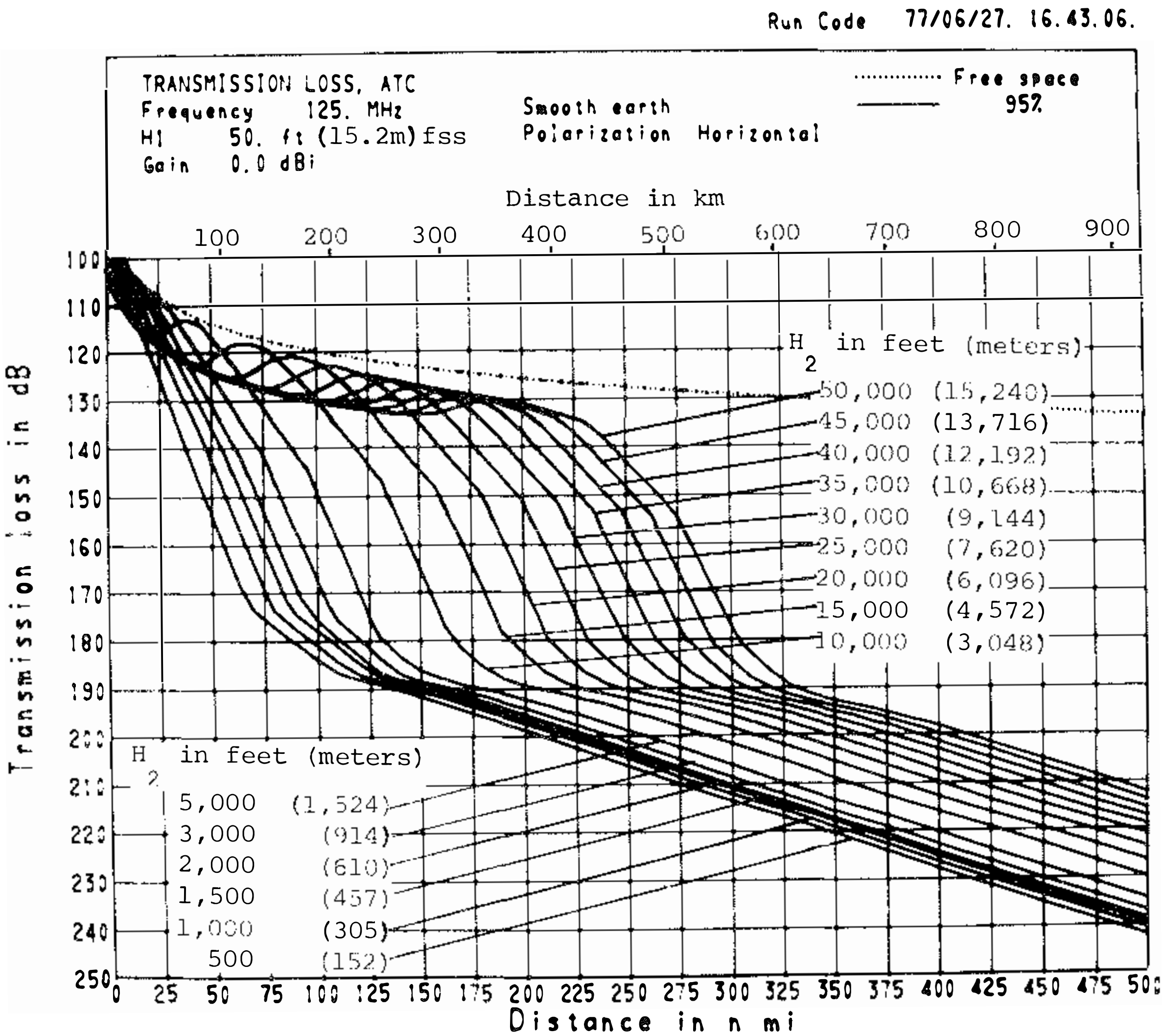


Figure 3-17. Transmission loss curves, air traffic control. Sample "applications" plot.

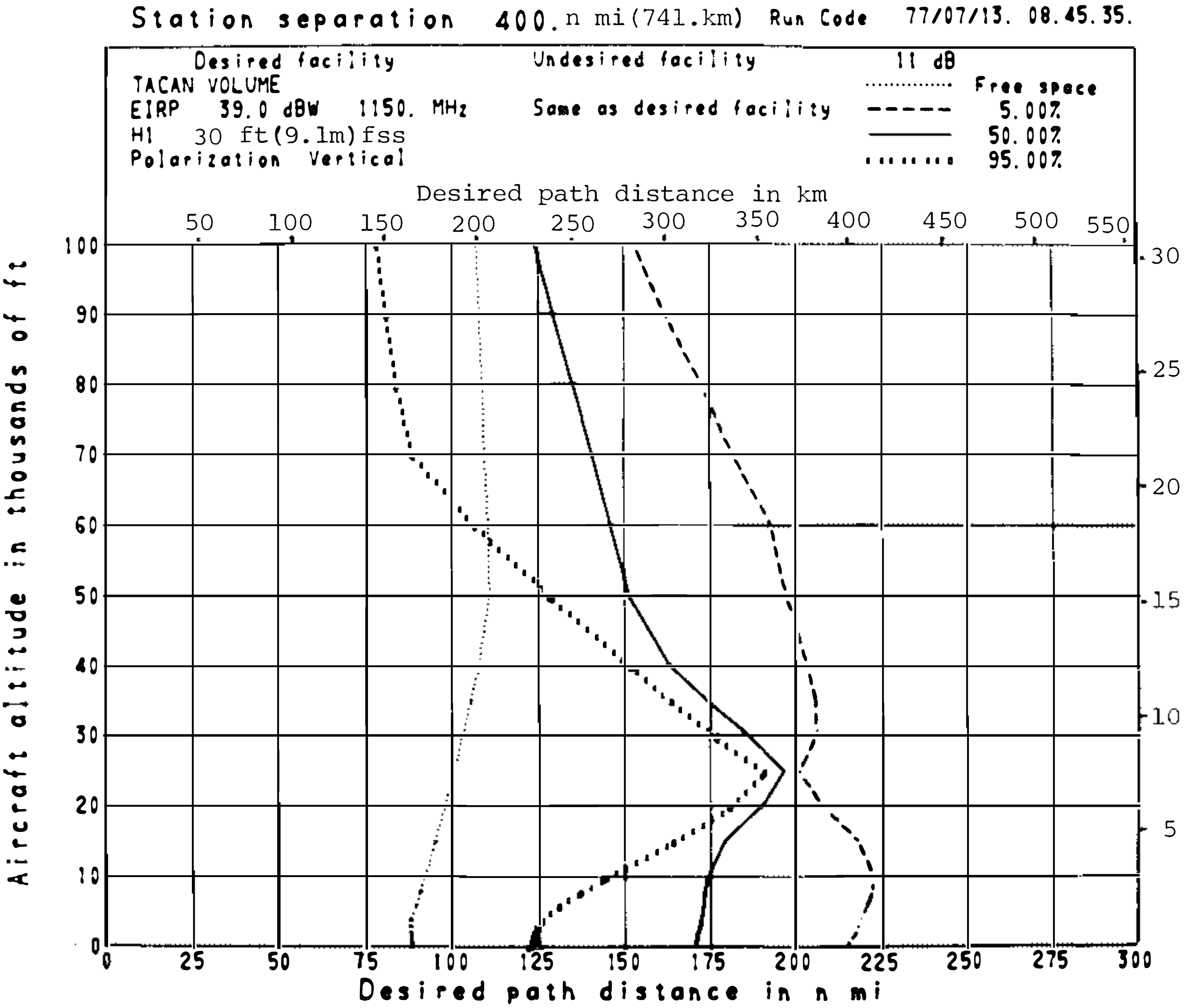


Figure 3-18. Service volume, TACAN. Sample "applications" plot.

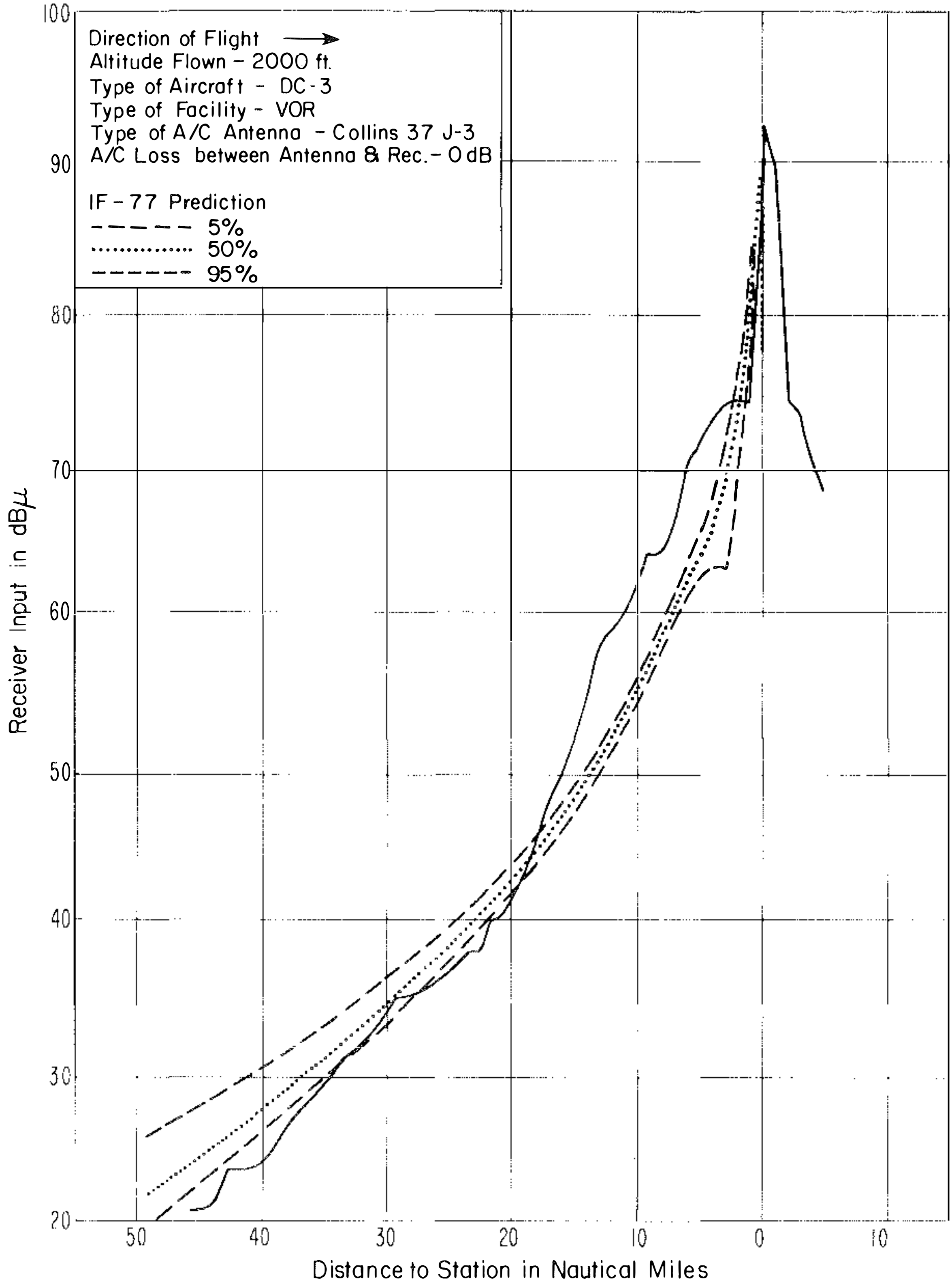


Figure 3-19. A sample comparison of predictions and measured data, this one being an actual facility overflight.

modified to (1) approximate the circularly polarized transmitter antenna pattern, and (2) include missile receiving antenna gain statistics for a random orientation in the calculation of signal level variability. Figure 3-20 is a sample of the predictions provided. It shows the air space (service areas) in which different received power levels at the missile would be expected to be available for at least 99.9% of the transmission time.

Hydro-Quebec is planning an extensive modernization of its land mobile radio system. Under this project, entitled Mobile Aids, 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 FY 78, we have supplied the sponsor with programs to estimate received signal levels on point-to-point communications links, from a mobile base station to a sequence of points along a road, and from a mobile base station to an entire area. All of these use a file of digitized topography which is soon to be implemented.

