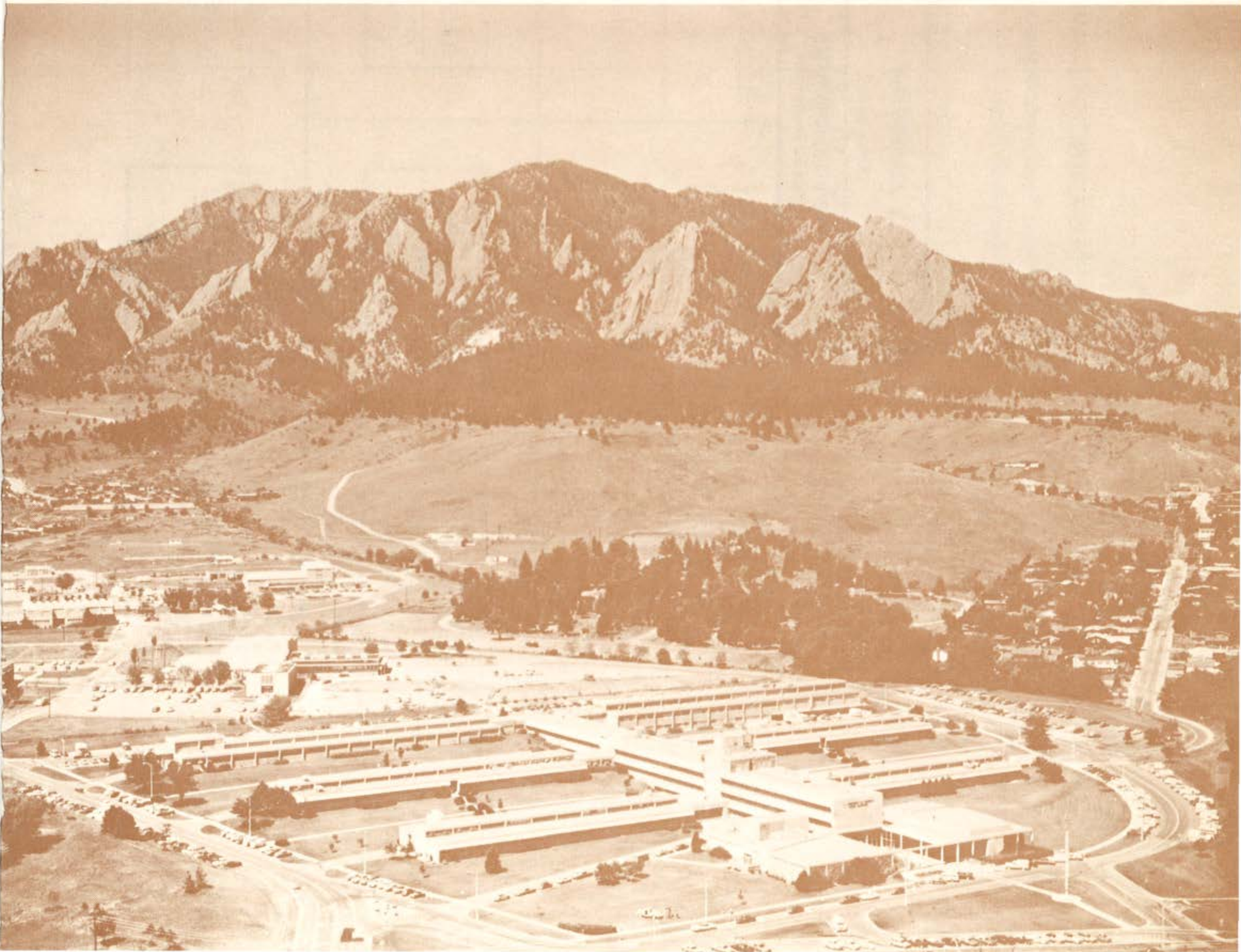
INSTITUTE FOR TELECOMMUNICATION SCIENCES OF THE NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

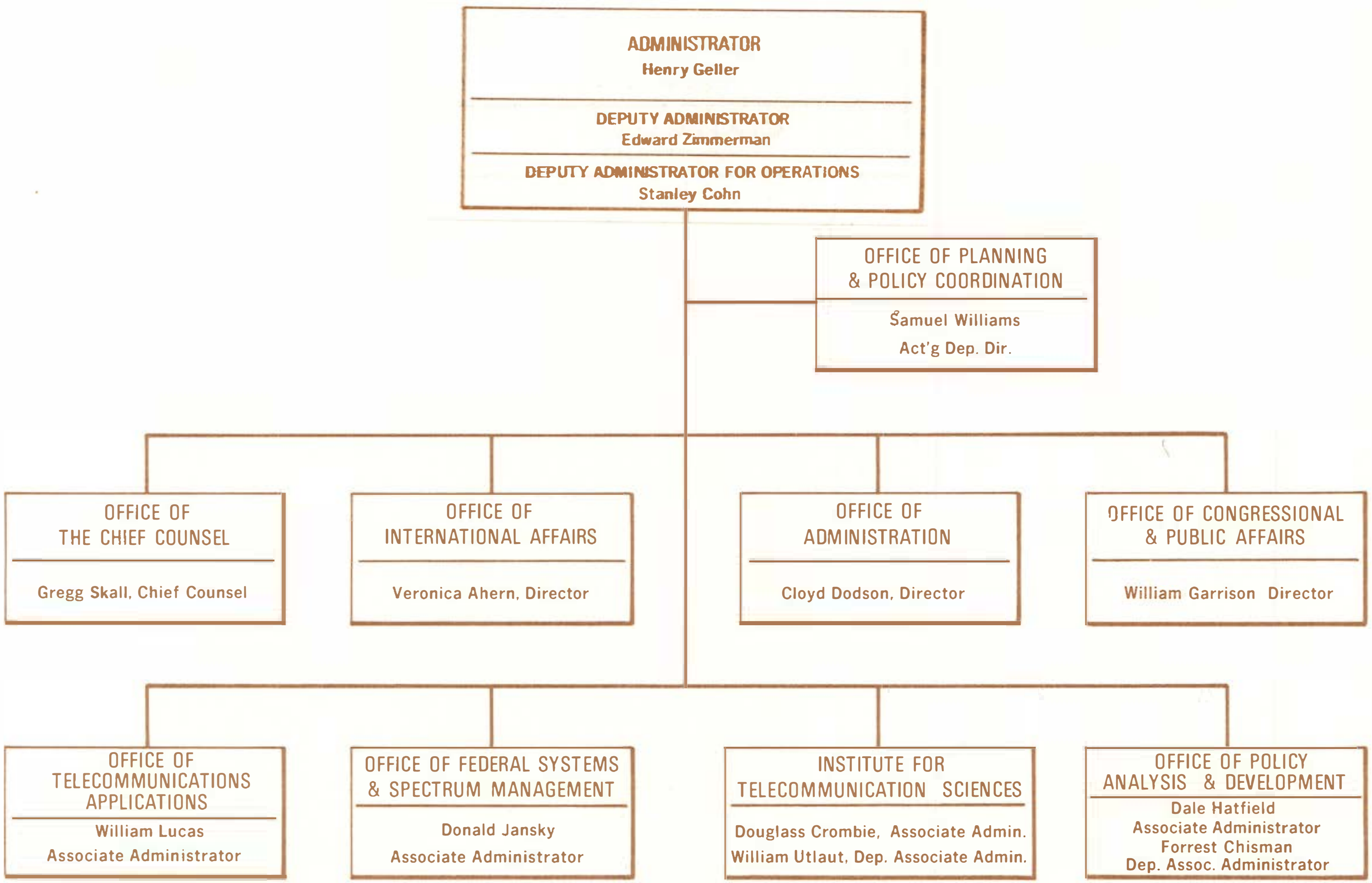
ANNUAL TECHNICAL PROGRESS REPORT 1979

For the period from Oct. 1, 1978 through Sept. 30, 1979



U.S. DEPARTMENT OF COMMERCE

National Telecommunications and Information Administration



ITS

ANNUAL TECHNICAL PROGRESS REPORT 1979

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

Henry Geller, Assistant Secretary
for Communications and Information

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INTRODUCTION

During FY 1979, a significant change in the organization of ITS was effected. This was the formation of a fourth Division, Advanced Communications Networks, under the leadership of Dr. McManamon. Because the reorganization occurred late in the year, the body of this progress report is prepared around the work of the three original Divisions. Thus the work of the new Division is reported in Chapter 2. The roles of the four ITS Divisions, reflecting this change, are outlined below.

Division Functional Descriptions

Division 1 - Spectrum Utilization -

Develops knowledge to more intensively use the capacity of the electromagnetic spectrum to meet rapidly growing communications demands by Government, industry, and the public. The Division conducts a selective program of research directed toward obtaining more efficient use of available spectrum resources, which is primarily related to interactions between radio systems and the electromagnetic environment. The work involves measurement and evaluation of spectrum consuming properties of receivers, transmitters, antennas; spectrum occupancy; and development of spectrum planning techniques and relates to NTIA roles in spectrum management.

Division 2 - Systems Technology and Standards -

Performs engineering studies which result in user-oriented telecommunication performance criteria, and develops and applies measurement methods required for Federally or publically operated systems. This involves activities such as operations research, system architecture definitions, and system design and evaluation.

Division 3 - Applied Electromagnetic Science -

Obtains, develops, and evaluates atmospheric propagation characteristics and develops models of these characteristics applicable to communication networks, system performance predictions and analysis, and for optimization of spectrum use; maintains a library of adequately documented propagation models and disseminates and applies these models to specific problems as required. Work is both experimental and theoretical and relates to the NTIA role of providing broadly applicable basic knowledge of EM propagation.

Division 4 - Advanced Communication Networks -

Conducts the technical program in support of NTIA's responsibilities for telecommunication protection; investigates technology alternatives for development of competitive, lower cost, communication networks providing improved services and better resource utilization; and conducts research and analysis of advanced networks incorporating technical, economic, market, regulatory, and policy factors in an integrated fashion.

The work of all the Divisions is complementary and interactive, supporting NTIA User, Industry, and Resource activities, as well as solving problems for other Federal agencies.

Significant accomplishments in the last year include:

- Integration of engineering and demographic techniques for assessing the coverage of broadcasting facilities.
- Analysis of spread-spectrum techniques for land-mobile radio showing that the new technique was less efficient in spectrum use than conventional modulation methods.
- Measurements of the patterns of UHF and VHF TV receiving antennas to form part of a data base.
- Acceptance of the ITS data communications criteria as an interim Federal Standard (FS 1033).
- Use of the entropy concept for distinguishing between data communications and data processing.
- Continued support to U.S. Postal Service in the area of electronic message systems.
- Studies on satellite communications, especially small earth terminal thin route systems.
- Support to U.S. Army in evaluation of Access Area Digital Switching Systems.
- Contributions of the technical aspects of NTIA's role in telecommunications protection.
- Completion and delivery to the U.S. Army at Ft. Huachuca of the first two Transportable Automatic Electromagnetic Measurement Systems (TAEMS).

- Reactivation of the Platteville high power HF transmitter for ionospheric scattering studies.

- Support to Department of Energy's Satellite Power System studies in the areas of possible ionospheric modification and electromagnetic compatibility.

- Responses to FCC Notices of Inquiry on AM stereo, TV drop-in methodology, quadraphonic FM services, and improvements to TV service.

- Significant technical contributions to NTIA's requests for rule making on FM services, and 9 kHz channel spacing in the MF broadcasting band.

These accomplishments show that, in addition to meeting our many commitments to other Federal agency sponsors in support of their national missions, we are becoming more fully integrated into NTIA by providing a technical basis for policy analysis and development. We look forward to growth in each of these areas.

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 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 those 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

We are concerned here with those techniques which can be used by policy makers, frequency managers, system designers and planners, and others concerned with the use of spectrum dependent systems in the increasingly congested real world. These are techniques that define the extent to which realistic sharing of frequencies, time, and space is possible. They also address problems in optimum choice of frequencies and rational trade-offs between limits on broad classes of equipment (limits on factors such as antenna height or power), the ability of a system to provide a required service, and the efficiency with which available spectrum is used. Techniques of this kind are extremely varied and must address a wide range of problems from the very specific (for the designer of a specific system at a particular location) to the very general (for the policy maker and regulator who must consider national or regional consequences in a single action).

Traditionally, spectrum engineering 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, in their initial form, 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 interactions) 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 advocated development of methods for improving the overall effectiveness of the use 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 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, 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.

The Re-Evaluation of Broadcast Frequency Assignment Criteria project goal has been to 1) establish the basis for more spectrum-efficient and service-oriented broadcast spectrum assignment criteria considering antenna patterns, topography, demography, and receiver characteristics, and 2) develop and document user oriented computer programs for the application of such methodology.

The following is an example of the project's output. Current FCC regulations prohibit broadcast transmitters being any closer together than a specified distance in order to limit interference. However, the specified distance does not depend on the transmitters' power or height characteristics, their antenna patterns, or the characteristics of the intervening terrain, all factors which could have a significant influence on reducing separations, thereby allowing additional service. In this example, an existing broadcast transmitter in Los Angeles operates with an effective radiated power (ERP) of 158 kilowatts and a height above average terrain (HAAT) of 3055 feet. Suppose a second transmitter were to operate on the same channel at Bakersfield, a situation not permitted under existing rules. The second station would operate with less than maximum facilities (e.g., ERP of 5 kilowatts and HAAT of 300 feet). Figure 1-1 shows signal coverage contours for the two stations. Using the current FCC method for computing signal coverage, Figure 1-2 shows the same signal contours. However, the effects of terrain on the contours has now been included. Using the FCC's criteria for co-channel interference, Figure 1-3 shows the rural grade signal service contours (solid lines) and the co-channel interference contours (dashed lines) for the two stations. The areas which are cross-hatched receive objectionable interference from the co-channel transmitter. Figure 1-4 shows the rural grade and interference contours when the effects of terrain on the signal propagation are included. Finally, a directional antenna is added to the Bakersfield facility to give better coverage to the Bakersfield area. The results are shown in Figure 1-5. Table 1-1 summarizes the area and population coverage results. The calculations indicate a same channel broadcast station could be introduced to the Bakersfield area which would not cause objectionable interference to the Los Angeles station.

TV Spectrum Planning Techniques is one of a series of projects conducted over the last several years with the objective of providing a range of planning tools that were both comprehensive and more valid than has been available in the past. Much of the impetus for such work has come from an increasing concern in the FCC, NTIA, and other agencies concerned with broadcasting matters for expanded service, particularly of television. These concerns arise in numerous contexts including the provision of initial service to rural areas, additional service in urban areas, comparability of UHF with VHF TV, and the expansion of educational TV. The most direct barrier to such expansion is the lack of suitable frequency space.

Our objectives for this effort are several, and we illustrate here our approach and current progress toward each. First, planning techniques must allow comprehensive assesments of TV service potential. Figure 1-6 is an example of service predictions for television stations currently operating in the U.S. as well as those under construction.

A second objective is to present results of complex analyses in terms easily interpretable by a wide range of interested parties including many without engineering backgrounds. The use of computer graphics techniques to produce map displays of this kind is one approach to this objective which has proven very successful.

Thirdly, we are concerned about providing analysis tools that are meaningful to and usable by experts in those other disciplines which contribute to telecommunications planning and policy making. One approach to this objective is the development of population estimates to go with maps of this kind. A wide range of population statistics are developed for service estimates of the kind shown here. Population patterns can be analyzed in urban and rural contexts, population receiving varying degrees of service, etc. These results are prepared using ITS developed methodology that provides a unique integration of engineering estimates (of field strength, for example) and population distributions.

A further objective is to rationally characterize the real world, particularly the wide variability in radio coverage experienced in practice. To this end, statistical methods have been developed which allow consideration of these variations.

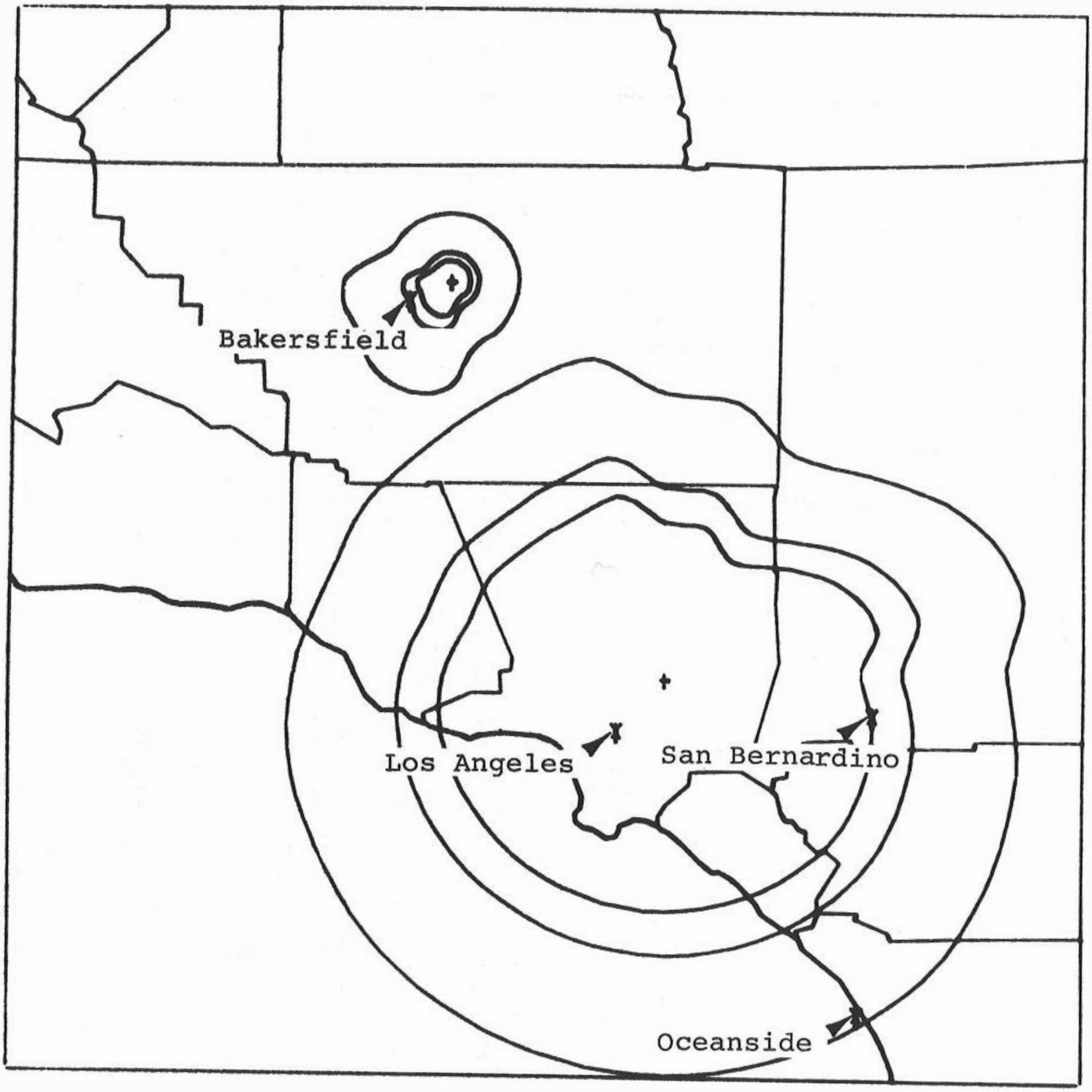


Figure 1-1. Coverage contours using FCC method.

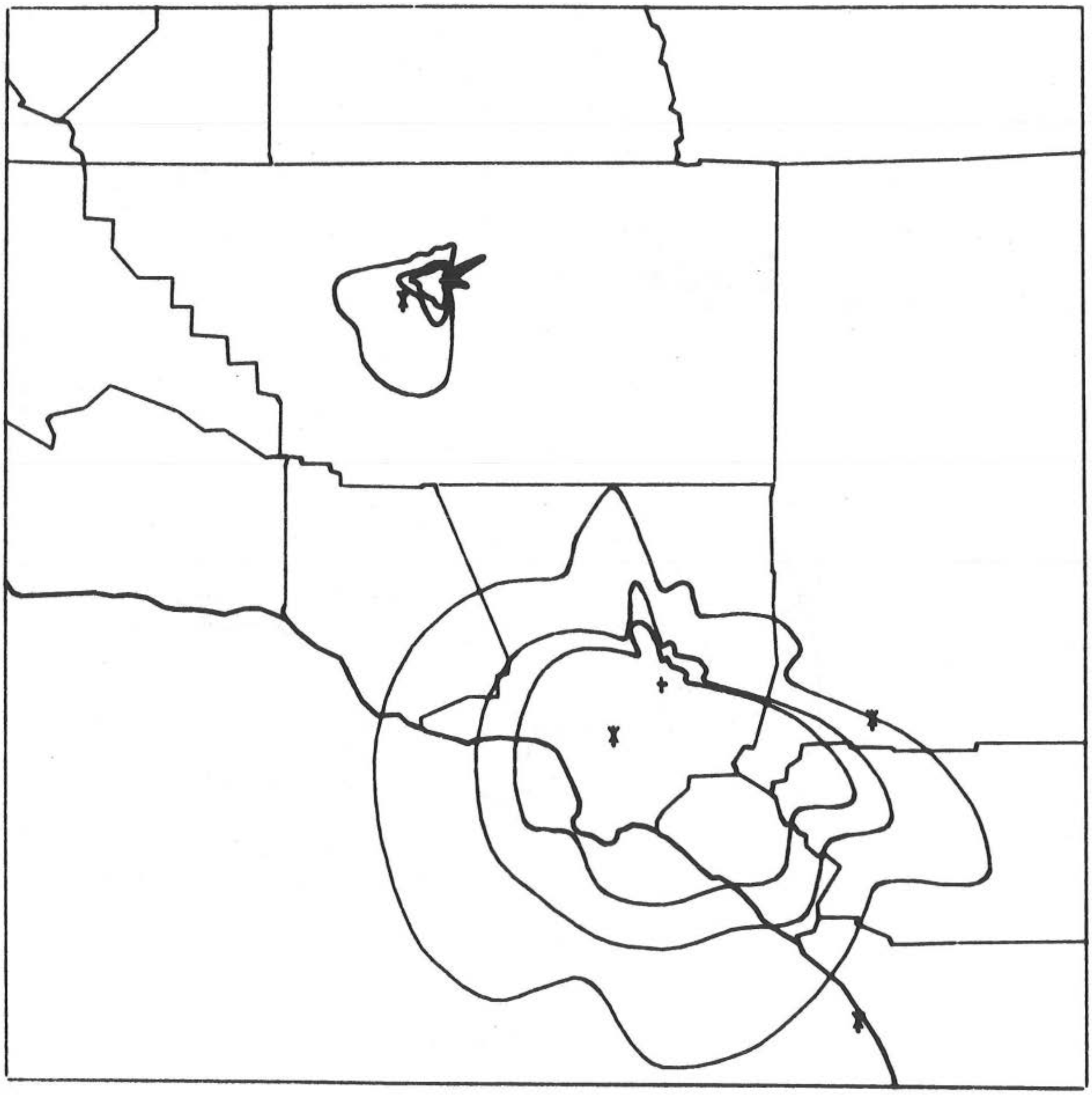


Figure 1-2. Coverage contours using terrain correction.

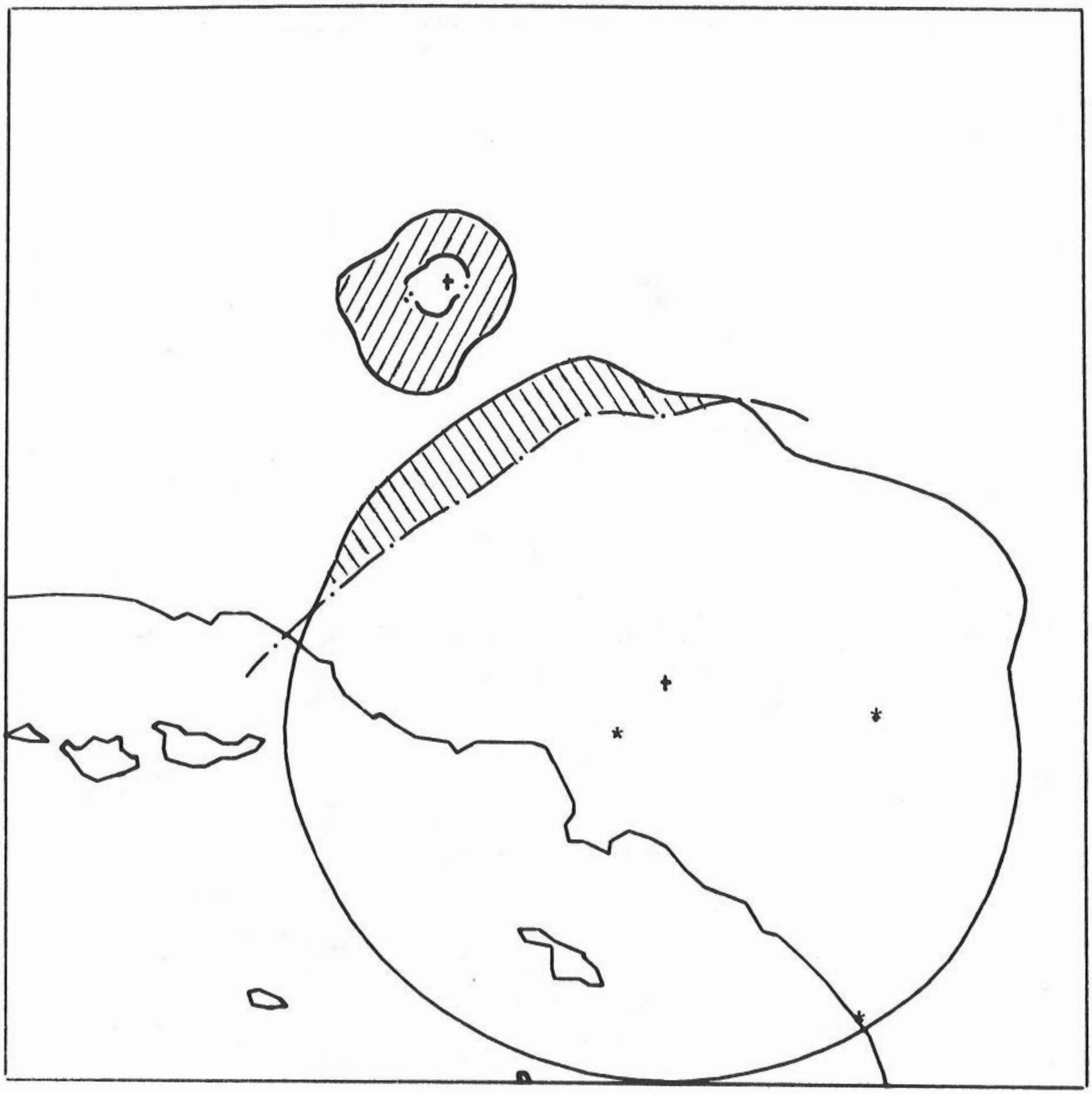


Figure 1-3. Coverage contours (solid lines) and co-channel interference contours (dashed lines) using FCC criteria.

Figure 1-4. Coverage contours (solid lines) and co-channel interference contours (dashed lines) using terrain correction.

Figure 1-5. Coverage contours (solid lines) and co-channel interference contours (dashed lines) using terrain correction and a directional antenna for the Bakersfield facility.

Table 1-1. Total Area and Population Covered by at Least Grade B TV Service and with Objectionable Cochannel Interference

Figure	Los Angeles				Bakersfield			
	Grade B		Cochannel Interference		Grade B		Cochannel Interference	
	Area (sq km)	Population (thousand)	Area (sq km)	Population (thousand)	Area (sq km)	Population (thousand)	Area (sq km)	Population (thousand)
_-3 (FCC method no terrain)	45856	9778	2448	11	2512	180	2240	147
_-4 (terrain effects)	23216	9138	-0-	-0-	1408	131	352	35
_-5 (terrain effects and directional antenna)	23216	9138	-0-	-0-	2064	161	560	24

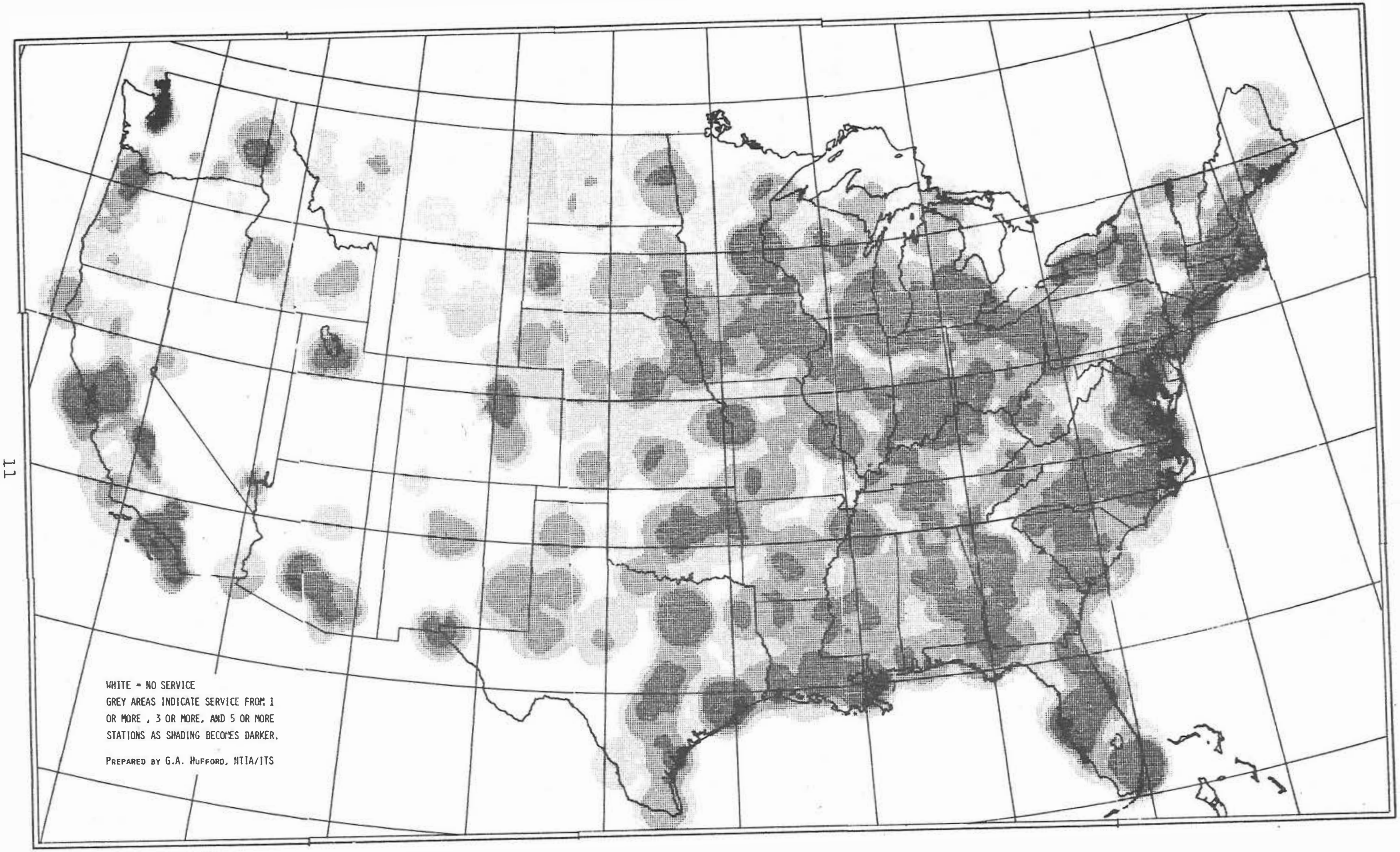


Figure 1-6. Grade B coverage from licensed and planned (CP) TV stations.

Objective number five is to provide techniques that allow policy makers, designers, and planners to evaluate a wide range of alternatives. The coverage map technique (which we refer to as COMAP) allows users to define such alternatives. Some examples include evaluation of service for:

1) educational stations only,

2) single networks,

3) proposed new stations, and

4) new technical regulations (such as revised constraints on maximum antenna heights.

A sixth objective is the development of estimates for improved technical accuracy. In this context, we have assembled "long term" radio data into a computer-readable form. This present collection contains time variability statistics for about 1000 fixed paths. It is, however, still in a somewhat primitive form, and we cannot, for example, use it in any very satisfactory wholesale manner to test out complete propagation models. What we have done instead is to test out the standard model of time variability, putting particular emphasis on the UHF band.

In our report on this test, we have criticized that model, saying it is more complicated than the data seem to warrant. Note, in particular, how in Figures 1-7 and 1-8 we have tried to display measured values of the so-called frequency factor g(f) for the 10 percentile. We have taken measured deviations from the medians and divided them by computed values from the CCIR curves which are supposed to be valid at 1 GHz. Figure 1-7 is a scatter plot and Figure 1-8 shows "running medians" with 10 to 90 percent confidence intervals. We think these figures show no reason for introducing the frequency factor; the hump at 400 MHz does not appear. Also, we suspect that the various radio climates usually employed should all be consolidated into one. This seems at least so for the middle range between, say, 10 percent and 90 percent of the time. At the tails of the distributions, we feel that it would be more appropriate to speak of specific probabilities of such phenomena as ducting and rainfall.

An additional objective is to establish generally applicable methods that can be readily integrated into a variety of analysis programs to meet specific needs. To this end, the most critical element of these techniques, the Longley-Rice propagation prediction computer programs, have been completely rewritten. Although the new implementation should give exactly the same results as previous ones, it is written in conformity with the ANSI Standard Fortran, and, hence, should be completely portable between machines. It is this implementation which we are now disseminating to the public on request. This standard form is now being incorporated in a number of our television coverage and interference analysis techniques.

A series of studies have been conducted to examine the potential for more efficient use of spectrum for land mobile radio applications. In evaluating the potential role of new technology, ITS has evaluated Spread Spectrum Applications to Land Mobile Radio. The possibility of overlaying a spread-spectrum system into frequency bands containing conventional FM land-mobile radio systems was examined. Overlaying here means the unrestricted operation of spread-spectrum and FM mobiles throughout a given service area and on the same frequencies. The systems thus must rely on the differences in modulation and spectrum characteristic to minimize interference. The project examines interference between systems for frequencies of 150 and 900 MH.

The conclusions of the study, as described in NTIA Report 79-23 ("A Compatibility Analysis of Spread Spectrum and FM Land Mobile Radio Systems", Juroshek, 1979), are that overlaying would cause significant interference. This conclusion is for conventional FM systems that service a large urban area. The small cellular concept of FM systems is not considered in the study.

An example of the output from the study is shown in Figure 1-9. Plotted in this figure is the separation distance d_{SS} that is required to prevent interference to an FM system. The distance d_{FM} is the victim transmission distance between FM base and FM mobile. The various forms of interference are shown in the figure with different shading. Also defined in the figure are regions where interference is expected to be highly probable due to expected propagation conditions and regions that are labeled "propagation dependent," where the occurrence of interference depends on the urban propagation characteristics. Similar results are also presented for interference to a spread-spectrum system from FM.

The project Spectrum Tradeoffs--Mobile examined spectrum utilization efficiency for two different land mobile radio services: small cell common carrier systems employing spread-spectrum modulation and interleaving of double-sideband and single-sideband channels in the Citizens Band.

The spread-spectrum radiotelephone system proposed by Cooper and Nettleton ("Efficient Spectrum Utilization with

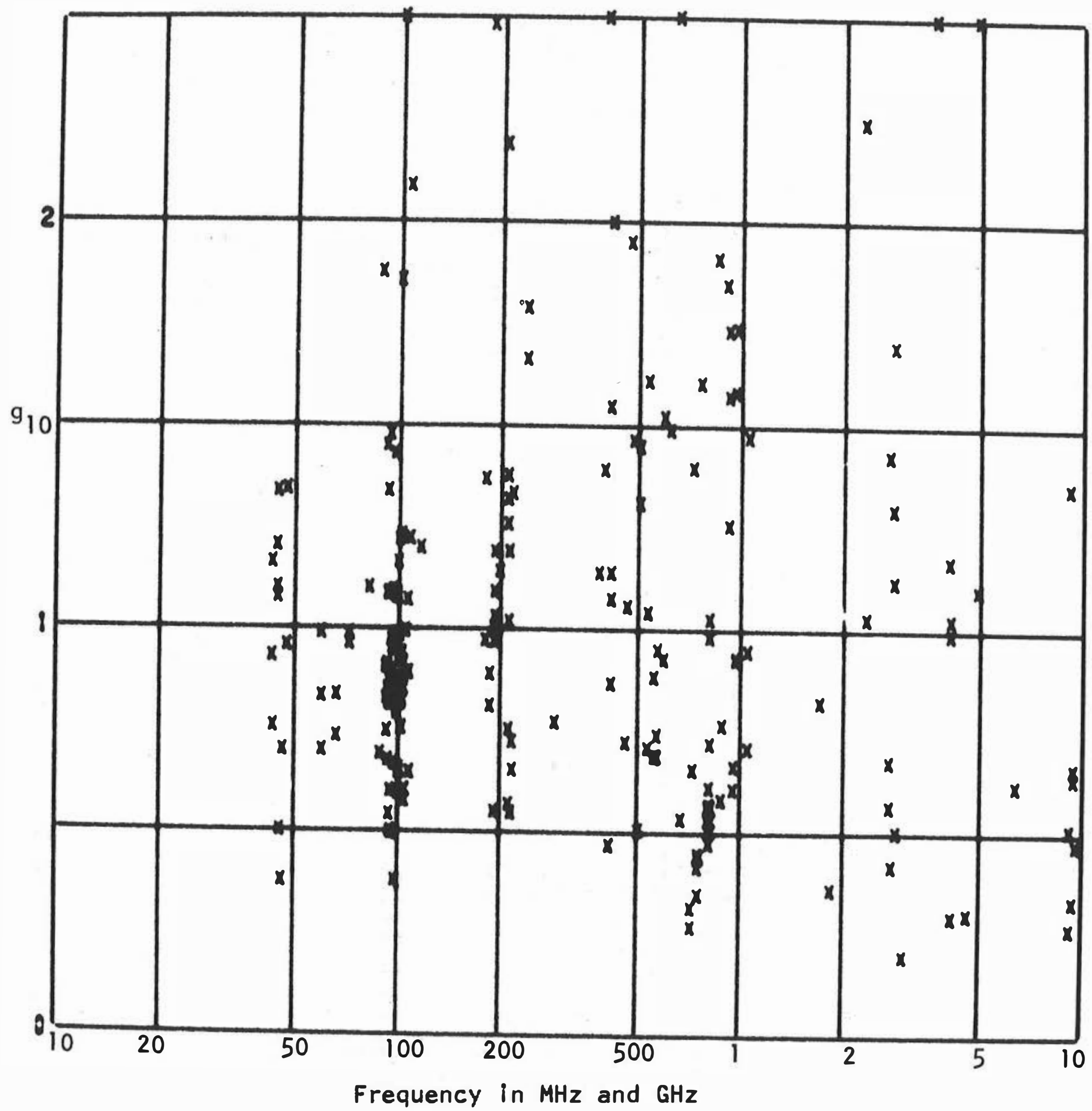


Figure 1-7. United States paths. A scatter plot showing measured values of g_{10} versus frequency for all over land paths with d_e greater than 80 km. Y_o (10) is obtained from the CCIR curves for a continental temperate climate.

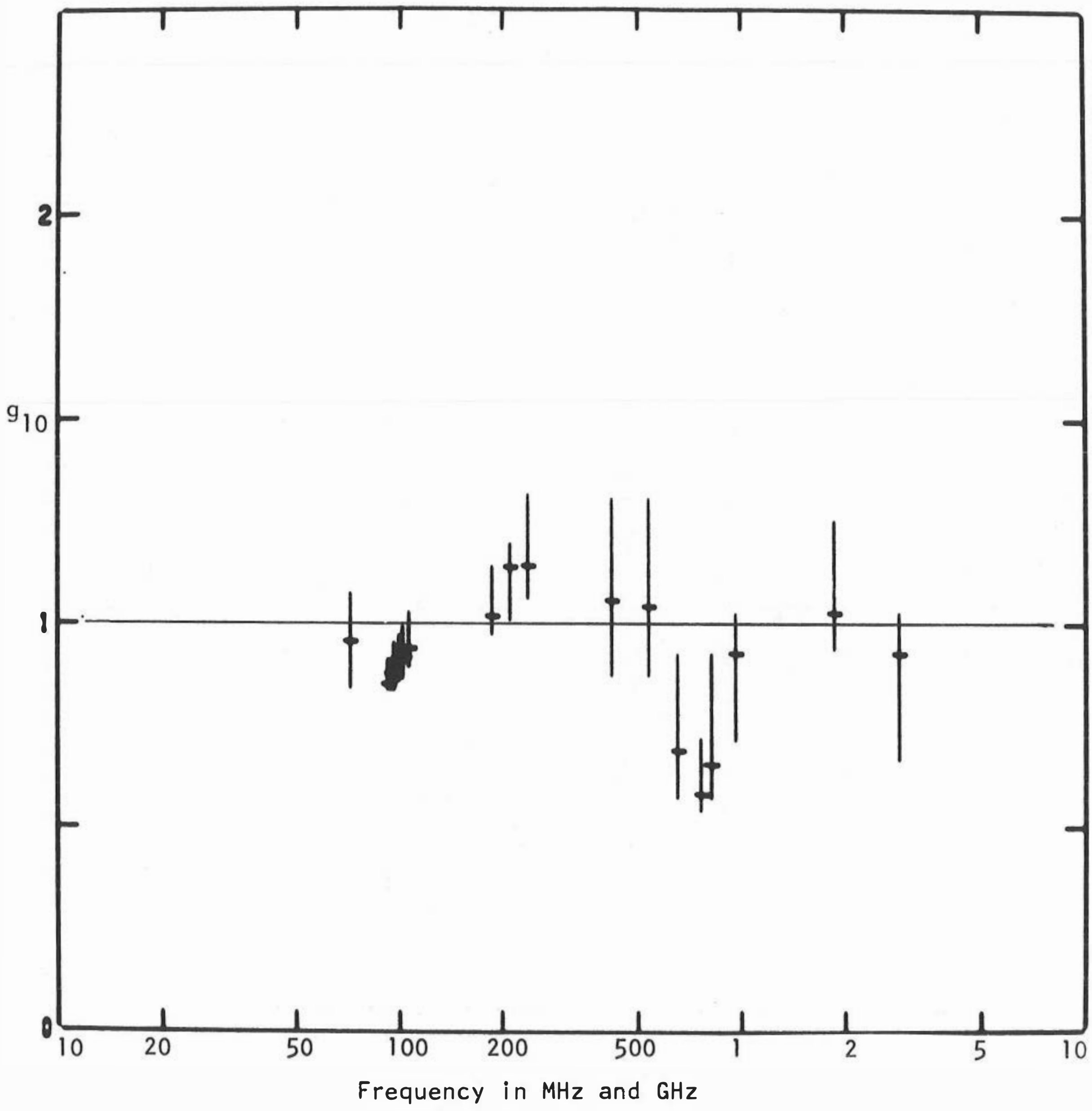


Figure 1-8. United States paths. Running medians of g_{10} versus frequency. Each median uses 31 points from Figure 1, and the bars show an approximately 10% to 90% confidence interval.