In a project devoted to VHF/UHF Model Development for Urban and Rural Communications, we completed an extensive study of what is known or surmised about propagation in rural areas. The report that describes this study also discusses the Longley-Rice model of propagation and gives suggestions as to how it may be modified to include an "urban factor."

In other directions, this same project has begun assembling measured data into a computer readable form. The emphasis here is on radio data (including its variability) in or near the UHF television band, for there is still controversy over what engineering parameters one should use in this important part of the spectrum. In addition, the project now has underway the preparation of several papers on the general subject of variability.

The second phase of a study of Power Fading Statistics is underway. Sponsored by the Electromagnetic Compatibility Analysis Center, Department of Defense, the purpose is to put on a firm foundation one aspect of the engineering design of microwave links. Heretofore, calculations of the magnitude of long-term (power) fading has been based on techniques developed ten years ago when there were few accumulated data at frequencies above 1 GHz.

In this second phase we are collecting together all the newly available data. We will compare these data with the present day techniques and suggest whatever adjustments seem necessary.

3.3.2. 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 predictions services to fit users needs.

Normal day-to-day and hour-to-hour departures of critical frequencies (foF2) and other ionospheric characteristics from observed median values have a significant effect upon the range of useful frequencies on HF communication circuits. Even greater effects result from disturbances in the earth's magnetic field and from certain forms of activity on the sun.

Development and Improvement of Prediction Formats. The ICA/VOA, in maintaining and improving its worldwide broadcast schedules on high frequencies, requires predictions of its expected broadcast coverage well in advance to prepare for its broadcast schedules. Predictions have been delivered on schedule, and VOA continues to make occasional use of their programs by remote access. Work has been done and will continue to adapt the new HF predictions program (IONCAP) to VOA's needs. IONCAP output will be compared with HFMUFES (the present program) output, and both will be checked (by VOA) against monitoring results.

3.3.3. Terrain Models

Ground Wave Propagation Over Irregular, Inhomogeneous Terrain: Comparisons of Calculations and Measurements. A method for calculating the ground-wave field over irregular, inhomogeneous terrain was developed by R. H. Ott, and several comparisons with alternative analytical methods were made for idealized terrain profiles like concave parabolas, sea-land-sea paths, and Gaussian ridges. The excellent agreement between methods like Fock currents for concave surfaces, classical residue series, an integral equation developed by Hufford, with Ott's alternative method based upon an elementary function (closely related to the Sommerfeld Flat-earth attenuation function) for the parabolic wave equation provided encouragement for the usefulness of Ott's method and the associated algorithm.

The research on this program in FY 78 extended and modified the original algorithm and compared the computed field strength with observed values obtained on 9 separate paths shown in Table 3-1. The polarization was vertical for all paths in Table 3-1 except the Buffalo path.

As an example of the comparison between the predicted and measured field strength

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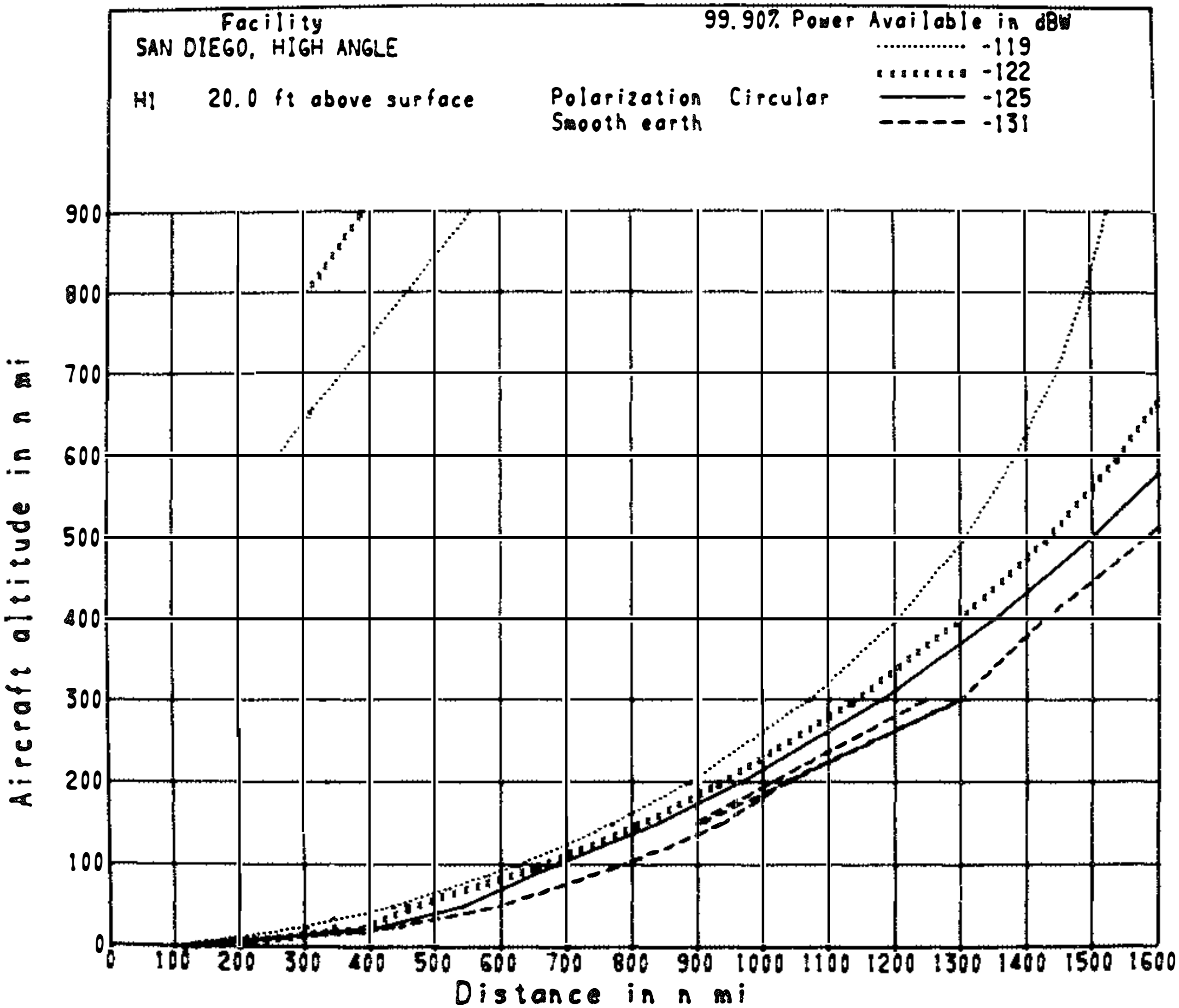

Figure 3-20. Service areas for command/destruct transmitting antenna with high beam elevation angle.

Table 3-1. Program Waglin Comparisons

Path	Frequency	Reference
Transmitter (WGR-TV) in Buffalo, NY-over Lake Erie toward Cleveland	59.75 MHz (horizontal polarization)	Ring, A.D.(1958) Field strength measurement survey for Association of Maximum Service Telecasters, Inc., Buffalo, NY, A.D. Ring and Associates, Washington, D.C.
Transmitter (KCBS) north of San Francisco Bay, south through San Francisco, over Santa Cruz Mountains	740 KHz	CBS Radio (1971), Field intensity measurements to establish performance of directional antenna rotation KCBS, San Francisco, CA, Report E 70704-A, CBS Radio, Columbia Broadcasting System, Inc.
Transmitter (KBLU) in Yuma, AZ, beyond Tinajas Altas Mountains toward Luke AFB.	560 KHz	Contact John Heckscher, Rome Air Development Center, Hanscom AFB, Cambridge, MA
Transmitter (KBOL) in Boulder, south over Davidson Mesa	1490 KHz	Contact W. A. Kissick, Institute for Telecommunication Sciences, Boulder, CO
Canyonlands, UT adjacent to Canyonlands National Park	.120, .180, .410, .510, 1.62, 2.0 MHz	"
From Mare Island, Valejo, CA south over San Francisco Bay over Marin Peninsula	.120, .180, .410, .510, 1.62, 2.0 MHz	Contact W. A. Kissick, Institute for Telecommunication Sciences, Boulder, CO
Santa Ritas, NM near Greenvalley, NM and adjacent to New Mexico Experimental Range	"	"
Dry Lake, NE, Transmitter on east slope of Highland Range, over Highland Peak to Dry Lake Valley	"	"
Colorado Mountain Data toward Berthoud Pass Campground	"	M. E. Johnson, et al. (1967) IER report number IER 38-ITSA 38-2

versus distance consider the Luke-Yuma path. RADC personnel made a number of field strength measurements in an area southeast of Yuma, Arizona, using as a source the Yuma commercial broadcast station KBLU (560 kHz). The path profile is shown on the lower portion of Figure 3-21. The path crosses a minor ridge (Vopoki Ridge) at about 45 km and, later on, a higher ridge (Tinajas Altas Mountains) at about 65 km. The electrical ground constants used in PROGRAM WAGLIN are shown in the upper right hand corner of Figure 3-21. In Figure 3-21 is a plot of the predicted path loss (solid curve) in terms of "DBU/KW" (dB above 1 microvolt per meter for 1 kw radiated from a half-wave dipole in free space), together with measured DBU represented by crosses. The predictions appear to agree very well with the observed values.

Automated Digital Topographic Data Techniques. The Automated Digital Topographic Data Techniques project designed and will improve a digital terrain elevation data base along with the related software. It is primarily to be used by USACEEIA in carrying out its worldwide responsibility for planning, trouble shooting, and installing routine and strategic communication systems. Methods for predicting the performance of communication systems generally of frequencies above 30 MHz require terrain information derived from profiles along a large number of potential propagation paths (see Figure 3-22). These require a rapid and accurate means of automatically generating these profiles from data stored on magnetic tapes or disks. To satisfy this requirement, ITS has designed a digital terrain elevation data base (TOPOG) that:

1. provides significantly greater detail than can be obtained from the data base currently being used by the sponsor;

2. can readily expand toward global coverage as additional data become available;

3. can be generated in a reasonably efficient way from existing and projected sources of raw data;

4. can be utilized in an acceptably efficient manner in profile generation and other telecommunications applications; and

5. minimizes storage space requirements subject to constraints imposed by conditions (1) and (4) above.

After a preliminary study in FY 77 of several alternative methodologies of creating and returning datum from data bases, the result was a data base consisting of the elevations at the nodes of a global grid of parallels and meridians whose basic value is 3 seconds. The primary source of raw data for the present will be the so-called Standard Digital Terrain Elevation Data Files being produced by the Defense Mapping Agency. The DMA tapes are not in a usable format for easily extracting terrain profile data. CONUS will be covered by about 75 TOPOG tapes (1600 bpi, 2400' reels) versus about 110 DMA tapes.

In FY 78, the project has developed (1) software for generating TOPOG records and tapes from DMA Standard Files (PROGRAM GENTOP), and (2) a basic retrieval subprogram (ELVAT) which, when given the latitude and longitude of an arbitrary point on the earth's surface, utilizes TOPOG to return the elevation of that point or informs the user that TOPOG does not contain the necessary data.

SECTION 3.4. 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.

3.4.1. Long-Term Ionospheric Predictions

The ICA/VOA requires regular predictions of "circuit" performance as an aid in planning appropriately for the continuation of its world-wide HF broadcasts.

The Radio Propagation Predictions project provides the VOA every second month with HF circuit performance predictions for about 180 broadcast circuits 8 months in advance. For about 150 of these circuits (from Tinang, Kavala, Greenville, Wooferton, Monrovia, Munich, and Tangier), the predictions include selection of optimum transmitting antenna.

CDC 6600 files have been maintained for local batch processing and, under the VOA Time Share Service, they are available for use by means of remote access from a remote TELEX terminal. Program files have been prepared and maintained to help in (1) preparation of input data for the prediction program, and (2) to give great circle distances and bearings for arbitrary circuit terminal locations. Files are also maintained on the XDS 940 for interactive time-share access by VOA to the prediction program.

In addition to VOA, there are other government agencies and industrial organizations requiring Numerical Prediction Services. This project provides HF radio propagation predictions and computer programs on a cost reimbursable basis.

HF radio propagation predictions were pro-

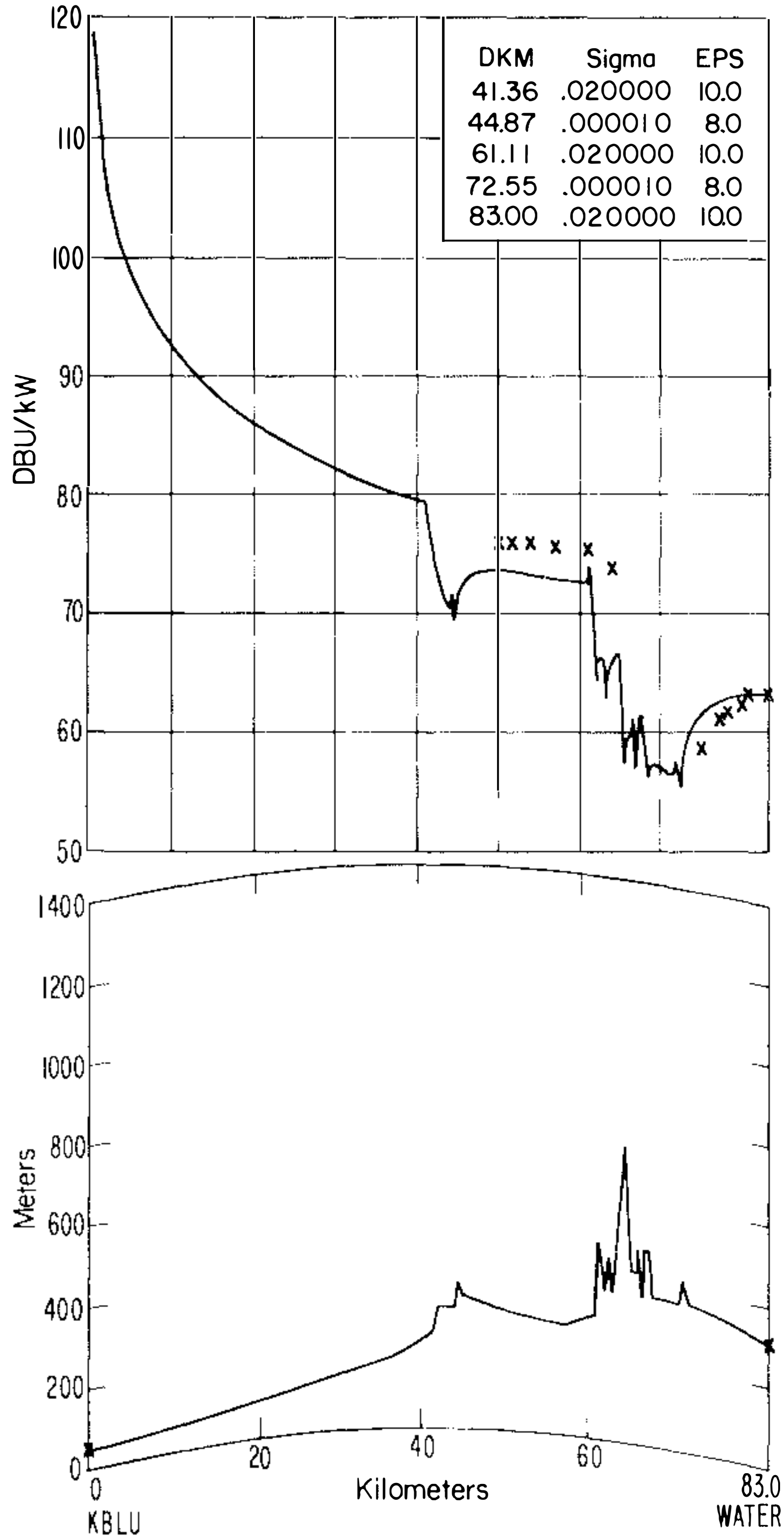

Figure 3-21. Path loss in dBU/Kw versus distance in km for a path with transmitter in Yuma, AZ, over the Tinajas Altas mountains toward Luke AFB.

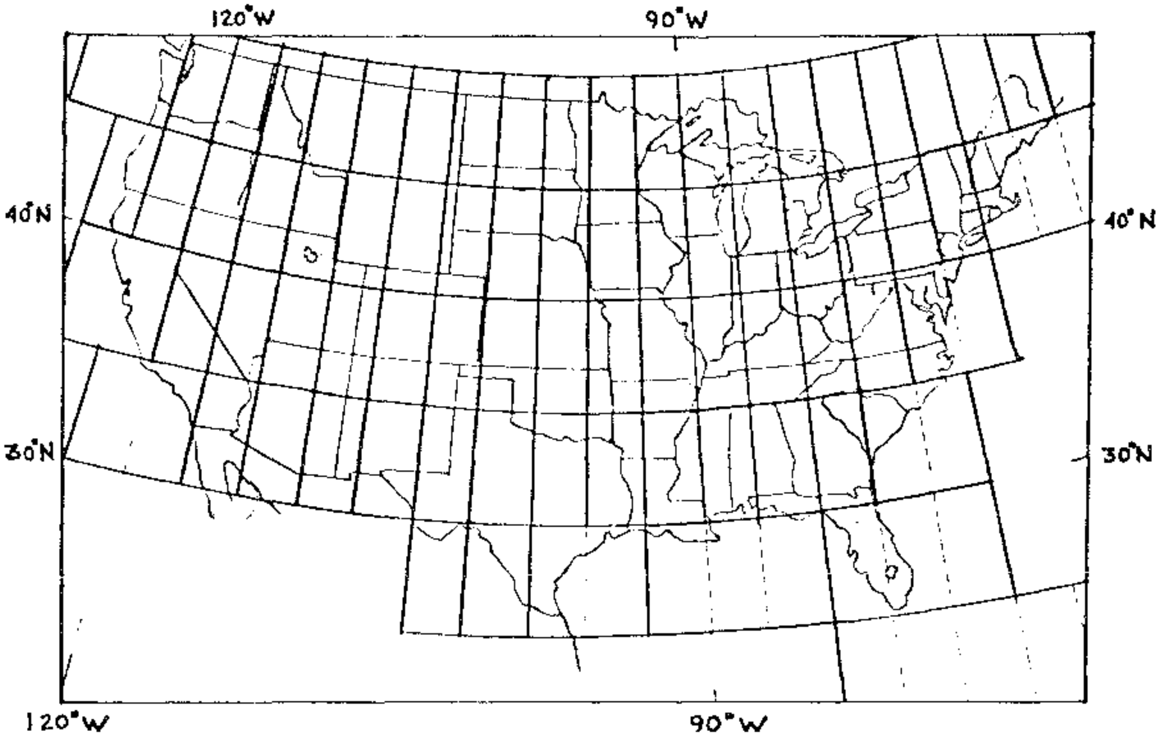

Figure 3-22. TOPOG tape areas for CONUS.

vided routinely to ITT World Communications, Associated Press, NOAA/SEL, and the American Radio Relay League (for publication in QST). ITS made predictions for Sperry Support Services (for the Coast Guard), USDA Forest Service, the World Radio Missionary Fellowship, and for Phillips Petroleum in support of the HF communications required in their operations. In addition, predictions were sent to the following companies in support of HF systems design and were supplied to foreign governments, especially in the Middle East: BR Communications, Canadian Marconi, CCA Electronics, DHV Incorporated, Sabre Communications, Scientific Radio Systems, Singer Products Inc., TAI, Techno Gener Ltd. (Iran). ATC in Denver needed predictions for the projected reception (for midwest rebroadcasting via cable) of VOA programs from the east coast of the United States. Also under the reimbursable Numerical Predictions Services project, program tapes were sold to Granger Associates, Hoyles Niblock International Ltd, Merle Collins Foundation, Shape Technical Center, National Institute for Telecommunications Research (South Africa), United Marine Electronics A/S (Norway), and Johns Hopkins APL. The program was provided without cost to the Radio Research Laboratories in Tokyo.

SECTION 3.5. 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.

3.5.1. Antennas and Radiation

Buried Antenna Studies--MX Phase II. The major part of the MX mobile antenna studies will be completed with a set of onsite measurements at the Luke-Yuma, Arizona, test site during September 1978.

Major tasks performed this year are as follows:

- Completed final report for Phase I.
- Obtained instrumentation van, installed test instrumentation and support systems.
- Developed and tested UHF antenna model for ground-to-air communications.
- Fabricated and tested full-scale MF antenna.
- Designed and tested electrically small MF dipole antenna and provided receive-only active antenna for onsite measurements from 10 kHz to 50 MHz.

Figure 3-23 is a photograph of the instrumentation van interior. All antenna power-gain pattern measurement data are reduced to plots onsite; some are plotted in real time.

Figure 3-24 is a plot of buried antenna power gain, versus azimuth, relative to that of an above ground reference vertical dipole antenna. The elevation angle to the source of test site illumination is about 13 degrees.

BOM Analytic EM Waves. Various subsurface guided wave mechanisms have been analyzed for the Bureau of Mines. The primary applications have been in mine communications, but some attention has also been given to electromagnetic methods for nondestructive testing of mine hoist ropes. The following specific areas have been studied during the past year.

The leaky-feeder communication technique is presently under consideration for use in mine tunnels. This technique normally utilizes a coaxial cable with some type of loose braid for the outer conductor. The propagation modes of such a structure have been studied both numerically and approximately using a quasi-static theory. By analyzing both circular and elliptical tunnel models, it was found that the shape of the mine tunnel does not strongly affect the propagation modes. Mode conversion can occur in leaky feeder transmission due to irregularities in either the cable or the tunnel properties. Both controlled mode conversion as produced by the cable design and inadvertant mode conversion produced by tunnel wall roughness have been analyzed. The transmitting and receiving antennas are usually loops or short monopoles, and total transmission loss calculations have been made for both types. Pulse propagation and bandwidth limitations for leaky feeder channels have also been analyzed, and the bandwidths are typically found to be quite large.

Trolley wire communications in mine tunnels utilize a quasi-TEM mode of propagation with forward current in the trolley wire and return current in the trolley rails. In practice, discrete shunt loads on the trolley wire can introduce losses and reflections which limit the range of transmission significantly. To extend the transmission range, a smaller "dedicated" wire can be utilized to provide a low-attenuation mode of propagation which is relatively insensitive to discrete shunt loading of the trolley wire. The typical frequency of operation is about 100 kHz, and the effects of shunt loading have been analyzed by an approximate transmission line analysis. Both the analysis and experiments performed by the Bureau of Mines confirm that the dedicated wire extends the range of transmission.

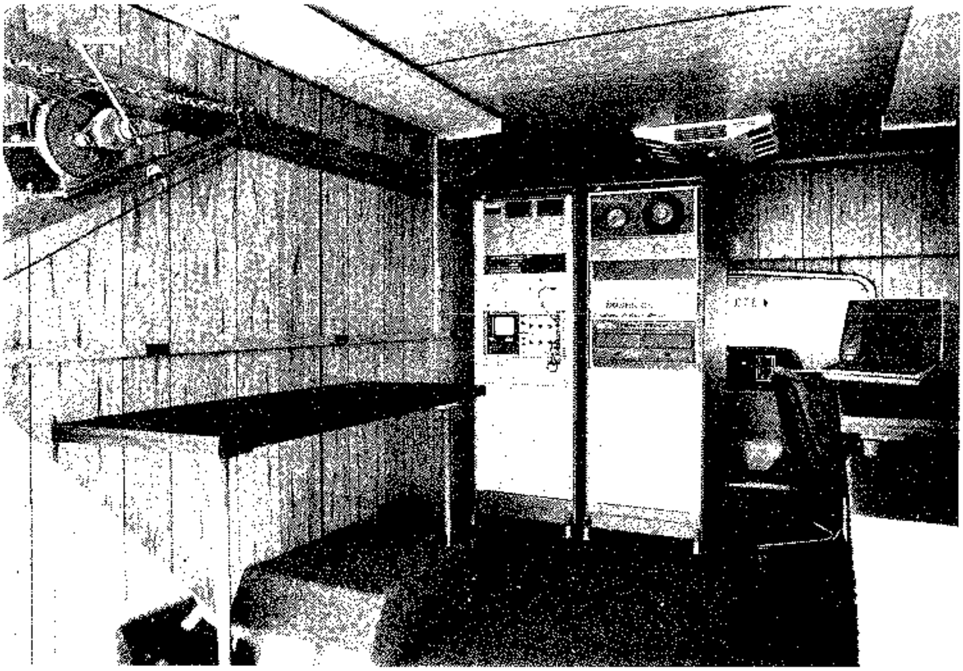

Figure 3-23. Interior view of onsite antenna measurement van capable of providing power gain versus azimuth and elevation angle over a frequency range from MF to X-band.