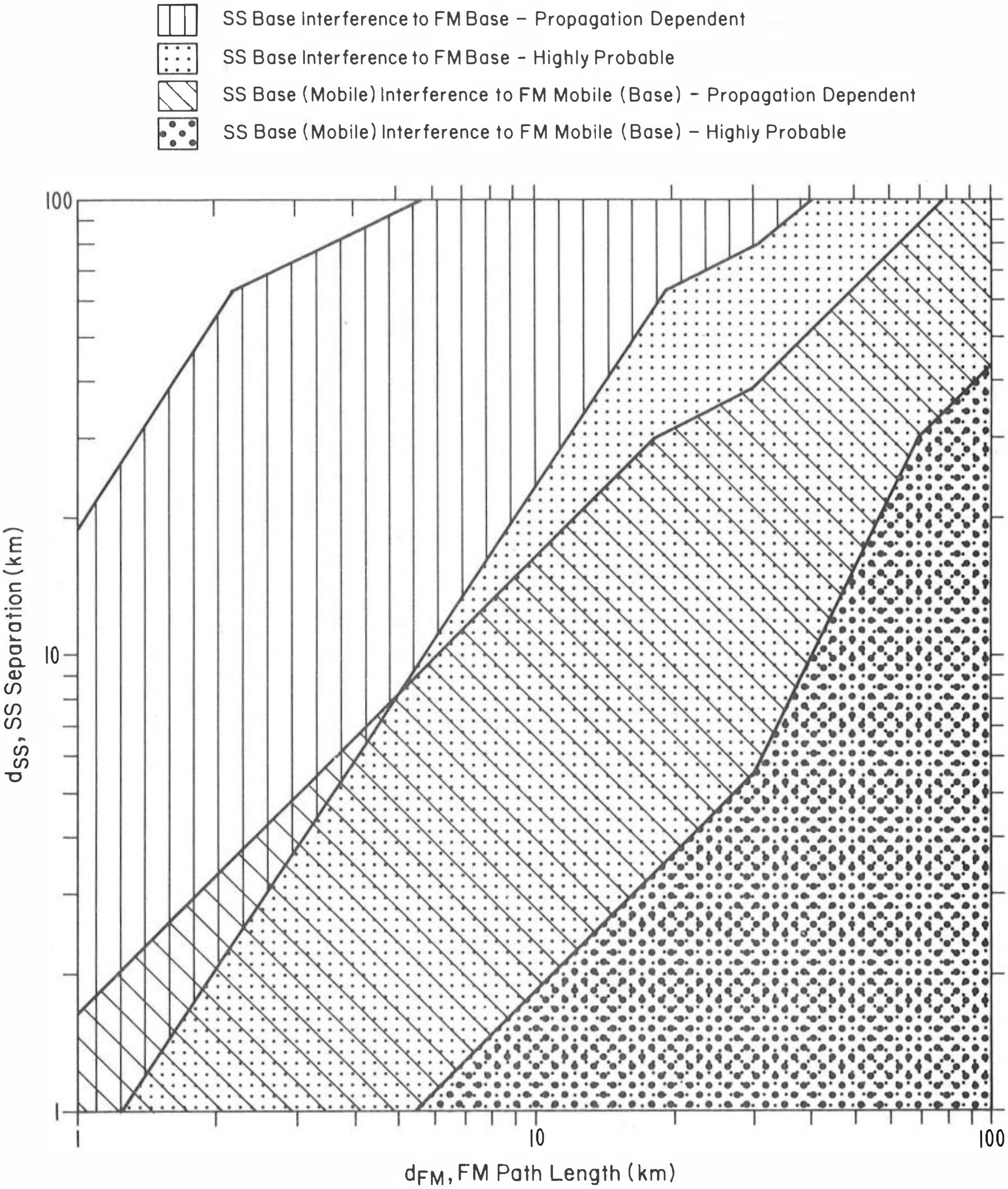


Figure 1-9. Separation distance d_{SS} versus d_{FM} that is required to prevent interference to an FM, land mobile system from a 10 MHz SS system at 150 MHz.

Wideband Signals," Purdue University Report TR-EE 77-12; "Spectral Efficiency in Cellular Land-Mobile Communications: A Spread-Spectrum Approach," Purdue University Report TR-EE 78-44) is basically a frequency-hopped, time-encoded system. Individual users are distinguished by a particular time-frequency code, and all users have instant access to the channel at all times. Disabling interference from a mobile close to the base station is avoided by controlling the power of each mobile so that all signals arriving at the base station have the same power. Cooper and Nettleton (1978) calculate that such a spread-spectrum system would be about twice as efficient (that is, allow about twice as many users per unit bandwidth per unit area) as channelized FM small cell systems such as proposed by Bell Telephone. They had earlier claimed larger improvement in efficiency (Cooper and Nettleton, 1977), but they now believe those claims were based on oversimplified calculations.

Even these claims are sensitive to the chosen propagation model. For attenuation rates observed on paths greater than 30 km long, the spectrum efficiency of the two systems reverses, with some doubt about the advantage of spread spectrum on paths 10-30 km long. Thus, the claimed advantage for the spread spectrum system is for very small cells, i.e., very high usage.

Cooper and Nettleton compute that their system (in one configuration) allows about 160 users per cell (Table 7.2 of Cooper and Nettleton, 1978). This has significant implications for the dynamic range required for the power control attenuator. Assume that there are n users spread randomly over a circular coverage area. (The coverage areas are said to be hexagons, but a circle is an adequate approximation.) If the attenuator is to have adequate dynamic range for 99% of the time, then the required dynamic range is between 60 and 80 dB, and should be accurate with 1 dB.

This may be only a lower bound to the required dynamic range of the attenuator, because it is based on median transmission loss, and does not account for location variability. Since the near transmitter is more likely to have a free space path than the far transmitter, the location variability could add 10 to 20 dB to the required dynamic range of the power control.

In the other study in this project, the increase in number of users resulting from interleaving channels was computed. The specific example was a proposal before the Federal Communications Commission to insert a single-sideband channel between the present Citizen's Band channels, which can be used for either single-sideband or double-sideband transmissions. Interleaved channels were not put adjacent to Channels 9 or 19, or between channels assigned to the Citizen's Band and channels assigned to other services. This resulted in 31 interleaved channels--an increase of 75%. However, calculations show that the number of users achieving a specified grade of service would only be increased by 20% to 30%.

The increase in users is not proportional to the increase in channels because of adjacent channel interference. The critical parameter is neither the adjacent channel rejection of the receivers nor the out-of-channel radiation of the transmitters. Rather, it is the relatively loose frequency tolerance of the center frequency of the emissions. This tolerance is large enough that some of the in-channel power of the transmitter is within the passband of the receiver in enough cases to cause troublesome interference.

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. Coverage, interference, and 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. Techniques developed in this project allow a wide range of coverage and interference situations to be evaluated for aeronautical services. Air/ground communications aeronautical navigation, and surveillance services are all treated by this capability. Representative results are shown in Figures 1-10 through 1-13, although the existing capability allows the production of a broad range of service estimates.

As part of a continuing effort to better understand and improve the reliability of spectrum planning techniques of this kind, ITS has reported on research which provides extensive comparisons of measured propagation data with predictions made by the IF-77 and other propagation models. Although IF-77 was developed for aeronautical applications, as mentioned above, it can be used for some point-to-point propagation paths, and the measured data selected for

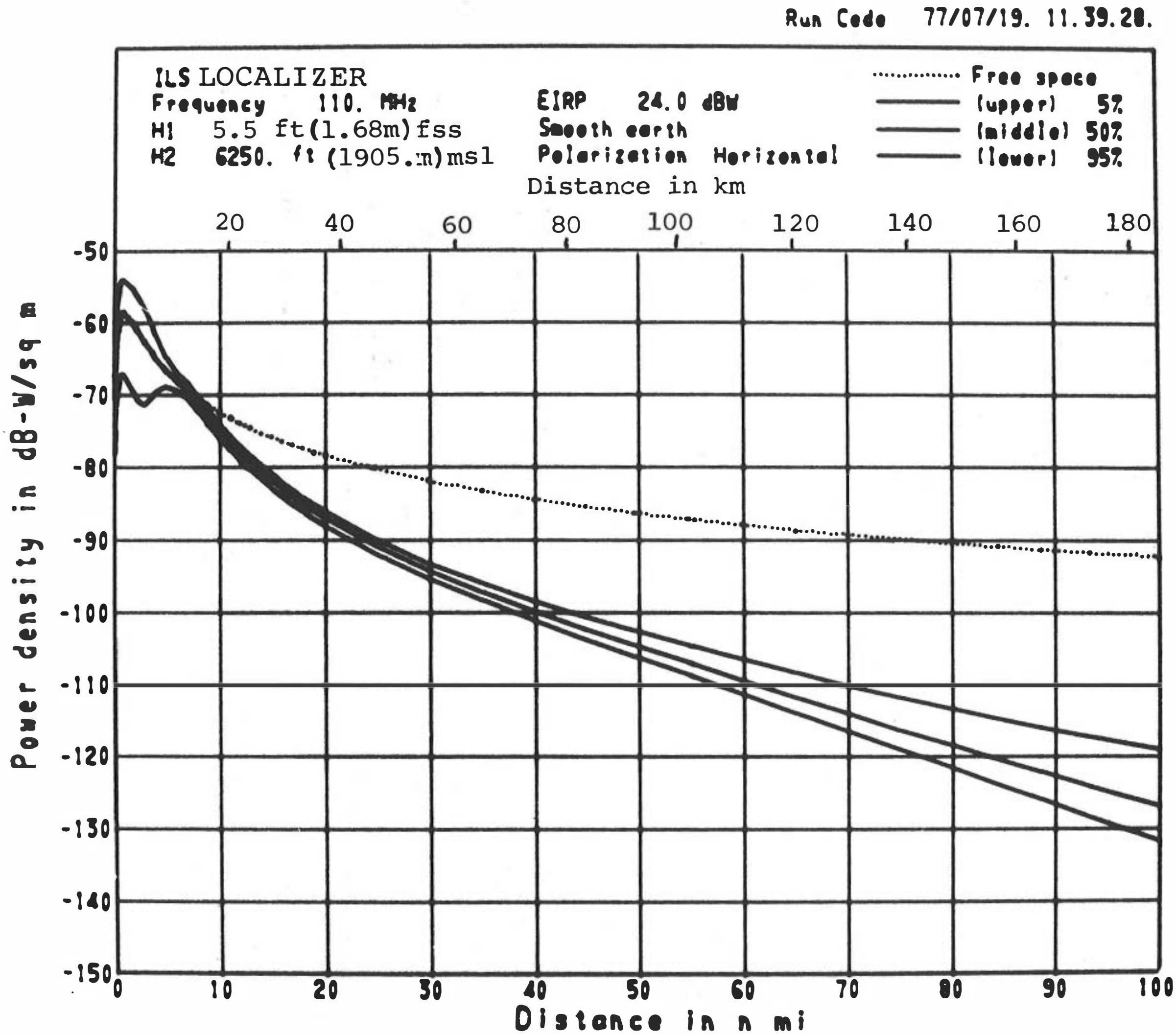


Figure 1-10. Power density, ILS. This graph predicts power density on the ILS localizer front course. In other directions, the predictions should be adjusted according to the localizer's horizontal antenna pattern.

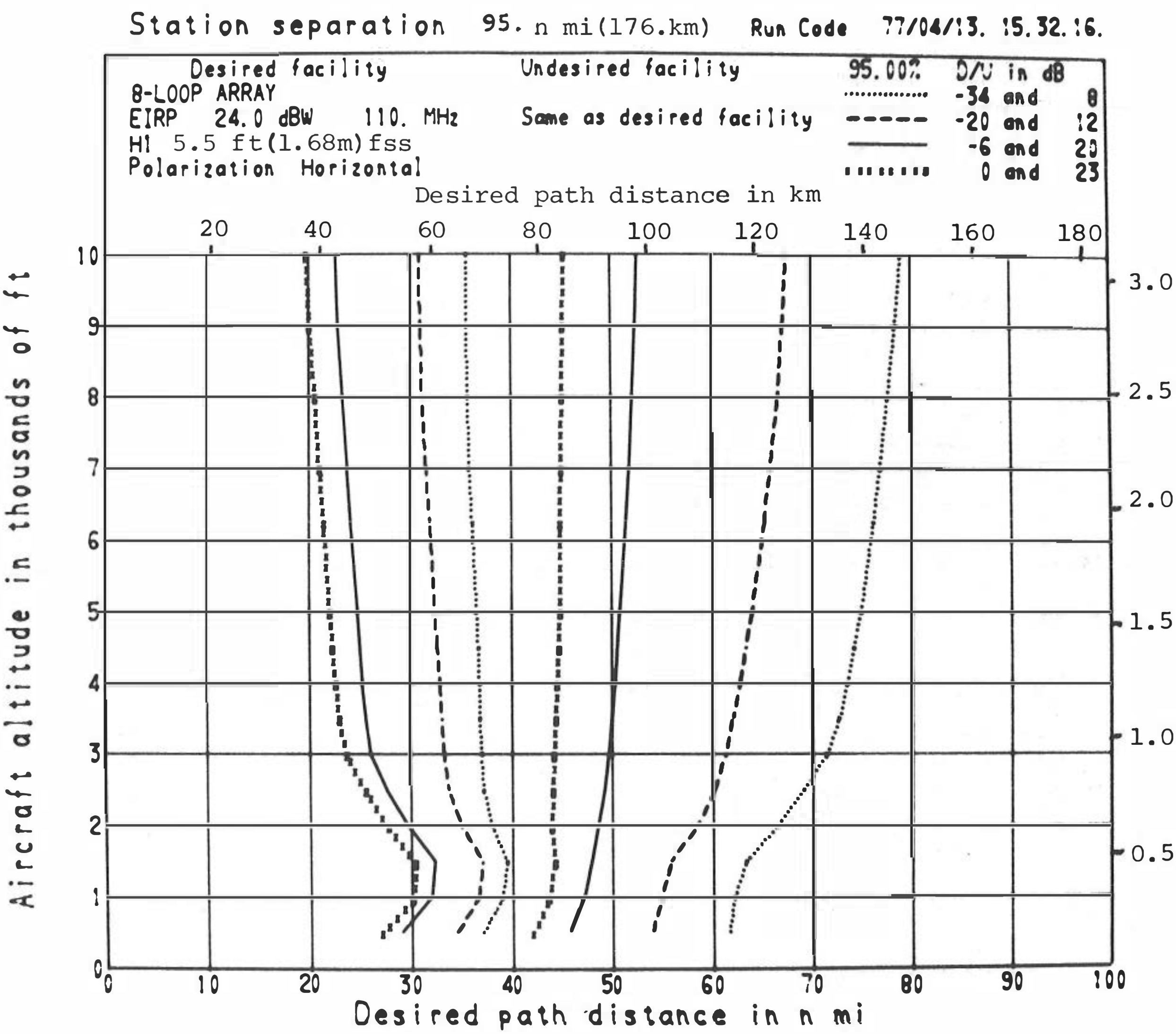


Figure 1-11. Signal ratio contours, ILS.

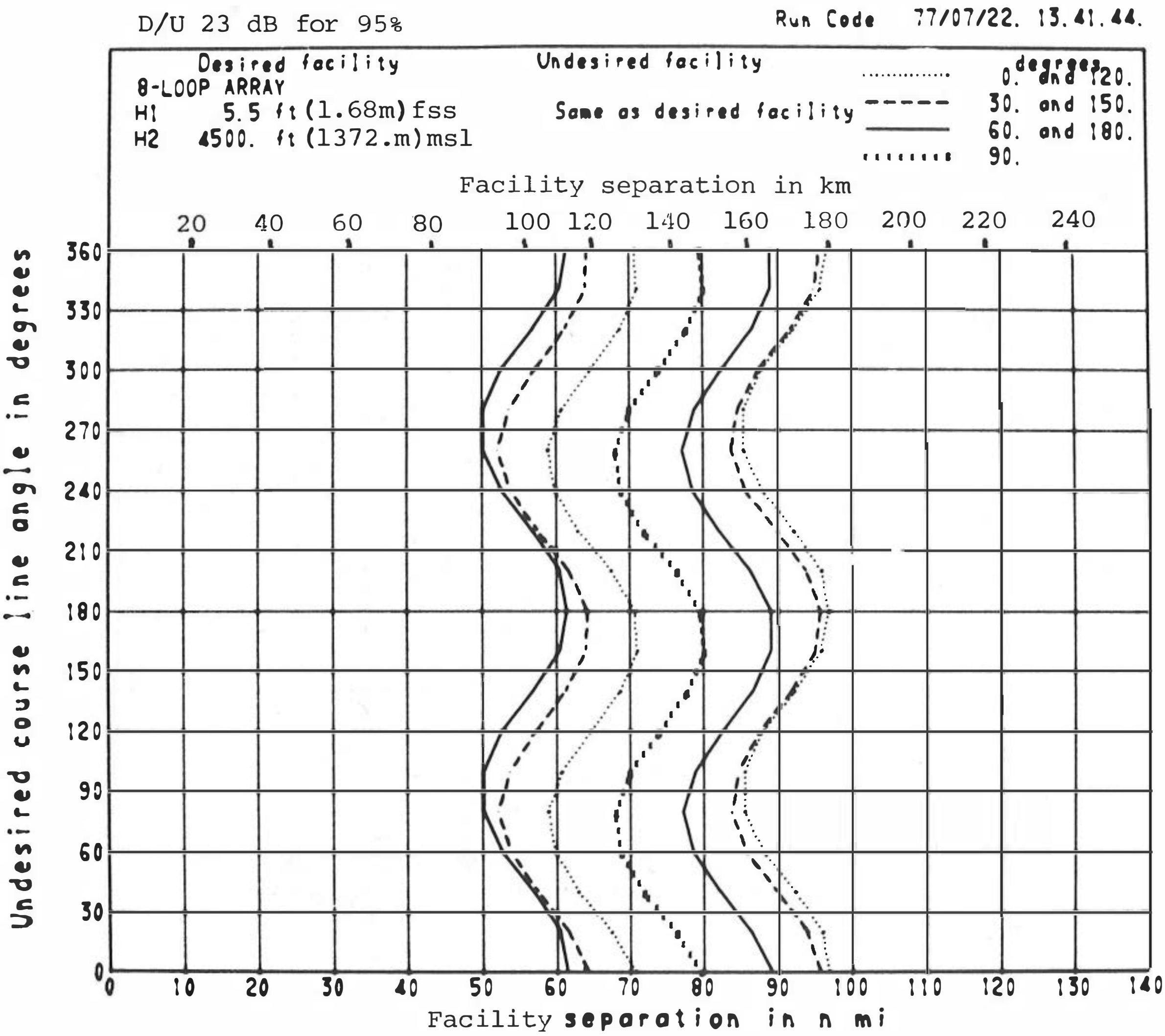


Figure 1-12. Orientation, ILS. Facility separation needed to obtain a D/U of 23 dB for a time availability of 95 percent is provided as a function of undesired (ordinate) and desired (line code) course line angles.

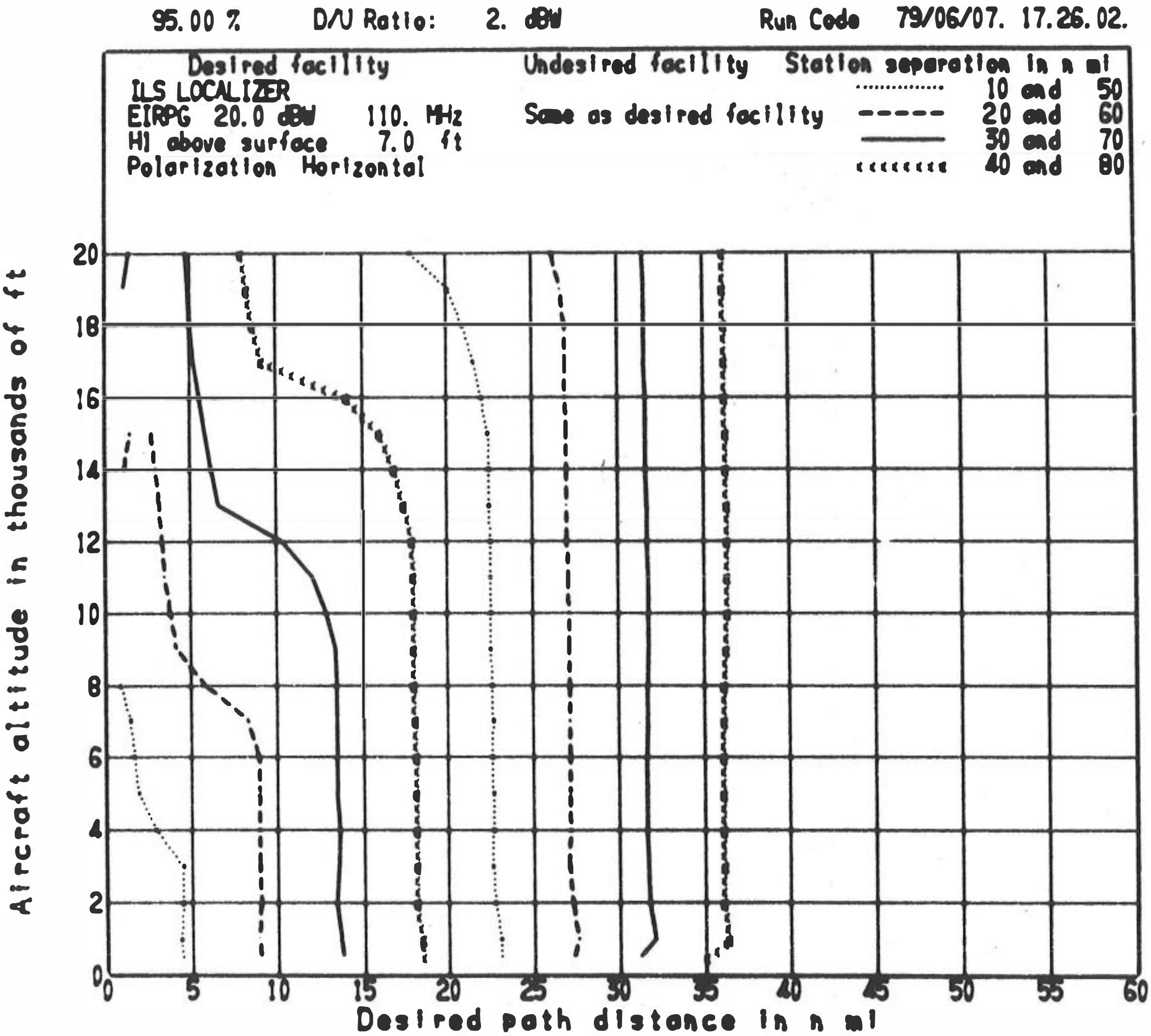


Figure 1-13. Interference limited coverage estimates for instrument landing systems (ILS).

comparison includes both types of paths. Examples of these comparisons are shown in Figures 1-14, 1-15, and 1-16. Figure 1-16 is for a ground-to-air path, and Figure 1-16 involves a comparison of desired-to-undesired (D/U) signal ratios at an aircraft for ground-based desired and undesired facilities. Approximately 870,000 hours of data are associated with the 242 paths used. Predictions made with IF-77 were always best or second best of the models tested, and were substantially better than those made with merely free space assumptions. The IF-77 model has a wide range of application and provides predictions compatible with the more specialized models tested.

The work currently underway on the project is in three 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.

3. New approaches to predictions are being developed that involve actual geographic station locations and the automatic use of a terrain data file to obtain path profile information for various aircraft positions.

A project to design and develop an interactive computer program to calculate jammer-to-signal ratios for user-defined scenarios is being sponsored by the U.S. Army Signals Warfare Laboratory. When implemented, the JAMMER program will allow the user to investigate the effects that changing various propagation and system parameters have on the jammer-to-signal ratios computed at selected locations. JAMMER uses the ITS standard area prediction propagation model developed by Longley and Rice (1968) and revised for standard applications this year. The software design plan has been completed.

This program can form the basis of a more generally applicable mobile communication system design program. JAMMER's features of program portability, ease of interactive use, and versatility of output, as shown in Figure 1-17, could allow a mobile system designer to easily make trade-off studies of his system parameters.

SECTION 1.2. SPECTRUM ENGINEERING FOR EFFICIENT 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.

CB Magazine recently petitioned the Federal Communications Commission (FCC) to expand the Citizen's Band Radio Service (CB) by adding 40 single-sideband (SSB) channels to the present 40 channels which can be used by SSB or double-sideband (DSB) transceivers. If the CB is so expanded, some channels will be separated by 455 kHz or more and second order intermodulation interference will be a possibility. In the project CB Intermodulation Interference, ITS calculated the probability of such interference, which is more important than the possibility.

A computer model for calculating the probability distribution of signal-to-interference ratio for quite general situations has been developed over the last several years as a part of the spectrum engineering techniques development effort. It accepts as input the spatial distribution of stations (random or deterministic), the time and frequency distributions of transmissions, and the statistical distributions of equipment characteristics, propagation loss, and radio noise.

CB radios are made by many different manufacturers, and have different susceptibility to intermodulation interference. The Probability distribution of susceptibility was determined using measurements made by the FCC laboratories.

Modeling assumptions (described in more detail in NTIA Technical Memorandum 79-15) were:

a) CB radios of interest are distributed randomly inside a circle of 20 kM.

b) Users distribute themselves uniformly over the channels.

c) Co-channel interferers have the same characteristics as the wanted transmitter, but users of the new SSB channels have ten time as much power on the average.

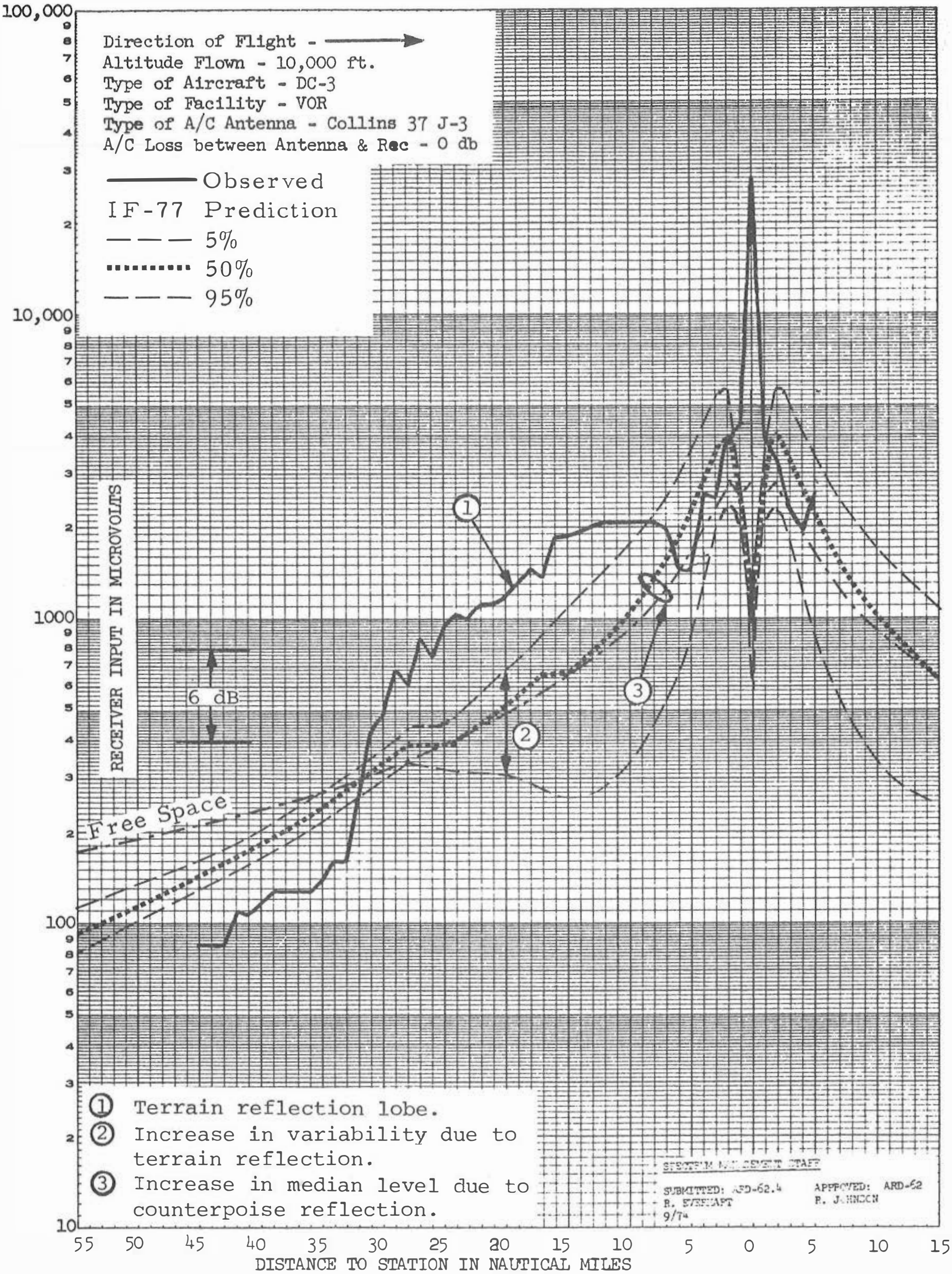


Figure 1-14. Comparison of measured and predicted received signal level, ground-to-air path.

HORNISGRINDE W GER - DARMSTADT W GER
PATHS 2363 TO 2366, 2440 TO 2443

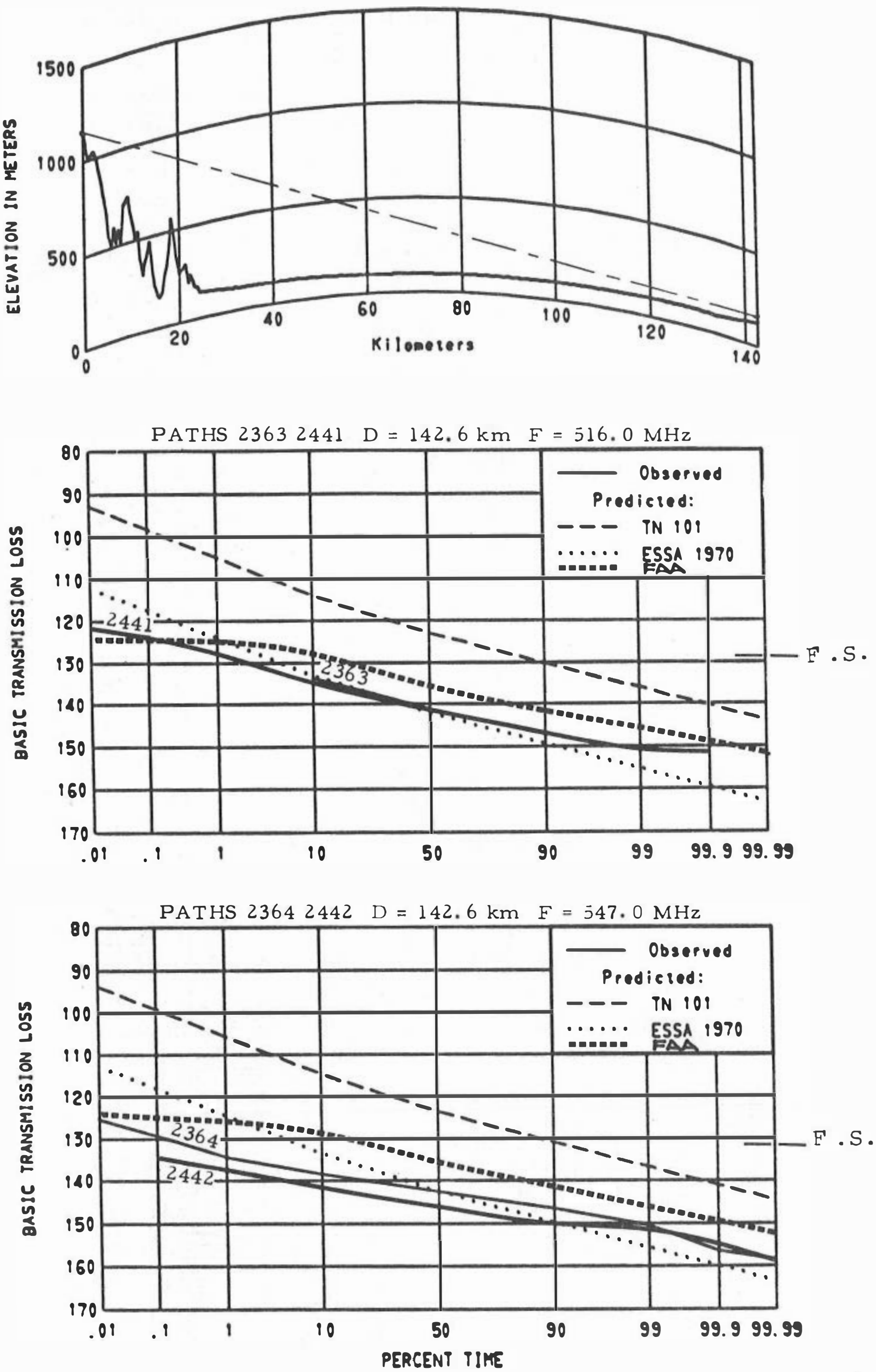


Figure 1-15. Comparison of measured and predicted basic transmission loss, point-to-point path.

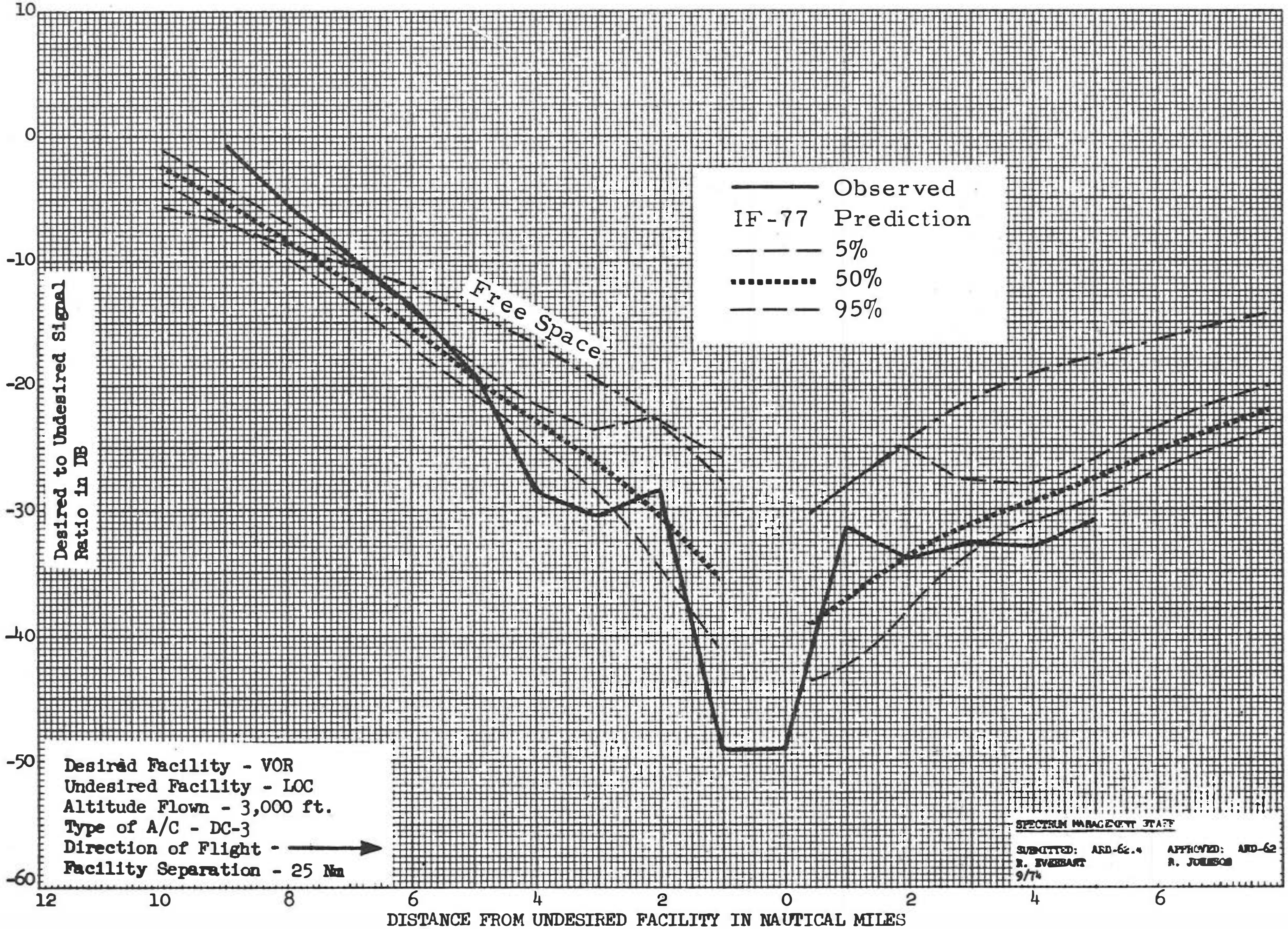


Figure 1-16. Comparison of measured and predicted D/U ratios at an aircraft for ground-based facilities.

Jammer Power (dBW)	Jammer Antenna Height (Meters)			
	1	3	5	7
Jammer-to-Receiver Distance (Kilometers)				
0.01	-63	-63	-63	-63
0.05	-56	-57	-58	-58
0.1	-49	-51	-52	-53
0.5	-41	-44	-46	-48
1.0	-35	-37	-40	-42
5.0	-26	-30	-33	-36
10.0	-17	-22	-26	-29

Figure 1-17. Output format.

d) The channel plan proposed by CB Magazine was used. This plan has 24 pairs of channels separated by 460 kHz, but none separated by 455 kHz.

e) Operation is in typical urban radio noise.

f) All 24 pairs of channels are contributing simultaneously to intermodulation interference.

g) SSB transmissions cause as much intermodulation interference as DSB transmissions.

Assumptions c), f), and g) are very conservative, making the calculated interference an upper bound of that which would actually exist.

Results are presented in terms of the operational range, $OR_f(17)$, which is the range at which the signal-to-interference ratio is 17 dB or greater on 100% of the attempted calls. The operational range for three cases is shown in Table 1-2. Case 1 is the baseline case which includes only the present 40 channels with no intermodulation interference. It is assumed that two CB radios are transmitting in the metropolitan area on each channel. One is the wanted transmitter and the other is an interferer. Many channels in urban areas will have more co-channel interferers than this. The three columns are the range at which the signal-to-interference ratio is 17 dB for 50%, 75%, and 90% of the attempted calls.

Table 1-2. Operational range in present 40 channels for three cases described in text.

	Operational range, km		
	0.5	0.75	0.90
Case 1	5.06	2.85	1.59
Case 2	4.74	2.74	1.55
Case 3	3.84	2.34	1.37

Case 2 includes the 40 SSB-only channels. There are now twice as many users, with half of them uniformly distributed in the new channels. The operational range shown is that for a DSB link in one of the present 40 channels. Intermodulation interference has decreased the median operational range by only 6%, and the 90% operational range by about 3%. This is a small price to pay for doubling the number of users, and will probably be unnoticeable.

Case 3 was an attempt to find the threshold of a significant effect, and to test the sensitivity of the results to the most uncertain factor, receiver susceptibility to intermodulation interference. In Case 3, the susceptibility of receivers to intermodulation interference was increased by 13 dB, to its value for channels separated by 455 KHz. For this implausible case, the median operational range is decreased by 25%, and the 90% operational range by 14%.