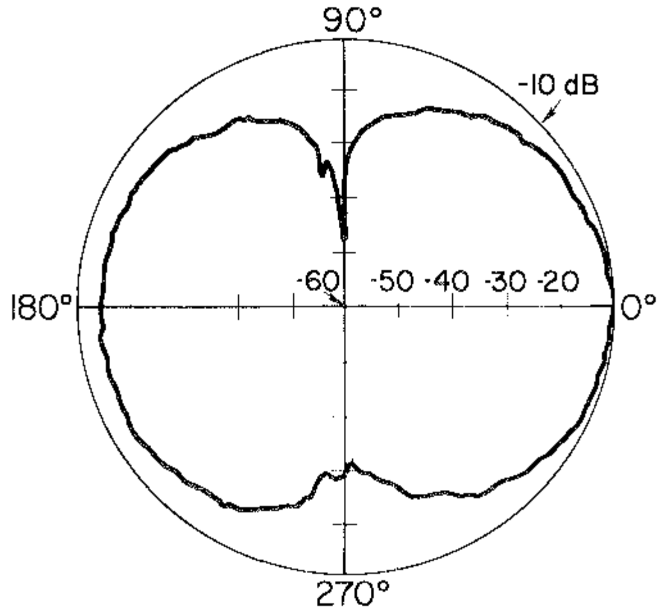

Figure 3-24. Buried MF antenna power gain relative to that of a short, vertical dipole versus azimuth--13 deg elevation angle.

In order to bring together workers in various areas of subsurface propagation, ITS organized and hosted a workshop on EM Guided Waves in Mine Environments, March 28-30. Some of the topics discussed were ELF propagation through the earth, MF propagation in coal seams, HF propagation on leaky feeders, and UHF propagation in empty tunnels. Numerous foreign countries were represented, and a conference proceedings has been published.

A related topic in mine safety involves nondestructive testing of mine hoist ropes. A review of electromagnetic methods for nondestructive testing of steel wire ropes was conducted, and the theoretical limitations of such methods have been studied. The past theory has been highly idealized and generally restricted to two dimensional analyses. More realistic three dimensional rope flaws and both solenoid and toroidal rope excitation have been analyzed. The difficult problem of characterizing the anisotropic properties of an actual stranded rope has also been addressed.

Future work on mine communications will continue. An important problem is propagation from a tunnel into cross cuts. Also the transmission of signals along metal drill rods and the input power requirements will be studied. Coupling of radio signals to blasting cap circuits continues to be a safety problem which requires further study. Work will also continue on the non-destructive testing of mine hoist ropes. The goal is to determine optimum excitation and sensing configurations.

Kodiak Site Study. The U. S. Coast Guard communication station Kodiak is located on Kodiak Island, Alaska, and due to its location is very critical to nautical communications in the northern Pacific and the Alaskan region. The responsibilities of communication station Kodiak currently include: communication to/from all Coast Guard vessels in the Northern Pacific/Alaskan region including aircraft on all routine and emergency missions, reports from foreign fishing vessels regarding location and catch within the 200-mile limit, continuous guard on several MF and HF distress and calling frequencies, continuous monitor of the AMVER (Automated Merchant Vessel Reporting) system, and assorted other duties as needed such as phone patches, land lines, etc.

The projected future operational requirements for communication station Kodiak indicate a greatly increased level of activity due to a variety of factors. Some of these factors are increased oil exploration and tanker traffic, an increase in the number of Coast Guard patrol vessels and aircraft in the Alaskan region, a possible 200-mile pollution control, and others.

Due to the strategic location of the communication station and the need for improvement of the physical plant, ITS was requested to undertake a study of the antenna siting at the communication station. The study was begun last fiscal year. An unpublished report was prepared that addressed the question of both MF and HF propagation to various regions of the Northern Pacific/Alaskan region considering the location of the communication station with regards to the ocean areas and the topography of Kodiak Island. Surface wave propagation predictions were made for the MF frequencies and were described in last year's ITS Annual Report.

Skywave propagation predictions were made for the HF frequencies, considering the ocean regions of interest and a set of seasonal, diurnal, and solar activity conditions. One output of these predictions is a histogram of the optimum frequency use. In addition, the associated distributions of take-off angle for each frequency were computed. The frequency use histogram is shown in Figure 3-25 and the set of associated take-off angle distributions is shown in Figure 3-26. These particular figures include the effects of all the seasonal, diurnal, and solar activity conditions; however histograms and distributions were also developed for the subset of seasonal, diurnal, and solar activity conditions.

Predictions such as those just described are used in determining the parameters required of the antenna system. The greatest problem at the Kodiak transmitter site is the local topography. The horizon elevation angle as observed from the center of the Buskin Table site can be as high as 12°.

A site survey was made to determine the station operations and to view the topographic situation. ITS has reviewed the predicted data, the existing physical plant, and topography and made recommendations to optimize the antenna types and siting for best communication.

3.5.2. Transmission Through the Atmosphere: Applications

DOE SECOM Technical Support. This program supports the ERDA Materiel Transportation SAFEGUARDS programs with the major thrust concerning systems engineering support to the functional enhancement and evaluation of the capabilities of the existing SECOM communications system. The program was initiated in FY 76, and concerned the development and implementation of an improved HF propagation model, mobile antenna evaluation, and the initial designs of a system management model.

The propagation model is a modified version of a newly developed HF model includ-

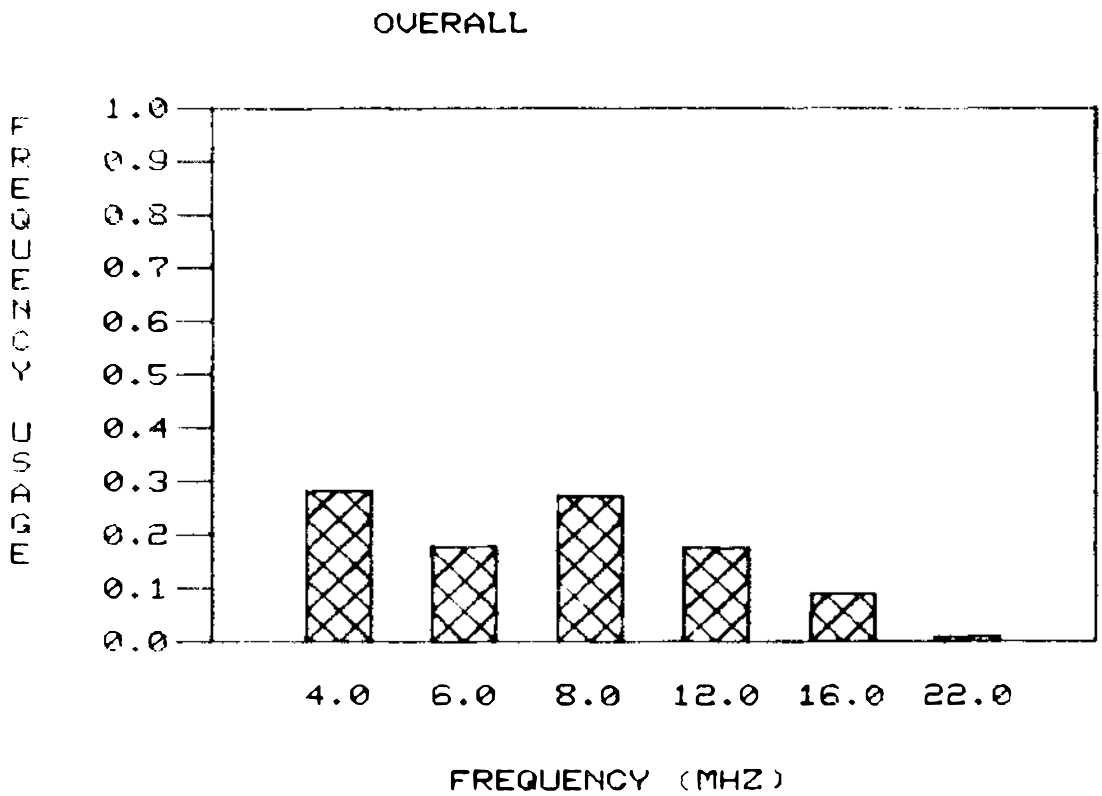

Figure 3-25. Overall frequency usage histogram.

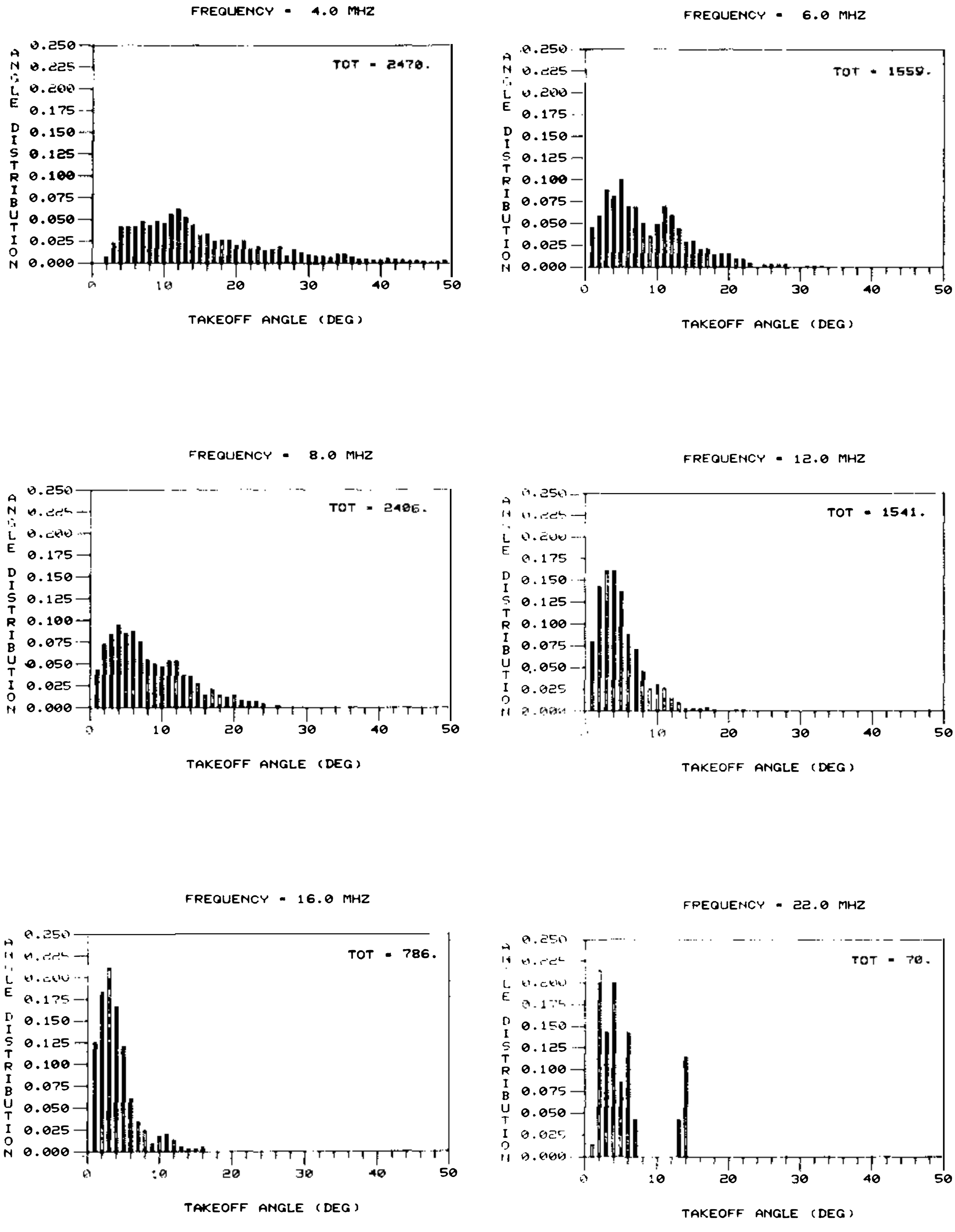

Figure 3-26. Overall take-off angle distributions.

ing a definition of multipath modes and temporal variations of ionospheric parameters that would be useful to predict error rates in digital transmission. This model is installed on the SANDIA Corporation computer facility. DoE applications include SECOM mission planning to assist in frequency selection and communications facility scheduling to maximize probabilities of communications systems performance. Real time support applications are also intended to assist in identifying unanticipated propagation-related problems and to provide guidance in control functions for the SECOM system, particularly in frequency selection and site antenna and processing control actions. Future applications will also involve multiple parametric software control features and signal discrimination where intentional or unintentional interference events could occur.