Because Case 2 represents an upper bound on the degradation from intermodulation interference, we conclude that 40 additional SSB-only channels added to the CB band will result in less than 10% decrease in median operational range even if the number of users is doubled.

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 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 1-18 is a sample of the predictions provided. It is applicable to the co-channel interference problem associated with the simultaneous operation of two command/destruct transmitters and provides the desired-to-undesired (D/U) signal radio available at the missile as a function of undesired facility-to-missile distance.

The Spectrum Analysis Support project provides special analyses, computations, and measurements in the direct support of NTIA's SMS program. Recently, the Justice and Treasury Departments purchased a large number of digitally-encoded voice transceivers for their land mobile radio applications. The transceivers provide secure communications links for their users, but, because of the modulation methods used by the transceivers, they may cause interference or be susceptible to interference from other transceivers in the land mobile band. Tests were conducted at ITS to determine the digital transceivers' performance in interference environments. Figure 1-19 shows an example of the performance measurement results with articulation score versus the input signal-to-interference ratio.

The CATV Radiation Measurements project, under the sponsorship of the FCC, developed a sensitive measurement system to measure levels of leakage from CATV systems in the airspace over selected cities. The project also supported

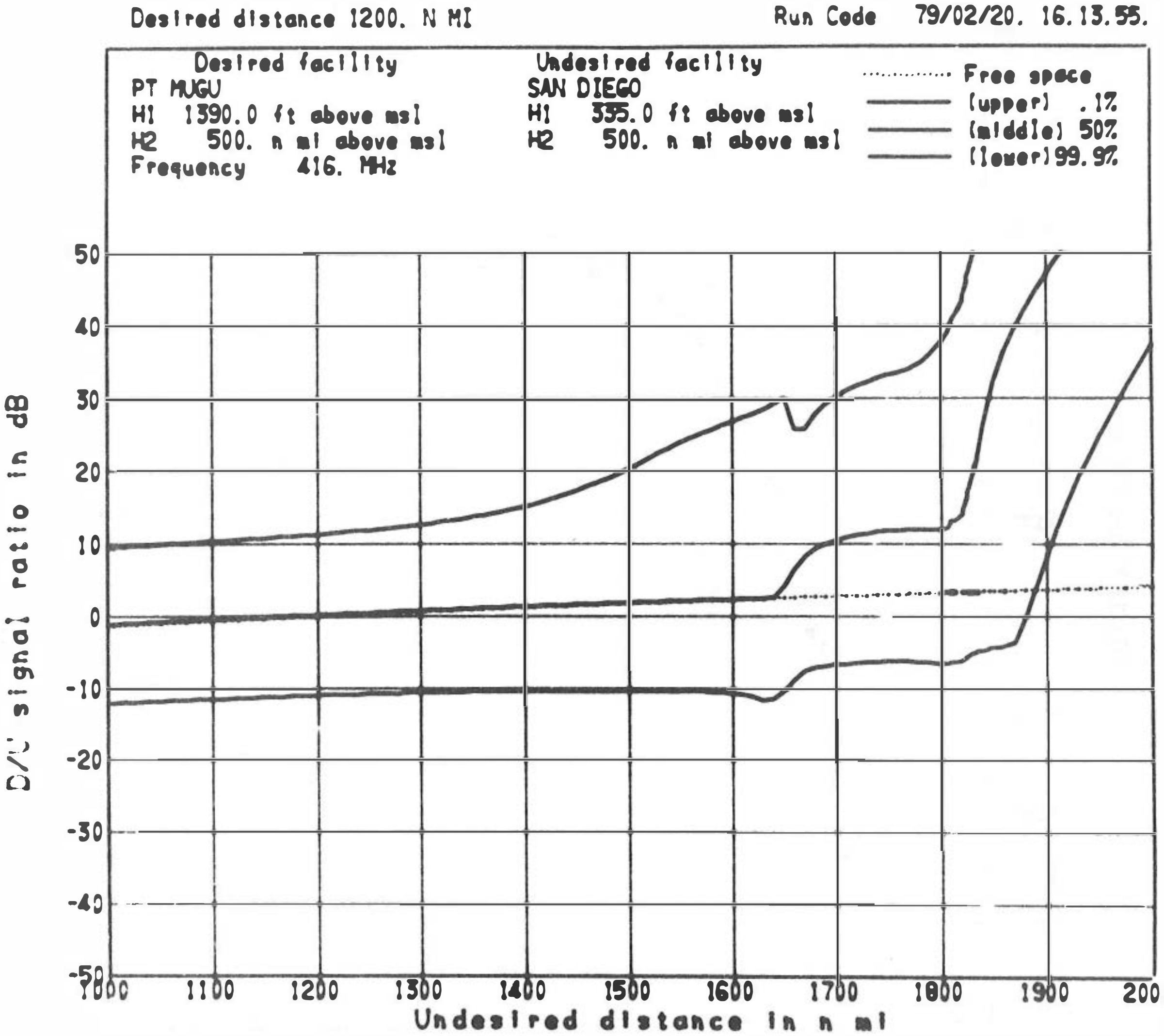


Figure 1-18. Sample co-channel interference prediction for command/destruct transmitters.

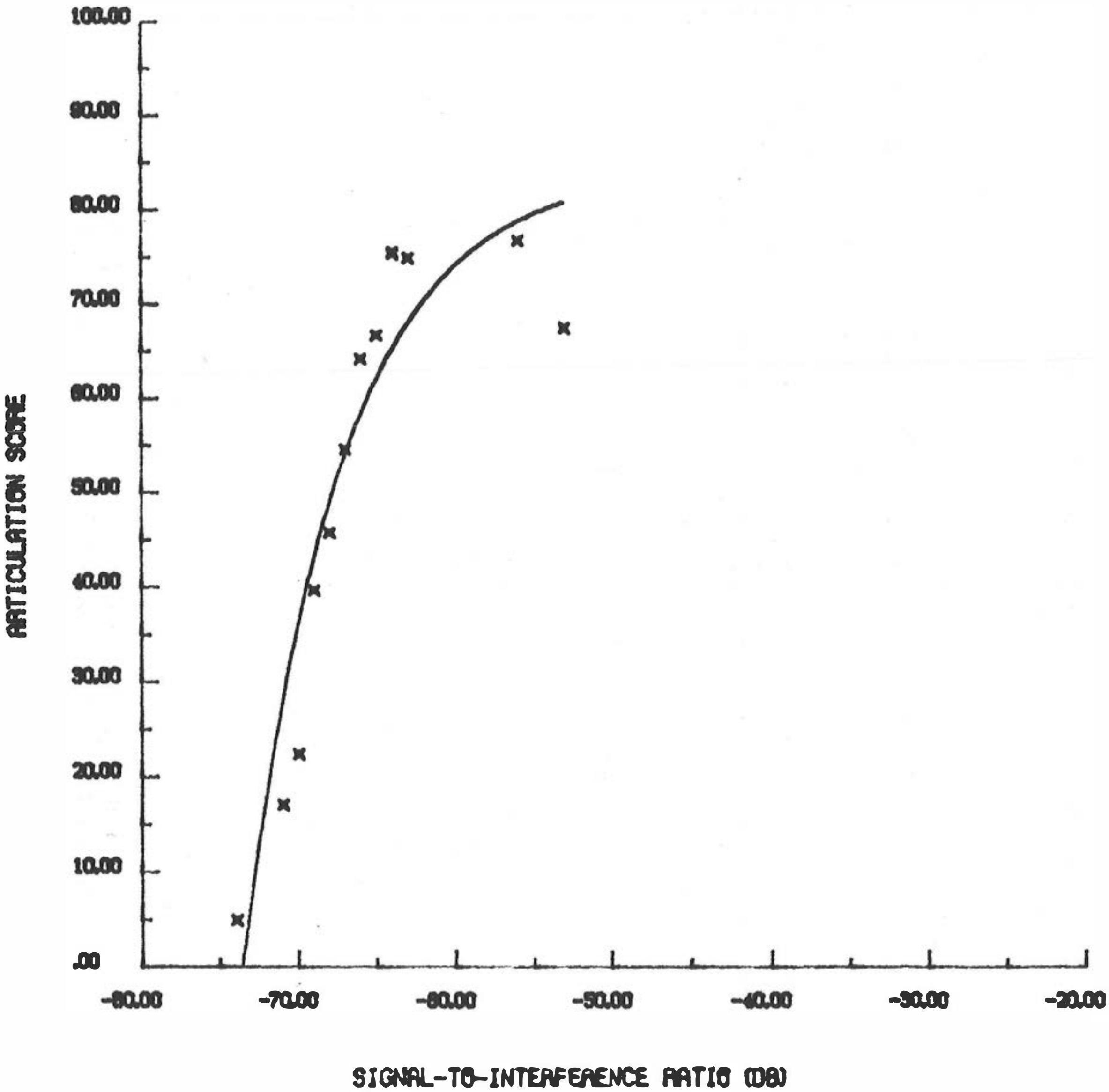


Figure 1-19. Plot or articulation score versus signal-to-interference ratio with FM transmitter interfering with a digital receiver tuned 20 kHz below the digital transmitter. The points represent measured data, and the solid line represents a least squares fit to the data.

consulting and advisory services to the FCC in the design of the measurements and the analysis of the data.

CATV systems tend to leak some rf energy which may then radiate, causing interference to users of the radio spectrum. The FCC initiated an advisory committee composed of members from the CATV community, the manufacturers of cable equipment, several Federal agencies including NTIA and the FAA, as well as other interested parties. This advisory committee met several times providing input to the FCC in a measurement effort to determine what levels of radiation might exist at several altitudes above a variety of CATV systems. The CATV systems to be measured were chosen so that both newly installed systems and older, poorly maintained systems would be tested.

The ITS measurement system consisted of a narrow band receiver with a -148 dBm tangential sensitivity at the 118 MHz test frequency; a computer controlled digitizer and real time analyzer; and a buffered digital data recorder. A stable cw oscillator source was connected into the cable system being tested, and the level adjusted to that of the closest operating video carrier. The measurement system was installed in a FAA aircraft and flown over the test cities in a grid pattern at up to three altitudes. These data were then recorded and returned to ITS where the data were reduced into distribution plots of amplitudes.

An interesting comparison of some of the output plots is shown in Figure 1-20. This figure shows the levels measured at one of the cities with the cw oscillator both on and off. This city is a relatively small one away from any major metropolitan areas. The signal received with the cw source off is due to ambient noise in the area. This was measured to have a mean level of -132 dBm. When the cw source was turned on, the mean level increased to -112 dBm, indicating that the CATV system caused a 20 dB increase in interference in the airspace. Figure 1-21 shows a second city that is part of a major metropolitan area. In this city, an ambient level of -117 dBm level was measured, and when the cw source was energized, the increase in mean level was less than 0.4 dB. We can draw the conclusions that the city of Figure 1-20 has 15 dB less background radiation or noise in this bandwidth than the city of Figure 1-21, and the CATV system of Figure 1-21 is a much better system from the standpoint of leakage.

These data and others were analyzed and will be a part of the final report of the advisory committee. These data will then be used by the FCC to determine if any restrictions need to be placed on the operation of cable systems in any of the frequency bands.

One facet of the operation of the United States Coast Guard is the Automated Mutual-assistance Vessel Rescue (AMVER) system. In this system, ships of many different flags voluntarily send regular radio reports of their position, course, speed, and search and rescue related capabilities (e.g., if they have a doctor aboard). These data, received at the various communication stations, are stored on a computer at the AMVER center on Governor's Island, New York. Then, in the event of an emergency at sea, such as a disabled or sinking ship, an ill crewman or passenger, or a plane down, these data can be rapidly retrieved in order to determine which ships are in the vicinity that can give aid to the stricken vessel or aircraft. Most of these AMVER reports are handled on the high-frequency (HF) maritime bands using Morse Code (cw) or in some cases single-sideband (SSB) voice.

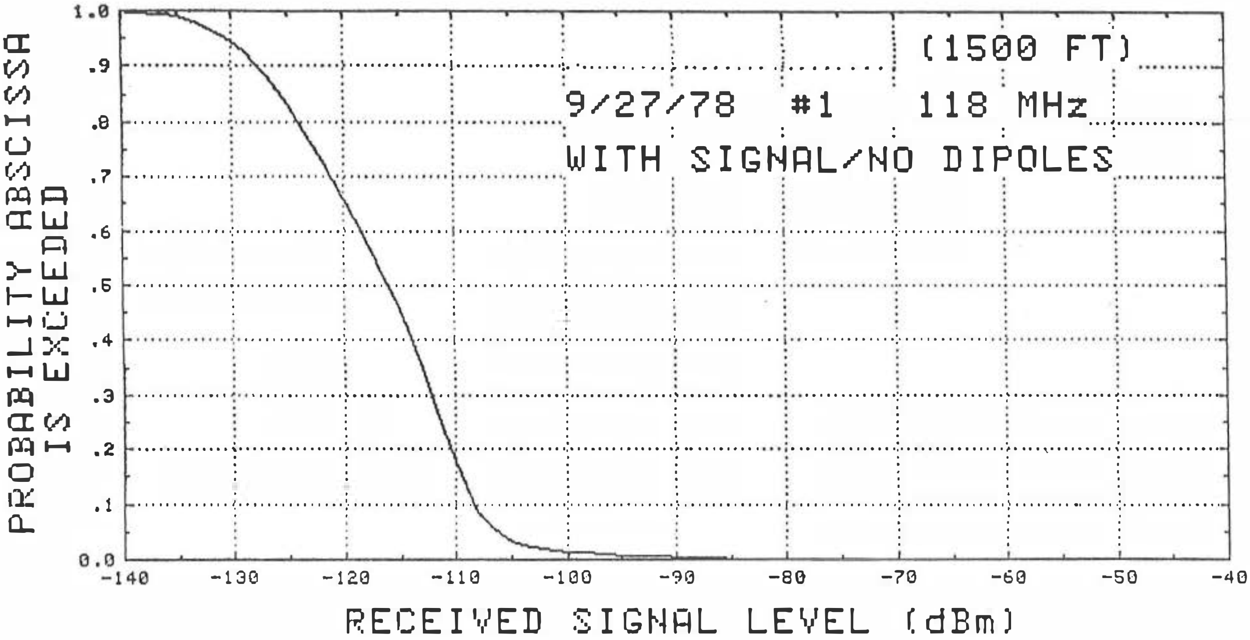
The purpose of the San Juan/Kodiak AMVER Coverage Alternatives Study was to examine the communication coverage regarding the AMVER reporting in two ocean regions - one in the Atlantic and the other in the Pacific. More specifically, this study assessed the impact of dropping the AMVER guard at San Juan, Puerto Rico, in the Atlantic area and the guard at Kodiak, Alaska, in the Pacific area. Further, a determination was made of which additional frequency bands must be guarded at other, existing communication stations to make up the coverage loss, if any, due to dropping the above guards.

Analysis for this problem was based on a series of 469 assumed ship positions in the Atlantic and Pacific oceans as shown in Figures 1-22 and 1-23. Predictions of communication reliability from each of the shore stations to each of the ship locations was made considering both signal level and noise statistics. Characteristics of the transmitters, their antennas, and the ionospheric transmission medium were also considered using the ITS developed skywave prediction model known as HFMUFES.

Results of this analysis provide maps and estimates of the percent of ocean area covered with at least a reliability of 85%. These data led to the following conclusions:

Atlantic Area

- San Juan contributes significantly to the coverage of the Atlantic area. This contribution is especially important during times of low solar activity and/or during the winter.



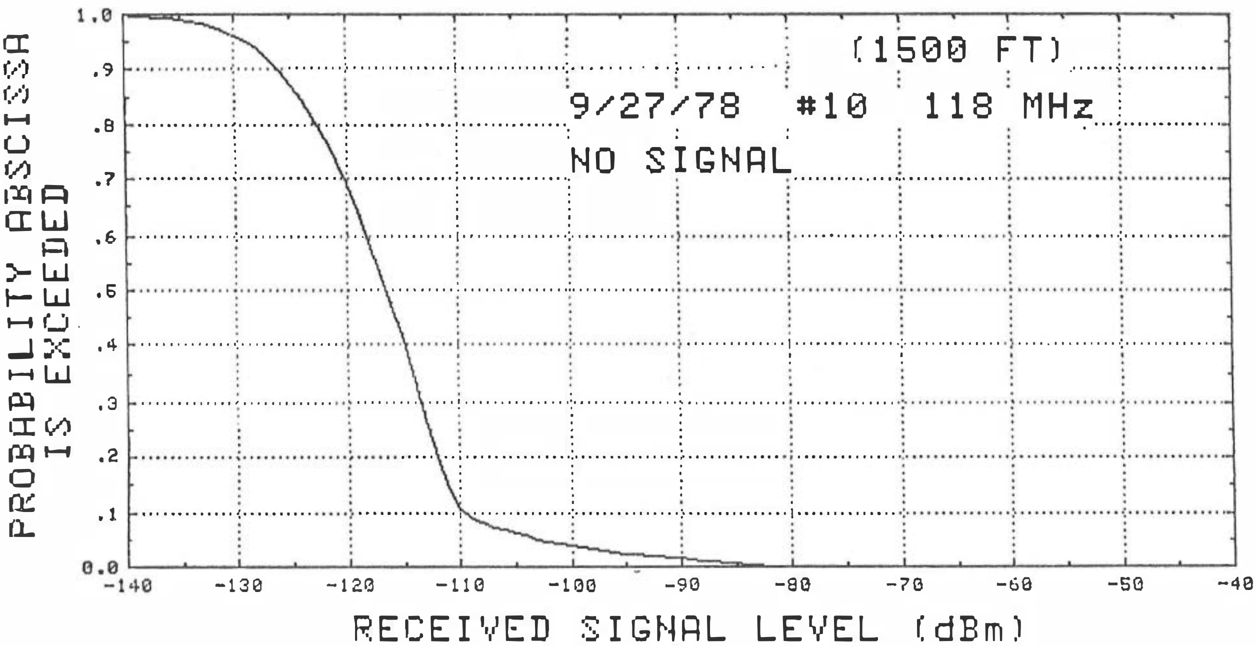


Figure 1-20. Measurements for city D.

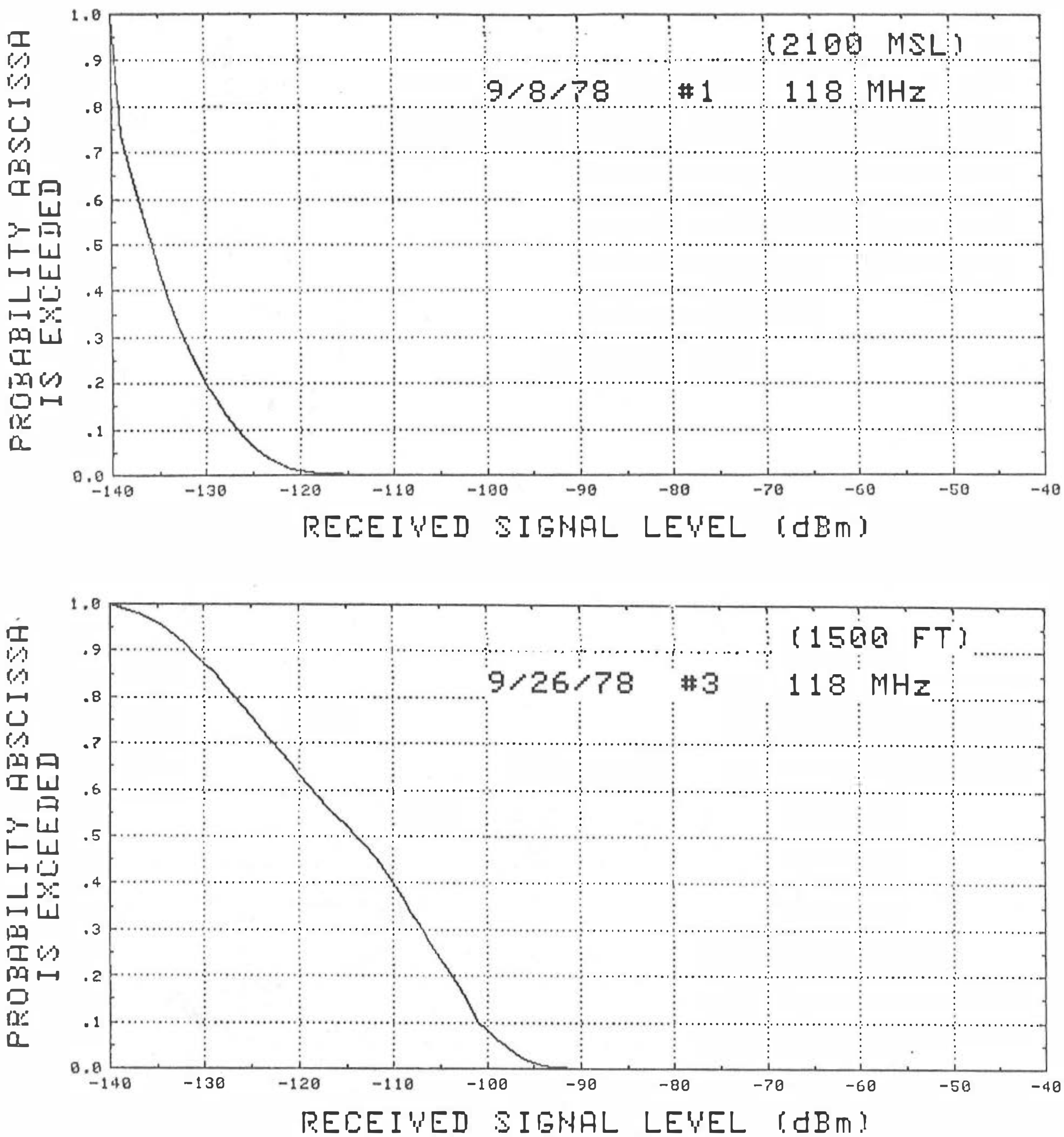


Figure 1-21. Measurements for city K.

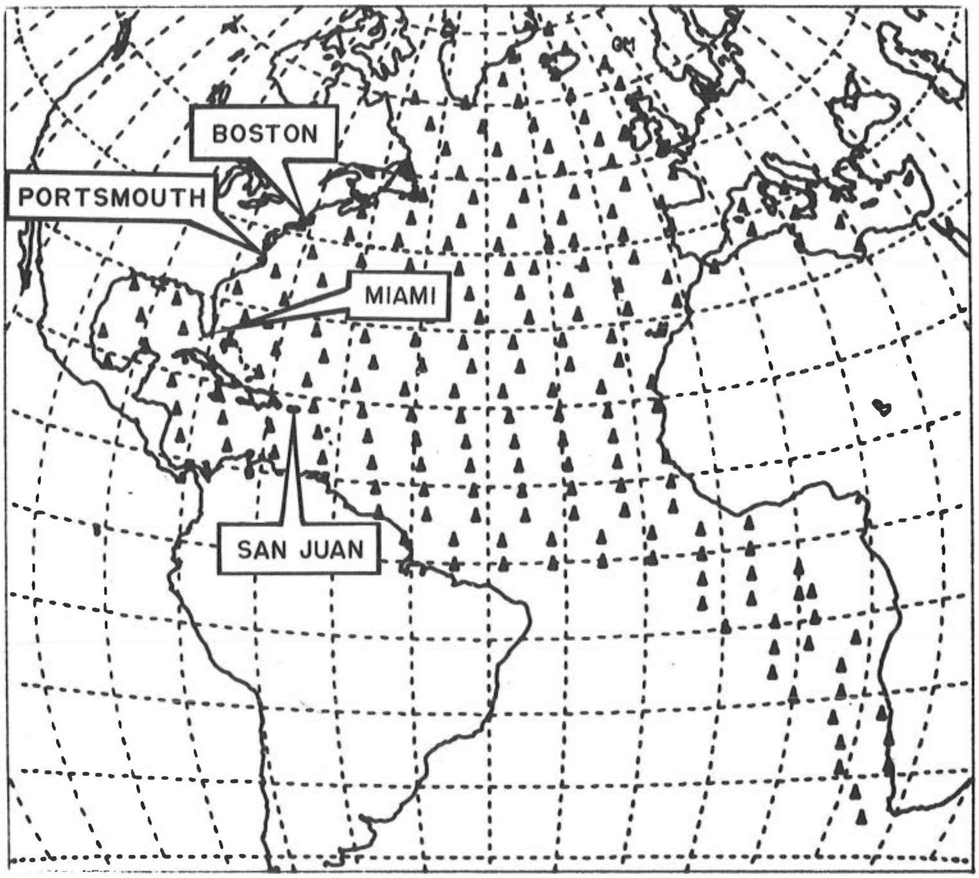


Figure 1-22. Simulated ship positions and shore stations for the Atlantic area.

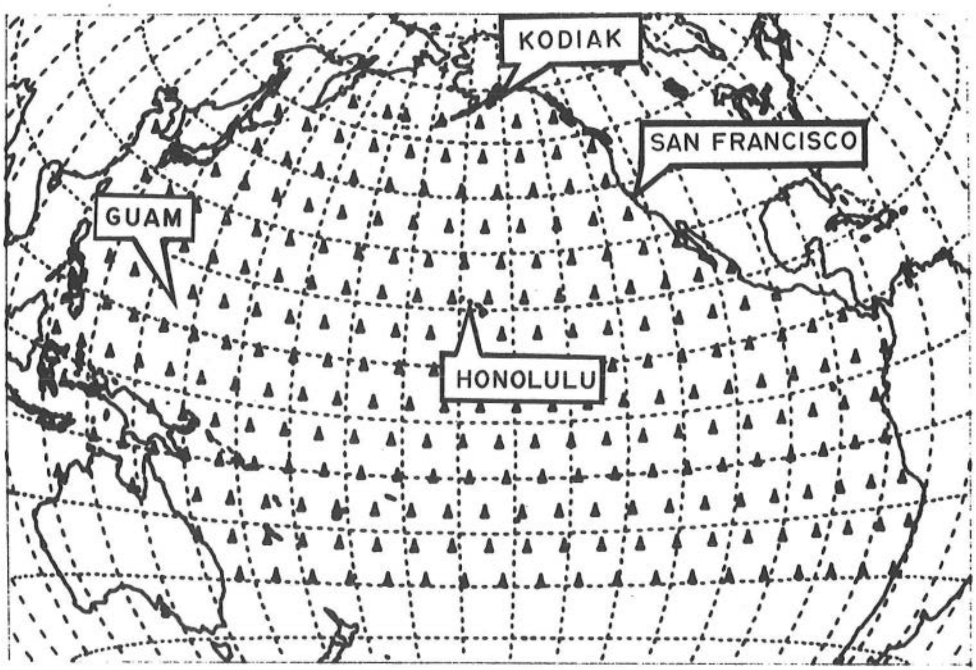


Figure 1-23. Simulated ship positions and shore stations for the Pacific area.

- The most important frequencies at San Juan are 16 MHz during the day and 8 MHz at night; 12 MHz contributes very little.

- One alternative, if San Juan is dropped, is the addition of 22 MHz during the day and 6 MHz at night at Portsmouth. This alternative is as good or better than San Juan except during times of low solar activity in the day.

- Another alternative to San Juan is to utilize Miami. The higher frequencies, 12 and 16 MHz, are best during the day and the lower frequencies, 6 and 8 MHz, are best at night. It may be sufficient to use only 16 MHz in the day and 6 MHz at night. This coverage may be inadequate during times of high solar acitivity, in which case two frequencies could be used.

Pacific Area

- Kodiak is a very insignificant contributor to the coverage of the Pacific area. The frequencies currently in use at San Francisco and Honolulu do an excellent job of covering the Pacific area.

The Power Line Carrier Interference project seeks to determine the extent to which radio signals intentionally transmitted along high-voltage power lines can interfere with the proper operation of automatic direction finder (ADF) radio compasses used for aeronautical navigation. Carrier current systems are widely used by power companies for communications using signal structures varying from single pulses for fault detection to FSK modulation for remote metering and control. SSB voice is often used for communications. There is a trend for some utilities to use higher powers for their power line carrier systems so that higher frequencies can be used over greater distances. ADF radio compasses operate in the same frequency band.

The effects of PLC radiation on the ADF radio compass systems are not well known. In fact, the degree to which PLC signals radiate is not well known. Some of the observed ADF errors have been correctly attributed to PLC radiation; there have been some notable examples in Europe. Then, too, some of the observed ADF errors that have been attributed to PLC radiation may, in fact, have been caused by re-radiation of the beacon signal by the nearby power lines. Due to the above factors and unknowns, the Federal Aviation Administration initiated this study at the Institute to help answer, at least, the following question: Do the power line carrier systems radiate sufficient energy to produce significant radio compass errors?

Early results of the ITS study established that power line carrier radiation is not easily predictable and, as a consequence, a measurement effort was instituted. The PLC radiation measurements will be made using an FAA flight inspection aircraft. The aircraft will be equipped with a spectrum analyzer/data recording system to make the required signal level measurements. The aircraft and data system are being supplied by the National Aviation Facilities Experimental Center of the FAA. The measurements will be made over power lines of the Tennessee Valley Authority (TVA). Several lines have been chosen, representing a variety of line lengths, substation complexity, PLC coupling methods, etc. These PLC radiation measurements are being flown as of this writing. The measurement program includes calibration of the airborne receiving system using carefully selected non-directional beacons in Texas and Oklahoma. Susceptibility measurements of ADF receivers will also be made at the FAA Aeronautical Center in Oklahoma City. Typical results of the measurements are shown in Figure 1-24. Further work is planned to assess the overall effects of power line carrier systems on ADF receivers based on the results acquired so far.

Spectrum engineering is also accomplished through a series of projects which provide consulting services to other agencies of government. The U.S. Coast Guard Consulting project provides "quick reaction" propagation predictions and short-term studies as needed by the Coast Guard in the operation of their large network of MF and HF communication systems. In addition, four-times-a-year propagation predictions are supplied to support the AMVER (Automated Mutual-assistance VEssel Rescue) system. These periodic predictions are distributed to the many AMVER participants to aid them in choosing the best frequency and Coast Guard communication station with which to log their AMVER reports.

Most of the "quick reaction" propagation predictions are requested by and provided to the communication stations directly. As one example, this last year predictions for circuits between San Francisco and Borneo were supplied to the San Francisco communication station.

FAA/Technical Support in Propagation and Spectral Engineering provides consulting activity in support of the Spectrum Management staff of the Federal Aviation Administration. The primary objective is

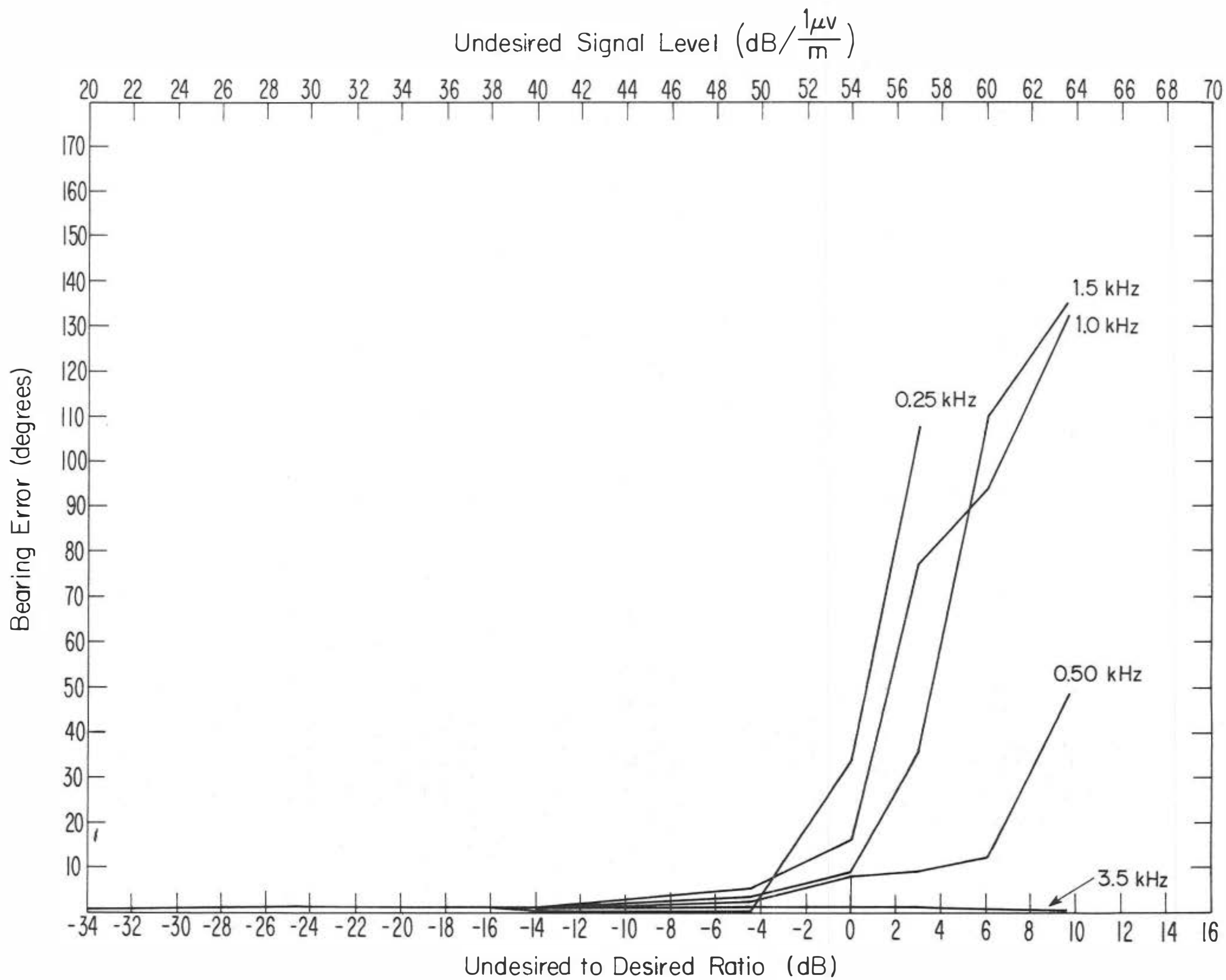


Figure 1-24. The indicated bearing error for ADF receiver A as a function of the undesired-to-desired ratio. The desired signal level is 500 μV/m at 200 kHz. The parameter on the graph is the frequency separation of the two signals and the difference in the direction of arrival is 90°.

is to provide technical support on a quick-response basis to questions that may be relevant to the FAA in the World Administrative Radio Conference (WARC) proceedings.

The Canal Zone RFI Survey project required an on-site visit to the Canal Zone for the Panama Canal Company for the selection of a weather radar site from 15 possible candidates.

A letter report was prepared and submitted for a compromise site that was the most logical and practical choice. Recommendations were also made for additional filtering in the radar transmitter and the reuse of microwave radio frequencies from the Atlantic side of the communication/control link.

Consultative services were provided to the National Weather Service of NOAA on problems related to Weather Radar Interference Surveys.

An on-site visit was made to the AFOS computer system at the Minneapolis, Minnesota, weather service office to investigate and solve problems of the computer system.

Technical assistance was provided to KXMC-TV Channel 13, Minot, North Dakota, for an interference problem caused by S-band radar.

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 and, to an increasing degree, large quantities of data are required to allow rational statistical analysis of characteristics that vary widely. In such cases, there is an urgent need for data recorded in digital form so that computer analysis is possible. 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) (Figure 1-25).

This year marks the end of the first six years of operation of the RSMS, a system fully dedicated to gathering measurements of the radio environment for frequency management purposes.

In that time, the RSMS has continued to survey general frequency usage in many parts of the United States, as well as to participate in measurements aimed at solving a particular problem. Complete usage surveys have been completed in seven large metropolitan areas. These surveys include measurements in about a dozen government mobile and radar bands between 30 MHz and 12 GHz.

In a typical operation, the RSMS will park at a selected measurement site (usually a hill overlooking most of the metropolitan area) making measurements of one band at a time. When all of the bands have been sufficiently measured, the RSMS will leave the site and move to another measurement location. In some cases, the earlier measurement will have identified some transmitters which will be measured in more detail by moving the RSMS close by and conducting coordinated measurements with the controlling agency. By the time that measurements in a typical area are finished, a total of about 100 million measurements have been made and processed into report ready graphs and listings.

The magnitude of the job described above would clearly not be practical with manually-operated measurement equipment. The RSMS was designed from the start as a computer-controlled measurement system. Programs written in BASIC control a general-purpose spectrum analyzer system (Figure 1-26). Frequencies between 100 kHz and 18 GHz can be tuned with synthesizer accuracy. Measurement bandwidths between 10 Hz and 3 MHz can be employed, along with peak detection or video integrating, to tailor the system to the particular measurement requirements. In certain mobile radio bands, a special-purpose communication measurement receiver (CMR) provides very wide dynamic range and rectangular bandpass characteristics which are more suited to the measurement of channelized communication bands. Specialized equipment is also available for radar measurements, including automatic direction-finding and pulse sorting techniques. These techniques permit more ideal measurement of a single radar by isolating it from other radars sharing the same spectrum. The whole system is designed to calibrate itself and to automatically add appropriate calibration factors to the measurements as the measurement are being made. Interactive graphics displays allow the operator to more easily follow the course of the measurement, and numerous controls allow the operator

Figure 1-25. Radio Spectrum Measurement System (RSMS).

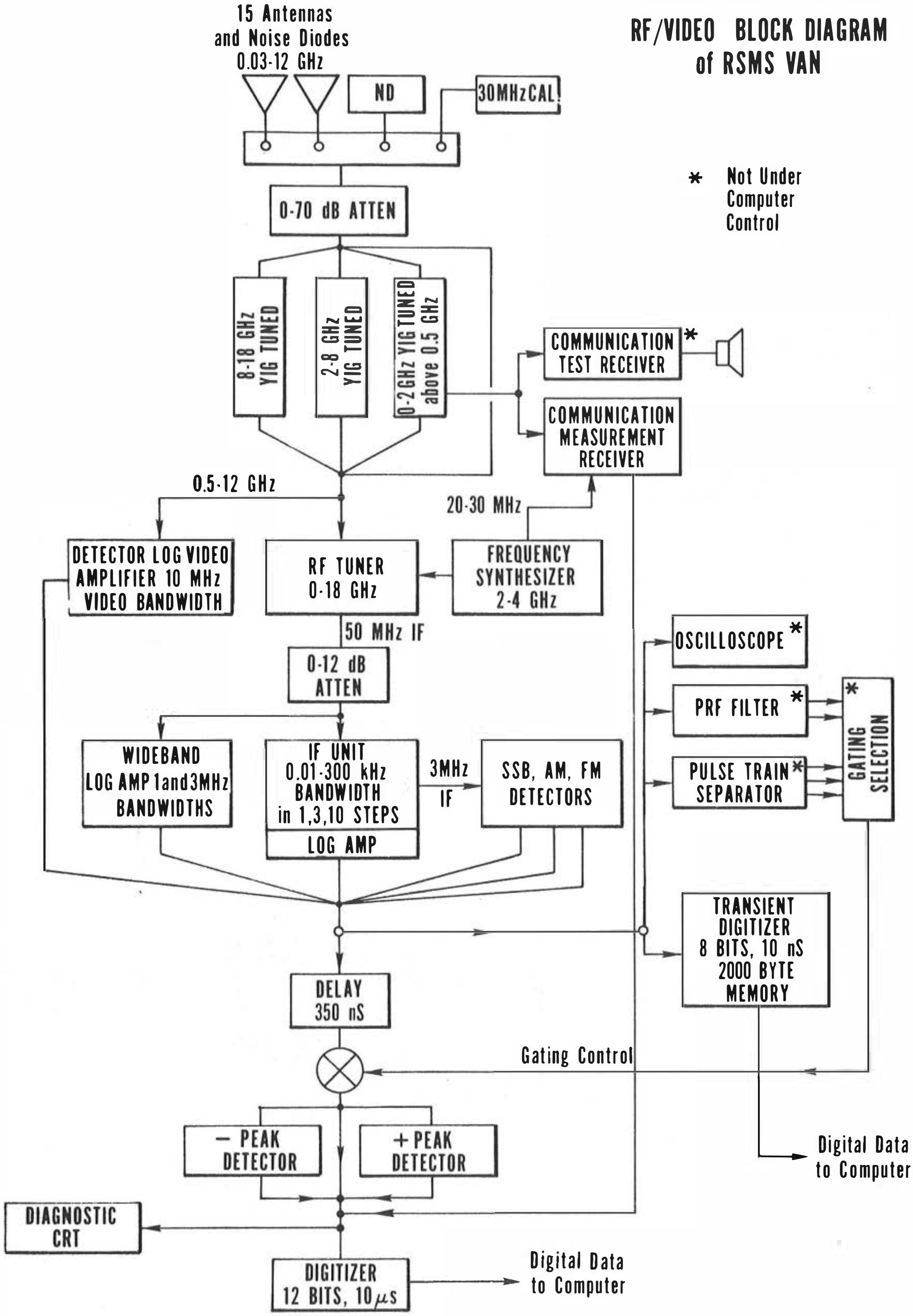


Figure 1-26. Block diagram of RSMS van.

the threat radars do not include receivers which could be used to measure and evaluate the airborne ECM responses. Instead, 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 preproduction AN/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.