The management model concerns primarily an organization of the operational and functional timelines for the transport operations, intraconvoy communications, and SECOM system. This provided identification of normal, unintentional accident, and physical threat circumstances with appropriate events identified and communications support linkages.

The emphasis in the management model concerns the development of the programs and supporting routines for the transport operations and the linkages to the communications event models. Communications models include VHF and the HF propagation modes, and system scoring models for the relay site and vehicle equipments. The scoring process develops the patterns of digital errors with relation to the address, verification/authentication, and data components. This segmentation is necessary to allow direct coupling to the operations event model and, in the case of a physical threat situation, develop communications performance relationships for support forces and units that protect the transport vehicles.

Since the communications support to the transport vehicles must include the multiconvoy communications operations, the event and technical characteristic models for the VHF systems have also been designed. This system has only voice mode with little protection from external deception or interference. Different modes of operation including relay configurations have been examined, and recommendations submitted indicating reliability advantages for different options in procedure and configuration. The basic management model organization is diagrammed in Figure 3-27.

The SPS EMC Assessment Project has as its objective a preliminary assessment of the impact of operation of a Solar Power Satellite (SPS) on the ionosphere, atmosphere, and telecommunication systems. The results of the study undertaken in support of this project indicated that significant effects to the ionosphere and telecommunication systems associated with SPS operation could give rise to ionospheric heating and the high energies associated with the SPS power beam could result in significant interference to a number of telecommunication users.

As a result of the preliminary study conducted by ITS, the Department of Energy implemented a detailed technical program of research and development aimed at establishing the environmental impact of SPS operation. ITS has program management responsibility for the Ionospheric Modification aspects of SPS. This work is carried out under the SPS Ionospheric Modification Project.

The Solar Power Satellite is envisioned to operate at a frequency of 2.45 GHz supplying between 5 to 10 GW of power to a ground receiver site. The system concept utilizes a satellite in geosynchronous orbits that converts solar radiant energy to microwave energy. This microwave energy is transmitted from the satellite to a ground station and then is converted in dc power and passed through a power grid.

The large amounts of energy involved can give rise to significant ionospheric heating and subsequent modification. As part of the support ITS is providing to DoE, a committee of nationally prominent experts has been formed (under ITS chairmanship) to develop a nationally oriented program devoted to assess the impact of the SPS operation on the ionosphere and telecommunications users whose systems are impacted by the ionosphere. It is anticipated that the ITS operated Platteville Heater Facility will be utilized to simulate SPS heating effects. Work is being undertaken to define the characteristics of the heater facility in order to assure that the energy levels employed in ground-based simulations of SPS operation are commensurate with SPS power levels.

ITS is also working in conjunction with NOAA and NCAR to develop realistic, accurate numerical models of the ionosphere and its variations under conditions of intense ionospheric heating. These models are used in conjunction with telecommunications' system simulation programs to determine, from a theoretical viewpoint, SPS impact on the performance of selected radio circuits.

SPS HI Q Study. The question was raised as to whether local free space field strength maxima (hot spots) inside habitable structures exposed to 2.45 GHz SPS radiation can exceed the uniform power density of the incident traveling SPS coherent plane wave radiation.

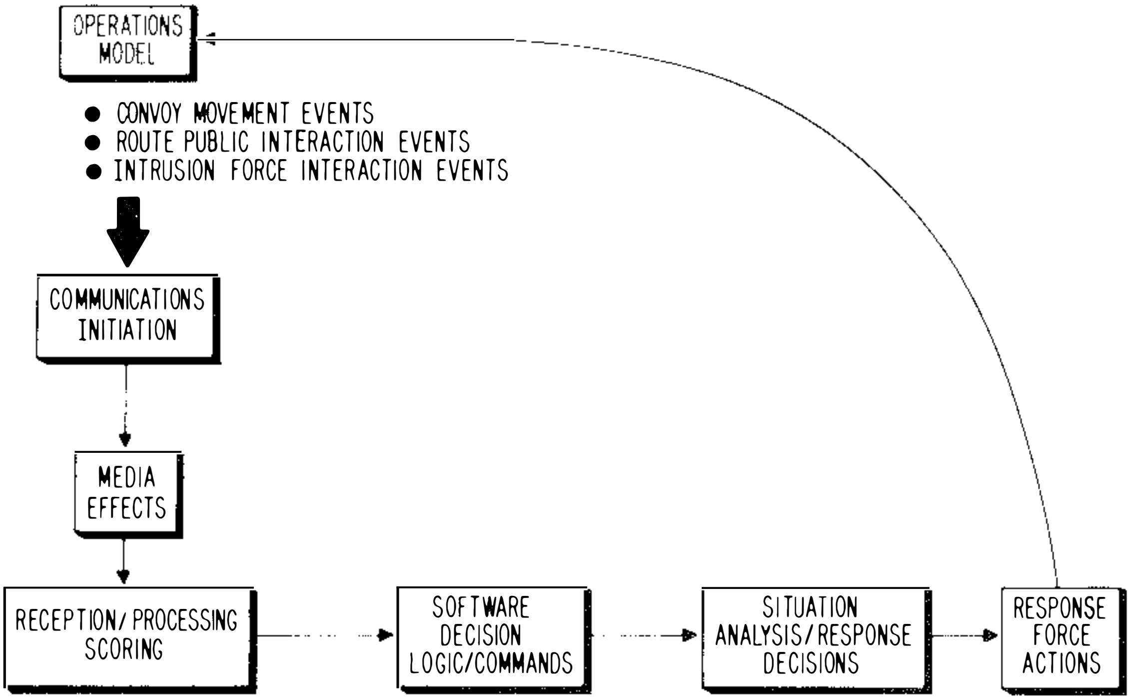

Figure 3-27. Management model organization.

The answer lies in the assessment of two electromagnetic effects:

1. Coupling and penetration of field energy into an enclosure.

2. Storage of field energy in the interior space.

To model the problem, habitable structures were categorized by means of the enclosure material as shown in Table 3-2.

The question was investigated using mode and field theory. The conclusion was that, though habitable space presents a poorly defined problem electromagnetically, field hot spots are very unlikely. The probability of a microwave hot spot occurring inside a habitable structure is probably not higher than that of a focal point for sun radiation occurring in nature with the potential of starting a fire. This finding is confirmed by the results of extensive measurements made by ITS of the 2.57 GHz signal from the ATS-6 geostationary satellite inside many single family dwellings across the continental U. S. These measurements yielded average insertion losses (inside-to-outside field strengths) between 6 and 9 dB.

A summary entitled "Field maxima inside habitable strucutres exposed to 2.45 GHz SPS radiation" was prepared. Measures to mitigate potential field hot spots are proposed. A more detailed technical report with over 30 references is being prepared to back up the preliminary findings outlined in the summary.

Solar Power Satellite EMC Analysis. The Department of Energy's Office of Energy Research has tasked ITS to assess the potential RFI/EMI effects of a proposed Solar Power Satellite (SPS) System. These satellites would use photo-voltiac cells to transform solar energy into DC voltage which would drive high power microwave sources to produce a high energy microwave beam at 2.45 GHz aimed at the earth. The beam would be received at a rectifying antenna site (rectenna) some 100 km^2 in area. The distribution of power across the beam is gausian with a power density at the center of 23 mW/cm^2 and at the edge of the rectenna 1 mW/cm^2. The total electrical energy output at the rectenna site is calculated to be around 5000 megawatts.

Because of the large powers involved the potential EMC problem is recognized as one of the most critical in the SPS assessment. Consequently, an agressive program has been initiated to perform analysis of the functional and operational degradation of electromagnetic systems (communications, radars, navigation aids) and other environment sensitive equipments and systems (computers, sensors, electronic medical instruments and devices, etc.) because of SSPS direct power coupling, and ionosphere and atmosphere media modification effects. Primary evaluation areas include EM environment verification computations, coupling analysis, functional-operational priority categorization, degradation evaluations, and impact assessment. Subsequent tasks address mitigation methods for degraded systems, and guidelines for designers and planners of future systems which may have to operate in a SPS environment.

Information was obtained from NASA on SPS system definition including: single microwave power transmission system radiation characteristics; geostationary earth orbit locations for multi-satellite operation; emission power spectra; side lobe structure, and candidate rectenna sites. A model is being implemented to predict field strength footprints at and near the surface of the earth from SPS microwave emissions. Priority rectenna sites are being analyzed from the candidates identified by NASA and DoE. Equipments and systems near the rectenna sites that are susceptible to SPS radiation are identified by selective retrieval from existing files, and categorized in relation to function, coupling modes, location, and interconnectivity. Functional degradation because of the SPS interference magnitudes include all performance events required to define supported operational compromises. Scoring models (signal/interference ratios) are multidimensional to allow adequate definition of the operational relationships. These are demonstrated in the functional degradation summaries presented in Table 3-3. SI scoring models are being designed for victim systems, and tests will be designed and implemented on candidate systems where data voids exist.

The impact of SPS EM energy on "victim" systems outside the rectenna area will come mainly from power beam side lobes, emission of harmonics of the primary frequency and spurious components, noise sidebands, and terrain reflections. Other sources of EM energy in the surrounding area of the rectenna would come from ionospheric and atmospheric effects such as scatter out of the power beam by rain. Ionospheric and atmospheric effects are now under study, but the main program in this area will be accomplished in FY 79.

Energy coupling to victim systems will involve in-channel and non-linear responses by out-of-band components relative to the primary receiver pass band. Different scoring procedures are required because of the wide variations in the latter in the characteristics of energy coupling and the intermodulation of components of the interferer with the desired signal. Scoring procedures applicable to this problem can be derived by extrapolation of existing empirical and analytical degradation models for receiver systems employed for communi-

Table 3-2. Categories of Habitable Structures

CASE	MICROWAVE PROPERTIES	REAL STRUCTURE EQUIVALENT
1	lossy dielectric	brick, stone, frame house
2	composite of lossy dielectric and metal	trailers, house with metal siding, plant building
3	metal with lossy dielectric layer plus aperture	aircraft cabin, vehicle interior

All geometric dimensions are generally much larger than one half-wavelength (6 cm).

Table 3-3. Selected Site Distances from Mojave Rectenna

	Distance From Rectenna	SPS Field Intensity (2.45 GHz)
SPS - China Lake Airstrip	64 km	1.3 v/m
SPS - Downtown Barstow	51 km	1.8 v/m
SPS - Edwards AFB Airstrip	43 km	2 v/m
SPS - Restricted Area R 2524	53 km	1.6 v/m
SPS - George AFB Airstrip	61 km	1.4 v/m

cations, radar, or a general range of metering applications. These define a range of performance characteristics in terms of probability density functions for signal to interference ratios. Most of the EMC problems related to the SPS that represent a significant expenditure in victim equipment modification will be concerned with the non-linear response category.

Computer devices, optical equipment, and medical instrumentation present unique scoring descriptives that relate to effective apertures and energy coupling into signal and control circuitry. These types of problems can, to a less degree, be extrapolated from experience with high-power radar illumination of surveillance and monitoring equipment required for military operations. Limited measurements will be required for the SPS problem to assure credibility in the predicted degradation and recommended functional modifications for these classes of equipment.

As the SPS program advanced and the concept appeared to be an obtainable goal and a viable alternative to the pressing energy needs of the future, candidate rectenna sites across the continental United States (CONUS) were identified by a NASA study. Subsequent coordination with the NASA/MSFC Advanced Planning Office indicated an active study emphasizing a Mojave desert rectenna site. The initial EMC analysis exercise addressed this site to provide EM impact data to this site characteristic review, and contribute to the development of site selection criteria for NASA/DoE.

Figure 3-28 shows the Mojave site and the surrounding area which would be impacted by SPS emissions outside the rectenna enclosure.

The rectenna site is shown (shaded area) with center at 35° 8' North, 117° 30' West. The rectenna covers an area roughly 100 km^2. The outer elipse is roughly 49 km in radius and corresponds to the peak of the 10th side lobe, and is approximately 45 dB below main beam peak power.

Preliminary assessments have been made at five sites surrounding the Mojave rectenna site. Those sites, their distance from the rectenna, and the expected field intensity of the SPS 2.45 GHz power beam frequency at the respective sites is given in Table 3-3. Added to this intensity due only to beam configuration would be energy scattered from the power beam by media effects such as rain, hail, dust and sand storms, atmospheric turbulence, etc. This could add from 20 to 100 mV/m of scattered energy into the sites depending on the severity of a given storm. The amount of potential EM energy from all forms of scatter, including that from the rectenna itself (not calculated yet), added to the power beam side lobe energy, could present a formidable problem for systems out to 100 km or so from the rectenna site.

To assess the impact on systems near the Mojave site, an area 145 km by 145 km with the proposed rectenna site at the center was chosen as our data sample area. All government and non-government EM systems operating within this geographic boundary between 75 MHz and 5 GHz were tabulated. The active files showed 813 government systems and 685 civilian authorizations operational within these boundaries.

The equipment/system categories identified in the file retrieval are as listed:

1. Military Development and Operational Test and Evaluation Support
2. Industrial Communications
3. Transportation Support Systems
4. Public Service Communications
5. Specialized Services.

These system categories are in the frequency range cited for the file retrieval and are susceptible to SPS power densities previously displayed.

The character of functional degradation induced into particular major equipment categories deployed near the candidate Mojave site is indicated in Table 3-4. Those functional systems included represent high priority operations that encompass relatively large geographic areas around the periphery of the rectenna site.

Various railroad, law enforcement, and emergency communications services will be incorporated into the functional categories as soon as degradation analysis is completed. These equipments use presently VHF and UHF analog voice or low data rate modes, and will therefore be minimally affected. Relays and base stations for these services could be readily modified where necessary by shielding and antenna pattern adjustments. Common carrier links will also be scored for future assessment analysis. These will include relays and mode stations.

The elements of performance degradation cited for the functional systems represent an average over all operating modes and geographic range. For example, instrumentation radar systems detection and tracking performance includes operation over a full hemisphere coverage, and the range of cross section magnitudes for military target vehicles (e.g., tactical fighter and reconnaissance aircraft, target drones). Track score variations include low elevation angle modes, where the accuracy degradation and loss of lock probabilities

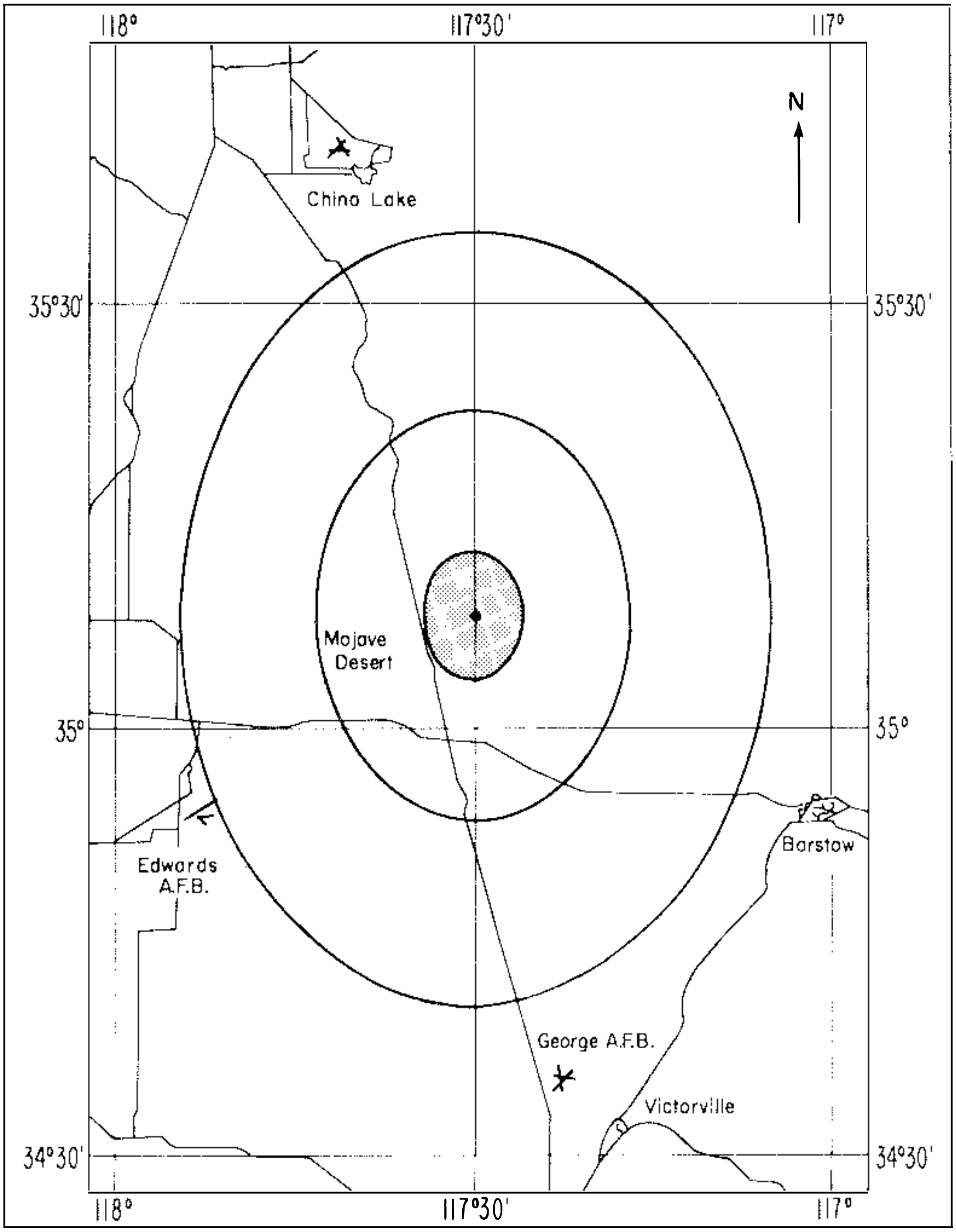

Figure 3-28. Proposed Mojave rectenna site.

Table 3-4. Induced Functional Degradation Summary - Mojave Area

FUNCTION	CHARACTERISTIC EFFECT
Instrumentation Radar (Military Test Ranges)	a. Cooperative target acquisition range: -8 to 20%
	b. Skin target acquisition range: -13 to 28%
	c. Cooperative target track error: +15 to 40%
	d. Skin target track error: +22 to 65%
	e. Loss of track loop lock (skin mode) probability increase: +10 to 40%
Command/Control and Telemetry Communications (Military Test Ranges)	a. Signal acquisition threshold: +5 to 20%
	b. Data error: +5 to 28%
	c. Sync loss probability: +3 to 25%
Tactical Signal Identification - Analysis Systems	a. False alarm probability outside mission zone: +3 to 25%
	b. False alarm probability within mission zone: +18 to 60%
	c. Receiver noise threshold: +5 to 40%
	d. Signal processing time: +45 to 115%
	e. Software overload probability increase: +2 to 26%
IR Scanner (Tactical System)	a. Video noise threshold: +2 to 26%
	b. Target detection/identification probability: -5 to 33%
Utility and Pipeline Command/Control/Telemetry Communications	a. Signal acquisition theshold: -5 to 15%
	b. Data error: +10 to 30%
	c. Link noise: +5 to 20%
Image Intensifiers	a. Video noise level: +10 to 45%
	b. Standard target detection/ identification range: -5 to 30%
	c. Multiple target spatial resolution: -2 to 60%
Non-Federal Government Communications	a. Channel noise: +5 to 15%
	b. Data error: +8 to 35%

expand by greater margins because of propagation factors. On-axis radar configurations are also represented since this mode will probably be increasingly employed for these test range applications. The track error scores include normal smoothing, prediction filtering, and coordinate computations in real time and postmission processing software.

The communications system degradation cited include single channel, and frequency and time-multiplexed units operated by the military test ranges, the State of California, local county and municipal governments, and resource control and service industries.

These operational compromises and the specific areas of functional degradation will be expanded to provide the basis for subsequent recommendations in equipment and system operations to assure an acceptable level of performance when illuminated by this high power source.

For this Mojave site and others having a similar operational military/civil system ratio, modification recommendations will emphasize the civilian area. Support equipment (e.g., radars, telemetry, TV, etc.) can be modified for operation within a range of 40-50 km from the rectenna site, assuming no media induced instabilities in the SPS array control. Military operational EM systems cannot be modified because of the unacceptable probability of operational compromise; system performance or procedures in the Test and Evaluation exercises would have little or a deceptive relation to combat operations.

Much of the major work of this present program will be accomplished in FY 79 including the development of mitigating strategies that would allow most classes of systems to operate satisfactorily in an SPS induced EM environment.

The preliminary assessment of SPS microwave emissions on "victim" systems as given here demonstrate the operational degradation that would occur to electronic systems in the SPS generated environment within approximately 100 km of the rectenna site. The Mojave site evaluation shows a wide range of performance degradation, particularly in those systems operated by the military. The basic functional and operational impacts of SPS are of such magnitude that in many instances they represent unacceptable or impossible compromises and biases to proper test and evaluation exercises performed by the involved facilities.

As mentioned previously, the evaluation of the Mojave candidate rectenna site provided impact data to NASA and contributed to establishing site selection and evaluation criteria, and allowed a limited exercise of the data retrieval and analysis procedures required for the EMC analysis of all candidate CONUS sites. This Mojave site originally considered by NASA allowed a reasonable rectenna isolation from areas of even modest population density, but presents serious interference impacts upon surface and aircraft electronic systems. At this site, military operations represent the majority of the interference problems, the degraded systems being integral components of complex Development and Operational Test and Evaluation programs. These military programs require the degree of isolation afforded by the Mojave region.

Based on the probable operational system degradations near the Mojave site and the inability to establish mitigating strategies without unacceptable probability of operational compromise, a second site north and east of the original site was proposed by ITS. A cursory look at the "victim" systems surrounding the new site indicates different functional classes which lend themselves to mitigating strategies. Modifications to most of these equipments could be accomplished to produce compatibility in the SPS generated environments.

The functional degradation of military, non-defense government, and commercial systems in the Mojave area is basically characteristic of the effects that will be encountered in other CONUS areas. Operational implications and therefore the associated economic impact will vary significantly because of the differing organizations and systems supported by the degraded equipments. Operational-functional relationships will exhibit differing sensitivities.

The Mojave area lends itself well to resiting because of the large expanse of open, flat terrain. The development of new sites in most geographic areas would not be as simple, if not impossible, due to population density, terrain features, "victim" system density, etc.

Generally the northern and eastern CONUS regions will have a smaller military-non defense equipment concentration in the rectenna areas than the original Mojave site reviewed. These regions will also include major transportation and commercial communications facilities. Because of the population and business densities, the total number of affected systems in the various operational categories will be larger.

A valid demonstration of rectenna site EMC analysis and impact evaluation has been developed. This has shown to be fundamental in making site selections, will help determine system performance impacts, and help develop mitigating strategies for victim systems. Several site evaluations in various geographical locations, particularly in northern and eastern CONUS regions will be carried out to establish a data base to be used in setting site selection criteria and geographically oriented mitigating strategies.

RADC Consulting. The U. S. Air Force is developing digital communication equipment for application to tropospheric scatter radio systems in Europe. This project is a consulting and advisory effort to assist the Air Force in testing and evaluating the communications equipment, and its performance over the proposed links. The work is performed as requested by RADC, and involves a broad spectrum of expertise from the ITS staff.

Microwave Propagation for Digital Radio. The U. S. Navy Pacific Missile Test Center (PMTC) at Pt. Mugu, California operates a network of microwave and other communication systems in support of the test center missions. Future plans for the microwave system include conversion to all digital transmission. However, some of the links are over-water paths extending from high locations along the coast to terminals in the Channel Islands.