The operational frequency range of the AN/MSR-T1 is .5-18 GHz. The system consists of four 0.5-18 GHz rf tuners (one with a 500 MHz IF bandwidth and three with a 20 MHz IF bandwidth), a spectrum analyzer receiver (3 MHz band-width), 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. 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's 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's configuration. Data is output to the aircraft's home base for aircrew training proficiency ratings and identification of malfunctioning airborne ECM equipment.

Air Force acceptance testing was completed in February 1979 and was followed by extensive user (SAC and TAC) Operational Test and Evaluation (OT&E) which is scheduled for completion in September 1979. Design changes and deficiencies will be identified so that production specifications can be prepared to acquire similar units for EW range deployment in early 1980.

A second derivative of the RSMS development, the Air Force (TAC) Signal Analysis System, is being developed for the Tactical Air Command, Tactical Fighter Weapons Center Range Group (TFWCRG), Nellis AFB, Nevada. The system 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 electronic warfare test and exercise evaluation. Its primary application is the evaluation of Electronic Countermeasures (ECM) emissions from airborne fighter platforms when stimulated by widely spaced (several kilometers) 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. 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 subsystem 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.

to vary the measurements according to a real-time measurement results.

As an example of the utility of computer-controlled systems to measure spectrum usage, consider the measurement of mobile radio channel usage. The RSMS (a) tunes precisely to a given channel center frequency; (b) makes a burst of 40 measurements and processes them to eliminate any impulsive noise; (c) uses various calibration factors to convert the digital data to absolute power units of dBm; (d) compares the final single value to a measurement threshold to determine whether the signal is system noise or a real signal; (e) updates statistics for that channel, showing the percent of time the channel is in use, the average signal level, and the maximum signal level; and (f) determines and tunes to the next channel to repeat the process. At the same time, another part of the system is testing for any very large signals in the band which could cause intermodulation; the data just measured will be suitably ignored if it could be contaminated. The aforementioned measurement cycle requires only about 8 milliseconds, allowing about 125 channels to be measured in a second. At the end of an hour, the accumulated statistics will be written to magnetic tape and the process will continue. This allows as many as 10 million measurements to be made on the channels in a band in one day, which makes it feasible to measure channel usage in a statistically significant manner.

In the past year, the RSMS was used to make measurements in Detroit, MI; Buffalo, NY; Malone, NY; and Boston, MA. The measurements made in the first three cities were made partly to learn how the Canadian allocation policies (different from those of the U.S.) affect band usage in the border areas. The Boston measurements included measurements on a number of the interesting radars in the Boston area.

The report on usage in the Washington, DC, area was finished in FY 79, although the measurements were finished near the end of FY 78. In an effort to make it easier to interpret the significance of the measurements as well as to discover more efficient measurement strategies, additional analysis was performed to help define the area of coverage from the RSMS measurement site. Frequency listings for transmitters within 50 miles of the Washington, DC, site were processed to give the median transmitter power antenna gain, and antenna height for fixed stations and for mobile units in each frequency band. Propagation to the RSMS measurement site was calculated using an ITS developed terrain-dependent propagation model along 12 radials. In some cases, it was necessary to "smooth" the results along a radial to get a single point, beyond which a majority of the locations did not propagate enough signal to be received by the RSMS. The results of this analysis were plotted on a map of the Washington, DC, area (<u>Figure 1-27</u>). Several contours were drawn: 1) dotted lines show the area within which a typical base station would be measured by the RSMS during at least 90% of the time it actually transmitted, 2) solid lines show where a typical base station would be seen at least 50% of the time, and 3) heavy dashed lines show where a typical mobile transmitter would be received at least half of the time. We have also plotted the positions of base station transmitters assigned to this band on the map, which shows that most of the transmitters are within the areas of best coverage. This means that the typical base station coverage is even better than the geographic coverage. Coverage to mobile units is less certain, but one would need much more data than is likely to be available to answer questions of this kind.

The results of this analysis were used to confirm that coverage of the Washington, DC, area could be effectively achieved from a single well-chosen measurement site. Previous measurements had been made from three sites to assure reliable coverage of the area. This analysis is now being performed on all general measurement sites, allowing selection the most efficient measurement location.

Several large-scale, computer-controlled receiving system developments have evolved from the RSMS experience. The Air Force Multiple Receiver System (AN/MSR-T1) is one such system, developed for the Air Force Systems Command. The project involves the development, acquisition, integration, and testing of a first article preproduction 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 countermeasure (ECM) systems.

EW training exercises are conducted at Air Force ranges equipped with multiple threat systems which are directed at aircraft which come within operating range. The radar threats emit simultaneous signals at different frequencies in the range of 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,

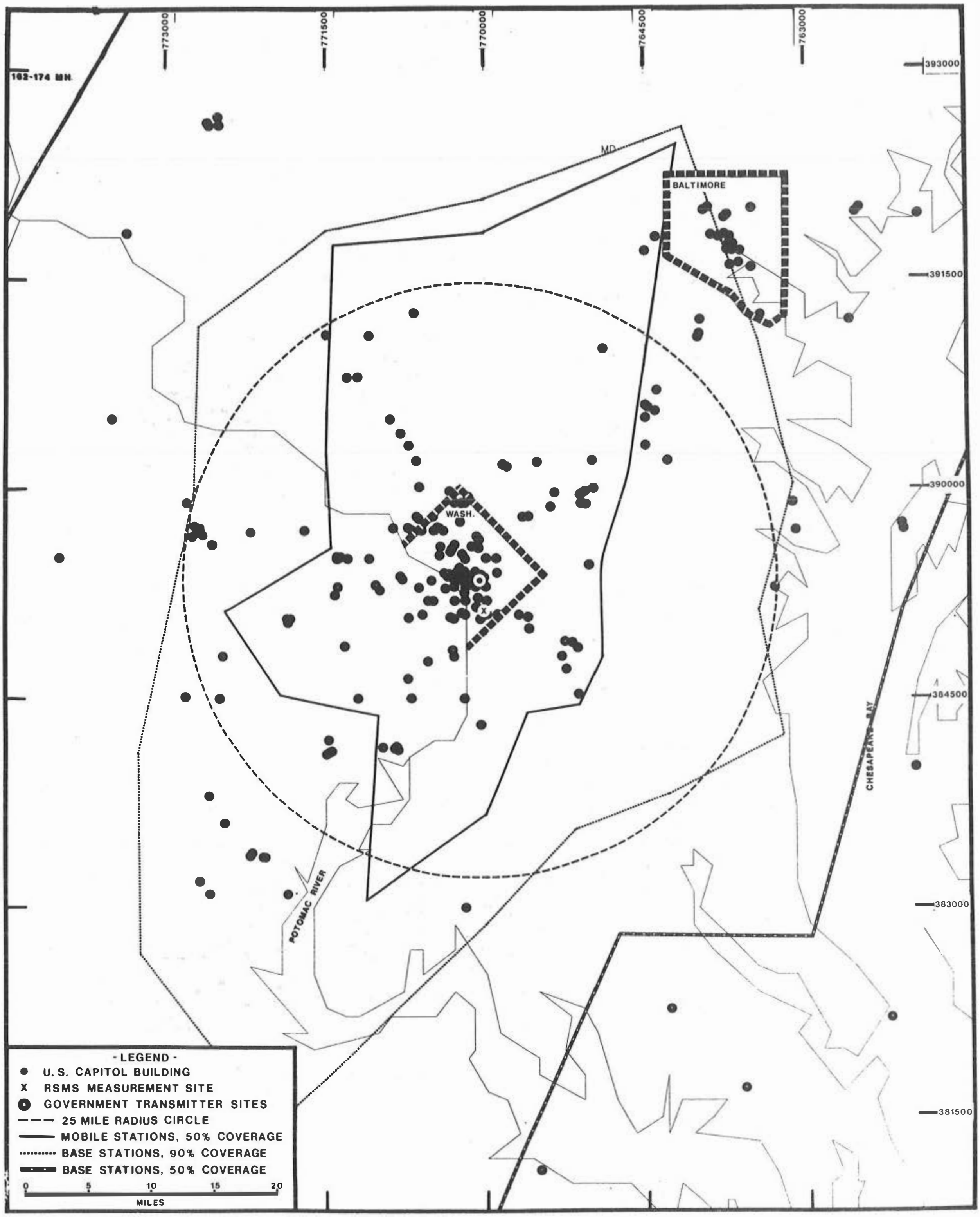


Figure 1-27. Coverage from RSMS site in Washington, D.C., 162-174 MHz band.

The system has been completed and extensive testing is underway at the Nellis AFB EW range complex near Tonopha, NV. Tests are to be completed in September 1979 when the system will be turned over to range operations for monitoring EW training activities.

A third large scale, computer-controlled instrumentation system has been under development for the U.S. Army Communications Electronics Engineering Installation Agency. The Transportable Automated Electromagnetic Measurement System (TAEMS) program has been supported by a number of ITS projects in FY 79. The Applications Software project provides software to operate the TAEMS. Programs developed can be divided into four categories:

1. a general scanning program,

2. hazards scenario programs,

3. satellite scenario programs, and

4. utility programs and subroutines.

The general scanning program allows the operators to set the equipment, basically a .1 kHz to 40 GHz spectrum analyzer, to the desired measurement parameters. They may then make a variety of measurements using also a variety of scan options. The measured data are plotted on the graphics CRT. A certain amount of analyis, such as smoothing, bandwidth measurement, and center frequency measurement, is available. This program is designed to be applicable to many situations and by itself can give an operator a very complete idea of what is happening in the entire radio spectrum.

However, for specific applications, special programs must be used. One of these is the hazards scenario. The objective of this scenario is to measure, record, and analyze the electromagnetic environment in the vicinity of ordnance and artillery sites. Very strong signals which are potentially hazardous to the site are of prime interest. The entire spectrum from 10 kHz to 18 GHz is scanned repeatedly with the results recorded on magnetic tape. Special programs measure both on-site radars and on-site communications radios, as these are likely to present high Rf levels because of their proximity. A set of analysis programs determines if the environment measured does or does not constitute a potential hazard. Various other utility and data presentation programs are also provided as part of the scenario programs.

Another specific application is handled by the satellite scenario programs. The environment around actual or potential satellite earth terminals is measured and analyzed to determine if interfering signals to the satellite communication exist. Basically, this is accomplished by measuring the area near the satellite terminal location at high sensitivity levels. The area measured is the area from which signals may be received on the main beam of the earth terminal antenna. Also, the area from which signals may be received on a side-lobe of the earth terminal antenna is measured at a lower sensitivity. This is permissible because of the rejection the antenna provides to side lobe reception. Both of these programs record all signals measured which are strong enough to be potential interferers. Again, a set of analysis programs is available. The culmination of the analysis occurs when the various measured signals are processed through a model of the earth terminal receiver. This model determines whether the signals will actually cause interference. If interference does occur, a guard band around the interference frequency is calculated.

The fourth category of application software - utilities - provides a set of programs and subroutines an operator may find useful on different types of missions. The programs provide stand-alone functions which the operator may run (for example, a signal direction-finding program). The subroutines provide useful functions when the operator must write new programs to cover new applications. This allows the operator to handle unforeseen applications with a minimum effort.

A second TAEMS project required the development of a Performance Verification Test Set. The test set is to be used to validate key performance parameters and to periodically calibrate the automatic receiver system. The pertinent key parameters to be verified are: 1) tuning accuracy, 2) selectivity, 3) sensitivity, 4) tuning time, 5) frequency response, 6) relative amplitude accuracy, and 5) isolation of input ports.

Based on previously established verification limits, a routine is configured to indicate to the operator of the receiver system when any of these key parameters are out of specification and that some sort of corrective maintenance needs to be initiated.

The verification test set will be semi-automated such that some of the test instrumentation will be under limited computer control. Software is to be developed to control various tests and to update previously stored calibration correction tables.

The TAEMS, as originally configured, had tuning frequency tracking pre-selectors and a low pass filter which effectively eliminated image and multiple response reception within the frequency range capability of the ARS-400 subsystem (500 MHz-2 GHz). In addition, spurious responses are virtually eliminated in the frequency range above 2 GHz in the down converter design. However, below 500 MHz, only band pass filters were available, which were not adequate to keep spurious responses generated with the ARS-400 from becoming troublesome. These spurious responses are produced when excessive signal voltages are input to the first mixer and drive it into nonlinear operation. Some measurement applications of the TAEMS, below 500 MHz, unavoidably will require reception of undesired signals of large magnitude which would generate harmonics and intermodulation products within the ARS-400.

ITS was tasked by the Army to design and integrate a Voltage Tuned Tracking Filter to cover the frequency range from 20 MHz to 500 MHz, which would largely eliminate these spurious responses in the ARS-400 throughout this frequency band. This was accomplished by using six (6) varactor tuned filters. Each filter covers approximately 0.8 octave. The filter frequency bands are as follows:

1. 20 MHz to 36 MHz
2. 34 MHz to 61 MHz
3. 58 MHz to 104 MHz
4. 98 MHz to 176 MHz
5. 168 MHz to 302 MHz
6. 283 MHz to 509 MHz.

The tune voltage for each band is a nominal +1 to +9V and is derived from the ARS-400. Since the ARS-400 tune voltage is a linear 0 to +10V for a 2.05 GHz frequency span, analog normalizing circuitry was designed to obtain the filter tune voltages.

Each filter has a 6 dB bandwidth of less than five percent of f_0 and a 50 dB bandwidth of less than forty percent. Filter tuning nonlinearity is within the 6 dB bandwidth.

The TAEMS system includes a tower system which supports a pedestal allowing antenna movement in both azimuth and elevator. A radio frequency equipment package is also located on the tower. The Remote Extension Project provided equipment necessary to allow the use of this tower at locations up to 300 feet from the TAEMS vehicle. Typical design of the electronics required is shown in the block diagram in Figure 1-28.

The rf/IF signal is passed through AII with no modification since the range of signals on this line is so great - 20 Hz to 2 GHz. Any attempt to equalize and/or amplify would involve a great deal of hardware. If the full extension capability is used, the noise figure (N.F.) of the system below 2 GHz will be degraded significantly. Above 2 GHz, however, the N.F. is determined by the down converters, and the added cable length has no impact.

The 2.05 to 4.1 GHz reference signal is equalized for cable losses and then amplified back to the needed level in AII. The 100-feet cable length was chosen because of the specifications of the equalizer and amplifier already used in the AII down converter. A significant departure from this cable length (± 20%) will jeopardize the phase lock ability of the down converters.

The 100 MHz reference signal is amplified in each AII to compensate for cable losses. The ATTN. Pad is used to allow a standard gain amplifier to be used.

In conjunction with the transferable measurement system, the Applications Enhancement project provided for a 100-foot extendable IEEE buss interface which was developed and is being used as the link to peripheral equipment in the TAEMS measurement system. Software was also developed to couple the control of this peripheral equipment to the measurement systems computer. Verification and graphics software was developed to verify and display characteristics of the measurement system as well as the equipment on the IEEE buss extender.

The TAEMS Training provides Army personnel with training on various aspects of the TAEMS System. This training consisted of three courses. The first of these was eight weeks covering computer operation and programming of the system and van deployment. The second course, on maintenance of the down converters (a part of the receiver system designed by ITS), lasted two weeks. The third course was also two weeks and covered the systems software used on the TAEMS. All of the courses were given at Fort Huachuca, Arizona, during the first half of 1979.

In addition to large scale instrumentation systems, ITS has been actively pursuing the development of smaller, lower-cost systems which still provide greatly improved field performance and produce digital records of valuable measurements that can then be subjected to a wide range of analysis. Such equipment finds wide application in the measurement of coverage, interference, propagation, system performance, and spectrum- consuming properties of equipment. One such development is the Automated Field Intensity Measurement System. The system will be used to make ordinance and personnel hazards measurements. The field intensity receivers

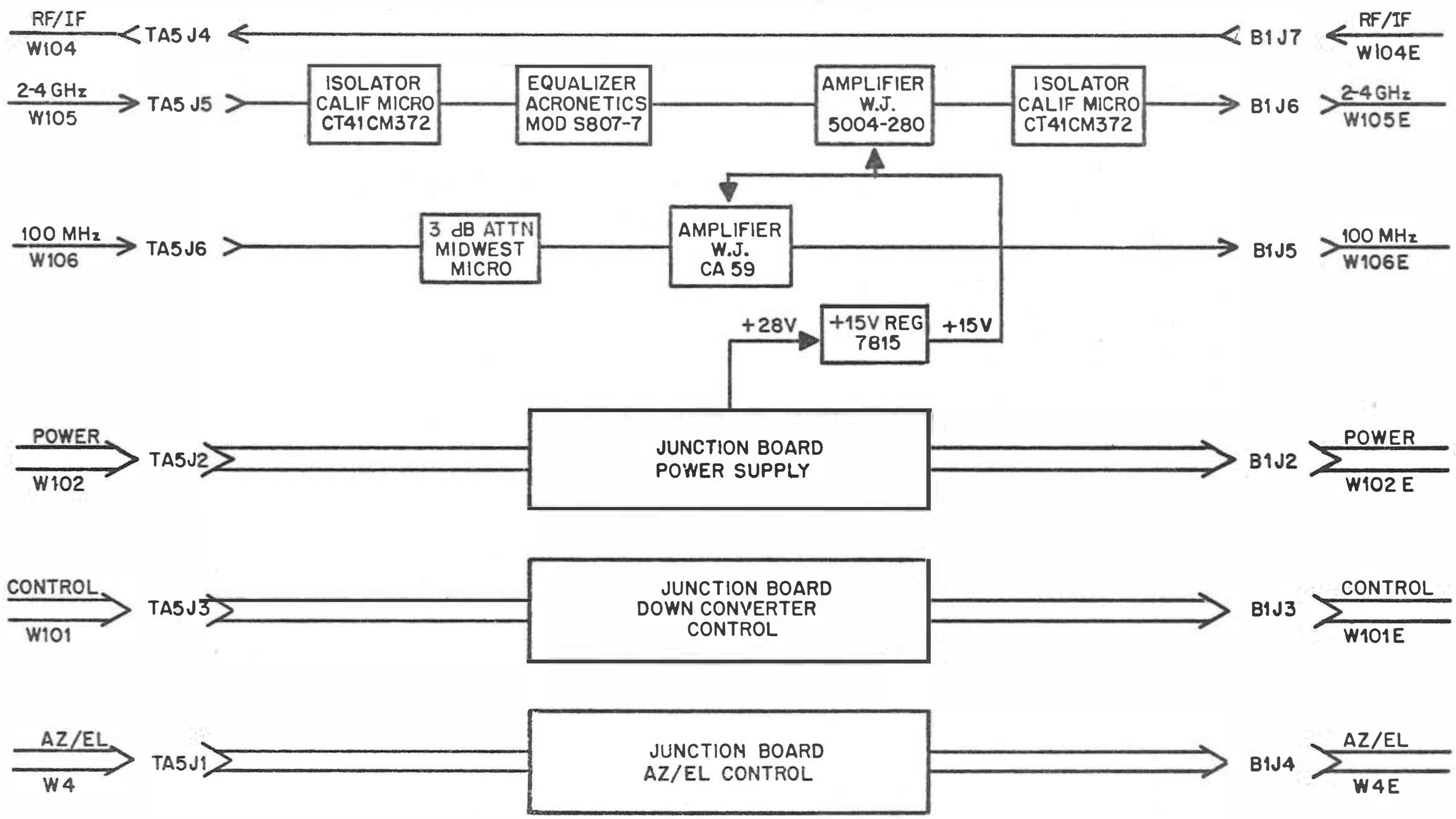


Figure 1-28. Block diagram, tower extension cable driver A11.

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 applcation software which could be utilized by other agencies having similar ordinance hazards measurement requirements.

The DM-4 was designed and built for the Army (CEEIA) at Ft. Huachuca to make measurements of electromagnetic noise and other signals which can be understood best in a statistical sense. This instrument (Figure 1-29) will operate as part of a larger system, processing an analog signal and sending the statistical measurements to a data-processing subsystem for further analysis or recording. To facilitate integration into the rest of the system, the DM-4 has been built with a full IEEE-488 bus interface, and the input signal can be anywhere within the 0 to 1 volt or 0 to -1v range. The DM-4 measures the amplitude probability distribution (APD) of the signal at 31 levels, with sampling rates up to 20 million samples per second. Although the 31 levels must be equally spaced in voltage, the highest and lowest levels can be set anywhere within 0 to 999 mv. Since the systems with which the DM-4 will be used supply a logarithmically-weighted signal (the output from a typical spectrum analyzer or field intensity meter), the equally spaced voltage increments of the DM-4 will actually refer to equal dB spacings at the measurement system input. This means that the DM-4 can be set for the maximum dynamic range which the rest of the system can handle, or it can be set to measure over a smaller dynamic range with finer resolution.

The DM-4 is currently being integrated into the TAEMS system and into a portable measurement system using a desktop calculator. The immediate use of the DM-4 will be to allow these systems to make electromagnetic noise measurements from thunderstorms, various types of machinery, etc. Associated computer programs will use the measured APDs to calculate some of the more traditional noise parameters like F_a (average noise power), V_d (ratio between rms and average voltage), and L_d (ratio between rms and average logarithm). Software will also be supplied to directly calculate the pre dicted system performance (for some of the simpler types of systems) based on the measured APD and an assumed signal

The system can be used for other types of measurements. For example, average radar power flux could be calculated from a measurement of the APD of a radar signal, eliminating some of the hand calculations used now. In addition to APDs, the DM-4 can be used to measure average crossing rates (ACRs). The APD shows how much of the time a signal was above a particular level. This could be used to measure pulse height distributions, for example, which would be useful in examining EW environments or interference in crowded radar bands.

A block diagram of the DM-4 is shown in Figure 1-30. The basic quantization into 31 levels is performed by 31 high-speed comparators. A buffer amplifier applies the input video signal to the inverting inputs of all 31 comparators in parallel. The voltage on the non-inverting input of each comparator is developed from a reference divider chain, which determines the exact voltage point at which each comparator senses the level of the video signal. Since the voltage at the end points of the reference divider chain is set by two digital-to-analog converters (DAC's), the DM-4 will sense signal levels spaced evenly between the DAC output voltages. Whenever the video signal exceeds the reference level of a given comparator, sampling clock pulses are gated into a counter associated with each comparator. At the end of a sampling period, the number of counts at a given level are compared to the total number of sampling clock pulses to get the percentage of time that the input signal exceeded each of the 31 levels.

Several auxilliary functions have been incorporated into the DM-4 to make it easier for the operator to assure that data is being measured properly. A counter and DAC provide a 1000-step ramp function (0-999 mV), which is used to automatically calibrate each of the 31 comparator levels. A small speaker allows the operator to aurally monitor the measured signal and a meter reading shows the number of comparator levels currently being exceeded (on a peak or average basis). A high-speed blanking input and an external clock input (to allow sampling at times determined by an external event) are also available.

Since the DM-4 uses a log video input, available from all of the more common modern field intensity meters and spectrum analyzers, and interfaces to an analysis/control system via the IEEE-488 buss, it is anticipated that this instrument will find uses in many types of measurement systems where statistical data is necessary to adequately describe the measured data.

Two projects for the U.S. Army Combat Development and Evaluation Command,

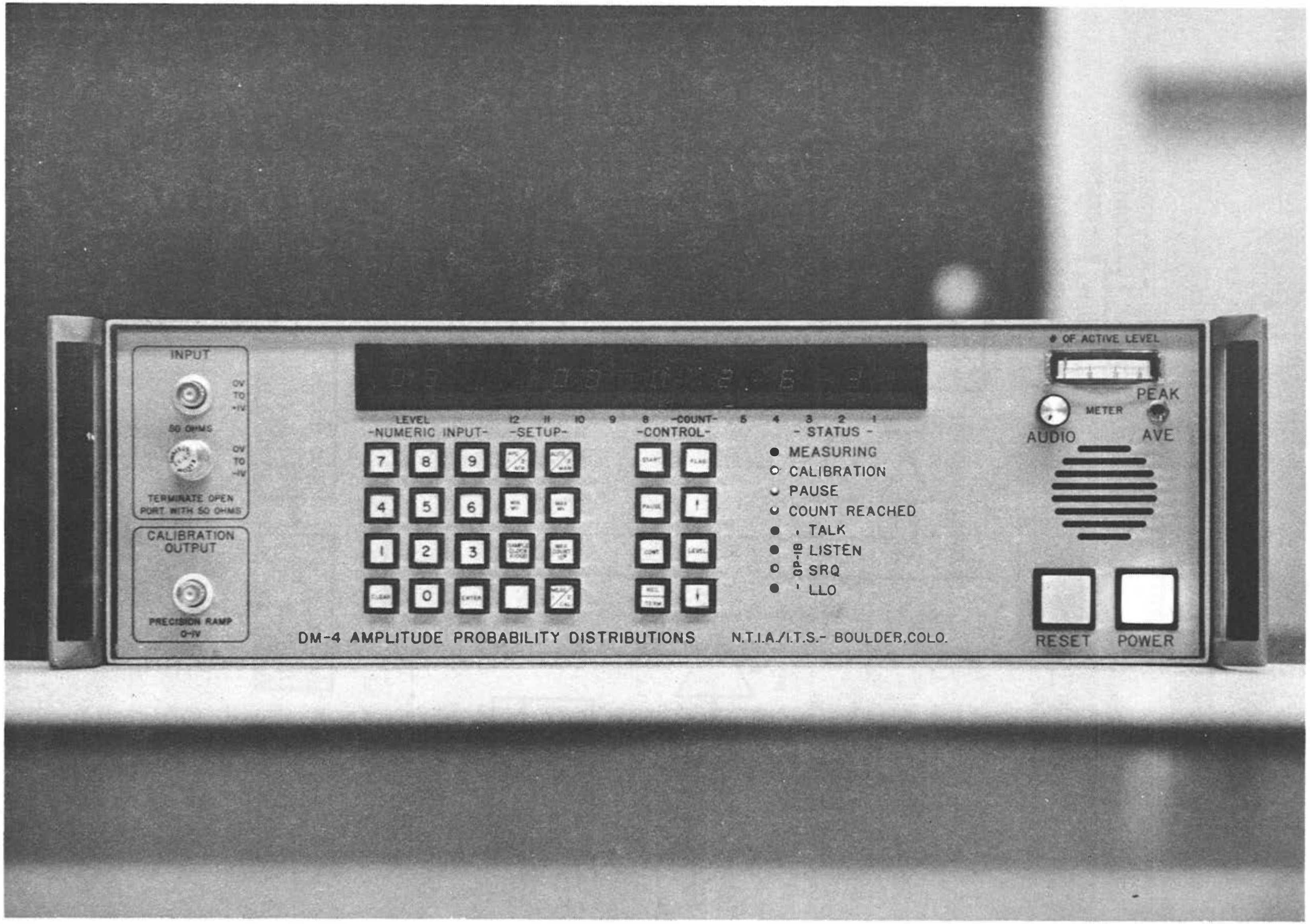


Figure 1-29. Front panel of DM-4.

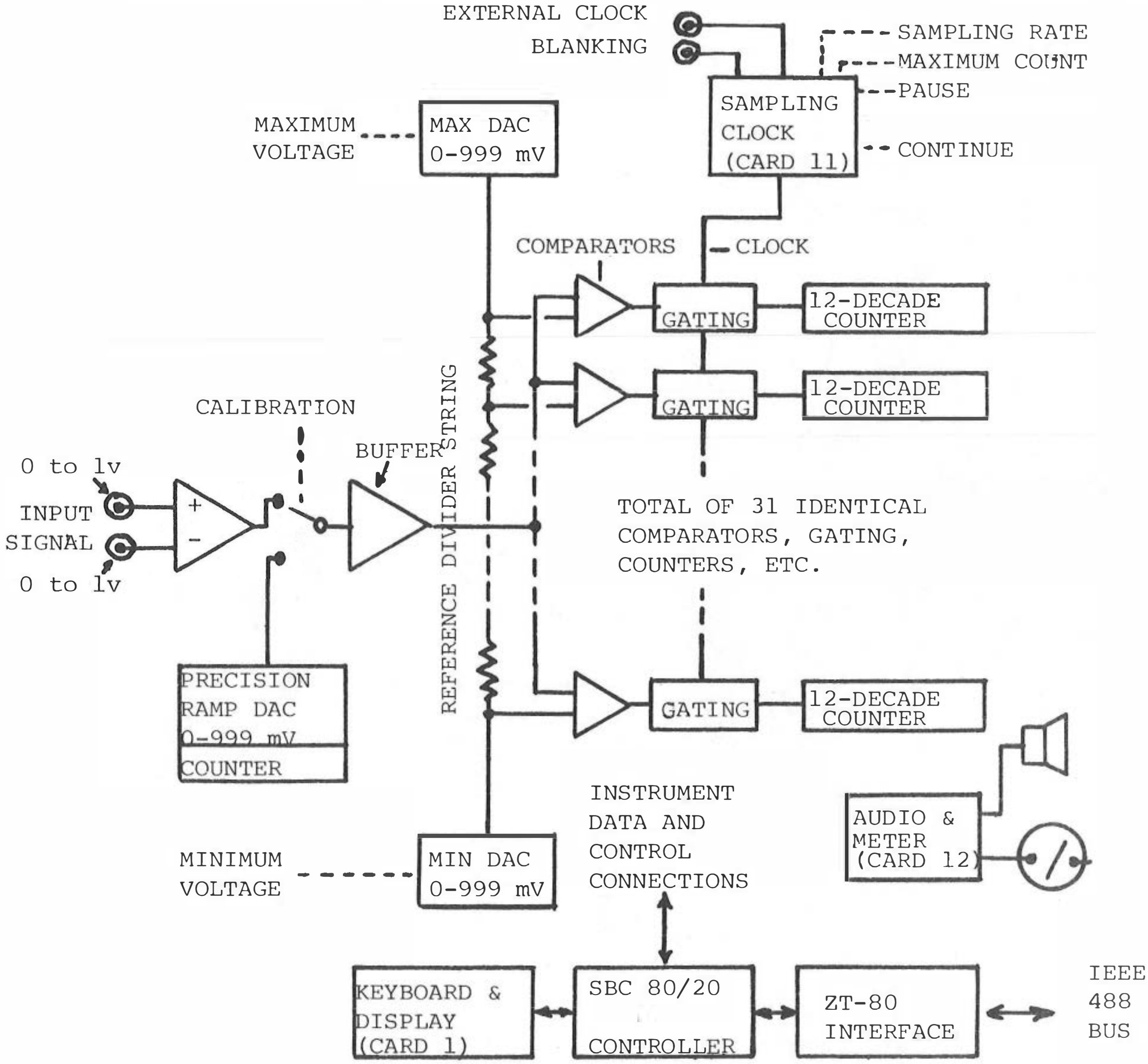


Figure 1-30. Block diagram of DM-4.

Spectrum Monitoring Unit and Frequency Extension of Spectrum Monitoring Capability, are designed around two spectrum analyzers that operate from 100 Hz to 18 GHz. The spectrum analyzers are complemented with selections of filters and preamplifiers to increase sensitivity and selectivity, and with antennas to provide direction finding as well as omnidirectional receiving capabilities from 30 MHz to 18 GHz. The rf switching between antennas, filters, preamplifiers, and appropriate spectrum analyzers, now manual, will allow easy conversion to automatic control. The antenna complement includes a loop, cavity-backed spirals, a fixed-frequency microstrip antenna for direction-finding applications, and a whip and conical monopole antennas for omnidirectional signal monitoring applications. All receiving equipments are housed in an 8 foot x 12 foot mobile enclosure which also has a heater/air conditioner for temperature control and motor generators to provide primary power. Location of the many antennas on the roof of such a small shelter has presented several challenging problems. Capabilities for communication with outside locations also are provided through two transceivers, one of which operates in the 30 - 76 MHz band and a second which operates at 141 MHz.

The Microprocessor System Upgrade project has improved the Army's Automatic Digital Recording of Electromagnetic Spectrum (ADRES) systems to permit the use of industry-compatible digital recorders, IEEE-488 standard instrumentation interface, faster processors, and commercial interfacing to the analog systems. In addition, the systems have been designed to withstand rough handling and vibration in transport. The programming language of BASIC was added to the system to allow some field modifications of software for those applications that may require this feature. Figure 1-31 shows a field unit attached to a spectrum analyzer for recording of spectrum data. The top unit is a 9-track 800 bpi digital tape recorder in a rugged case. The lower unit houses the microprocessor system with all of the control and interface cards.

SECTION 1.4. DETERMINATION OF SPECTRUM CONSUMING PROPERTIES

A major barrier to effective planning for efficient spectrum use is a lack of knowledge of the extent to which the electronic equipment consumes spectrum beyond that needed to directly perform its intended function. While the most obvious categories of spectrum-consuming equipment are antennas, transmitters, and receivers, a wide range of other electronic equipment exhibits some spectrum-consuming properties.

Spectrum consumption is somewhat of a misnomer since spectrum dependent telecommunications is a non-depleting use of the resource. Even so, the process of using the spectrum either as a sender or a receiver (and from the broad perspective, both must be considered together) "consumes" spectrum by denying its use to others for the duration of operations.

In this section we discuss a series of projects whose principal objectives are to better define these spectrum-consuming properties.

We have been particularly interested in the spectrum-consuming characteristics of television receiving systems which have been addressed in three projects:

Spectrum-Consuming Properties of TV Antennas, Measurement and Analysis of Indoor TV Antennas, and TV Antenna System Performance. The gain and pattern as a function of frequency were measured for 19 different home television receiving antennas which varied in cost from $1.00 to $78.00. These antennas included 13 antennas designed for outdoor erection and 6 indoor antennas. Four of the outdoor antennas were designed only for VHF reception, five were designed only for UHF reception, and four were designed for both VHF and UHF reception. One of the indoor antennas was designed only for VHF reception, four were designed only for UHF reception, and one was designed to receive both VHF and UHF signals.

In addition to the antenna performance characteristics which were measured, loss versus frequency characteristics also were measured for a selection of baluns (transformers) designed to match 75-ohm unbalanced transmission lines to 300-ohm balanced transmission lines and signal splitters (devices used when both VHF and UHF signals are coupled from the antenna to the TV receiver using a common transmission line). Attenuation versus frequency characteristics for commonly used transmission lines also were extracted from manufacturer's data.

A summary of our measurements is presented in Table 1-3. Considering the characteristics of these several discrete components of an antenna system, we have hypothesized performance for home TV receiving antenna systems. Figure 1-32 shows expected received power, normalized to power received by a half-wave dipole antenna, for four typical types of home antenna systems, when the power density is 1 W/m^2 at the antenna. Details for applying this information to real-world situations are presented in the project final report ("Television Receiving Antenna System Component Measurements," by R.G. FitzGerrell, R.D. Jennings, and J.R. Juroshek, NTIA Report 79-22, June 1979).

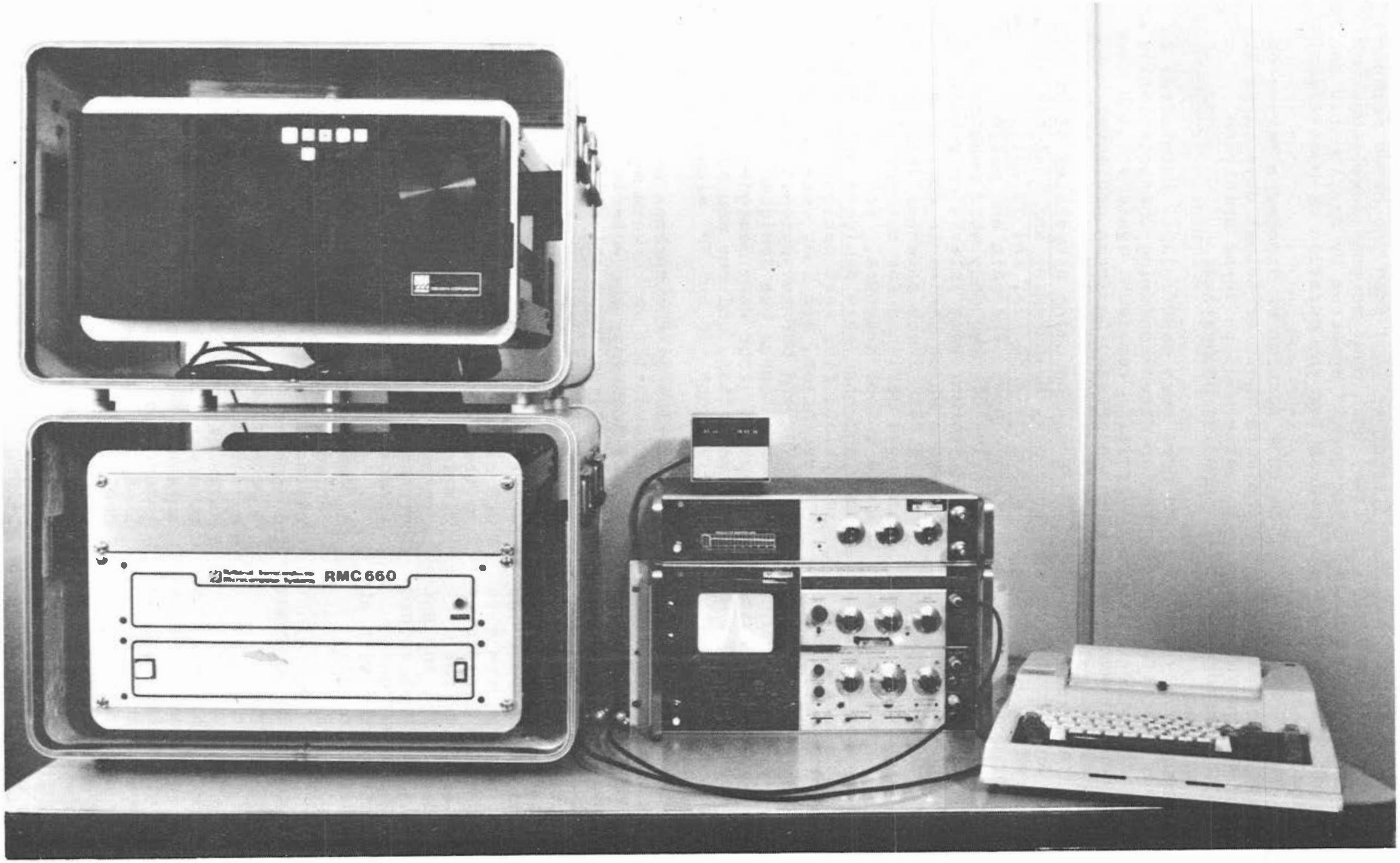


Figure 1-31. Photograph of one of the upgraded field systems with spectrum analyzer.

Table 1-3. Summary of Measurement Results and Extracted Data for Home TV Receiving Antenna System Components

Component/Parameter	Number Tested	Number of Frequencies	Minimum Absolute	Minimum Average	Maximum Absolute	Maximum Average
VHF Indoor Antenna Gain, dB	2	4	- 6.0	- 5.8	- 2.3	- 2.4
VHF Outdoor Antenna Gain, dB	8	4	- 6.3	- 3.1	10.4	8.1
UHF Indoor Antenna Gain, dB	5	10	-10.6	- 5.2	8.5	3.9
UHF Outdoor Antenna Gain, dB	9	3 for 8 Ants. 10 for 1 Ant.	- 3.2	- 3.5	10.4	8.3
VHF Balun Loss, dB	13	4	0.1	0.2	3.0	1.5
UHF Balun Loss	13	3	0.4	1.0	7.3	3.6
VHF Signal Splitter Loss, dB	5	4	0.0	1.6	5.6	3.8
UHF Signal Splitter Loss, dB	5	3	0.2	0.6	4.2	4.0
Transmission Line Attenuation Bounds vs. Frequency, dB.		100 MHZ	500 MHz		900 MHz	
300-ohm "Twin-Lead"		1.0, 3.6	3.0, 8.4		4.3, 11.5	
75-ohm RG-6 Type Coax		2.0, 2.8	5.0, 7.3		6.7, 10.5	
75-ohm RG-59 Type Coax		2.5, 3.7	6.1, 9.7		8.4, 13.9	

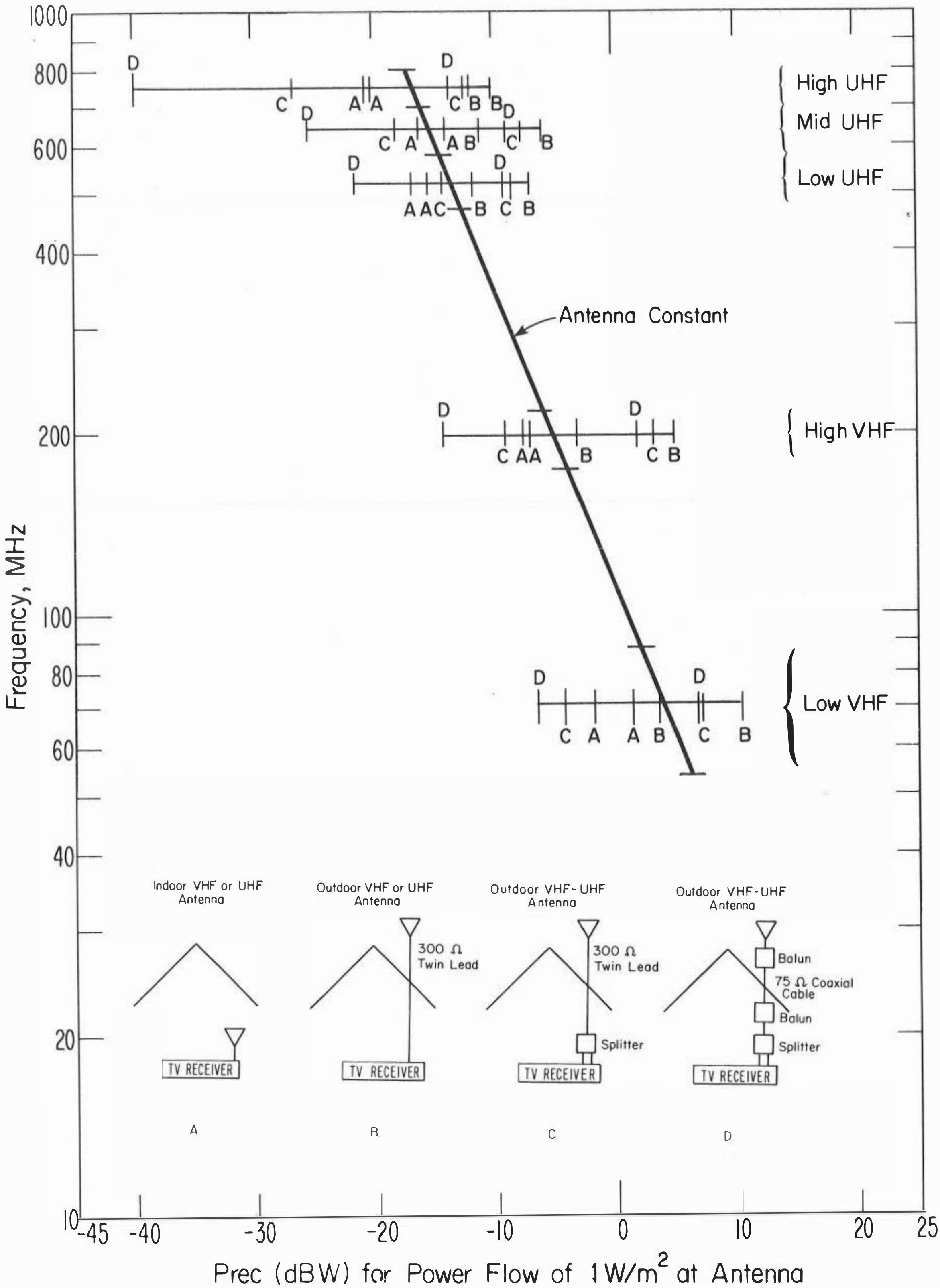


Figure 1-32. Expected received power, normalized to power received by a half-wave length dipole antenna, for four typical types of home TV receiving antenna systems when the power flow is 1 W/m at the antenna.

Actual measurements will be made late in FY 79 at 50 homes generally located in a corridor from Chicago to Peoria. Figure 1-33 shows a map of the area with arcs drawn to define sectors along the corridor. We hope to obtain measurements at seven or eight homes in the east sector. These measurements will demonstrate actual performance of typical home TV receiving antenna systems and provide some comparison of VHF and UHF service.

As part of a program to make more efficient use of the broadcast spectrum so that additional UHF TV channels can be assigned, the Evaluation of UHF TV Receivers project has developed a statistical model of the TV receiver based on measured data. In addition, measurements of TV performance were made in an attempt to develop a more quantitative measure of performance and begin a data base of performance for current receiver models.

Currently, the assignment of a TV channel to an area is based upon a fixed channel spacing determined some years ago by the FCC. These assignments have a number of restrictions on their use due to potential interference to existing channels. The determination of what constituted interference and the resulting minimum distance spacing to preclude that interference resulted in a table of minimum distance spacings for specified channel combinations that has been called the UHF taboos.

The receiver model functional blocks are shown in Figure 1-34. The model determines if a pair of desired and undesired channels is one of the taboo combination If it is, the model then determines the expected percentage of TV receivers that will be affected by any specified input signal-to-noise ratio. If none of the taboos apply, then the model determines the expected level of performance based on TASO grading.

The measurements have concentrated on the rf portions of the receiver and on methods that can be easily implemented so that a large number of receivers could be efficiently measured. Numerous difficulties in making these types of measurements were encountered, such as lack of easily accessible test points on the receiver chassis, and different impedances and test connectors on different receiver models. Some of these problems and recommended solutions have been filed in response to FCC Notices of Inquiries.

The measurement of selectivity on one of the test receivers is shown in Figure 1 35. The measurements were made by stepping a cw signal through the passband of the receiver and measuring the response on the IF AGC with the rf AGC and AFT disabled.

In Figure 1-36, photographs of the signals input to the TV receiver and at the output of the second detector are shown. In the top photograph, a little over two lines of the baseband signal are shown. The top trace is the signal before the receiver, and the bottom trace is the signal at the output of the second detector. The interference can be seen as amplitude modulation on top of the desired modulation. The middle photograph shows the signals going into the receiver in the frequency domain. The large amplitude signal on the left is the 50 kHz modulated interferer at the lower adjacent channel frequency. Finally, the bottom photograph shows the picture as seen on the receiver itself where the interference is visible as horizontal lines across the picture.

Satellite earth terminals highlight the spectrum-consuming properties of antennas because of their need to coordinate spectrum use with point-to-point microwave systems which operate in the same frequency bands, both in the U.S. and abroad. Such coordination requires a knowledge of antenna performance at all angles of radiation in the upper hemisphere. A series of measurements of these characteristics has been made for the U.S. Army using a newly developed automated antenna performance measurement system. In the Large Earth Terminal Antenna Measurements project this system has been upgraded and will be used to measure the spectrum-consuming characteristics (three-dimensional antenna patterns) of three large earth terminal antennas being developed by the U.S. Army Satellite Communications Agency for use with the Defense Satellite Communications System. These antennas are (1) the Medium Terminal Antenna, a 38-foot (11.6m)-diameter, parabolic antenna with G/T-34; and (2) a 44-foot (13.4m)-diameter, parabolic antenna with G/T-78. No measurements have been done because the antennas have not been available, and it was necessary to extend our capability for making these types of measurements due to the much greater ranges required between the source of test site illumination and the test antenna when testing these very high gain antennas. (Our measurement technique and basic capability are described in the 1977 Annual Report.) A significant capability extension has been realized through the purchase of an automatic, optical tracking system, shown in Figure 1-37. This system will allow us to track small aircraft at a range of five miles (8 km). Measurements on the G/T-34 Medium Terminal Antenna are expected to begin in January 1980.

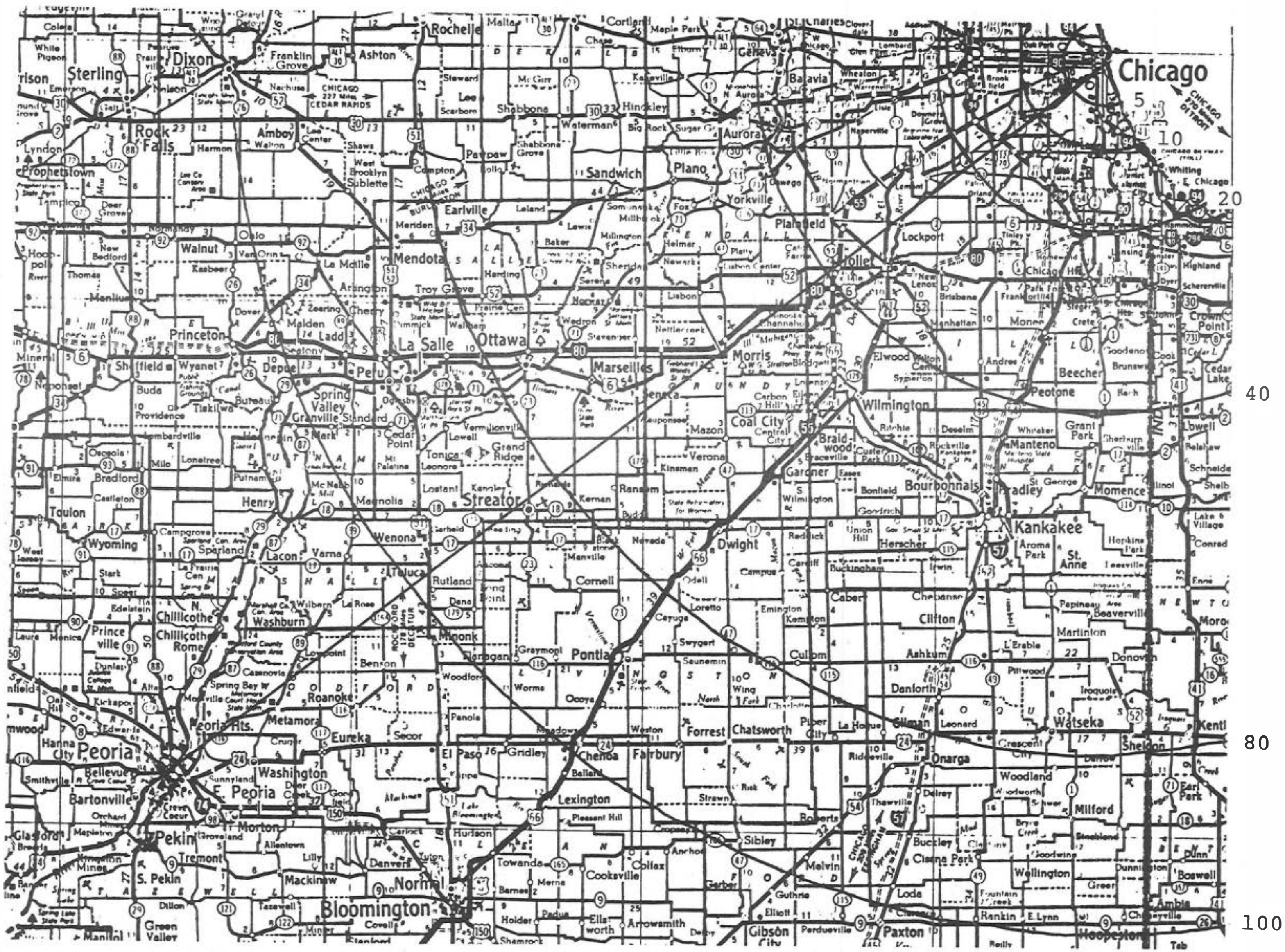


Figure 1-33. Map of the Chicago-Peoria area where the home TV receiving antenna system measurements will be made.

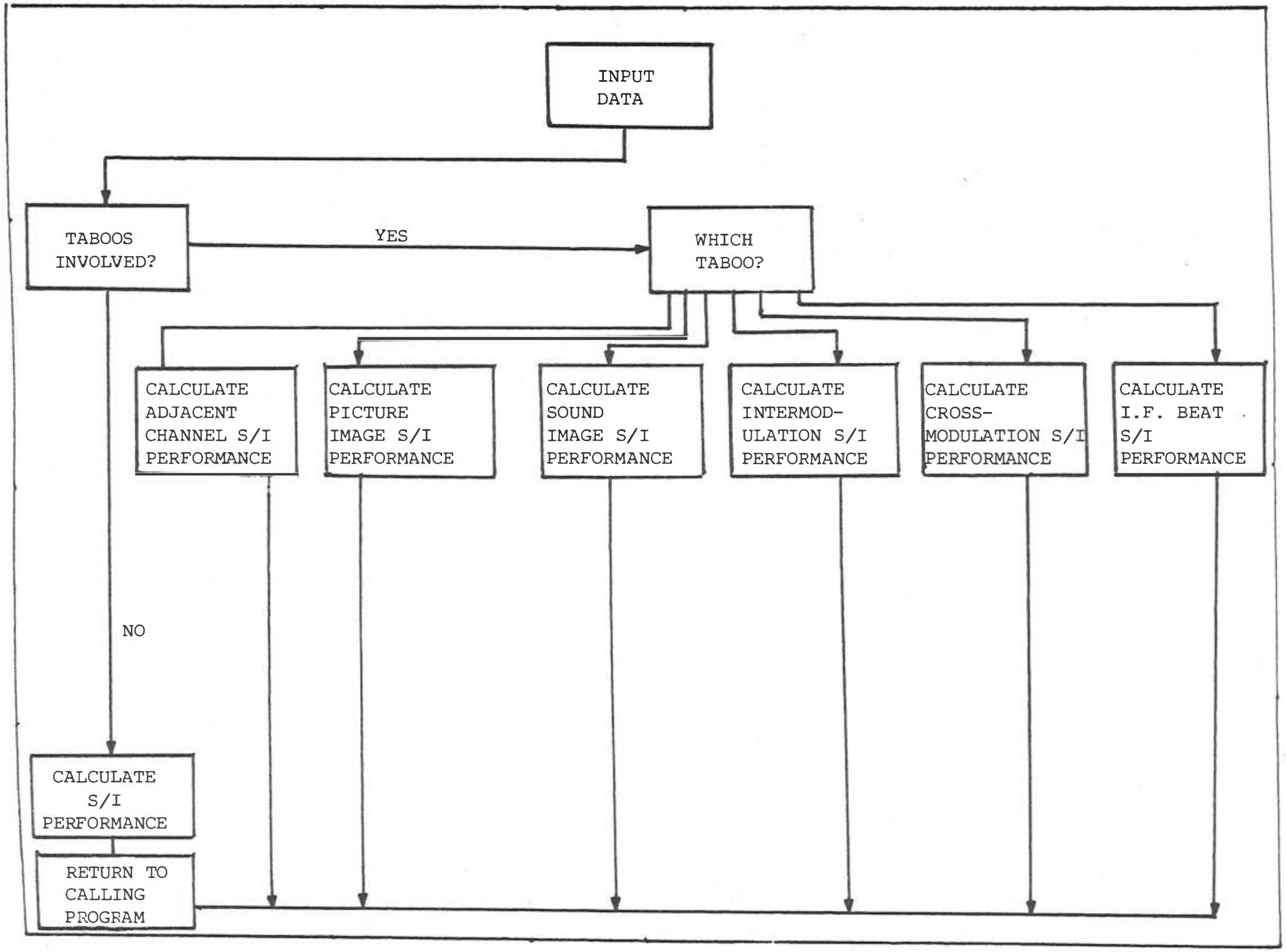


Figure 1-34. Conceptual diagram of TV performance model.

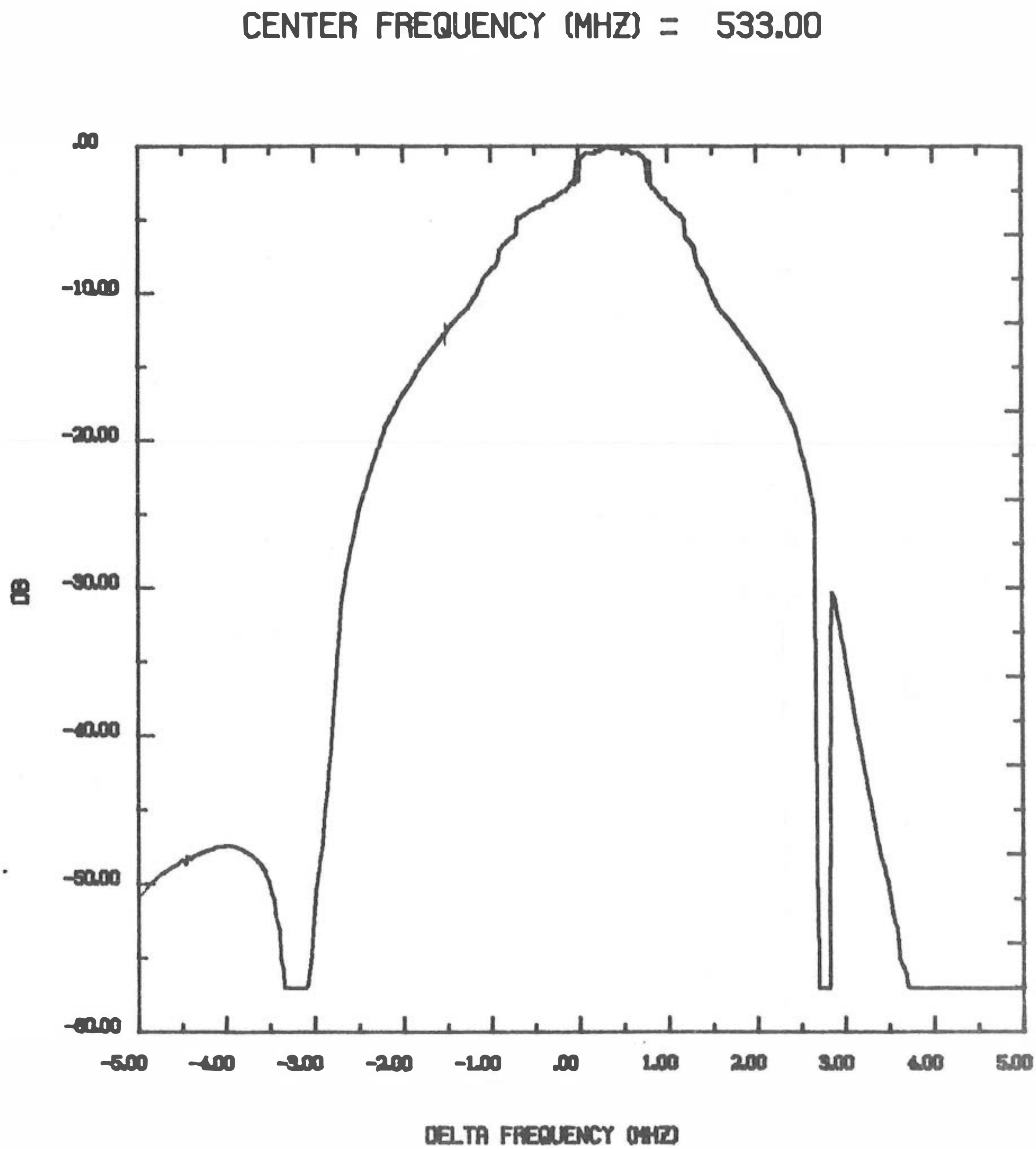
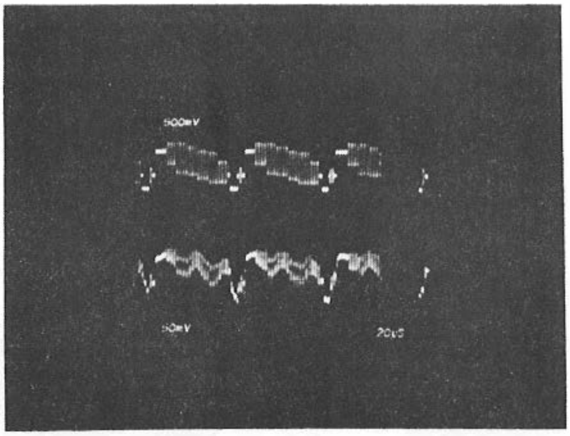


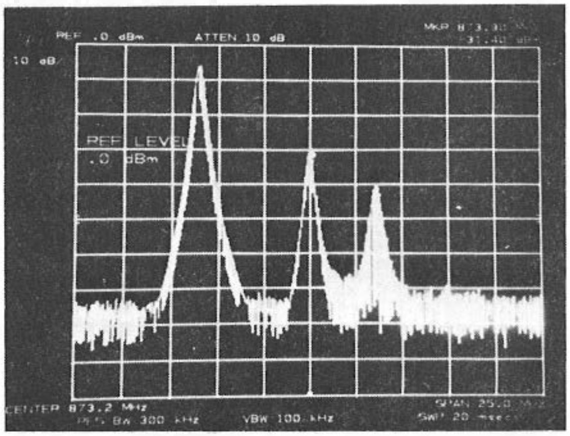
Figure 1-35. Selectivity of a TV receiver as measured at the second detector output.

Time
Domain



Baseband
Receiver
Output

Frequency
Domain



Receiver
Picture

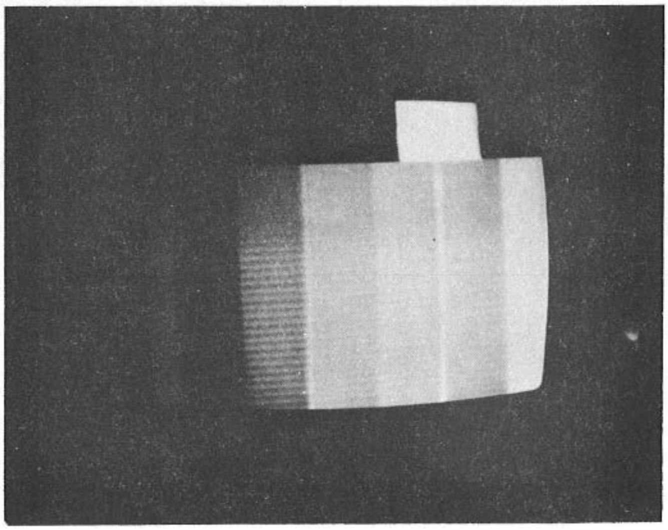
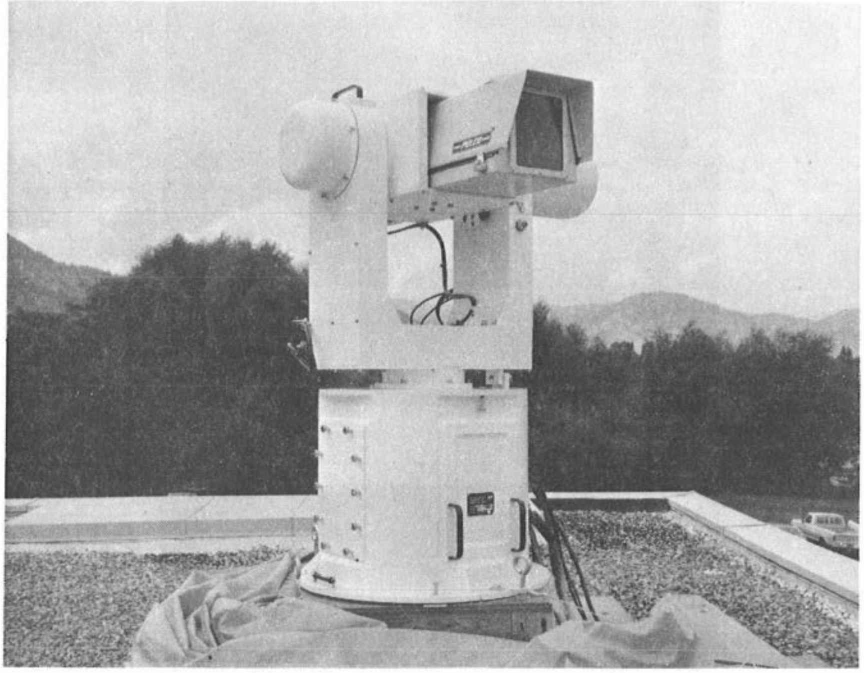


Figure 1-36. Photographs of TV performance measurements.



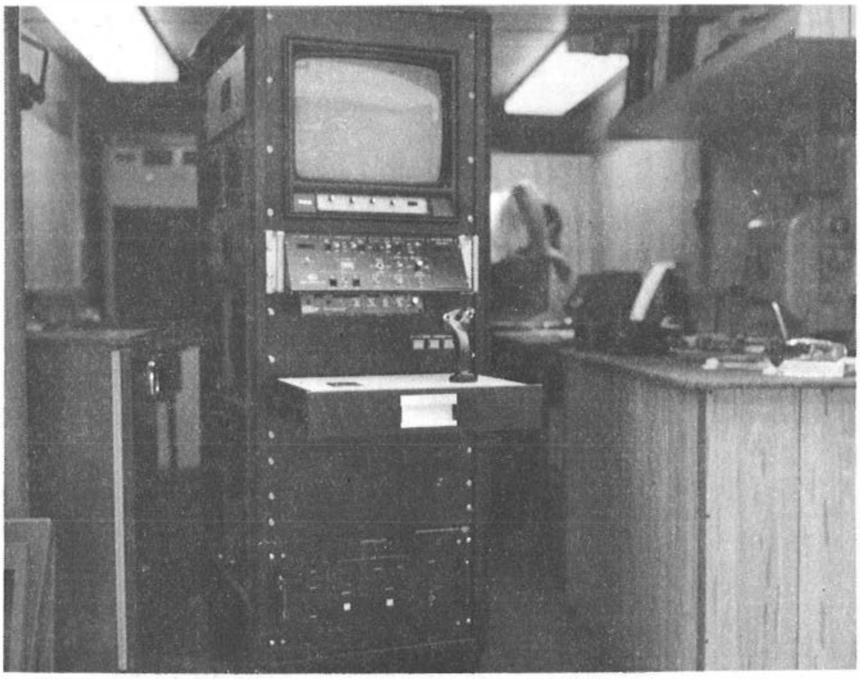


Figure 1-37. The automatic, optical tracking system. The elevation axis over azimuth axis, continuous rotation pedestal with zoom lens optical subsystem is on the top. The rack of control and display equipment is on the bottom.

The ability of receivers to perform in the presence of interference is a fundamental characteristic affecting consumption of the radio spectrum. In the Interference Effects of LMR Receivers project, the performance of an FM land-mobile receiver was examined in a multiple, land-mobile interference environment. Measurements were made showing the effects of multiple interfering FM signals as a function of modulation index, signal-to-interference ratio, signal-to-noise ratio, and frequency offset between the victim and interferer. The conclusions of the study are that, above threshold, the performance with multiple interferers is nearly identical to the performance with a single interferer. However, significant differences do exist in the "below threshold" performance.

Examples of the results of the study are shown in Figures 1-38 and 1-39. The first of these figures shows the measurement of receiver SINAD in a single FM interference environment, while the second figure shows measurement results in an interference environment composed of 3 equal amplitude FM interferers. The quantity S/I_{IN} in these figures is the ratio of signal power to total interference power at the input to the receiver, while θ denotes the peak frequency deviation of all FM signals. The results of this study are described in a report entitled "Measurement of an FM Receiver in FM Interference" (to be published).

The Theoretical FM Performance in Interference project has provided tractable general results pertaining to the interference problem in a general, for non-ideal, FM receiver. In handling such non-linear problems, it is found that a fully general approach is, surprisingly, much easier and analytically simpler than attempting to analyze "simple special cases (e.g., the standard harmonic analysis techniques)." Subsequent reduction to special cases of interest is made at once, without potential loss of key model structure or use of implicit assumptions. It is also rather surprising to see how far the analysis can be carried in tractable form before approximations, and possibly simulation of some of the analytic forms, must be resorted to.

The results are new in the following respects:

1. non-ideal discriminators are included;

2. general interference is specifically structured, including combined AM and angle-modulation, with front-end distortion by the receiver stage;

3. explicit, manageable, general results for the instantaneous envelope (e) and frequency (θ) of the receiver output are obtained which permit direct calculations of both instantaneous and (time) average values.

This analysis has provided, for example, analytical techniques to describe the effect of interference from a number of FM transmitters on a single, like receiver.

Computations are currently underway to determine the effects of one and multiple co-channel interferers, and various cases of adjacent channel interferers on the desired received baseband output signal.

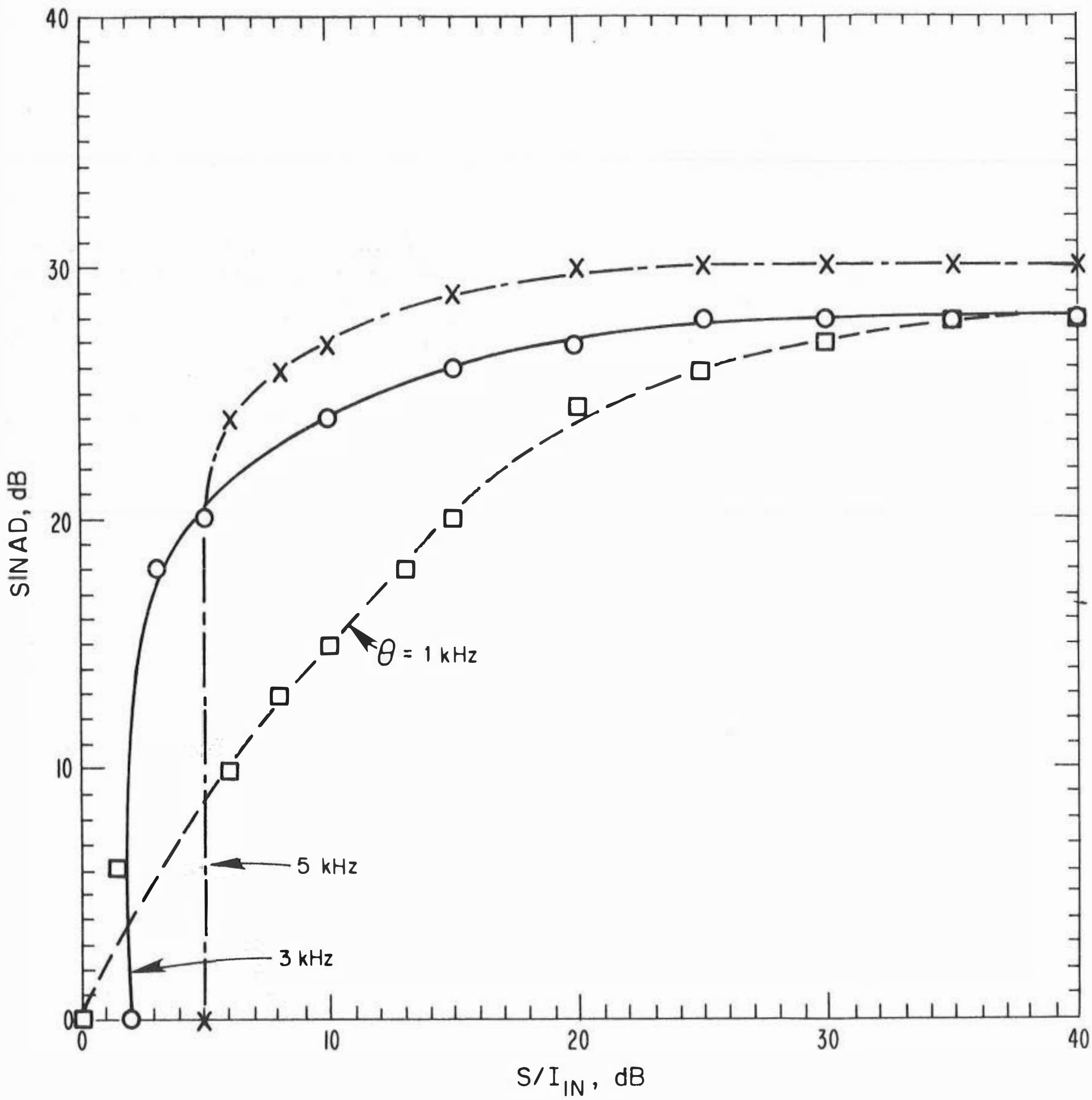


Figure 1-38. Measured performance of an FM receiver with a single FM interferer.

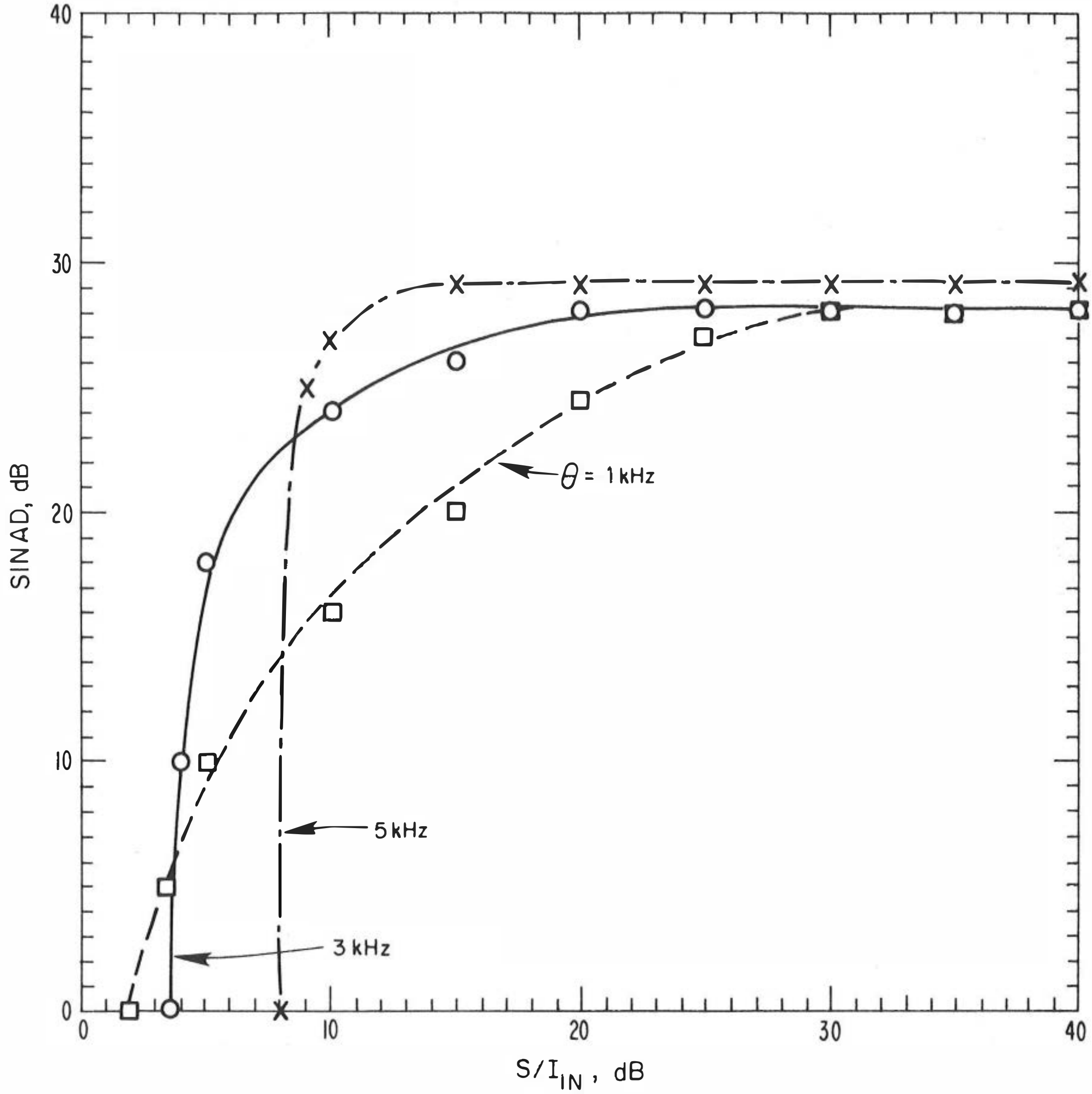


Figure 1-39. Measured performance of an FM receiver with three equal amplitude interferers.

CHAPTER 2. SYSTEMS ENGINEERING AND EVALUATION

The objective of this program subelement is to provide telecommunication system oriented studies that include system requirements, definition, cost trade-offs, design and evaluation, or acceptance criteria. These studies are user oriented where the user is a Federal mission agency or a public service user. Consulting services to meet these user requirements take the form of analyses, measurements, and performance evaluations with the results generally published in NTIA reports or, when applicable, in technical journals. The resultant performance criteria and measurement methods are used by Federal agencies in planning, designing, specifying, procuring, leasing, and operating telecommunication systems.

In July of this fiscal year, a new Division was formed as described in the preface to the report. Those projects which were transferred to Division 4 during the last quarter of the year are grouped together as indicated in Section 2.1 below and include Section 2.2 on Satellite Communications. These projects will be reported under a new program heading next fiscal year.

Section 2.1 addresses those projects which relate to communication systems and communication services engineering; Section 2.2 presents those projects oriented toward satellite communications, Section 2.3 summarizes the terrestrial radio system performance and monitoring studies; Section 2.4 deals with radio channel simulation and radio system performance standards; and Section 2.5 presents related work in fiber optic communications.

SECTION 2.1. COMMUNICATION SYSTEMS AND 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. The projects described are: Data Communications, Non-Speech Telecommunication Services, Project Green Thumb, Technical Concept Papers, U.S. Forest Service Study, Aircraft Obstruction of Short Microwave Links, Rural Telecommunications, EMS Communications, International Data Communications, and MARAD Assistance.

Data Communications. The past decade has produced two fundamental changes in the data communications industry: an enormous increase in the demand for high-quality data communication services, as a result of the growth of distributed computing, and a rapid proliferation of new sources of supply for these services, as a result of the FCC's various pro-competitive regulatory decisions. In 1970, the total market for data communication services and equipment was $600 million. Today's market is over ten times as large - $8.7 billion - and market growth in excess of 20% per year is expected through the mid-1980's.

These industry changes have substantially increased the complexity--and the importance--of the communications management function. The communications manager essentially operates as a broker, or middle-man, between a user requiring communication service and supplier who provides such services. Typically, the user knows his application well, but has little technical knowledge of communications; conversely, the supplier knows communications well, but knows relatively little about particular user applications. The communications manager's task is to bridge the gap between these two parties, to optimally match offered systems and services with end user needs.

An obvious requirement for effective communications management is a "common language" for relating the performance needs of a particular user with the performance provided by a particular system or service. NTIA's Data Communications project has been undertaken to meet that need through the development of user-oriented, system-independent performance parameters and measurement methods. Specific project objectives are to develop three related Federal Telecommunication Standards:

1. Federal Standard 1033 -- defines standard, universally applicable, user-oriented parameters for specifying data communication system performance.

2. Federal Standard "1033A" -- will define standard measurement methods to be used in conjunction with the standard parameters in assessing delivered performance.

3. Federal Standard "1033B" -- will define standard performance classes and requirements for interconnection of dissimilar networks.

The Data Communications project is being conducted under the auspices of the Federal Telecommunication Standards Committee (FTSC). This committee is responsible, under the guidance of the General Services Administration (GSA), the Office of Science and Technology Policy (OSTP), and the National Communications System (NCS), for the development, coordination, and approval of Federal Telecommunication Standards. Proposed standards approved by the committee are promulgated by GSA, and ultimately become mandatory for use by all Federal agencies in the procurement of telecommunication systems and services.

Figure 2-1 summarizes the overall approach used in developing performance parameters for Federal Standard 1033. The parameter development process consisted of four major steps:

1. Model Development. Existing and proposed data communication services were surveyed and certain universal performance characteristics shared by all were identified. These characteristics were consolidated in a simple, user-oriented model which provided a system-independent basis for the performance parameter definitions.

2. Function Definition. Five primary communication functions were selected and defined in terms of model reference events. These functions (access, bit transfer, block transfer, message transfer, and disengagement) provided a specific focus for the parameter development effort.

3. Failure Analysis. Each primary function was analyzed to determine the possible outcomes an individual "trial performance" might encounter. Possible outcomes were grouped into three general outcome categories: successful performance, incorrect performance, and nonperformance. These categories correspond to the three general performance concerns (or "criteria") most frequently expressed by end users: efficiency, accuracy, and reliability.

4. Parameter Selection. Each primary function was considered relative to each performance criterion in matrix fashion, and one or more specific parameters were selected to represent performance relative to each function/criterion pair. Parameters were selected on the basis of expressed user interest and consisted of probabilities, waiting times, time rates, and rate efficiencies. The matrix approach ensured that no significant aspect of communication performance would be overlooked in the parameter selection process.

Figure 2-2 illustrates the standard parameters ultimately selected to represent access performance. Three specific parameters were chosen, one associated with each of the three general performance criteria noted earlier: efficiency, accuracy, and reliability. The selected parameters are:

1. Access Time - Average value of elapsed time between the start of an access attempt and successful access. Elapsed time values are calculated only in access attempts that result in successful access.

2. Incorrect Access Probability - Ratio of total access attempts that result in Incorrect Access (i.e., connection to an unintended destination) to total access attempts counted during a parameter measurement.

3. Access Denial Probability - Ratio of total access attempts that result in access denial (i.e., system blocking) to total access attempts counted during a parameter measurement.

A key aspect of the FED STD 1033 parameter definitions is their expression in mathematical form. This approach eliminates the ambiguity associated with traditional narrative definitions and ensures that the parameters will be applied in a consistent way in all situations.

The same general approach used in the access case was followed in selecting and defining performance parameters for the user information transfer and disengagement functions. A separate probability parameter was defined to express the likelihood of each possible failure outcome, and the successful performance outcomes were expressed in terms of waiting times and (in the case of bit and block transfer) time rates. Bit and block transfer rate efficiencies were also defined, to express system performance from the standpoint of resource utilization.

A major milestone in the Data Communications project was achieved in FY 79 with the FTSC's decision to approve publication of FS 1033 as an interim Federal Standard. It is anticipated that the standard will be available from GSA in the final published form early in FY 80.

Initial promulgation of FS 1033 on an interim (optional) basis is intended to accomplish two objectives:

1. Allow Federal agencies maximum flexibility in selecting initial applications.

2. Improve the Standard by means of feedback from such trial applications.

ITS recently began work on a project which will apply FS 1033 in the specification of performance requirements for a major Federal network, the future digital Defense Communications System (DCS II). This pilot project, which is being conducted for the Defense Communications Engineering Center (DCEC), is described elsewhere in this report.