From past experience, it is known that severe propagation conditions exist in the Pt. Mugu region. These conditions are primarily caused by meteorological factors such as deep refractive layers with very high negative gradients. These layers develop due to a high marine layer of air at the coast line. The propagation is characterized by deep signal fading, caused by a mixture of power fading and multipath signals. In order to determine the digital data rate that these circuits will support under such conditions, the ITS was tasked by the PMTC to conduct some experiments over a link between Laguna Peak and San Nicholas Island, a distance of approximately 65 miles over water. The experiment consisted of three measurements as follows:

1. The impulse response of the transmission channel.

2. Bit-error-rate (BER) performance measurements.

3. Fading statistics on a pair of receiving antennas oriented for angle diversity.

The first two measurements were performed using the ITS pseudo-random noise (PN) probe (R. F. Linfield, R. W. Hubbard, and L. E. Pratt, "Transmission Channel Characterization by Impulse Response Measurements," OT Report 76-96, 1976). The binary bit stream used as the test signal in this instrument is correlated with a replica signal at the receiver to develop the impulse response. This output of the receiver indicates multipath reception directly in the time domain, and at a data rate that can be conveniently recorded on analog magnetic tape. The primary data from this phase of the measurements uses a clock rate of 150 Mb/s, providing a total resolution of approximately 6 ns in the impulse response. However, delayed components less than this value are easily distinguished in the output. The same bit stream is detected from the bi-phase modulated signal, and fed to a commercial error analyzer for the second phase above. In this case, the clock rate of the system was reduced to either 10 Mb/s or 50 Mb/s; rates that are more commensurate with the desired data rate for the proposed PMTC system. However, the resolution of the impulse response is less at the lower clock rates. Therefore, most of the data were measured in tandem blocks. The high clock rate was first used to observe channel conditions for a period of time, the clock rate was then reduced to obtain a measure of BER performance under the varying conditions.

Measurements were begun in August 1978 to capture the worst propagation conditions that have historically prevailed during that month. The measurements will not be completed until early in the calendar year 1979. Preliminary analyses of the August data indicate that the strong surface ducts in the region give rise to very severe multipath propagation as well as flat power fading. Delays of up to 20 ns have been observed in the impulse data for the multipath components. In addition, it is frequently found that the delayed component is of much greater magnitude. The time variability is also a significant factor, as the stronger component both leads and lags in the response. Changes of this type cause synchronizing problems in digital systems. It appears that space diversity is effective most of the time. However, there are occasions when the multipath structure is observed on the spaced receiving antennas almost simultaneously. Data from the tilted beam experiment have not been analyzed as yet. These results will be published in a final report in FY 79. An example of the impulse response during a short period of strong multipath is shown in Figure 3-29, which presents a sequence of responses measured 100 ms apart.

3.5.3. CCIR Participation

Support to the International Telecommunications Union's (ITU) advisory International Radio Consultative Committee (CCIR) was provided by ITS personnel in the fields of tropospheric (Study Group 5) and ionospheric (Study Group 6) propagation. The U. S. National Chairmen of CCIR Study Groups 5 and 6, Drs. H. T. Dougherty and C. M. Rush, are both members of ITS's Applied Electromagnetic Science Division.

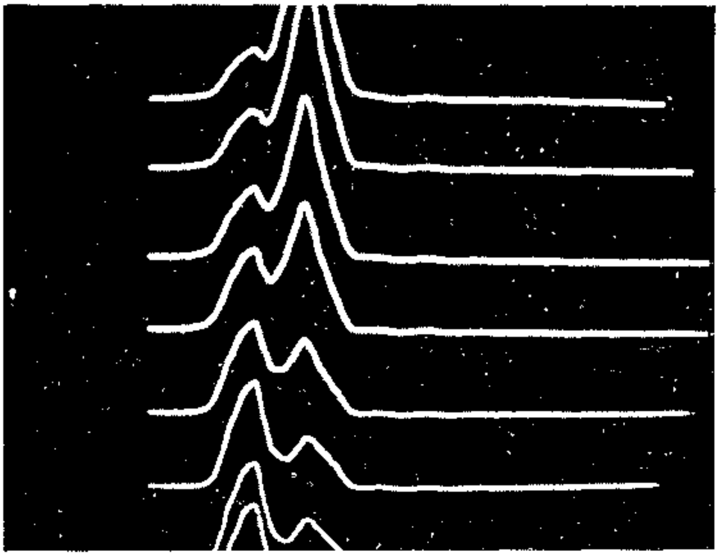

Figure 3-29. An example of multipath observed in the impulse response measured over a long over-water LOS microwave path. The sequence progresses from top to bottom in time, at 100 ms intervals. The delay time scale is 10 ns/cm. The response shows a two-path propagation mode with a delay of approximately 8 to 10 ns.

In addition, numerous ITS personnel actively participate in the CCIR. For example, at the Final Meeting of Study Group 6 held at Geneva in January 1978, there were four (4) ITS staff personnel as members of the U. S. delegation (which totaled 9).

Areas of specific concern to CCIR in which ITS personnel play key roles include: ionospheric mapping; ionospheric operational considerations; skywave field strength calculations at frequencies above 1.6 MHz; microwave system design; fading phenomenon on LOS links; the role of rainfall in microwave system performance and interference; and the ionospheric and tropospheric aspects of radio noise.

ITS personnel participated in the International Telecommunications Union (ITU) Advisory International Radio Consultative Committee (CCIR) XIV Plenary Assembly that was held at Kyoto, Japan, in June 1978. Figure 3-30 is a photograph of part of the U. S. delegation to that meeting.

In addition, ITS personnel have been particularly active in the preparations for the CCIR Special Preparatory Meeting (SPM) scheduled for Geneva in October and November 1978. These preparations included the assembly of U. S. documents as inputs to the SPM and the review of input documents provided by other nations. The objective of the SPM is a report to the General World Administrative Radio Conference (GWARC-79) to be held in Geneva in 1979. The ITS-supported efforts serve the objective of preparing a receptive atmosphere for adoption by the SPM of U. S.-supported quantitative technical assistance for the use of the policy makers of the ITU.

Figure 3-30. A portion of the U.S. delegation to the CCIR XIV Plenary Assembly, which included four of the NTIA/ITS staff.

ANNEX I
ITS PROJECTS FOR FY 78
ORGANIZED BY DEPARTMENT AND AGENCY

Project	Title	Leader
AGRICULTURE, DEPARTMENT OF		
9103483	FIRESCOPE Communications System Design	Morrison
COMMERCE, DEPARTMENT OF (DOC)		
	National Telecommunications and Information Administration (NTIA)	
9101076	TSC Standard Working Group Support	Murray
9102085	Analysis & Development Support	Haakinson
9103095	RSMS Development	Matheson
9103096	RSMS Operations	Matheson
9105098	Special Project	McManamon
9107262	Urban Propagation Model	Hufford
9108111	AM Stereo	deHaas
9108200	EM Wave Transmission M&S	Lucas
9108201	Frequency Extension Research	Thompson
9108202	Frequency Reuse Research	Dougherty
9108203	Scattering Effect/Inform Bandwidth	Ott
9108204	Satellite Scintillation Model/ 19 & 28 GHz	Ott
9108206	MW Trans/Tropo Ducts	Wait
9108207	Propagation Models & Data Base	Rush
9108208	VHF/UHF Urban/Rural Model	Hufford
9108209	Satellite Observance at 19 & 28 GHz	Grant
9108221	Data Communications	Seitz
9108222	Optical Communications	Bloom
9108226	EMS Technical Planning	Hull
9108232	Trade-offs in Spectrum Use	Berry
9108234	Needs Study	Murray
9108237	Spread Spectrum Interference Plan	Murray
9108250	Direct Satellite Communication	McManamon
	Maritime Administration (MARAD)	
9102419	MARAD Assistance	deHaas
	National Bureau of Standards (NBS)	
9103551	IACP/NBS Test Program	Bolton
	National Oceanic & Atmospheric Administration (NOAA)	
9103412	Propagation Consulting	Dougherty
9103417	Weather Radar RFI Surveys	Tary
9103506	Engineering Support	Wortendyke
9103535	SPS Hi Q Study	Liebe
9103536	SPS RFI/EMI Analysis	Grant
9103537	SPS Ionospheric Modification	Rush
DEFENSE, DEPARTMENT OF (DOD)		
	Air Force Communications System (AFCS)	
9103484	Automatic Measurement System Upgrade	Wortendyke
	Air Force Systems Command (AFAL)	
9103530	RADC Technical Support	Hubbard
	Air Force Systems Command (ESD)	
9103479	EFAS/PEP II Program	Skerjanec
9103528	HF Ionospheric Scattering Study	Violette

Project	Title	Leader
DEFENSE, DEPARTMENT OF (DOD) (Continued)		
	Air Force Space & Missile System (SAMSO)	
9101463	Buried Antenna Studies - MX Phase II	FitzGerrell
9103502	Propagation Path Loss Measurement	Haakinson
9103503	Application of PROGRAM WAGNER	Ott
	Air Force Miscellaneous	
9103441	MSR-T1 Multiple Receiver	Barghausen
9103486	Propagation Over Irregular Terrain	Ott
9103492	TAC-Signal Analysis System	Barghausen
9103493	Power Fading Statistics	Hufford
	Naval Research Laboratory (NRL)	
9102370	Project NONESUCH	Tveten
9103508	Navy Optimum Communications	Spaulding
	Pacific Missile Range (PMR)	
9103497	Ground/Air Propagation Predictions	Gierhart
9103543	PMR Microwave Link Tests	Hubbard
	Navy Miscellaneous	
9103515	Calibration of Water Vapor Measurements	Thompson
9103553	Atmospheric EHF Propagation Study	Liebe
	Army Research Office (ARO)	
9103550	DM-4/Calculator Software	Paulson
	Army Communication Command (USA/CC)	
9103382	Army Mobile Automatic Receiver System	Carroll
9103427	EMC Van, Part II	Carroll
9103434	Access Area Digital Switch Program	Nesenbergs
9103446	Applications Software	McLean
9103447	CEEIA Fiber Optics Handbook	Hubbard
9103452	EMC Data Recording System	Harr
9103463	Operation Sky-Wave	Rush
9103465	EMC Cosite Analysis Capability	Adams
9103470	EMC Remote Extension	Diede
9103474	Automated Digital Topographic Data Techniques	Spies
9103478	EMC Van, Part III	Carroll
9103491	Follow-on Maintenance	Stewart
9103499	Video Tapes on TAEMS	Tary
9103501	Application Enhancements	Stewart
9103504	Automated Digital System Engineering Models	Hause
9103505	Automated Field Instnsity Measurement System	Haakinson
9103507	TAEMS Noise Measurements	Spaulding
9103509	Topographic Files	Hufford
9103511	Voltage Tuned Filter	Carroll
9103513	TAEMS Repair Parts	Stewart
9103514	Non-Tactical Radio Networks	Hubbard
9103531	ADRES System Upgrade	Harr
9103532	Multipath Fading on Long LOS 15 GHz Paths	Hause
9103533	Aircraft Blockage Effects on Microwave Links Traversing Runways & Taxiways	Skerjanec
9103534	Channel Probe Measurement/MW Links	Hubbard
9103538	Verification Test Set	Smith
9103546	TCN Related Services	Lucas
9103547	Digital System Performance Verification	McQuate

Project	Title	Leader
DEFENSE, DEPARTMENT OF (DOD) (Continued)		
	Army Miscellaneous	
9103498	Long Distance Propagation Study	Lloyd
9103525	Spectrum Monitoring Unit	Adams
9103527	Frequency Extension of Spectrum Monitoring Capability	Adams
9103544	Microwave Intervisibility Propagation Loss Measurements - Division 1	Haakinson
9103545	Microwave Intervisibility Propagation Loss Measurements - Division 3	Thompson
9103555	30-300 GHz Communication Links	Thompson
	Defense Communications Agency (DCA)	
9101534	MEECN Simulation	Watterson
9103512	Glossary Update	Hanson
	National Security Agency (NSA)	
9101518	NSA Consulting	Spaulding
9103549	Musketeer Freda V.	Stewart, A.
9103552	Topside Noise Morphology	Rush
ENERGY RESEARCH & DEVELOPMENT ADMINISTRATION (ERDA)		
9103450	SECOM Management Model	Rush
9103523	SPS EMC Assessment	Rush
FEDERAL COMMUNICATIONS COMMISSION (FCC)		
9103510	Sharing of Broadcast & Radiolocation Services	deHaas
9103516	Spread Spectrum Land Mobile Radio Systems	Berry
9103517	Spread Spectrum LMR-TV Sharing	Berry
9103518	Waiting Time Probabilities for LMR	Berry
9103519	Translator Service	Hufford
9103520	TV Coverage Maps	Hufford
9103522	Compatible SSB for HF Broadcast, Phase I	deHaas
9103539	CATV/ATC Interference	Adams
INTERIOR, DEPARTMENT OF (DOI)		
9101453	BOM Analysis of EM Waves	Wait
INTERNATIONAL COMMUNICATION AGENCY (ICA)		
9101498	Remote Access Computer Service	Agy
9101499	Radio Propagation Predictions	Agy
9101501	Development Improvements of Prediction Formats	Agy
9101503	VOA Consulting	Haydon
9103524	Revision of HF Broadcast Methods	Agy
9103540	VOA Consulting	Haydon
9103542	Remote Access Computer Services	Agy