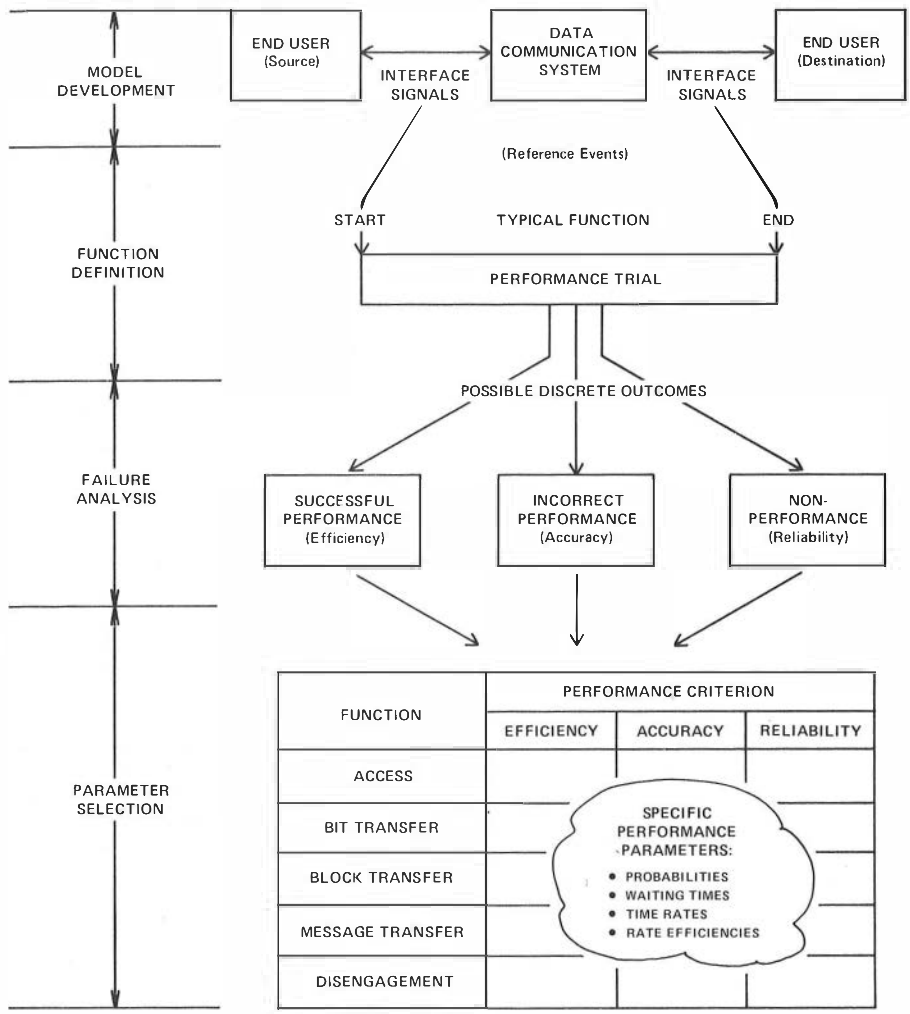
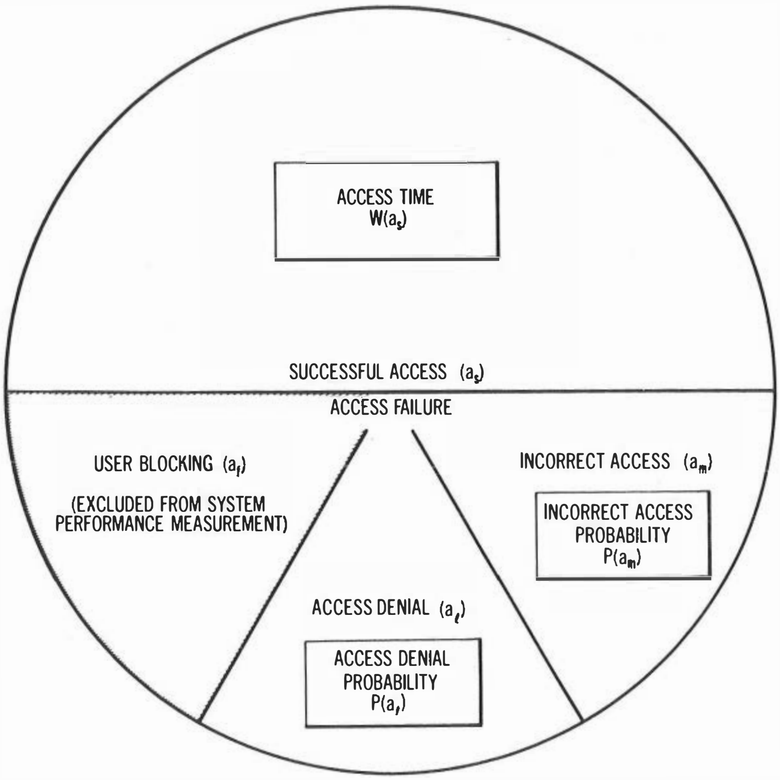


Figure 2-1. Federal Standard 1033 parameter development approach.



ACCESS PARAMETERS

1. Access Time $= W(a_s) = \frac{1}{A_s} \sum_{a_s=1}^{A_s} w(a_s)$
2. Incorrect Access Probability $= P(a_m) = A_m/A'$
3. Access Denial Probability $= P(a_\ell) = A_\ell/A'$

DEFINITIONS

A_s = Total number of Successful Access outcomes counted during an access parameter measurement.

A_m = Total number of Incorrect Access outcomes counted during an access parameter measurement.

A_ℓ = Total number of Access Denials counted during an access parameter measurement.

A' = Total number of access attempts counted during an access parameter measurement: $A_s + A_m + A_\ell$.

$w(a_s)$ = Value of access time measured on a particular successful access attempt.

Figure 2-2. Selected access parameters.

Another FY 79 happening of significance to the Data Communications project was the decision of the American National Standards Institute (ANSI Task Group X3S35) to develop an industry performance standard based on FS 1033. This ANSI project will improve the standard by bringing additional industry expertise to bear on the performance specification problem, and will promote industry understanding and acceptance of the user-oriented approach. It is anticipated that the resulting standard will ultimately be adopted by the FTSC as a mandatory Federal Standard.

Current ITS efforts on the Data Communications project are being focused in two areas:

1. Support of the ANSI review/development effort.

2. Development of standard data reduction software for FS "1033A".

It is anticipated that a final output of the Task Group S3S35 effort will be ready for formal ANSI coordination by about the middle of FY 80, and that an initial draft of FS "1033A" will be completed by the end of FY 80.

The real importance of the Data Communications program lies in its substantial cost savings potential. It is estimated that the Federal Government will be spending about $2 billion annually on data communications by 1980. An independent National Research Council committee formed to advise the Institute for Telecommunication Sciences 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 provide the essence of such a method.

Non-speech Telecommunication Services. NTIA/ITS has become involved in evaluation of a group of new telecommunication services known generically as broadcast VIDEOTEX (simplex systems) and interactive VIDEOTEX (duplex systems). (It is to be noted that, during early evolution of several such services, various generic descriptors have appeared in the literature; the CCITT has tentatively adopted the term VIDEOTEX.) Some of these services are presently offered in other countries, and one or more may soon be offered to the U.S. public.

VIDEOTEX systems typically make use of the home TV receiver as a display terminal for information transmitted as alphanumeric/test or graphic/pictorial material. Some systems, however, are being designed for business terminal display and will provide increased information bandwidth compatible with medium and high resolution CRTs. None of the presently offered services make use of audio to augment the video presentations; hence, the term "non-speech telecommunications." This does not, however, preclude the valuable addition of voice transmission at a later stage in the implementation of such services.

Based on an extensive survey of available literature, an NTIA report is being prepared to describe, in summary, various proposed and operational systems in the United Kingdom, Western Europe, Japan, Canada, and the United States. Comparisons are offered in terms of system performance and capabilities, formats, costs, applications, and user-oriented criteria. Also discussed in the report are possible barriers to broad implementation, as the result of the lack of standards and protocols, and various issues concerning policy, economics, and privacy.

The report also addresses the potential impact of interactive VIDEOTEX traffic upon local loop telephone service. Of particular concern are the effects of widespread use of these interactive systems (that make use of home telephones and local switching areas). The summary of a preliminary analysis of this problem appears later in this discussion, using Project Green Thumb as a pilot case.

Several types of VIDEOTEX services have attracted widespread attention and discussion. Considerable recent domestic news coverage has been devoted to explicit systems in terms of their potential use in the U.S. These include Project Green Thumb, GTE INSAC, Viewdata, KSL-TV's Teletext, and a host of others. An early interest has been expressed throughout Japan and Western Europe, where some systems are now operational. Currently operational services provide visual display of information on the home TV reciever. The British have pioneered in two of the most widely known of these services: Teletext and Viewdata. Teletext is a broadcast VIDEOTEX system that makes use of TV broadcast or CATV to deliver information to the home from the central data bank. Information is carried on the vertical retrace or blanking interval of the video subcarrier. The receiver has a conversion unit to strip this information for display on the TV screen. The service transmits news, weather, public interest items, stock market reports, and dozens of other topics in alphanumeric and graphic form for display on the home TV receiver. In Britain, Teletext currently may be received by any of 20 million home receivers provided that they are equipped with a decoder box and have been modified to receive, capture, and display the information transmitted as a portion of the television subcarrier. To date only a small handful of such TV sets are so equipped.

Another VIDEOTEX system which is quite similar in appearance to that of the Teletext system is the British viewdata system trademarked under the tradename Prestel. The system connects the home TV receiver to a computer bank through the user's telephone and the common carrier switched network. This type system permits the user to request a particular file or set of information "pages" by punching a few keys on the decoder box at the home receiver. The interactive capability allows user access to a much larger data base than can be handed by the one-way type of general information service. Customer/store transactions, real estate previews, banking, legal, and broker transactions, medical information access, travel reservations, and hosts of other interactions become practical with such interactive data services.

An NTIA report will include an in-depth discussion of Project Green Thumb, an interactive VIDEOTEX service planned for near term implementation in the U.S.

Project Green Thumb. NTIA/ITS has been asked by the Department of Agriculture to work with them on an Agriculture Advisory Service known as Project Green Thumb. The role of NTIA/ITS is to be strictly that of technical advisor or consultant. Participation has been based on technical expertise in interactive computer and telecommunication local loop capabilities. It was agreed that such participation was not to be construed as endorsement by the National Telecommunications and Information Administration of any particular project or system. An NTIA report will provide a technical description of the program and an assessment of such systems with respect to capacity, performance, and potential usefulness.

The Green Thumb systems, when widely implemented, are expected to be justified on the basis of helping to reduce the more than one billion dollar annual losses of food and fiber, which are directly or indirectly attributable to adverse weather conditions, crop diseases, insect invasions, harvesting too early or too late, and other problems facing the U.S. farmer in his decision making processes involving his agricultural business.

There follows a descripton of the various participants in Project Green Thumb, together with goals expected to be reached sometime in 1980-81 as the Green Thumb system is implemented.

The U.S. Department of Agriculture Extension, with the support and assistance of the National Weather Service (DoC/NOAA), has drawn up plans for a prototype experiment to test the feasibility of having state extension personnel operate a computerized network for farm and weather information dissemination directly into the farmer's home from a computer data bank. Two counties in the State of Kentucky were selected as test sites for equipment location and demonstration. Each county is to select 100 farmers to participate in the test. The farmers will receive an electrical box with a numeric keypad and the necessary cables for plugging into the telephone and TV receiver. The electrical box is a microprocessor-controlled encoder-decoder plus telephone modem that permits the farmer to select several items from a "menu" of current information stored in a computer data base. After selection of the information and placement of a local telephone call, the data is automatically transmitted to memory in this electrical box and the telephone connection broken. The information, which may be alphanumerics, full graphic, or a mixture, may be viewed one frame at a time on a TV set, either in color or black and white. The architecture for this information system includes a medium sized state-operated computer which handles all the inputs and updates local county computers as often as four times per hour. An added potential dimension for the test includes the possibility that several of the farmers may input user-observed data into the data bank via their encoder-decoder box.

In summary, the government is interested in:

1. testing the feasibility of operating a computerized system for dissemination of weather, market, and other agricultural production and management information on a day-to-day basis;

2. development of a prototype software support system for the test; and

3. providing test parameter data to evaluate the usefulness and acceptability of the information and the information dissemination system.

A chapter of the NTIA report on Non-speech Telecommunication Services, entitled "The Impact of Information Systems on Public Switched Networks," presents results of an ITS analysis of potential future telephone traffic problems resultant from widespread use of interactive VIDEOTEX systems. Project Green Thumb parameters are used in the analysis, which addresses the possible effects of such systems usage on rural local loops and local switching centers. In addition, the report shows that the number of trunks to the information data bank markedly affects the service provided.

In rural areas, where lines may be noisy, this traffic analysis showed that, for the Project Green Thumb in Kentucky, blocked calls could be out of the acceptable range when as few as 100 VIDEOTEX subscribers are participants in the system.

The traffic analysis was based on the hypothetical example of 100 farmer installations, each originating one call per hour, presumably at morning and evening hours not conflicting with field work. Holding time (elapsed time from telephone connect to disconnect) was 2.4 minutes per call for a 4 kilobyte memory (8 "pages") and 4.8 minutes per call for an 8 kilobyte memory. For noisy channels, holding time was doubled in order to permit completion of transmission of page information.

Results were obtained for 7-, 14-, and 21-trunk groups connecting the local switching center to the information data bank. Calculations made using telephone traffic engineering tables indicated the percentage of blocked calls based on the numbers of trunks terminating at the computer. Results are reproduced in Table 2-1.

Technical Concept Papers. The U.S. Army Communications Command has responsibility for a wide range of communication systems, including strategic, tactical, and non-tactical. Many operational problems result from a mismatch in communication requirements, formats, or cryptography. This program is addressed to a general understanding of these problems. The intent is to write two technical concept papers which will give an overview of two distinct communication problem areas. It is hoped that they will assist management in better understanding the options available to them.

The two technical concept papers will concentrate on the following:

1. secure voice communications,
2. communications mapping for the gateway interfaces.

The first of these examines the current plan for military secure voice communications and the associated interface problems. There exists a variety of interface needs due to a variety of military secure voice terminals and signal formats. This leads to a rather complex interface problem which portends a high financial and temporal cost. The interfaces must handle a variety of cryptographic keys and a variety of signal formats. Signal format conversions (at interfaces) are particularly troublesome in view of the voice quality degradation and speaker recognition impairment that is suffered at each conversion. The paper addresses these technical concepts.

The second paper concentrates on the variety of communication gateway interfaces that are encountered in the current military plan. In some cases, there appears to be only ill-defined requirements for the interfaces, and there is a distinct possibility that the impact of the needs of the interface are not understood. This paper discusses a mapping of the interfaces encountered in the military communications heirarchy with a view to assisting military planners in more fully understanding future needs and trends.

U.S. Forest Service ADP Communications Study. ITS has reviewed U.S. Forest Service Region I telecommunication requirements for upgrading the ADP services and enhancing the communication services at the Forest Service Northern Region. The project consists of defining the operational support requirements, developing candidate data system configurations, making performance-cost trade-off analyses, recommending a data-communications system configuration design, and preparing implementation plans reflecting time-phasing of the procurements.

Functional diagrams have been prepared from which the ADP and communications requirements may be developed. The objective of the project is to develop and document the methodology of specifying and procuring such telecommunication system improvements. The results should be applicable to other agencies of the Federal Government.

Aircraft Obstruction of Short Microwave Links. This project was a continuation of an experimental program initiated in the previous fiscal year. It was supported by the U.S. Army, CEEIA, at Fort Huachuca, AZ. The objective was to determine the effects of aircraft penetration of a microwave transmission beam over relatively short links, with emphasis toward digital communication systems. The two important parameters in the measurements were the power fade depths caused by the aircraft and the multipath that might be caused by reflections.

The experimental data were obtained from existing microwave links operated by the Federal Aviation Administration at the Atlanta/Hartsfield Airport in Atlanta, GA, and at O'Hare International Airport at Chicago, IL. The results were summarized in the Annual Technical Progress Report 1978 issued by NTIA/ITS. An NTIA Report-79-14 entitled "Aircraft Obstruction of Microwave Links" was published in January 1979, and is available from ITS, Boulder, CO.

Table 2-1. Blocking Estimates For Green Thumb Test

	4 k Mem Quiet	4 k Mem Noisy	8 k Mem Quiet	8 k Mem Noisy
Call attempts/hour	1	1	1	1
Holding Time	0.04h	0.08h	0.08h	0.16h
Offered Load per subscriber (Erlangs)	0.04E	0.08E	0.08E	0.16E
Blocking %				
7 Trunks				
Lost Model	6%	35%	35%	65%
Held Model	11%	68%	68%	98%
14 Trunks				
Lost	<0.1%	3%	3%	25%
Held	<0.1%	3.5%	3.5%	70%
21 Trunks				
Lost	0	0	0	5%
Held	0	0	0	16%

This assumes 100 subscribers make 1 call attempt per hour with holding time of 2.4 min/call for 4k memory (Quiet) or 4.8 min/call for 8k memory (Quiet) and holding time doubles for noisy channel.

Rural Telecommunications. This project is a technical supporting activity for the broader NTIA Rural Communications Program. ITS hosted a planning workshop in March 1979. Three rural communities have been selected by NTIA for evaluation and special emphasis in determining specific rural telecommunication needs. These are Haywood Country, NC, Rio Arriba County, NM, and San Joaquin Valley, CA. Representatives from these communities presented reports on surveys conducted by them to determine local needs. Industry representatives from eight sectors ranging from telephone services to slow-scan video and satellite services presented highlights from their industry which may be useful in meeting rural telecommunications needs. Three working groups representing mobile communications, broadband and video communications, and telephone and data communications were formed with ITS representatives participating in these groups.

A specific need for mobile communications to support medical services in the Rio Arriba County, NM, site was identified for follow-up by ITS. Field site visits were made and agreements for use of the New Mexico State EMS system were developed. Further developments have pursued a radio coverage problem in one portion of the country. This specific problem has led to the need for defining waiver criteria for the use of dedicated EMS frequencies in rural areas. Efforts are continuing to define, in a generic way, recommendations for telecommunications infrastructure for rural communities. The addition of telecommunications into the economic development plans for these communities seems to be a reasonable approach to stimulating appropriate developments in response to the Presidential initiative in this area.

Emergency Medical Services (EMS) Communications. During FY 1978, ITS prepared an Emergency Medical Services Communications System Technical Planning Guide. After extensive review by concerned Federal agencies, the guide was published as NTIA SP 79-3. It was introduced at a conference, "Rural EMS Under Construction," in Oklahoma City in May.

The primary effort during this fiscal year has been directed toward a study of EMS telecommunication subsystems to develop techniques and examples which will aid system managers and planners to better understand the telecommunications processes and to evaluate the performance of existing or planned systems. The study resulted in an EMS simulation model which can be employed in evaluating the following subproblems:

- o What time delays are incurred in gaining access to emergency medical resources?
- o What time delays are incurred in the dispatch of appropriate medical resources to the emergency scene?
- o What time delays are incurred before the appropriate medical resources commence advanced life support or some other level of emergency care?

The objectives of the study were designed to assist telecommunication managers and planners by providing analytical, simulation, and measurement techniques for:

- o understanding the individual EMS delay components and their impact on the delivery system,
- o adaptation of a simulation modeling technique for evaluating existing or planned EMS telecommunication systems or subsystems,
- o collecting and evaluating time delay data on existing EMS telecommunication systems, and
- o providing a cross reference between specific EMS delay components and previous applicable research (literature).

For the purpose of this study, the EMS system was considered to be composed of three subsystems or processes; namely: Citizen Access, Dispatch and Resource, and Medical. This is shown diagrammatically in Figure 2-3. Detailed descriptions of these processes and the time events are contained in the resultant Master of Science Thesis submitted to the Department of Electrical Engineering, University of Colorado entitled, "Simulation Modeling of Emergency Medical Services (EMS) Telecommunication Systems," by H. David Hunt.

The demonstration model in this study employs a dynamic, stochastic simulation technique that accurately accounts for the passage of time during the process depicted in Figure 2-4. The model is capable of closely representing the stochastic nature of the EMS environment. The model was validated against analytical equations which are known to represent certain empirically derived results. The model was validated using data on Emergency Telephone Circuit Analyses, Emergency Operator and Dispatcher Staffing Analyses, Radio Dispatch and Emergency Medical Channel Analyses, and Medical Unit Traffic Analyses. The difference between probability measures calculated using the analytical models and the results of the simulation model was generally 1% or less.

A cross-reference matrix between the model flow-chart decision points/subprocesses delay blocks and relevant bibliographic references (a total of 96 different references) provides the reader a source for the reference values used in the model.

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 at national (RTCM) and international (CCIR) committees,

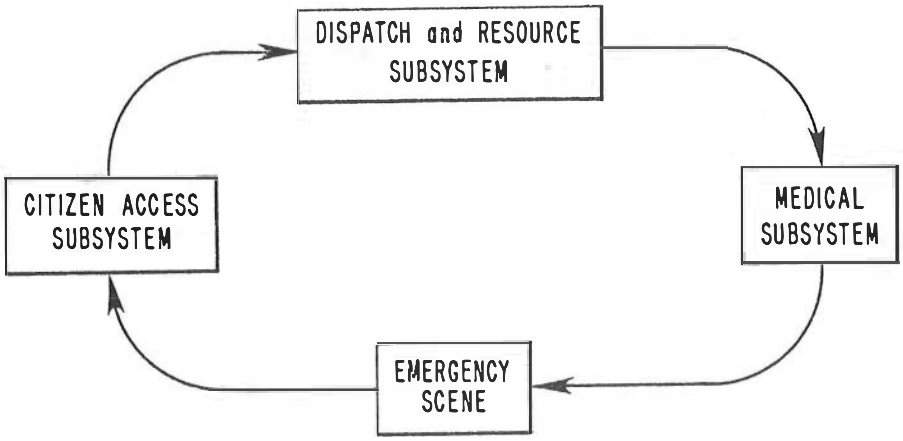


Figure 2-3. EMS telecommunications subsystems

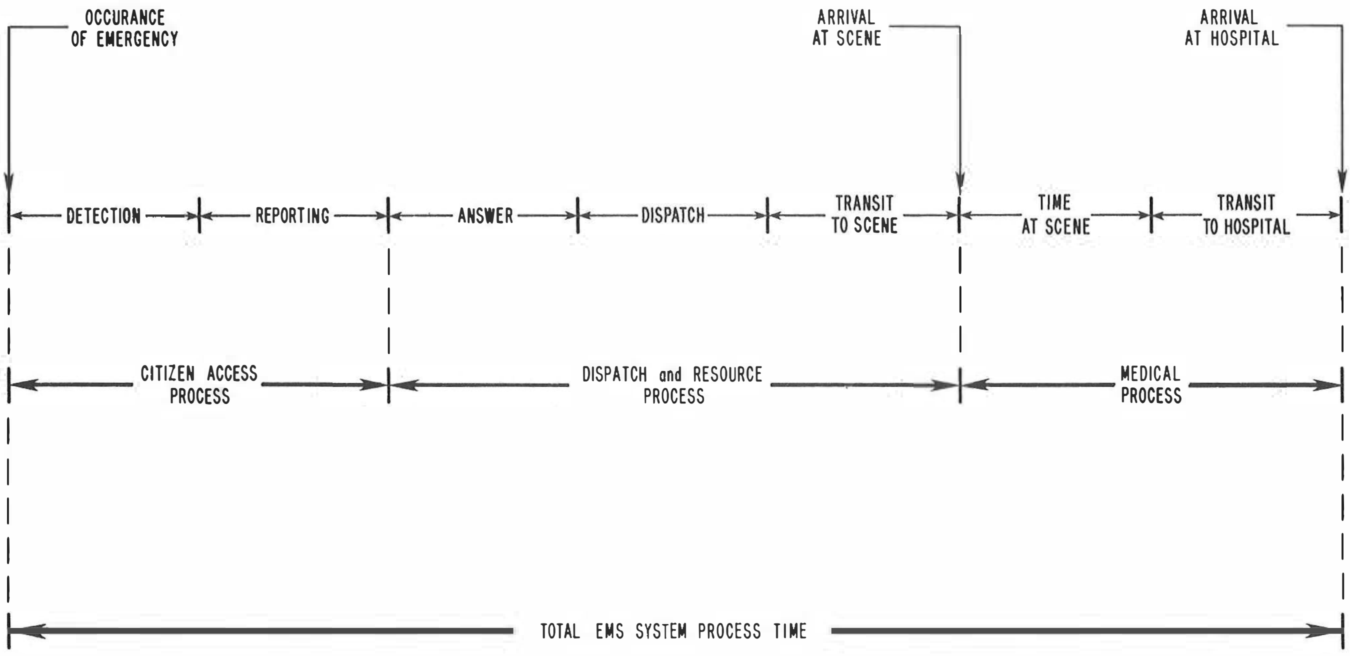


Figure 2-4. Emergency system processes.

and advanced communications studies. Some of the specific efforts in FY 79 are described in the following paragraphs.

1) ITS provides major technical input towards the development of an Automated VHF/UHF Maritime Mobile Telephone System through participation in RTCM Sub-Committee 71 and CCIR Interim Working Party 8/5. ITS analyzed the traffic handling capacity of dedicated calling channels for such a system under various operational conditions and submitted a report to the IWP. The system concepts evolving in the U.S. and in Europe are somewhat different, largely due to different geographical and political aspects. In the U.S., "trunking",that is, time-sharing of radio channels by several coast stations, is generally thought to be essential for development of a spectrum efficient system. In Europe, trunking is not generally considered acceptable due a) to the great number of political boundaries, b) in certain cases the many coast stations needed to cover a relatively small area due to geographical (terrain) features, and, c) the requirement for simultaneous calling by these coast stations to minimize call set-up time. ITS has been instrumental in the development of unified signaling procedures over the radio channel so that compatible shipboard signaling equipment will be possible at a minimal cost increment.

2) ITS is conducting a systems study to evaluate the feasibility and capability of an overlay spread-spectrum communication system in the VHF (156 to 162 MHz) band. A major impetus for this study is the fact that in the U.S. only a relatively small number of the channels in this band are available for maritime use, in part due to grandfathering clauses (e.g., use by the railroads of certain channels). A spread-spectrum system could use the full band available and provide additional communications capability, provided it does not cause interference to the existing services and that the interference by other users to the spread-spectrum system does not exceed acceptable levels.

3) A new CCIR Interim Working Party 8/8 was formed in May 1979 to determine the operational procedures and any other matters necessary for the early introduction of Digital Selective Calling (SELCALL) in the Maritime Mobile terrestial service. ITS has for many years been a major contributor to the development of SELCALL and to the international adoption of this system (CCIR Recommendation 439-1, adopted at the 1978 CCIR Plenary). T. de Haas has been named as a U.S. member to the new IWP 8/8 and participates in the work of RTCM Sub-Committee 74 where most of the preparatory effort is taking place.

NOTE: The following projects (through Section 2.2.) were under the new Division 4 for the last quarter of the fiscal year.

USPS Electronic Message Service System. This project now constitutes Phase VII of the NTIA/ITS support of the Electronic Message Service System (EMSS) program for the U.S. Postal Service. Again, the ITS provides technical support, analysis, and documentation in support of the EMSS program. The current agreement requires ITS participation in the development of an integrated EMSS program plan, providing assistance to the USPS in preparation of the statement of work (SOW) for the inception of an EMSS, developing software analysis and computer modeling of the EMSS, and developing a dynamic message flow simulation model of the initial EMSS. Other tasks require ITS to determine message security requirements and complete development of trunk network planning factors.

The previous work of ITS has aided in the development of 52 EMSS concepts which then led to the selection of three and then a single candidate by the USPS. EMSS services would be phased in over a number of years depending on customer demand and implementation strategy to be employed, which is subject to market factors such as customer acceptance. Various computer modeling alternatives and growth strategies were employed by a private contractor for the three final candidates in cooperation with the ITS. These economic analyses aided in the selection of the final candidate by varying growth strategy with services and market response as variables. The services at various phases would offer magnetic tape, optical character recognition, facsimile, and public terminals for input applications. Output services could include black and white printing or color. The market response strategy was based on 1) a slower than expected market, 2) a market that develops as predicted, and 3) a faster than expected market. The modeling used alternatives that takes the EMSS more than 20 years to develop to maturity or to have the EMSS terminated when market demand is low in as short a period as 8 years. This would permit capital investment to be recovered if the EMSS fails to gain customer acceptance.

The candidate chosen by the USPS has the characteristics shown in Table 2-2 for a mature system which could take 20 years to implement.

The EMSS has the potential of operation as envisioned in the accompanying diagram (Figure 2-5). The principle of the EMSS is as follows: the USPS would accept physical media such as paper copy messages and magnetic tapes through conventional mail carrier pickup or customer delivery at designated facilities such as associate

Table 2-2. Characteristics of Mature Final EMSS Candidate

Annual Volume (Billions)	Average Letter Size (Bits)	Number of Stations	Size of EMSS Staff	Number of Public Terminals
25.0	67,000	87	4,387	67,052

Cost/1000 Messages ($)	Total Investment ($ millions)	Annual Operating Costs ($ millions)	Productivity Million Messages per Person Year
19.5	1791.3	309.3	5.7

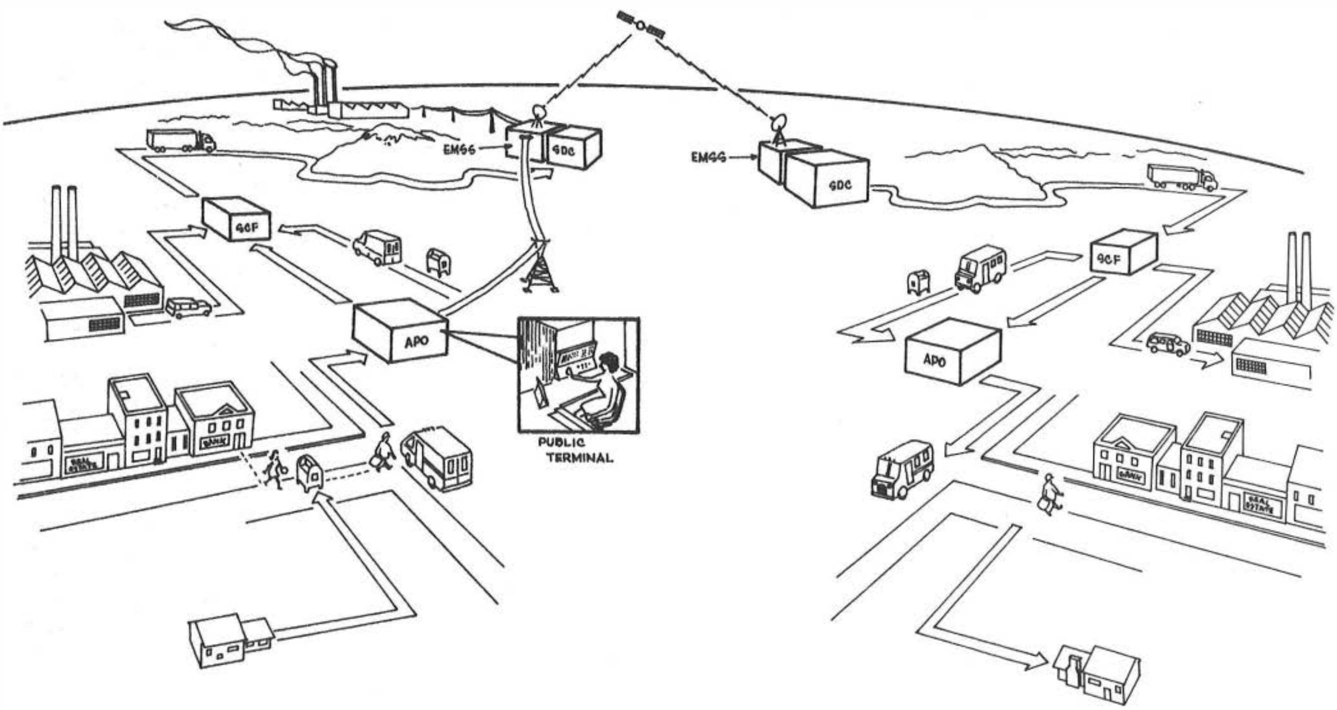


Figure 2-5. EMSS message routing.

post offices (APOs) or sectional center facilities (SCFs). The messages would be converted at EMSS stations for transmission via leased common carrier services such as satellite links to EMSS destination stations. On message receipt at the EMSS station, the messages would be stored in computer memory, sorted in memory, and then printed and enveloped for carrier delivery. The messages would be distributed to the customer by truck or mail carrier as in current practice.

Other message entry might be by the customer at a public terminal or from company offices, the former via leased lines and the latter via leased or customer-owned lines to the EMSS station. No electronic message distribution by the USPS would take place.

During the past year the ITS has prepared an EMSS System Engineering document which provides a planning guide to promote development of the EMSS in an orderly manner. The document contains a system description, requirements, and development planning factors for the EMSS. Two areas are covered in the document: service planning and system planning.

The first area, service planning, involves development of applications-oriented service groups and definitions rather than technology-oriented services. There are five applications-oriented service groups. They are: Transact-mail which includes billings, invoices, purchase orders, and payments such as money orders; Ad-mail which includes various forms of advertising; Express letter which would be a general message service among businesses, government, and household; Tele-mail includes priority forms of transactions, advertising, and general messages; Custom mail which might permit unusual features such as special ink and paper.

The planning for these applications is defined in terms of input mode, method of collection, output mode, method of delivery, and service features such as method of payment, level of message security, and whether colored paper and ink other than black is to be used. For example, a bill to a customer may start at a company as part of a large number of magnetically encoded bills on a reel of tape (input mode), collected by the USPS (collection mode), black ink printed on white paper at the destination station using a standard level of security (service features), and delivered by the USPS to the addressee (delivery mode).

Service requirements for applications are developed in the document which serve as guidelines for customer, USPS, and EMSS facility interfaces. These interfaces establish procedures to be followed at EMSS stations, public, and user terminals. An operating format is established which identifies use of message forms, labeling of media container for magnetic tape, method of billing, method of media delivery or pickup by the message originator, and other operating procedures.

Service implementation planning considers factors which influence station design requirements. These are the number of messages, bits per message, the number of media conversion devices to be required, and the service features. This implementation planning helps serve as the basis of modification of software which was used for the growth and economic analyses described earlier, but is now being undertaken by ITS in more detail. Another section is used to develop algorithms that will be used to examine relative frequency of message arrival at an EMSS station and estimated message volume for each application at each station so that station and system requirements can be analyzed.

The service planning summary section of the document lists 22 applications with over 20 possible services considered for each of the applications.

The second area of the document, system planning, develops guidelines for the EMSS physical system, its functions, and operations. Planning guidelines have been considered for EMSS stations, trunk networks, and local telecommunications. Interface planning has been considered within EMSS stations, among EMSS stations, trunk networks, local telecommunications networks, public terminals, and user (customer located) terminals.

Another area of support has been in computer programming and data base adaptation. The ITS has succeeded in modifying a contractor-developed parametric analysis model of the EMSS and a network costing program for operation on the Boulder Laboratories CDC 6600 computer. Significant changes were made in the software to enable successful operation. This work is continuing for the current contract.

Currently, completion of an integrated program plan for the EMSS is underway. This task requires a review of EMSS program plans, identification of program areas requiring planning support, areas critical to EMSS inception, and development of a total program plan for EMSS to maturity.

The development of a draft document contractor SOW of hardware/software requirements for EMSS inception is also in progress. Service and system planning are part of the document which requires contractor generation of functional specifications for the initial EMSS.

There are three areas of effort in software development. One is in the identification of software by functional analysis at and between EMSS stations that will control message input/output processing, message sorting, control functions, and bookkeeping. A second is writing software that will permit estimates of message arrivals at stations and for the entire initial EMSS. This work is then related to the earlier programs which were used to determine EMSS and station costs. The third is the development of a dynamic message flow simulation model handling input/output flow of message traffic at EMSS stations and through the trunk networks whether satellite, terrestrial, or hybrid. This software will be capable of handling variable message flow rather than peak loads, and will be used to establish adequacy of equipment specified in the EMSS.

Another task is underway that will review requirements for message protection of physical media and electronic data. Protection of the physical media includes protection from fire, theft, and tampering with message contents. Message protection during network transmission may be through the use of encoding based on the Data Encryption Standard (DES) and the applicability of proposed Federal Standards 1026 and 1027 which define compatibility and security requirements. Costs associated with both protection areas will become part of the EMSS data base.

Completion of work started during previous agreements is expected in trunk network development factors. Starting with 10 cities specified for EMSS inception, the trunk network will be expanded to accommodate 18-25 cities and finally a mature network of close to 100 cities. This trunk network will be based on leased private line services. Plans are being made for a network topology growth which will not hinder hierarchal network development. Link capacity assignments will be made and network flow controls planned. This trunk networking is interrelated with the network cost software effort described earlier.

<u>Determination of Digital Transmission Technical Criteria</u>. This project, sponsored by the Defense Communications Engineering Center in Reston, VA, was initiated in June of 1979.

As the primary engineering arm of the Defense Communications Agency, the Defense Communications Engineering Center (DCEC) has the major responsibility for developing and implementing the second-generation Defense Communications System (DCS II). This planned system, which will gradually supplant the existing AUTOVON, AUTODIN, and AUTOSEVOCOM systems during the 1980's, has been motivated by two fundamental changes in the military communications environment:

1. A substantial increase in the demand for high quality data and secure voice communication services, in recognition of the powerful "force multiplier" effect of communications.

2. Dramatic improvements in the technologies of digital transmission and network resource sharing, typified by the development of the Digital European Backbone (DEB) and the ARPANET.

Recent Defense Department planning documents indicate that the second-generation DCS will differ from the current system in three major respects:

1. The analog circuit switches and FDM transmission facilities currently supporting AUTOVON will be replaced by digital equipment.

2. The traditional AUTODIN store-and-forward message switching network will be augmented and, to a growing extent, replaced by AUTODIN II - a second-generation packet switching system based on the ARPANET.

3. The existing AUTOSEVOCOM system will be replaced, under the Secure Voice Improvement Program, with improved narrowband secure voice services provided by the new AUTOVON facilities. The number of voice subscribers receiving security protection will be significantly increased.

The planned DCS II network represents a direct application of the new technologies of digital transmission and resource sharing to the post-1985 needs of military communications users. In comparison with its predecessor system, DCS II offers the potential of substantially improved end-to-end performance, broader geographical and organizational coverage, and more flexible adaptation to growth and change.

In addition to these operational benefits, the planned DCS II network offers the potential of major cost savings. The superior reliability and maintainability of the digital DCS will translate into reduced training, operation, and maintenance costs; and its improved performance will encourage military users to employ the common-user network in preference to inefficient, costly dedicated services.

While the potential benefits of DCS II are substantial, their realization will not be easy. Its designers face major problems in determining user requirements for services; in evaluating the performance of candidate facilities; and, perhaps most importantly, in relating these two variables. The success of the DCS II system will depend to a large extent on how effectively these problems are addressed during the next two to three years.

The ITS will contribute to the solution of the problems noted above by developing precise technical performance criteria to be used in the specification of DCS II systems and subsystems. The overall project has been divided into three major phases. Each phase requires approximately one year of effort. Figure 2-6 illustrates the ultimate objective that ITS hopes to achieve. User-oriented parameters and values will be developed in phase A for one digital and one analog service mode. In phase B technically-oriented parameters and values will be determined for various subelement interfaces of the two systems. These must be related back to the user-oriented values. Finally, in phase C the results obtained in phases A and B will be applied to other service modes and other user applications. Thus, ITS ultimately expects to "fill in the blanks" shown on the figure.

This project relies heavily on the data communication program which is concerned with developing user-oriented standards (e.g., FS 1033) for digital communication services. The specification of user-oriented parameters for analog services is a crucial step in the technical criteria development process.

Figure 2-7 illustrates the basic issues that must be addressed in conducting a systematic analysis of user communication performance requirements. End-users are depicted as processes or functions. The objective of the user requirements analysis is defined as the effectiveness of this function and the impact the system has on it.

Phase A of this project is expected to be completed in the spring of 1980.

Access Area Digital Switching System (AADSS). The U.S. Army's Communications Systems Agency (CSA) at Ft. Monmouth, NJ, is evaluating concepts and alternatives for providing an efficient interface between the future Defense Communication System (DCS) network and contiguous military base environments called access areas.

ITS is conducting analyses in support of this AADSS program. Previous ITS efforts have included studies on (1) parametric cost alternatives for local digital distribution systems, (2) preliminary evaluation of hub alternatives, (3) an example of the design for a digital time division switch with stored program control, (4) traditional signaling techniques for controling the switch, (5) a study of the new and complex signaling issues which arise in an integrated (voice/data) communications network, and (6) an evaluation of switch element capacities in access area digital switching systems.

Studies 1 through 4 were reported earlier and are described in previous annual reports. Studies 5 and 6 were completed in 1979 and are described here.

NTIA Report 79-13, "Control Signaling in a Military Switching Environment," discusses various factors including network topology, traffic characteristics, switching technology, and transmission media which affect the choice of control signaling techniques to be used in future military networks.

One of the major issues which arises in the design, development, and deployment of a telecommunications network is the specification of the network management and control. The design of the control signaling system for DCS access area switches is a prime example. Because military networks tend to evolve slowly, perhaps over a decade or two, resolution now of the key control signaling issues could influence, if not fully determine, the direction networks will take in the 1980's and 1990's.

Emphasis is on those systems using common signaling channels. Digital signaling systems having potential application on both the line and the trunk side of a digital switch are also examined. Some of the potential signaling interfaces to an access area digital switch are illustrated in Figure 2-8.

This report provides an introduction to these concepts and issues involved by reviewing the more important advanced signaling concepts available today.

A second report entitled "Switch Elements Capacities in Access Area Digital Switching Systems" is being reviewed by the sponsor for publication as an NTIA report during the summer of 1979. This report defines the parameters which determine the capacity of modern switching systems in terms of four major switch elements: the interface, the switching matrix, the control processor, and the signaling elements. Existing commercial switching systems are used to exemplify the characteristics of representative switches. Numerical parameter values are developed for a range of switch sizes having application in military access areas. Teletraffic engineering concepts which influence switch capacity are introduced. The study results are applied to a specific military complex whose communications profile is known. A digital switch concept using local and remote concentration units is used in the example. Figure 2-9

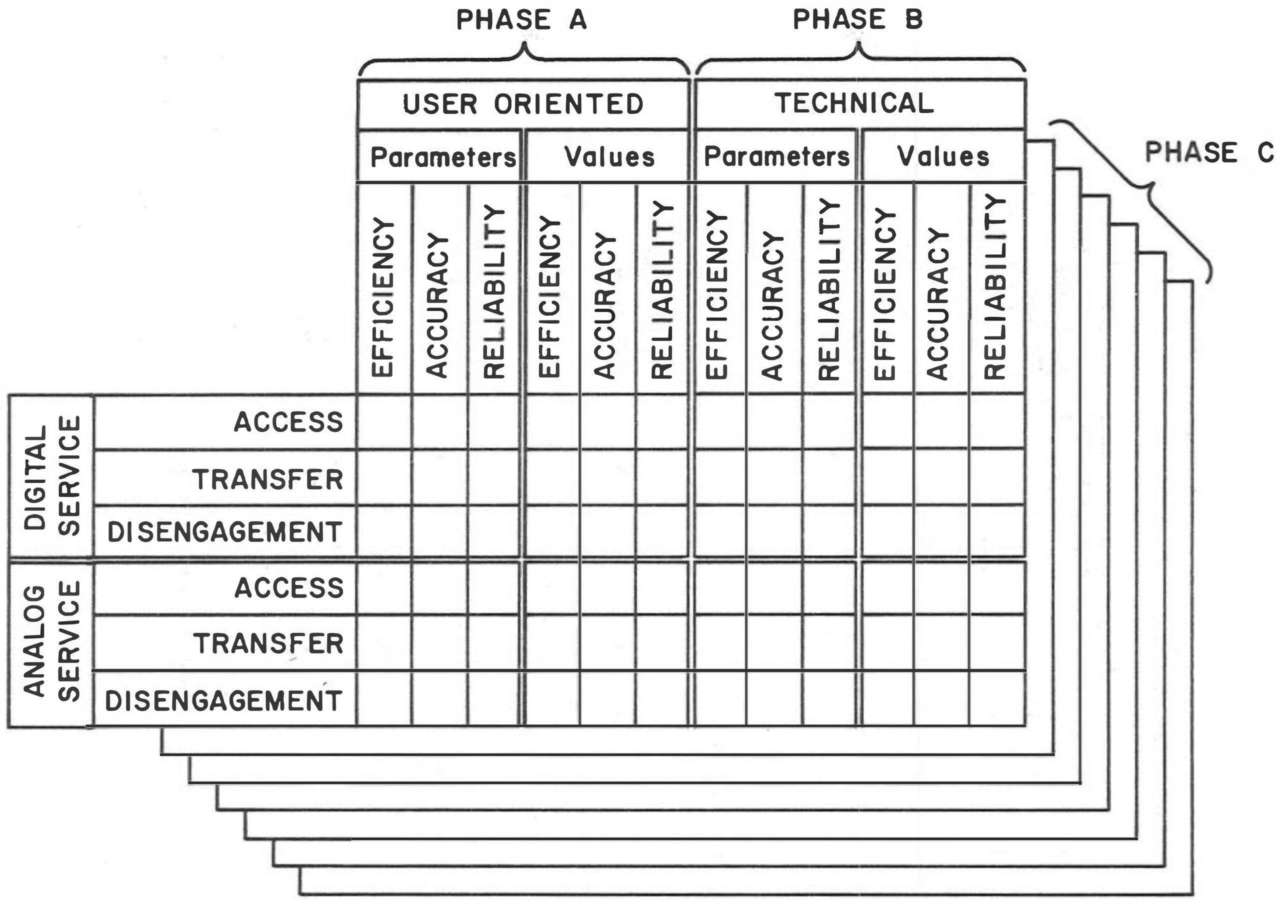
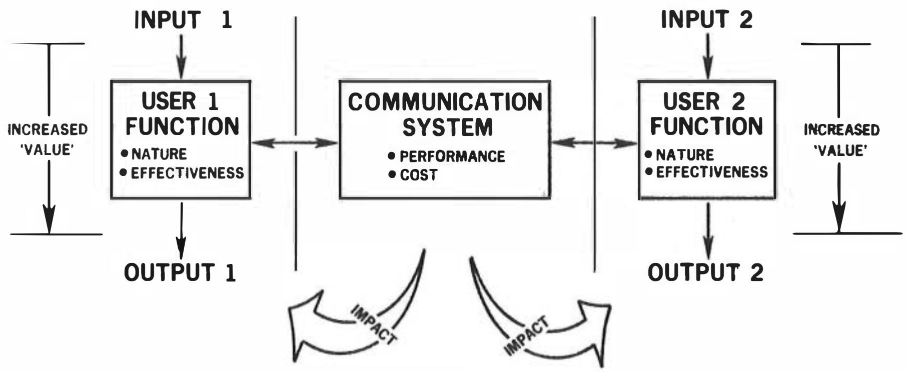
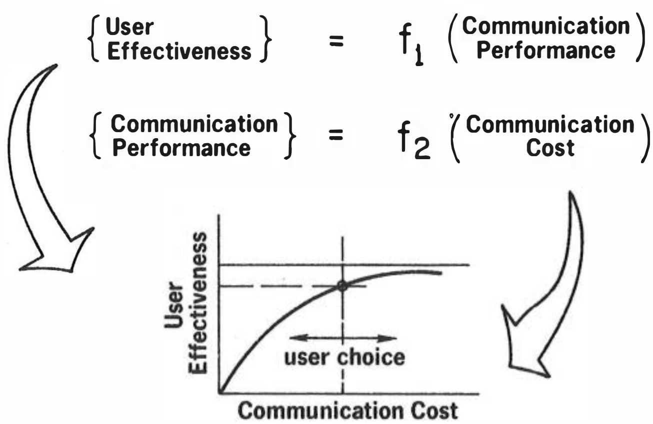


Figure 2-6. Criteria development project overview.



A. GENERAL MODEL



B. COST/EFFECTIVENESS RELATIONSHIPS

Figure 2-7. User requirements analysis concept.

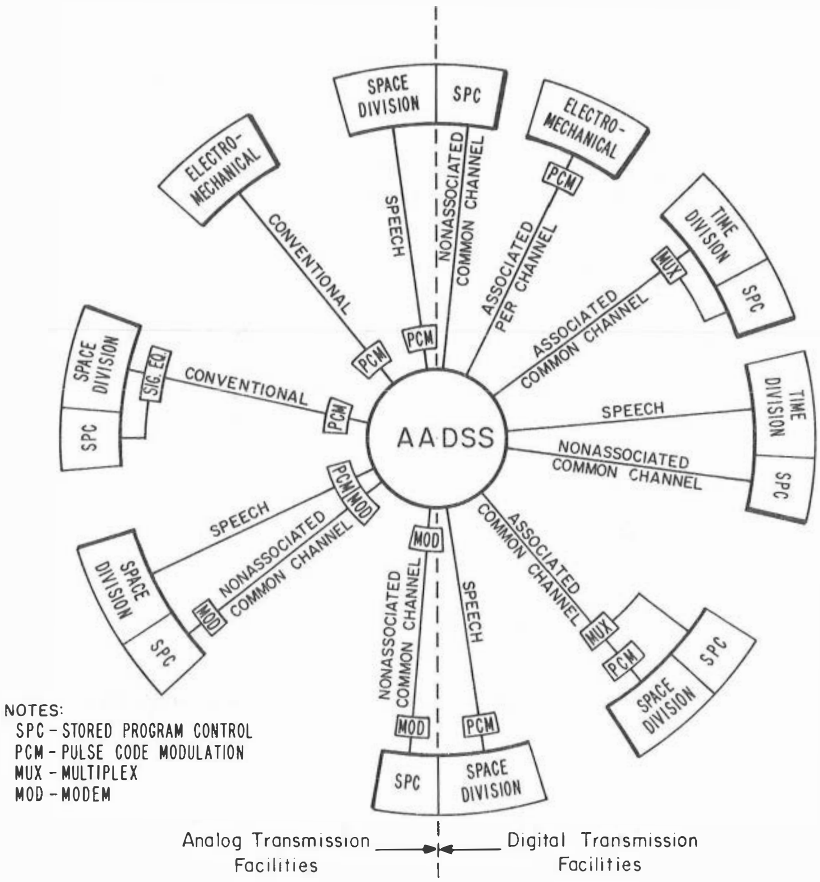
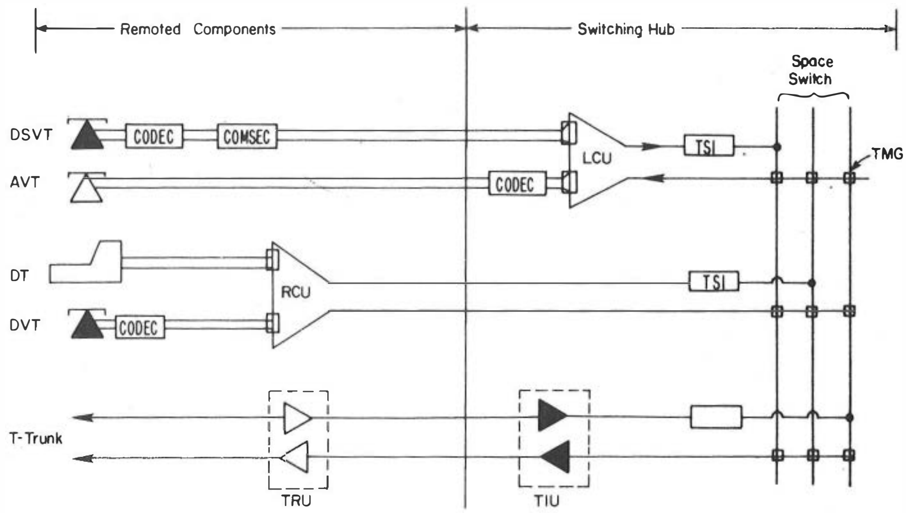


Figure 2-8. Potential signaling interfaces to access area digital switch for transitional network environment.



Legend

DSVT:	Digital Secure Voice Terminal	RCU:	Remote Concentration Unit
AVT:	Analog Voice Terminal	TRU:	Trunk Repeater Unit
DT:	Digital Terminal	TIU:	Trunk Interface Unit
DVT:	Digital Voice Terminal	TSI:	Time Slot Interchange
LCU:	Local Concentration Unit	TMG:	Time Multiplexed Gate

Figure 2-9. Local and remoted components of a switching hub.

illustrates the concept employed for the remote switching hubs serving as private automatic branch exchanges. These hubs home on a central switching hub which serves as the access to commercial carriers and to the DCS backbone switches; see Figure 2-10.

One of the primary benefits of the AADSS will be reduced DCS access line costs by eliminating direct homing of each military installation to the backbone network. Inter-base connectivity enroute to the backbone DCS can reduce the overall access circuit mileage, increase access circuit utilization in portions of the access network, and eliminate backbone switch traffic for intra-area calls. On a current project, ITS expects to analyze the AADSS for two specific military regions and to include all of the multi-service access points within each region. The study will include an assessment of the technical and practical feasibility as well as the cost effectiveness of various intra-area and AADSS backbone connectivity alternatives.

Command Post/Signal Center Bus Distribution Concept Design Program. The semi-tactical nature of transportable Army Command Posts and Signal Centers (CP/SC) poses many real operational problems to the Army Field Commanders. This appears particularly true for the internal CP/SC communications distribution systems. Such a system must often be installed, modified, or transported rapidly. The system must be survivable, movable, and flexible. Its telecommunications performance must meet all military operational requirements faced by transportable CP/SC scenarios.

ITS is taking an in-depth look at new and evolving technologies to ascertain whether and how new system concepts (such as bus-type distribution) can beneficially replace the existing facilities. This ITS effort is sponsored by the U.S. Army's Communication Electronic Equipment Installation Agency (CEEIA) at Ft. Huachuca, Arizona. The prime objective is to provide a functional design and specification of a bus-type transmission system to replace currently used wire pairs and cables used in transportable tactical command posts. During the course of this program, ITS has collected a considerable amount of information relating to command post signaling centers and bus-type distribution centers. This has been accomplished by literature search, discussions with cognizant personnel, and by visits to tactical field exercises at Ft. Huachuca, AZ, and Ft. Hood, TX. This information is being evaluated and will be summarized for inclusion in the final report to the sponsor. A major section of the report deals with overall CP/SC network design. The current method used for interconnection of functional units in a typical area signal center is shown in Figure 2-11. The functional units shown in this figure may be spread over an area 3 km to 5 km in diameter. Other topologies such as loop and star-loop combinations are being evaluated for bus-type networks. It appears that the two measures of effectiveness--deployment time and survivability--are often conflicting. The ITS is attempting to develop methods for quantifying the survivability of potential bus-type architectures used at the command post level. One promising means for providing such a quantitative measure of survivability is to determine the effect of inoperative nodes and links on the grade of service. The results of this study can then be used to optimize the topology to enhance survivability and simultaneously reduce deployment time.

A report describing the results obtained is planned for the fall of 1979.

Telecommunications Protection. The Telecommunications Protection program was started in fiscal year 1979 by NTIA in order to conduct the Presidential Directive (PD/NSC-24) Executive Agent responsibilities in communication protection assigned to the Secretary of Commerce and delegated to the Administrator, NTIA. The program is directed by the NTIA Special Projects Office in the Office of Federal Systems and Spectrum Management. The Special Projects Office in Washington, DC, develops policy recommendations and conducts Federal agency telecommunication protection surveys. The technology and technical evaluation part of the program is conducted at ITS in Boulder, CO.

Presidential Directive PD/NCS-24 provided certain policy guidelines that included:

1. Government classified information relating to national defense and foreign relations shall be transmitted only by secure means.

2. Unclassified information transmitted by and between government agencies and contractors that would be useful to an adversary should be protected.

3. Nongovernmental information that would be useful to an adversary shall be identified and the private sector informed of the problem and encouraged to take appropriate protective measures.

The organizational structure established to address the PD/NCS-24 directive includes the National Security Agency acting in its traditional role relating to classified information and national security. NTIA assumed a new role dealing with the protection of unclassified, non-national security related information. The delegation of these responsiblities is summarized in Figure 2-12.

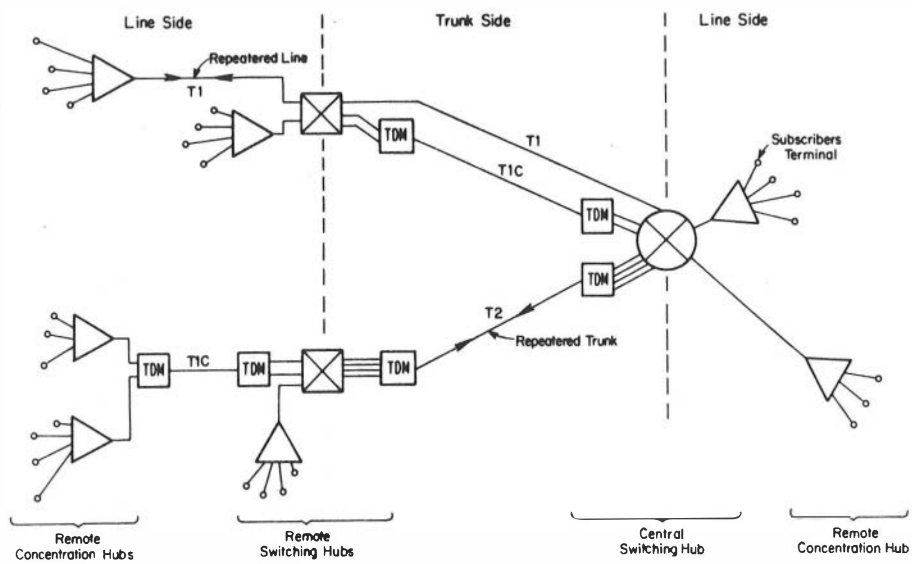


Figure 2-10. Implementation concept for digital concentration, multiplexing, switching, and transmission in the access area.

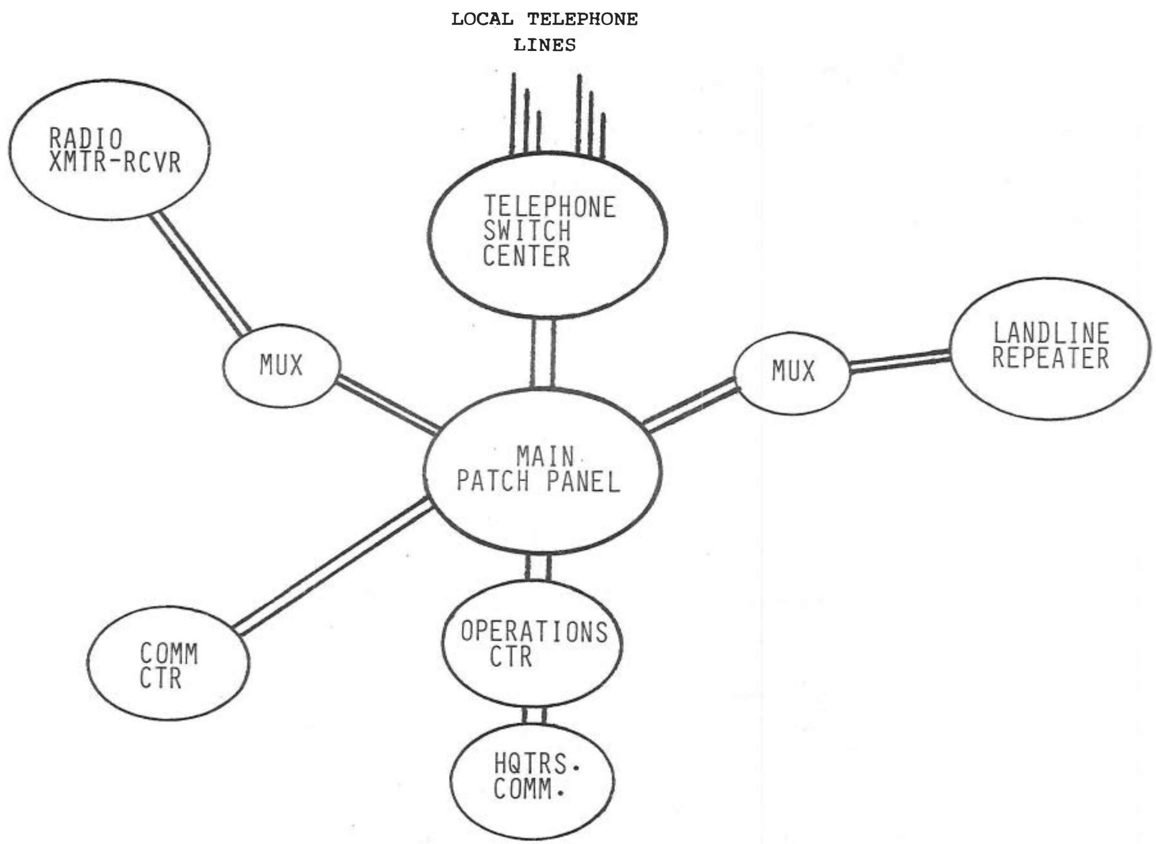


Figure 2-11. Interconnection of functional units for a typical area signal center.

Figure 2-12. Delegation of responsibilities.

Most aspects of the program are classified including the specifics on ITS' role and activities. The report given here, therefore, is by necessity broad and describes the program as a whole rather than focusing only on ITS' technical evaluation role.

The principal threat to telecommunications that NTIA is addressing is the vulnerability of both terrestrial and satellite microwave radio to eavesdropping. The types of information of concern to NTIA in their telecommunications protection role include:

- o Financial Information
  - o Planned changes in prime interest rates
  - o Support of the dollar in foreign exchange markets
- o Commodity Market Forecasts
- o Supply of Critical Materials
- o Strategies for International Negotiations
- o Selected High-Technology Information.

NTIA has identified long range goals and objectives to meet the responsibilities delegated to NTIA by the Department of Commerce as executive agent. In telecommunications protection of government-derived unclassified information, the goals are:

- o Assure adequate protection is available, as warranted, against appropriate threats for selected U.S. Government, U.S. Government contractors, and private sector elements.
- o Formulate a national policy on public cryptographic research.

The second goal deals with the difficult area of balancing the private sector's right to pursue research in the area of cryptography with the issues of national security. Short-term objectives include the development of a National Security and Implementation Plan based upon:

1. Policy analyses concerning key issues and national impacts, and legal and regulatory requirements.
2. System analysis to select a system concept and recommend specific technical solutions consistent with available technology, industry plans, and effectiveness.
3. User-requirements analyses to specify user protection needs, user priorities, and vulnerabilities.

ITS also participates in the writing of telecommunications standards concerned with encryption. Two standards are in the final stages of development. They are Federal Standard 1026 (draft) and 1027 (draft) dealing with the encryption of data for communications and the physical security of the encryption equipment. The work is being accomplished in Subcommittee Three (SC3) of the Federal Telecommunications Standards Committee (FTSC).

SECTION 2.2. SATELLITE COMMUNICATIONS

The main effort in the satellite communications program area during FY 1979 has been on a continuing direct-funded program. On this program, the regulatory, economic, and technological aspects of the development of small-antenna earth station systems have been studied. The major long-term goals of this program are:

1) To foster the use of new and existing telecommunications systems and services by public service agencies (including private groups and all levels of government) to help those agencies meet their needs and goals more efficiently and economically.

2) To help develop for public service agencies the technical means to improve the efficiency and cost effectiveness of their communication systems.

3) To provide technical bases for the development of policies for the future evolution of new satellite communication technologies with significant public service benefits.

During FY 1979, the program was separated into two projects, one addressing orbit/spectrum capacity and regulatory aspects and the second addressing public service applications of satellite communications. These projects are discussed below.

Frequency/Orbit Resource Study and Support of U.S. Proposals for 1979 WARC. The objective of these projects was to encourage the development of low-cost, small antenna earth stations in the fixed-satellite service through the development of technical and policy options and proposed rules relevant to the U.S. proposals to the 1979 General World Administrative Radio Conference (GWARC) and the 1983 Regional Administrative Radio Conference.

During FY 1978, work on these projects focused on preparation of the U.S. proposals through the IRAC Ad Hoc Committee 144. The U.S. position document was completed early in FY 1979. Although the formal proposals had been completed, technical analysis to support these proposals has continued. These studies addressed proposed changes in the allocation of the 11.7 GHz to 12.7 GHz band.

The three related studies dealt with (1) the increased orbit/spectrum capacity that would result from the proposed allocation changes, (2) the feasibility for spectrum sharing between broadcasting-satellite services and terrestrial services in the 12.2 GHz to 12.7 GHz band, and (3) the economic advantages and disadvantages associated with moving the broadcasting-satellite service to the 12.2 GHz to 12.7 GHz band. Results of these studies were provided to the U.S. delegates to the 1979 GWARC.

Technical planning for the 1983 Regional Administrative Radio Conference was initiated during FY 1979. The purpose of the 1983 RARC is to develop a plan for the broadcasting-satellite service for Region 2 of the International Telecommunication Union. As a part of this study, a statistical analysis was made of the orbit-slot and frequency channel assignment plan for Regions 1 and 3 which was developed at the 1977 WARC-BS. The initial technical planning also included a review of computer programs developed by others for analyzing proposed orbit-slot/frequency channel assignment plans.

Public Service Communications. The objectives of this project were to perform public service requirements and cost tradeoff modeling studies and to monitor the development of technology applicable to low cost earth stations for rural and other thin-route satellite communications applications.

On this project, ITS staff have participated in the work and meetings of the Interagency Committee on Satellite Telecommunications Applications. The National Aeronautics and Space Administration (NASA), as a contribution to the work of the Committee, developed a network costing model. This model was used to assess the cost of distributing a video signal from Washington, DC, to 14 other major cities that have Federal office buildings in the downtown area. The resultant network consisted of a satellite uplink terminal near Washington linked to Federal Government departments via microwave relay and receive-only earth stations at each of the federal office buildings in the 14 cities.

The ITS performed a cost analysis of a terrestrial video distribution network using common carrier facilities. The results of these analyses show the cost of the satellite network to be about one-seventh the cost of the terrestrial network. In the analysis of both networks, the capital investment and installation costs were amortized over 10 years.

SECTION 2.3. TERRESTRIAL RADIO SYSTEM PERFORMANCE

This activity is directed toward the design, evaluation, acceptance, operation, and upgrading of existing or proposed systems operated by the Federal Government. The projects generally result in recommendations for systems design and/or upgrading as requested by the other Federal agencies.

EFAS/PEP II Program. The EFAS program addresses the technical performance characteristics of the Digital European Backbone (DEB) communications system shown in Figure 2-13. The DEB program is directed at the conversion of the wideband analog communications systems to secure digital communications systems. An extensive alarm, switching, and status remoting system is imbedded in the new system.

Alarm and status reporting and remote switching is controlled by one of three minicomputers connected to the system that are managed by application programs developed by ITS. The computer system controls polling of the remote sites and presents system conditions in a form most useful to the system manager. The computers also archive all system changes for later analysis. Two of the display formats are shown in Figure 2-14.

The PEP II Program is undertaken to collect information on other parameters not associated with the alarm and switching system. Among these will be rapid sampling of received signal levels at a site that is one terminal of a 160 km link. This path is known to have severe atmospheric layering. Also, station power will be monitored for reliability and channel block reliability and availability will be evaluated.

EFAS/PEP II Program Analysis. The Digital European Backbone (DEB) system contains several links where propagation causes some concern. It also has one site which has a severely restricted antenna mounting area and is one terminal of a 160 km link which is known to occasionally experience severe multipath fading. The maximum obtainable antenna spacing may be inadequate to realize the diversity reception needed on this link. In addition, the effectiveness and accuracy of monitoring techniques for digital equipment is still unproven on a system basis.

This program is to address the aforementioned concerns by acquiring propagation data on the links that are known to have severe atmospheric fading. Data will be collected on system availability and quality to assess system performance. Further, data will be collected to assess the effectiveness of the performance monitoring system.