Project	Title	Leader
NATIONAL AERONAUTICS & SPACE ADMINISTRATION (NASA)		
9103494	Orbiting Standards Platform Analysis	Dougherty
OFFICE OF TELECOMMUNICATIONS POLICY (OTP)		
9108520	RSMS Development	Matheson
9108521	RSMS Operations	Matheson
9108522	Spectrum Analysis Support	Haakinson
9108524	TSC Support	Murray
9108527	SED Propagation Development	Hufford
TRANSPORTATION, DEPARTMENT OF (DoT)		
	Federal Aviation Administration (FAA)	
9101477	Air Navigation Aids	Johnson
9103489	Technical Support in Propagation & Spectrum Engineering	Hubbard
9103500	Air Traffic Control Services	Hartman
9103526	Air Navigation Aids	Johnson
	U.S. Coast Guard (USCG)	
9101532	Consulting USCG	Kissick
9103488	KODIAK Antenna Improvement	Kissick
9103548	San Juan/ADAK Trade-off	Kissick
9103554	FAA Propagation Study	Rush
U.S. POSTAL SERVICE		
9103432	U.S.P.S. Electronic Message Service	McManamon
9103529	U.S.P.S. Electronic Message Service	McManamon
OTHER		
9101583	LF Models	Berry
9101585	GOES Equipment Certification	Bolton
9101586	Tropo Predictions	Johnson
9101587	Numerical Prediction Services MFA	Agy
9102580	Analysis Services	Adams
	Miscellaneous Federal Agencies	
9101504	HF Consulting	Haydon
9103482	Safeguards Communication Analysis	Morrison
	Miscellaneous Non-Federal Agencies	
9102378	Mobile Aids	Hufford
9103521	Bell Consulting	Spaulding

ANNEX II
ORGANIZATIONAL DIRECTORY
INSTITUTE FOR TELECOMMUNICATION SCIENCES
NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, DEPARTMENT OF COMMERCE
325 Broadway, Boulder, Colorado 80303
(303) 499-1000 (FTS dial 323 + extension)

NAME	EXT.	ROOM
DIRECTOR'S 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
STONER, Russell B. (Publication and Technical Information Officer)	3572	3009
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 HULL, Joseph A. (Acting)	4136	2034
2.4 Systems Technology deHAAS, Thijs	3728	2030
2.5 Systems Assessment McMANAMON, Peter M.	3570	2237
DIVISION 3 - APPLIED ELECTROMAGNETIC SCIENCE		
LUCAS, Donald L. (Associate Director)	3821	3421
3.1 Spectrum Extension Research & Analysis THOMPSON, MOODY C.	3508	3442A
3.2 Congested Region Performance Predictions & Model Development RUSH, Charles M.	3460	3411
3.3 Advanced Communication Technology & Applications GRANT, William B.	3729	3447
3.4 Advanced Analysis & Special Projects LUCAS, Donald L. (Acting)	3821	3421

ANNEX III
INSTITUTE FOR TELECOMMUNICATION SCIENCES
NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION
DEPARTMENT OF COMMERCE
Alphabetical Listing of ITS Employees
September 1, 1978

Name	Ext.	Room
ADAMS, Jean E.	4301	4517
ADAMS, Steven W.	3513	3442
AGY, Vaughn L.	3659	3441
AKIMA, Hiroshi	3392	2210M
ALLEN, Kenneth C.	3513	3442B
BARGHAUSEN, Alfred F.	3384	3443
BEASLEY, Keith R.	3731	4524A
BEERY, Wesley M.	3501	3463
BERRY, Janet S.	4129	4518A
BERRY, Leslie A.	4474	4528B
BLOOM, Louis R.	3485	2245A
BOLTON, Earl C.	3104	2236M
BROOKS, Minnie	3929	3451
CANADAY, Lois S.	3634	3417
CARROLL, John C.	3601	3459
CHAVEZ, Richard	3584	3430
CHILTON, Charles J.	3815	3420
COLEMAN, Susan J.	3883	3450
COURTNEY, Brenda L.	4162	4530
CROMBIE, Douglass D.	4215	3020
CROW, Edwin L.	3452	2210
CURLANDER, John L.	3358	3450
deHAAS, Thijs	3728	2030
DEL PIZZO, Rose M.	4162	4527
DIEDE, Arthur H.	3103	3458B
DOUGHERTY, Harold T.	3913	3453
DROUILLARD, Patricia H.	4337	3015
DUTTON, Evan J.	3646	3454C
ESPELAND, Richard H.	3882	3410M
FALCON, Glenn D.	4361	2222C
FARROW, Joseph E.	3607	2230
FitzGERRELL, Richard G.	3737	4524D
FRITZ, Olive M.	3778	2213
GALLAWA, Robert L.	3761	2217
GAMAUF, Kenneth J.	3677	3430
GEISSINGER, Marcia L.	3500	3020
GIBSON, Beverle J.	4215	3020
GIERHART, Gary D.	3292	2222M
GLEN, Donald V.	3893	2210
GODWIN, John R.	4302	4515
GOULD, Beverly A.	3588	4525
GRANT, William B.	3729	3447
GRAY, Evelyn M.	3307	2210B
HAAKINSON, Eldon J.	4304	4511
HAIDLE, Leroy L.	3233	4524B
HANSEN, Ruth B.	3513	3442C
HANSON, A. Glenn	4449	2223
HARMAN, John M.	3655	2030
HARR, Thomas A., Jr.	4191	4518B
HARTMAN, William J.	3606	2210D
HAUSE, Laurance G.	3945	2230B
HAYDON, George W.	3583	3420C
HILDEBRANDT, Thomas H.	3175	2230

Name	Ext.	Room
HILL, David A.	3472	2209
HOROWITZ, Renee B.	4162	4529
HOWARD, Allen Q.	3485	2245
HUBBARD, Robert W.	3414	2243
HUFFORD, George A.	3457	4523
HULL, Joseph A.	4136	2034
HUNT, Howard D.	3778	2213
HYOVALTI, Duane C.	3447	3451
JEFFREYS, Charlene E.	4414	3021
JENNINGS, Raymond D.	3233	4524C
JOHNSON, Mary Ellen	3587	4522C
JUNEAU, Robert I.	4202	2222
JUROSHEK, John R.	4362	4528A
KIMMETT, F. George	3945	2230B
KISSICK, William A.	4258	4520C
LANGER, Susan K.	4162	4527
LAWRENCE, Vincent S.	4202	2222
LAYTON, Donald H.	3584	3430
LIEBE, Hans J.	3310	3426
LINFIELD, Robert F.	4243	2236A
LLOYD, John L.	3701	3419M
LONGLEY, Anita G.	3470	4521
LUBEN, Robert A.	4125	4520A
LUCAS, Donald L.	3821	3425
MADONNA, Nancy	3821	3421
MAJOR, Jeanne C.	4122	4520B
MARLER, F. Gene	3412	3446B
MATHESON, Robert J.	3293	2221
MARTIN, William L.	3195	3424
MAYEDA, Kathy E.	3998	3420
MELLECKER, Carlene M.	3330	3458A
MENDOZA, John R.	3584	3430
MILES, Martin J.	3506	2246
MILLER, Charles M.	4496	3454A
MINISTER, Carl M.	3805	2242
MITZ, Albert R.	3513	3442
MOLLARD, Jean R.	3821	3421
MONTGOMERY, Carole J.	3291	2219
MORRISON, Ernest L.	4215	3013
MURAHATA, Sueki	3513	3442
MURRAY, John P.	4162	4533
McCARROLL, Patricia A.	3883	3449
McCOY, Elizabeth L.	4281	2245
McLEAN, Robert A.	3262	3462
McMANAMON, Peter M.	3570	2218
McQUATE, Paul L.	3778	2213
NESENBERGS, Martin	3337	2210M
NEY, Linda	3396	4524A
OLSON, Marylyn N.	4136	2030
OTT, Randolph H.	3353	3467

Name	Ext.	Room
PAULSON, Sara J.	3874	4519
PAYNE, Judd A.	3200	2214A
PHILLIPS, Robert E.	4125	4520A
POKEMPNER, Margo	3460	3413
PRATT, Lauren E.	3826	2234B
RANDELL, Holly L.	3786	4515
REASONER, Rita K.	3184	4522A
ROACH, David L.	3253	4524
ROSICH, Rayner K.	3109	3415M
RUSH, Charles M.	3460	3411
RUSSELL, Jane L.	3387	4524B
SANCHEZ, Patricia A.	4166	2218
SAUER, Joseph A.	4122	4520B
SEITZ, Neal B.	3106	2214
SEXTON, Alma B.	3883	3449
SHELTON, Lenora J.	3572	3011
SKERJANEC, Richard E.	3157	2230
SMILLEY, John D.	4218	2222M
SMITH, Dean	3661	2223
SPAULDING, Arthur D.	4201	2222A
SPIES, Kenneth P.	4275	4516B
STEARNS, Charles O., III	3883	3450
STEELE, Francis K.	3815	3420
STEWART, Arthur C.	3998	3419
STEWART, Frank G.	3336	3450C
STOEBE, Suzanne M.	3562	3413
STONEHOCKER, Garth H.	3756	4516D
STONER, Russell B.	3572	3009

Name	Ext.	Room
TARY, John J.	3702	3450
TELFER, Thelma L.	4162	4529
TETERS, Larry R.	4430	3417M
THOMPSON, Barbara D.	3821	3421
THOMPSON, Moody C., Jr.	3508	3442A
TVETEN, Lowell H.	3621	3445
UTLAUT, William F.	3500	3020
VanSTORY, Carol B.	3267	3017
VAUGHAN, Margo S.	4129	4518
VIOLETTE, Edmond J.	3703	3446A
VOGLER, Lewis E.	3668	3450
WALLER, Freda L.	3618	2030
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
WEBER, Bradley D.	3358	3450
WELCH, William M., III	4321	3458A
WELLS, Paul I.	4368	2235
WIEDER, Bernard	3484	3014
WORTENDYKE, David R.	4241	2234

ANNEX IV
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ANNEX V

GENERAL AND HISTORICAL INFORMATION OF ITS

The Institute for Telecommunication Sciences, largest component of the National Telecommunications and Information Administration, is located at the Boulder Laboratories of the Department of Commerce and has (as of Sept. 30, 1978) a full-time permanent staff of 100 and other staff of 45. In FY 1978, its support consisted of $1.9 million of direct funding from Commerce and $7.5 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 National Telecommunications and Information Administration. 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 National Telecommunications and Information Administration also has its Boulder Division of the Office of Policy Analysis and Development 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 Propagation 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.

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.

In March 1978, President Carter signed Executive Order 12046 which established the National telecommunications and Information Administration and merged some of the functions of the Office of Telecommunications Policy with those of the Office of Telecommunications in the new agency. ITS was assigned the responsibility of managing the telecommunications technology research programs of NTIA and providing research support to other elements of NTIA as well as other agencies on a reimbursable basis. Among other assigned tasks, the Institute was to remain "...the central Federal Government laboratories for research on transmission of radio waves."

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 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 three of the eleven Study Groups of CCIR is directed by members of ITS (U.S. Study Groups 1, 3, and 5), and staff members of ITS participate in many of the other Study Groups. ITS actively supports the Interdepartment 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, NTIA 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 NTIA'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 and Introduction 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.

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