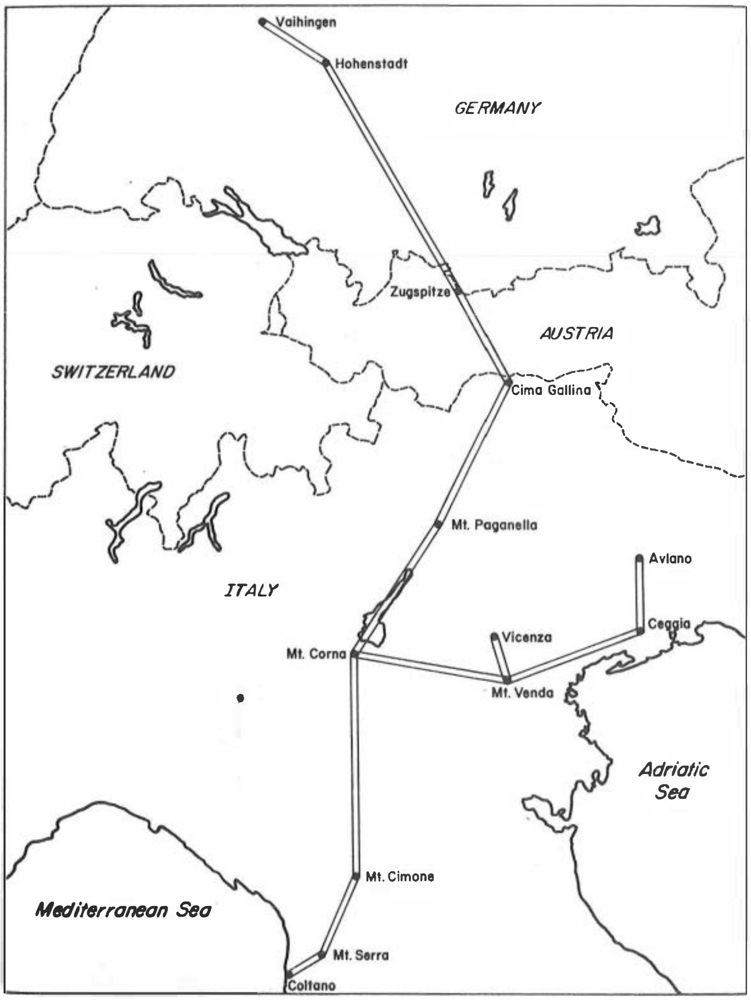


Figure 2-13. Digital European Backbone System, Phase I.

```
212/04:42:45          ***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 2-14.   Sample enhanced fault alarm system displays.

The third minicomputer is to be installed and put in operation on the DEB system. The system software will then undergo intensive testing.

Data obtained from the closely spaced diversity antennas are being analyzed and a letter report will be prepared for the sponsor. Contents of this report are not to be made public without the sponsor's approval.

RADC/Technical Support for the Air Force Killer Kat Communications System. This project was established to provide technical support and consultation to the Rome Air Development Center (RADC) in respect to the development of a special digital troposcatter communications system. ITS personnel have provided review of technical test plans and have participated in program review meetings with the sponsoring agency and the equipment contractor. On-site observation and consultation will be provided later in the fiscal year when the system is installed in Europe.

H.F. Ground Wave. The general goal of this project is to determine optimum antenna aperture distributions for maximizing the ground wave field strength at distances beyond the optical horizon. The primary application is low-angle radar coverage over both land and sea.

The feasibility of exciting the Zenneck surface wave was first examined. By matching either the vertical or horizontal aperture field to that of the Zenneck wave over a flat earth, it was found possible to launch a Zenneck-like wave in the near field. However, for antennas of realistic size, the Zenneck surface wave character vanishes in the far field, and the remaining field has the usual ground wave character. Calculations were actually performed for both flat and curved earth models and for both land and sea paths. In all cases, the Zenneck wave excitation was found to be ineffective.

Surface roughness (land or sea) and sublayering (ice or earth crust) can result in an inductive surface impedance which can strongly enhance the ground wave field strength. The curved-earth attenuation function was calculated for a large range in amplitude and phase of the effective surface impedance. Such calculations cover all expected land and sea path cases of interest.

Using the previous results for ground wave propagation and excitation, optimum antenna aperture distributions for both vertical and horizontal antennas will be determined.

Performance Improvement of HF Communications. Because of the vulnerability of satellite radio to destruction under wartime conditions, the armed forces need to retain and improve their capability in HF digital radio communications. The objective of this project is to make a comprehensive survey of HF digital radio communication techniques to determine the best methods that might be used to improve the performance and reliability of HF digital radio systems.

A study was made of the specific design features of HF digital radio systems that affect their performance. A basic HF digital radio system consists of three major parts: the transmitter, the HF ionospheric channel, and the receiver. The performances of such systems can be specified in terms of bit-error probability and spectral efficiency (information rate/signal bandwidth). The bit-error-probability performance of a system is determined by the signal processing techniques that are used in the transmitter and receiver, and by the types and magnitudes of the distortions that are imposed on the signal by the equipment and the HF channel. The spectral efficiency of a system is determined by the signal processing techniques and is independent of channel and equipment distortions.

The transmitter in general contains an error coder, a modulator, an HF transmitter, and an antenna. The characteristics of the transmitter that affect system performance were considered in detail by classifying and describing; the types of error codes (block and convolutional); the digital keying methods (ASK, PSK, APSK, FSK, and CPK); the multiplexing techniques (frequency multiplexing and concentric multiplexing); the HF transmitter operation (frequency translation, filtering, and amplification); the size, gain, bandwidth, and steering characteristics of a large variety of transmitting antennas; and the additive, multiplicative, and nonlinear equipment distortions introduced by the various parts of the transmitter.

The HF channel in general consists of a number of propagation modes or paths over which the signal travels from the transmitter to the receiver. Because the paths introduce different propagation delays, the channel introduces time-scatter multiplicative distortion, and because each path introduces Doppler shift and Rayleigh fading on the signal, the channel introduces frequency-scatter multiplicative distortions. Noise and interference that are present constitute additive channel distortions. A validated HF channel model was used to characterize the channel.

The receiver in general contains an antenna, an HF receiver, a demodulator, and an error decoder. The characteristics of the receiver that affect system performance were considered in detail by classifying and describing: the types of antennas (including adaptive receiver antennas for suppressing interference); the HF receiver operation (frequency translation, filtering, and amplification); the types of demodulator filters (matched and nonmatched nonadaptive filters and quasi-static and dynamic adaptive filters); the bit-decision or detection methods (coherent, partially-coherent, differentially-coherent, and noncoherent); the types of error decoding (hard and soft); and the additive, multiplicative, and nonlinear equipment distortions introduced by the various parts of the receiver. Also classified and described were the types of diversity operation: single-transmission polarization and space diversity; multiple-transmission frequencies and time diversity; and performance monitoring and prediction methods.

The bit-error-probability performance of a system with respect to the various types of channel and equipment distortions are affected by nine system design features: the fundamental pulse waveform, the keying method, the multiplexing method, the type of demodulator filter, the bit-decision (detection) method, the transmitter power, the antennas, diversity, and error coding. The spectral efficiency of a system is determined by the first four and last two of the same design features. The effects of the system design features on bit-error-probability performance were evaluated with respect to additive channel and equipment distortions, multiplicative channel and equipment distortions, and nonlinear equipment distortions in turn. The effects of the system design features on spectral efficiency were evaluated in conjunction with the evaluation of the bit-error-probability performance. The results of the evaluation were then used to determine the best methods of improving the performance and reliability of military HF digital radio communications. A final report was prepared that describes the study and presents specific conclusions and recommendations [Watterson, C.C., Methods of Improving the Performances of HF Digital Radio Systems, NTIA Rept., 1979 (to be published)].

DOE SECOM Technical Support. This project supports the ERDA Material Transportation SAFEGUARDS programs with the major thrust concerning systems engineering support to evaluate the capabilities and vulnerabilities of the existing SECOM system to support communications with commercial trucking systems transporting nuclear material. 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 design of a system management model.

During this fiscal year, ITS has participated in an evaluation program which involves three Federal agencies: The Department of Energy as operator of the SECOM system and manager of DOE sensitive material transport operations, the Nuclear Regulatory Commission (NRC) Technology Assessment and Test and Evaluation Branches of the SAFEGUARDS Division. In addition, a transportation service contractor will participate in the evaluation. Test direction is the responsibility of the NRC Test and Evaluation Branch.

ITS has developed the test methodology and a detailed test plan. The methodology identifies specific communications and operations event relationships for selected route profiles and provides event temporal and connectivity sensitivities as derived from existing operational and functional models. Communication elements include SECOM and intra-convoy modes. Mission operations include pre-mission system entry at departure sites, enroute status reporting and incident events, and clearance reporting at route termination. The detailed test plan specifies mission planning procedures, data recording methods and analysis processes, appropriate system diagnostics, and convoy crew and intruder force training requirements. The test plans and test procedures are designed to determine the performance of the HF communications system under three conditions; namely: normal transport conditions, unintentional accident, and physical threat (equivalent to airline hijacking or terrorist). In the latter case, the scenario of the simulated threat, which is considered to be non-military in nature, has been defined and sources of public information available to such counter forces as well as the types of military surplus jamming equipment available to an informed adversary have been identified.

Using these test plans and procedures, an actual simulated communications countermeasure event will be staged to determine the vulnerability of the communications system to such intentional jamming. ITS will participate in a DOE/NRC planning session and serve as a technical advisor and resource in the planning of this test. The tests will actually be performed by DOE contractor personnel with the counterforce being supplied by U.S. military personnel who will be given the information which ITS has generated and resources to develop the communications countermeasure system from commercially available equipment.

Digital System Performance Verification. The U.S. Army Communications Command (USACC) at Ft. Huachuca, AZ, found it necessary to convert two 4-5 GHz transhorizon transmission paths from analog-to-digital operations. A DCEC Technical Report describes the bit-error performance expected of a transhorizon digital system. However, the prediction models used are based on models contained in NBS Technical

Note 101, or variations of this model. The Technical Note 101 model was developed from measured data concentrated in the 40-1000 MHz frequency range. The prediction associated with using frequencies outside the actual operating range is discussed in Volume II of NBS Technical Note 101.

A method for reducing the performance prediction uncertainty by decreasing the width of the confidence interval is available and it makes use of measured data. The measured data are particularly valuable if the data are obtained on the actual transhorizon path.

Path-loss data were obtained from a 60-day measurement program on the two transhorizon paths. The hourly medians were combined, for each path, into a cumulative distribution of hourly medians, and calculations were made using these data to decrease the width of the confidence limits. The total width of the confidence limits were decreased roughly 9 dB for each path.

The improvement in the confidence of performance predictions led to suggesting that the link performance criteria for these paths could be met by replacing the present waveguide with new types having half the attenuation and realigning the obviously poorly pointed antennas. This resulted in discarding any thoughts about increasing the power amplifier output power from 1 kW to 10 kW, a significant reduction in cost.

SECTION 2.4. SIMULATION AND STANDARDS

Radio system 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.

MEECN Simulation. The present objective of the project is to complete the development and evaluation of an experimental adaptive filter that can be used in digital spread-spectrum radio receivers to suppress interference (unwanted signals).

Most digital radio systems use nonadaptive (time-invariant) receiver filters, usually matched filters that optimize the receiver performance with respect to white noise. Matched receiver filters generally provide suboptimum performance with respect to interference; however, generally better performance can be obtained with an adaptive filter that automatically adapts or adjusts its response, according to the characteristics of the interference, to maximize its output signal-to-interference ratio. As described in more detail in ITS Annual Technical Progress Report for 1978, adaptive filters can be particularly effective in spread-spectrum receivers where the performance improvement they provide is in 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 and the bandwidth ratio increases, with relatively little or no improvement remaining when the bandwidth ratio approaches one.

Prior to FY 79, an experimental adaptive filter, based on a relatively simple delay-line model, was designed and built. It was temporarily incorporated in a U.S. Air Force 616A VLF-LF spread-spectrum digital radio system, and channel-simulator experiments were performed on the modified system to determine the performance improvements provided by the adaptive filter. The expected substantial performance improvements were observed in the experiments, which also confirmed the expectation that dynamic nonlinear operation of an adaptive filter can provide greater performance improvement than quasi-static linear operation. During FY 79, a classified report was prepared on the design and characteristics of the adaptive filter and the results of the channel-simulator experiments [Watterson, C.C., An adaptive receiver filter for interference suppression in digital spread-spectrum radio systems (U), NTIA Technical Memorandum 79-9C, 142 pp, February 1979 (Secret), U.S. Department of Commerce, Boulder, CO 80303.]

DCS II Standards Development. This program was contracted to ITS to provide technical assistance to the Defense Communications Engineering Center (DCEC) for identifying areas where standards are required for the DCS II program. The FY 79 effort is to evaluate evolving communications technology, review standards, define functional standards areas, and define one major function area for investigation in regard to the functional area selected. ITS will identify standards requirements, look at cost impact, assess feasibility, and recommend standardization action.

FED-STD-1037, Vocabulary for Telecommunications. This comprehensive glossary of telecommunication terms and definitions is the result of a joint effort by numerous DoD and non-military Federal agencies. It will serve as the nucleus of a commonly agreed upon language for both the MIL-STD-188-100 and the FED-STD-1000 series of system performance standards.

The initial data base for the glossary was MIL-STD-188-120, Military Communication Standard: Terms and Definitions, edited by ITS and published in 1975. This portion of the vocabulary has been extensively reviewed and updated by DoD agencies in order to keep abreast of advancing technology and continuing revisions of the MIL-STD-188-100 series.

Primary additions, consisting of over 700 new terms and definitions, came from the Federal sector. Many were drawn from evolving federal performance standards such as FED-STD-1033, Telecommunications Digital Communications Performance Parameters. These new data were added to the computer-stored MIL-STD data base to produce a draft of approximately 2000 entries. This draft was distributed to 75 reviewers within the DoD and Federal communities. Reviewer inputs were considered by a joint DoD/ Federal Resolution Subcommittee of the Federal Telecommunications Standards Committee, meeting in two 2-week sessions in late FY 78. ITS was a participant in both sessions and has been responsible for incorporating the extensive editorial modifications into the draft document. ITS is currently engaged in final corrections to the revised glossary and in a comprehensive cross referencing of the integrated document. Publication is scheduled for early FY 80. This work has been funded by the National Communications System and the U.S. Army Communications Command/Communications-Electronics Engineering Installation Agency (USACC/CEEIA), and coordinated via The Standards Branch of CEEIA. Figure 2-15 summarizes primary tasks involved in creation of this Standard, as well as current status of the various tasks.

ITU Participation. T. de Haas, Chairman of the U.S. CCITT Group for Data Transmission, led U.S. participation in CCITT Study Groups VII and XVII. Some of the notable outputs from these Study Groups are a world-wide numbering plan for data networks which also includes capability for interconnection between data-, telephone-, and telex-networks, a new Recommendation for 1200 bps duplex modems for use on the public switched telephone network, and several new and updated Recommendations relating to packet switched data services.

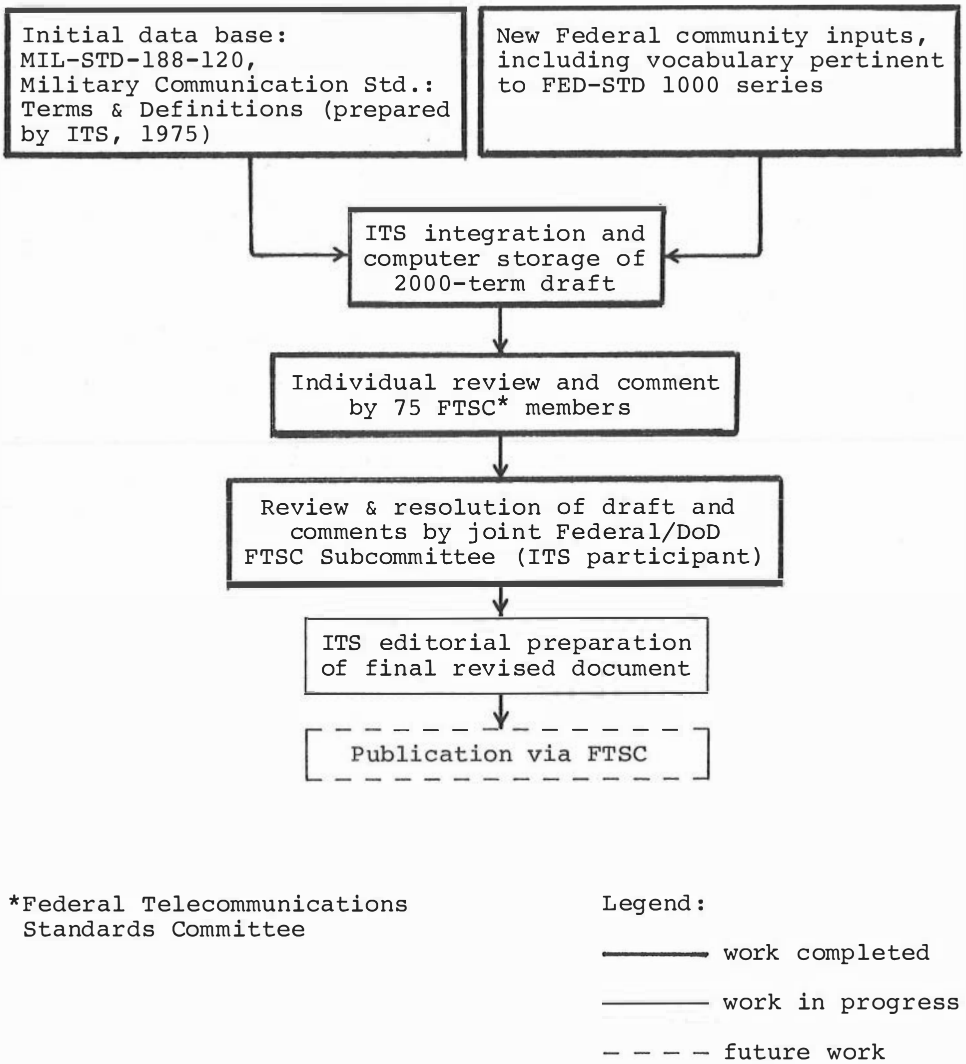
In the CCIR, Mr. de Haas is International Chairman of Study Group 3, dealing with radio systems in the Fixed Service operating at frequencies below 30 MHz. He also participated and was a Topic Coordinator in the Special Preparatory meeting of the CCIR which prepared the technical bases for the 1979 World Administrative Radio Conference. ITS is also contributing to the work of Interim Working Parties (IWP's) 8/5 and 8/8 in the maritime mobile services, as detailed in the MARAD Assistance program description appearing in Section 2.1.

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 the Chief U.S. Delegate to the International Electrotechnical Commission Subcommittee on Fiber Optics. These activities are discussed in detail below.

Optical Communications Task Force. Prior to 1970, optical fiber "light pipes" fabricated from commercial grade optical glasses yielded transmission attenuation typically ranging from 800 to a few 1000 dB/km, precluding their use for any practical communications applications. In that year, the first low-loss optical fiber waveguides, fabricated from ultrapure fused silica, were successfully produced by a U.S. manufacturer. Attenuation was measured, in the laboratory, at approximately 20 dB/km. It was almost another five years before the first such low-loss optical waveguide was made available (on special order, in custom production) in cable form--by the same domestic firm. In 1979, dozens of manufacturers in the U.S. and abroad offer, as commercial shelf items, a broad variety of optical waveguide cables. Laboratory measurements of uncabled fibers are currently as low as or less than 1.0 dB/km, and cable attenuation, after systems deployment, runs as low as 3 or 4 dB/km. The guided wave optical transmission line has technically come into its own as not only a practical, but an extraordinally efficient, communications medium. The worldwide operational success of hundreds of systems attests to the simultaneous rapid development of optical sources, detectors and other systems components.

Parallel with this technological evolution has been the activity of the Optical Communications Task Force (OCTF) formed by ITS in FY 75. Creation of the Ad Hoc Task Force was in accordance with the OT mission "... to assist the Department of Commerce in fostering, serving, and promoting the nation's economic development and technological development by promoting man's comprehension of telecommunication science and by assuring effective use and growth of the nation's telecommunication resources...." Continuation of the Task Force work is in support



*Federal Telecommunications Standards Committee

Figure 2-15. Status of FED-STD-1037, Vocabulary for Telecommunications.

of the NTIA mission of serving as a national focus for Federal policy and decision making in those areas vital to the Nation's economy in this new Age of Information.

The OCTF was developed to provide an informal, interactive forum among government, university, and industry technologists, potential systems users, and policy makers in order to explore jointly the technological and economic potential of optical communications applications. The emphasis of the Task Force is now on guided wave technology, as the result of the growth of its varied and successful system applications. Optical transmission through the atmosphere has also advanced remarkably within the same past few years, but applications have been more limited because of both bandwidth and range restrictions imposed by an often hostile environment.

In the coordination of the OCTF, ITS has assumed a catylytic role with other Government agencies in the evaluation of this new technology by interagency participation in semiannual workshop sessions, augmented by ITS preparation and distribution of Summary Reports of presentations given during the meetings of the OCTF Applications and Users Working Group.

These Working Group meetings have been consistently well attended by senior representation from industry, leading universities, and government, including the DoD. Task Force participants have benefited from the informality of the Working Group. This often has resulted in the early and opportune dissemination of technical information and product availability, and also in the open discussion of economic aspects that are infrequently introduced in formal communications society meetings. One such topic surfaced during the first Workshop meeting in FY 79. The representative of a U.S. system manufacturer presented a summary of his firm's product line, emphasizing that "the technology is ready" for volume production, but that their market analysts were unable to predict a near-term market adequate to justify those costs required to tool up for mass production. This presentation was followed by that of a representative of a leading domestic producer of (uncabled) optical fiber waveguides, who announced that his firm's mid-1978 sales volume had reached the level previously predicted for 1980. Workshop participants found these two statements paradoxical, asking the fiber manufacturer where his market was, in view of the pessimistic outlook for domestically-produced systems. The reply was: "Germany, Italy, the U.K., France, and Japan." Various conclusions may be drawn relative to potential effects upon U.S. balance of trade; the point to be made here is that the OCTF is fulfilling the Department of Commerce mission by providing a forum wherein such interchange does take place and where potential policy issues, as well as avenues of technological development, may be identified.

The two FY'79 Working Group meetings have covered a broad range of topics including: component development; experiences in various physical types of installations of optical transmission lines; computer interfacing; integrated optical circuits; need for and progress in standards; alternate configurations of optical data buses; user needs, including those of the Federal government and the DoD; descriptions of trial and operational systems; and discussions of economic factors and the impact of potential policy and regulatory decisions.

Optical Waveguide Communications Glossary. The rapid emergence of optical fiber waveguide communications from the laboratory into commercial systems applications has been accompanied by the growth of a specialized vocabulary. Some terms have been borrowed freely from the disciplines of optical physics and communications engineering; others have been coined independently.

In this process, inevitably, some ambiguity and impreciseness have resulted. More significantly, perhaps, some terms have been used to specify a product--and are beginning to be accepted by manufacturers and users--but are not precise descriptors beyond rather narrow limits. The absence of a precise, common language among researchers, manufacturers, systems designers, and users is a hindrance to effective technology development and utilization. The need for such a common language has become pronounced as numerous standards working groups in both government and the private sector, nationally and internationally, have become engaged in preparation of performance standards covering components and systems.

In recognition of this need, ITS compiled a preliminary vocabulary data base during FY 1978. This effort has been continued throughout FY 79, attracting broad interest and technical support from outside individuals and organizations. Early in FY 79, ITS enlarged the initial data base, writing definitions for numerous terms commonly employed in optical communications but not concisely defined in the literature. This initial draft was computer stored to facilitate text editing during the anticipated several generations of review and revision. At this time, it was decided that the scope of the glossary--and the accuracy of its definitions--would be augmented by contributions from physicists with backgrounds in measurement standards, to complement ITS experience in communications engineering. As the result, two NBS scientists, both actively engaged in optical measurement studies, were added to the editorial staff, thereby creating a joint ITS/NBS effort.

Individual contributions from this group of editors were added to the initial draft, and the revised document was critically reviewed during numerous interactive meetings of the editors. Selection of terminology was deliberately restrictive, with the goal of including only terms specifically applicable to the field--and of defining those terms rigorously. This definition process entailed some subjective decisions, a few of which are anticipated to create controversy.

After completion of ITS/NBS review, the first external release of the glossary was as a draft input to the ITS-chaired North American Advisory Committee of the Joint CCITT/IEC Working Group "O" on Definitions and Terms for Fiber Optical Communications.

This Advisory Committee consists of U.S. and Canadian representatives from private industry and government (including ITS and NBS), all active workers in the field of optical waveguide communications. This committee subjected the draft to further review and expanded its scope by inclusion of additional terminology pertinent to component manufacturers and systems performance standards groups.

The resultant document, therefore, reflects the experience and backgrounds of a select group of professionals with widely varying expertise in the field. The glossary is currently in the process of publication as an NTIA Special Publication. It will have been presented (Sept. 1979) in Amsterdam, The Netherlands, by the (ITS) Coordinator of the CCITT/IEC Advisory Committee as the coordinated North American (U.S./Canadian) Position on Vocabulary to the first international session devoted to creation of standard terminology for the field. It will also have been submitted, by request of the IEEE Standards Office, to IEEE Standards Committee 10 for publication in The IEEE Standard Dictionary Series.

Requests have been received for distribution of the NTIA Special Publication to numerous performance standards working groups including EIA P6.6 on Fibers and Materials, CCITT Working Group 15 on Standardization of Fibres, IEC Working Group 1 on Fibres and Cables, and IEC Working Group 46E on Fibre Optics. The glossary will be submitted at the appropriate time for inclusion in the first revision of FED-STD-1037, Vocabulary for Telecommunications (also prepared by ITS). The block diagram of Figure 2-16 summarizes the evolution of this glossary and its planned distribution.

Optical Waveguide Transmission System Engineering. ITS has continued its catalytic role in fiber optics technology by interacting with the technical community at large. A small project has resulted in a study (and publication) which attempts to evaluate the U.S. position relative to foreign competition in capturing a fair share of the world market in fiber communications components. The study is based on active participation of the leading countries in publishing, capturing patents, and presenting technical results at international meetings. The results of the study show that Japan is a strong competitor, and the relative position of the U.S. and Japan is reminiscent of the TV industry a few years ago.

In another small project, we assembled data on fiber optics installations in North America and Australia and the results were combined with similar data from Europe and Japan to yield a survey of world-wide fiber installations. The results were presented in a plenary paper at an international meeting in Washington and have been presented for publication in IEEE Spectrum, a publication having a circulation of about 180,000. The study attempted to alert potential users of new systems to the problem encountered thus far and the solutions that seem to be working in the field. Concentration in the North American survey was on non-government installations.

A small project, which is just being started as FY 79 draws to a close, is the development of a user-oriented software package for desk-top mini-computers to analyze and synthesize fiber optic systems.

The program will operate in a menu-drive mode, allowing for use as a learning tool when the need is apparent. If the user is familiar with component specifications, the tool can be used for complete analysis or synthesis (including proposal evaluations) of fiber optic systems.

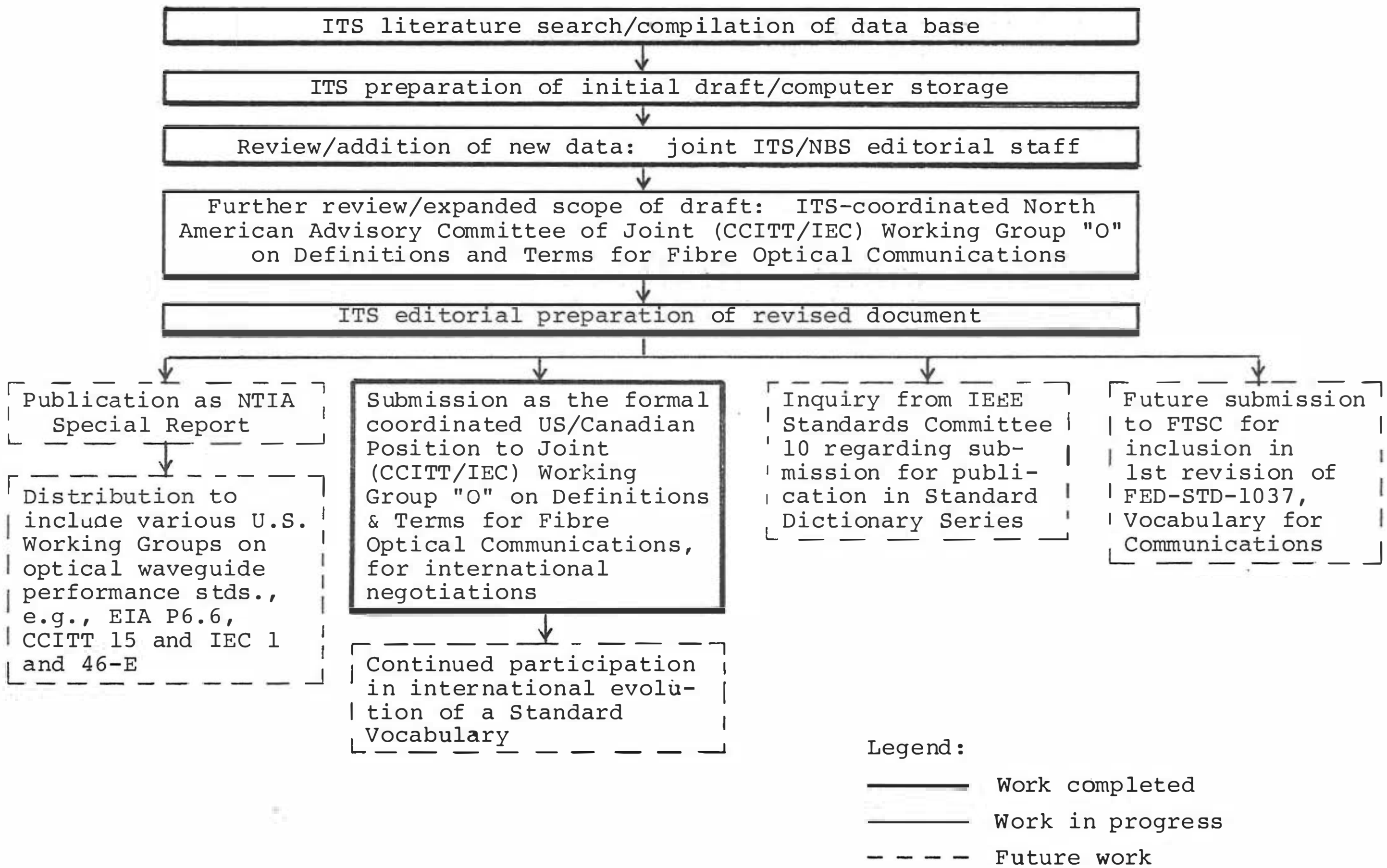


Figure 2-16. Status of glossary on optical fiber waveguide communications.

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 studies 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.

Multipath Fading. Radio signals in the mm/cm wavelength range are subject to severe fading (e.g., > 30 dB) on terrestrial paths of a few tens of kilometers or more. Such fading is in addition to attenuation by rain and is often omitted from consideration in point to point link design. These amplitude variations through clear air may be caused by:

a. phase interference from surface reflections,

b. misalignment of the antenna beams by refraction,

c. focussing/defocussing of the beams by refraction, or

d. atmospheric (surface and/or elevated) ducts, one of the more complicated fading mechanisms to investigate and possibly the main mechanism for fading on LOS links.

The objective of this program is to provide an improved model for understanding the physical mechanisms of the amplitude and phase of the received signal for systems expected to experience non-rain fading.

An example of the potential fading from phase interference is shown in Figure 3-1 for a system at 30 GHz having a surface reflection coefficient of 0.95 at mid-path. Antenna heights are equal and the abscissa (log scale) is the ratio of the depression angle (to the reflection point) to the (equal) antenna beam widths. The curve labelled R is the ratio of the amplitude of the reflected and direct signal components. The two curves FE show the fading "envelope" corresponding to the extremes of in- and out-of-phase conditions for the two components, and FR is the difference between these extremes, i.e., the potential fading range. For a path of 25 km (at 30 GHz), a change in refractivity lapse rate of only 8 N/km could produce a fade equal to FR.

Measurements of fading are being made on a 23 km path at 9.6 and 28.8 GHz from the

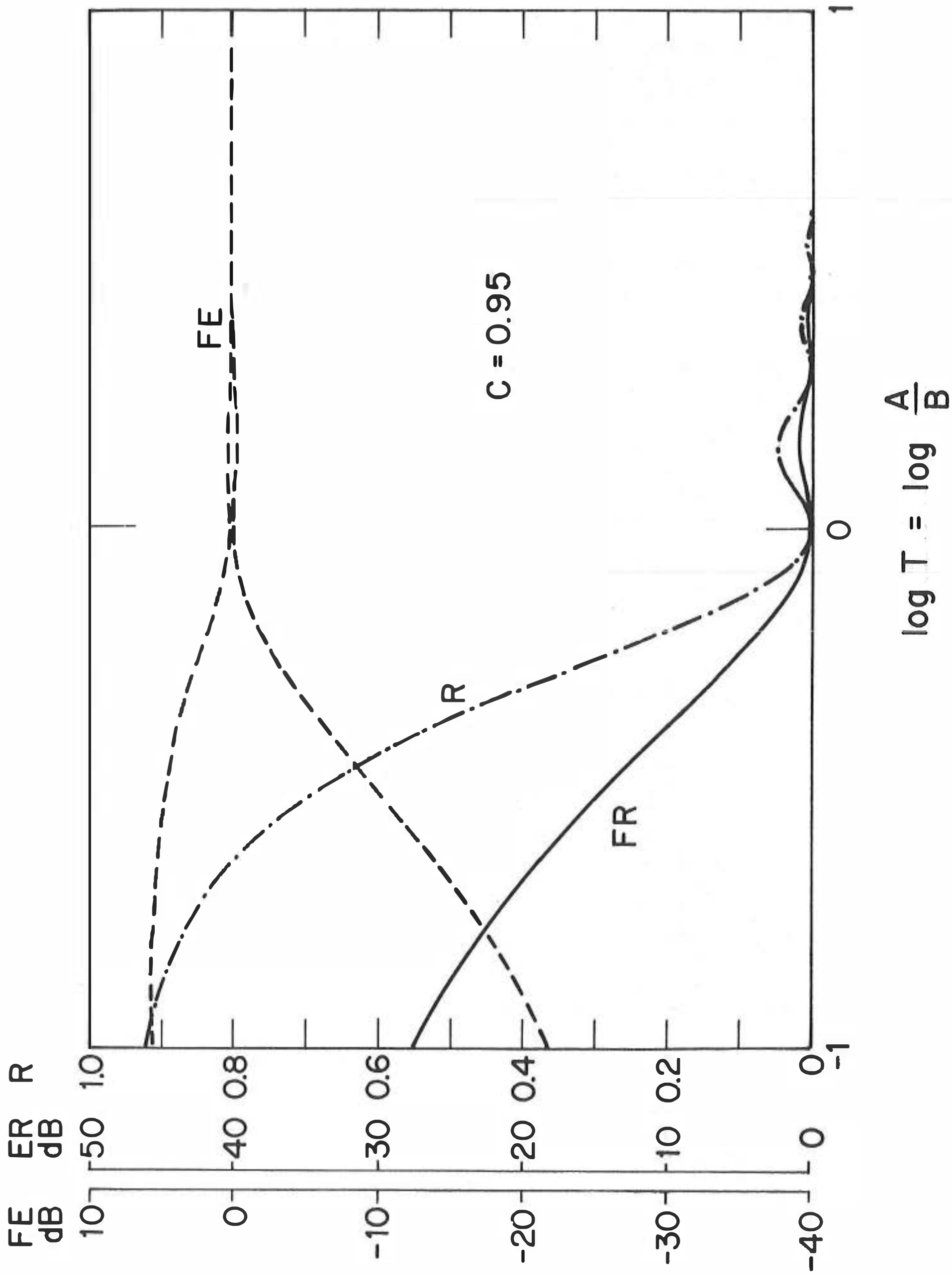


Figure 3-1. Effects of path/antenna geometry on received signal with phase interference by one ground-reflected component. Amplitude of resultant signal: R; envelope of maxima and minima: FE; fading range: RF. Abscissa is ratio of depression angle of reflection point to antenna beamwidth.

Radio Building to the Boulder Atmospheric Observatory of NOAA near Erie, Colorado. The transmitters are mounted on the elevator of a 300 m tower. This permits height-gain measurements which give information about surface reflection coefficient and location. More importantly, this path will allow a determination of the effective earth's radius and thereby provide a calibration on possible measurements of refractive index and its gradient. The path profile (for an effective earth radius factor of k = 4/3) is shown in Figure 3-2. The path passes over a relatively thin ridge which is expected to minimize surface reflections and act as a diffraction edge. Figure 3-3 shows a ray trace for a duct having a gradient three times the critical value (i.e. -471 N units/km). The transmitter could be located within the layer while the receiver is located below the layer. This is an obvious example where ray tracing would fail to predict the signal strength and where a full wave solution is required. Figure 3-4 compares the measured data with the results expected from knife-edge diffraction theory.

The receiving terminal is presently being moved to the ITS Table Mountain field site (north of Boulder) to provide a path which is expected to include a significant surface reflected component. The planned experiment will include measurements of refractivity gradients in the path vicinity by microwave refractometers on the tower and flown in a small aircraft.

SECTION 3.2. CHARACTERISTICS OF THE TRANSMISSION MEDIA

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

3.2.1. Atmospheric Characteristics

Modeling of EHF Propagation in Clear Air. The number of millimeter wave systems operating through the atmosphere in the EHF band (30-300 GHz) is growing rapidly, in part due to their ability to penetrate smoke, dust, fog, clouds, or light rain, which gives them an advantage over infrared and electro-optical devices for adverse weather applications. Areas where EHF systems are a logical choice include broad bandwidth communications, surveillance radars with high spatial resolution, space radars with the possibility of ground-clutter reduction by molecular absorption shielding, strato-mesospheric trace gas studies from SPACELAB, and satellite meteorology where radiometry provides global vertical profiles of temperature and water vapor. In all cases it is essential to have accurate knowledge of atmospheric EHF characteristics, in particular, to be able to predict their variability with weather, location, and height.

Atmospheric propagation effects inherent to the gaseous atmosphere are of foremost importance since they are always present. EHF applications are dependent on a description of the somewhat complicated interaction between millimeter waves and the molecules that comprise the atmosphere. The purpose of the work was to translate molecular spectroscopy into an engineering data base which can be readily applied to generate attenuation, phase dispersion, and emission properties for modelled radio paths within, into, and through the neutral atmosphere (h = 0 to 120 km).

The relatively stable air mass of the first hundred kilometers in altitude h is a unique filter and generator in the EHF band with transfer, shielding, and emission properties not found at any lower frequency. 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. It is possible to predict such behavior for a radio wave traversing a clear, inhomogeneous atmosphere if the physical parameters [height profiles of pressure p(h), water vapor density $\rho(h)$, temperature T(h), and trace gas number densities $v_i(h)$, and geomagnetic field strength H] along the radio path are known. The interaction between radiation and air is expressed through a complex refractivity

$$N(\nu, p, \rho, T, H, v_i) \quad .$$

The N-calculation takes into account 36 O_2 lines, 6 H_2O lines plus a nonresonant spectrum, and if needed, includes a data base for trace gas spectra (>100 O_3, 2 CO, 64 N_2O lines) which are generally weak. The calculation scheme has been verified to a large extent by laboratory measurements. An uncertainty remaining is the empirical prediction of anomalous water vapor absorption, which reduces at high relative humidities the transparency in the window ranges (centered around 40, 90, 140, 220 GHz).

Various computer calculations of molecular transfer characteristics were performed using numerical approximations for the cumulative behavior along slant paths. Results from these modelling efforts are depicted in Figure 3-5.

USAF-ESD/AN/TRC-170 Digital Tropo Tests. This project was in support of the Air Force Electronic Systems Division. The objective was to perform path-loss and delay-spread measurements over a number of designated troposcatter paths in southern Arizona. The particular paths were selected

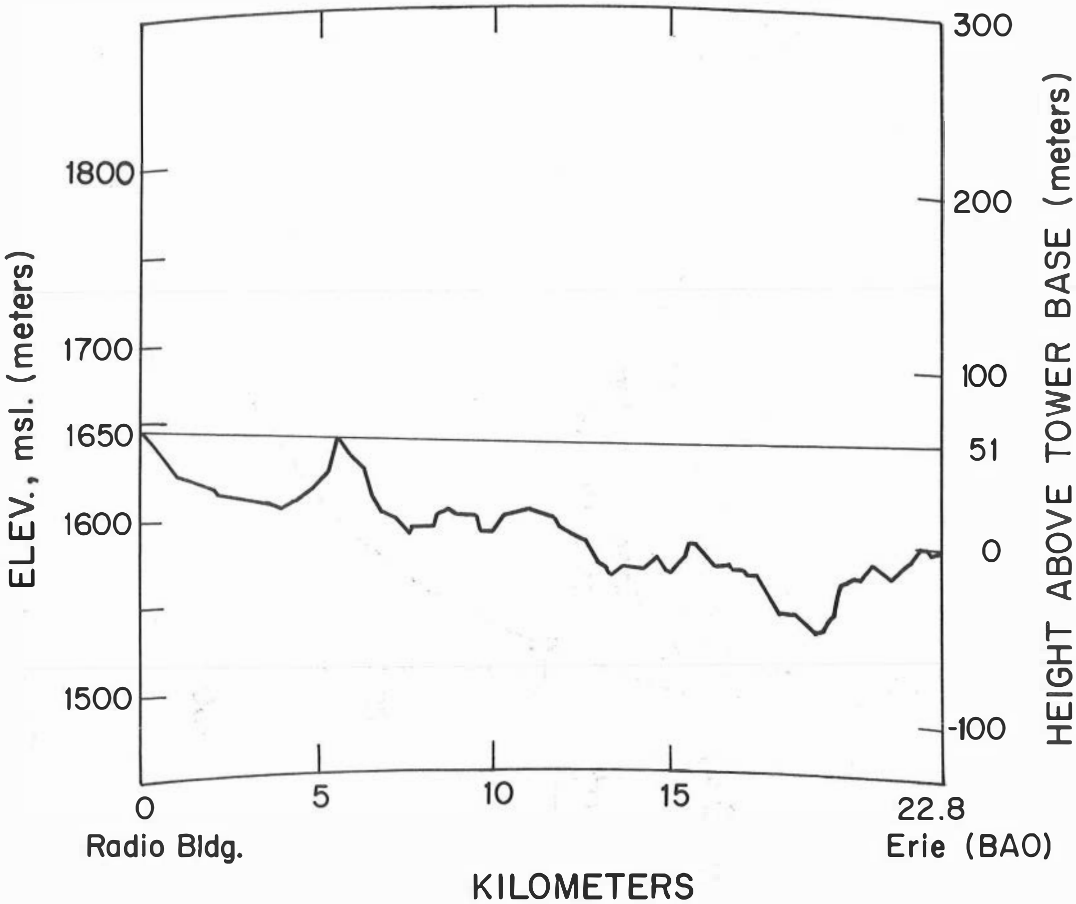


Figure 3-2. Profile of Radio Building/BAO Tower for k = 4/3 showing diffraction ridge.

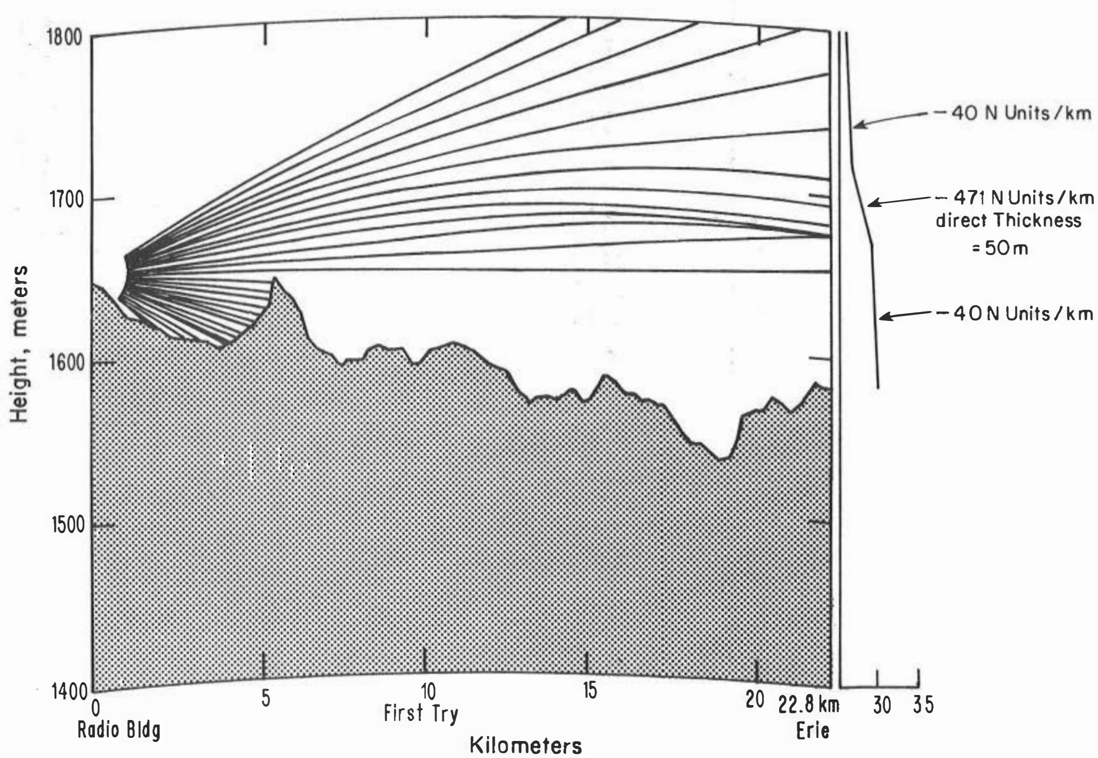


Figure 3-3. Ray tracing for layer with ducting gradient of -471 N/km.

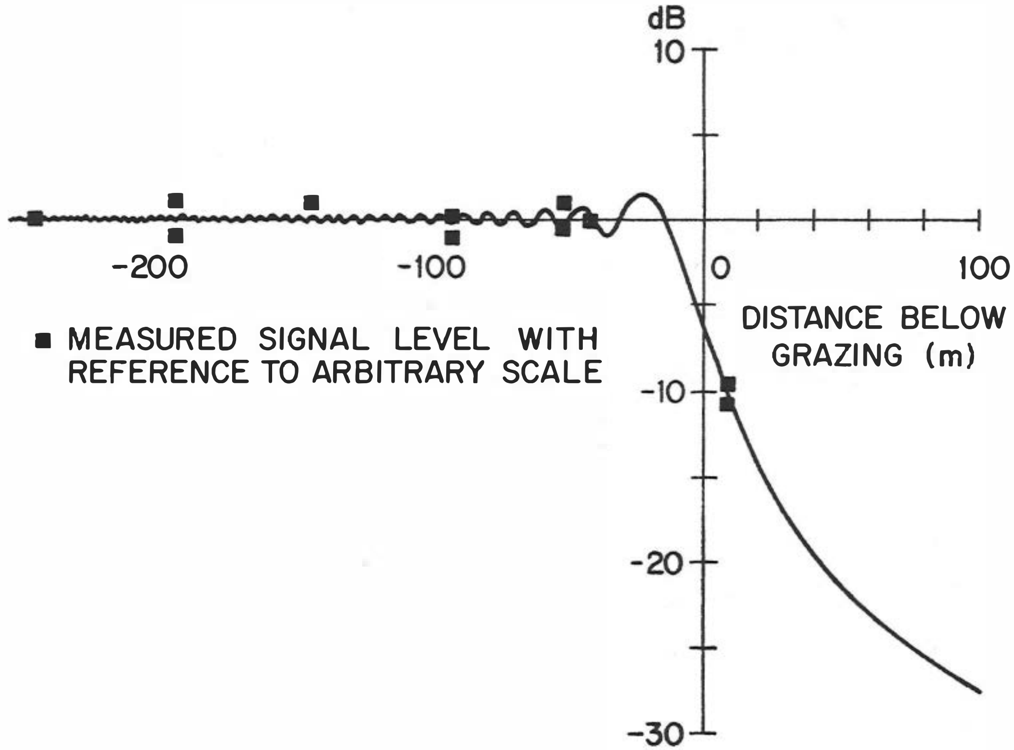


Figure 3-4. Example of measured data at 28.8 GHz compared with results expected from knife-edge diffraction theory.

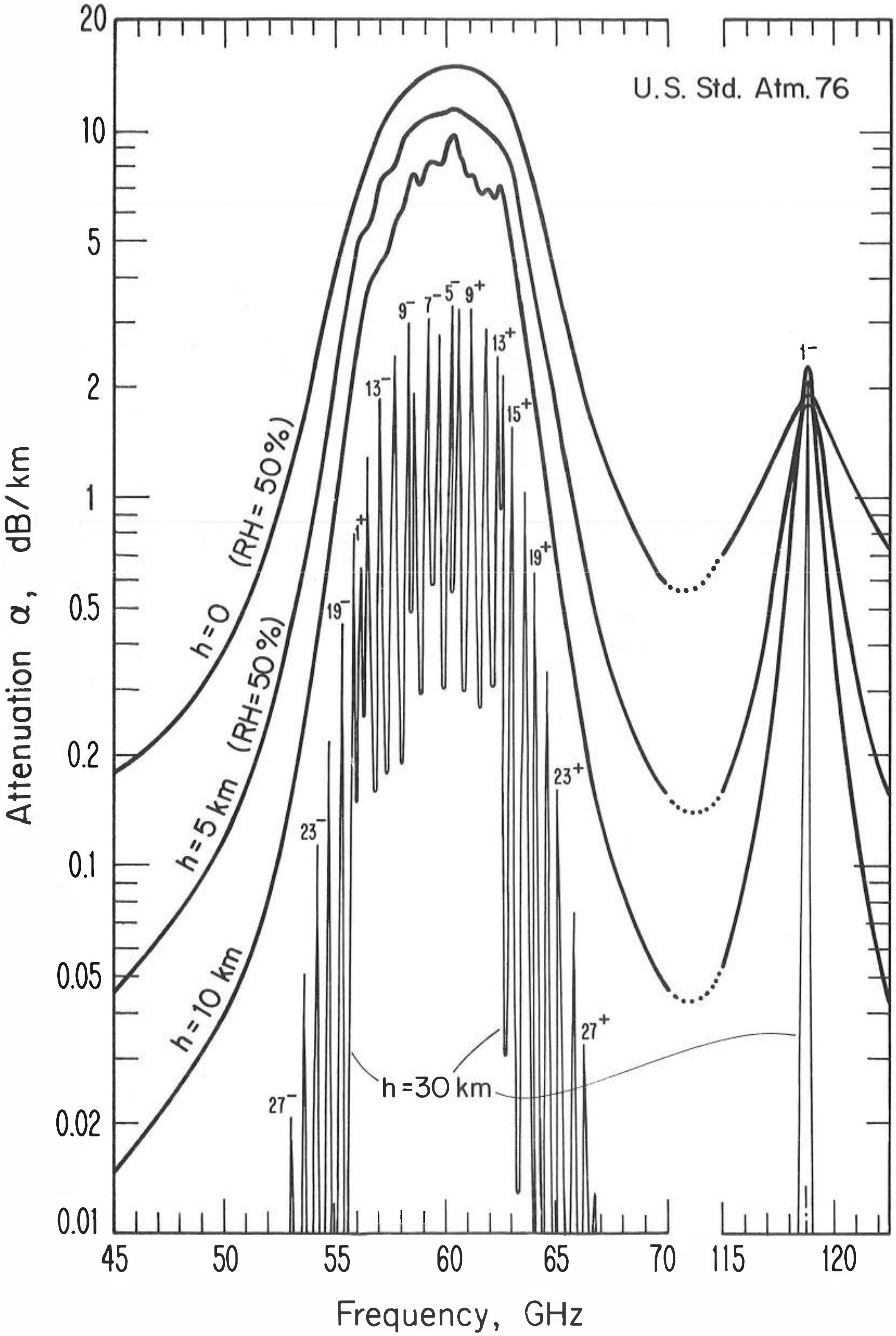


Figure 3-5. Molecular (mainly O_2) attenuation rates at four height levels between 0 and 30 km for medium (R. H. = 50%) humidity.

by the Air Force Tactical Communications Test Office with support of the MITRE Corporation at Fort Huachuca, AZ. The paths were chosen as potential test paths for the AN/TRC-170 Tactical Tropo Equipments being developed under the TRI-TAC Program. Full field test and evaluation programs for the AN/TRC-170 equipments are expected to begin in fiscal year 1980 at these locations.

The purpose of the measurements was to provide a "calibration" of the path loss and delay-spread parameters of each path, to ensure that they were not beyond the design specifications imposed on the developers of the AN/TRC-170 systems. The equipment configuration used an AN/TRC-97A analog troposcatter system as the host radio, which was furnished by the USAF. The radio equipment was installed and operated by the 3rd Combat Communications Group from Tinker AFB, OK. The delay-spread parameter was measured using the ITS Psuedo-Random Noise (PN) Channel Probe. The latter is an instrument designed to measure the effective impulse response of a radio transmission channel. A PN test signal, generated in the form of a binary data stream is used to bi-phase modulate an IF signal in the transmitter, and is then mixed with the propagating frequency. The receiver of the system uses a multiplex type correlation detector (in each of two channels), and develops the equivalent low-pass impulse response by correlating the received data stream with a locally generated replicum of the transmitted code pattern. The probe was designed for application in both microwave LOS links and troposcatter circuits. The PN code may be clocked up to 150 MHz, providing a time resolution on the order of 6ns. However, for the troposcatter measurements the clock rate is generally held to 10 MHz, so that the signal BW is commensurate with the capabilities of the transmission system. In this case, the time resolution of the impulse measurement is on the order of 0.1 μs. For high clock rates, the IF is 600 MHz, while at the lower clock rates and for interface with existing radio systems, a 70 MHz IF signal is used. The latter configuration was used in this program so that a direct interface with the AN/TRC-97A radios could be effected. The final amplifier stages of the transmitter were carefully tuned to accomodate the broadband PN test signal. The transmission frequency for the tests was in the tuning range of the TRC-97A system, between 4400 and 5000 MHz. Calibration for the received signal level (RSL) was accomplished with a calibrated signal generator at the rf input to the radio receivers. The generator frequency was adjusted with the aid of a frequency counter that monitored the IF at 70 MHz. All of the data were recorded on analog magnetic tape.

Four radio paths were tested in the program, ranging in length between 38 and 140 miles. The probable propagation mechanisms included diffraction as well as troposcatter. The experiments were performed during January and February, 1979, spending approximately one week on each path. Data were obtained almost continuously in order that diurnal effects could be determined. In general, each path proved to be acceptable for the future AN/TRC-170 test program, under the criteria established for the propagation conditions, and specific test plans can be finalized based on the measurement results. Delay-spreads on the average ranged from 0.3 to 0.5μs, with longer spreads of 0.8μs for shorter periods of time. These values are given in terms of the 2σ values of the distributions, assuming a Gaussian function. The analyses were made using a time-series computer that measured the distribution of the impulse width. The majority of the functions displayed a Gaussian character, with the exception of the path that contained a strong diffraction component. An example of the impulse response measured over one of the test paths is shown in Figure 3-6. The photograph was made from a display on a storage oscilloscope with a few seconds time lapse. It illustrates the time variability of the response.

Path loss measurements and predictions were comparable for two of the paths tested. However, all of the data processing was not completed at the time of this report, and thus no detailed comparisons were possible. A final report on the project will be published in the final quarter of FY 79.

Radio-Optical Refractometer. In the atmosphere, microwave signals propagate slower than optical signals, due principally to the effect of water vapor. Measurements of the difference in velocity over a transmission path can be used to calculate the total amount of water vapor along the path. For a path of 10 km through saturated air at sea level, the difference in transit times for a 10 GHz (3 cm) microwave signal and a 475 THz (6328A) laser signal is about 3 ns.

To estimate the integrated water vapor density to 1% thus requires measurement of the differential transit time to 30 ps. This accuracy can be achieved by measuring the phase difference between a 100 MHz sinusoidal modulation on the laser beam and a 10 GHz signal generated coherently from the 100 MHz oscillator and transmitted over the path. This method was demonstrated on a 45 km path with fixed terminals in 1967 and patented in 1969.

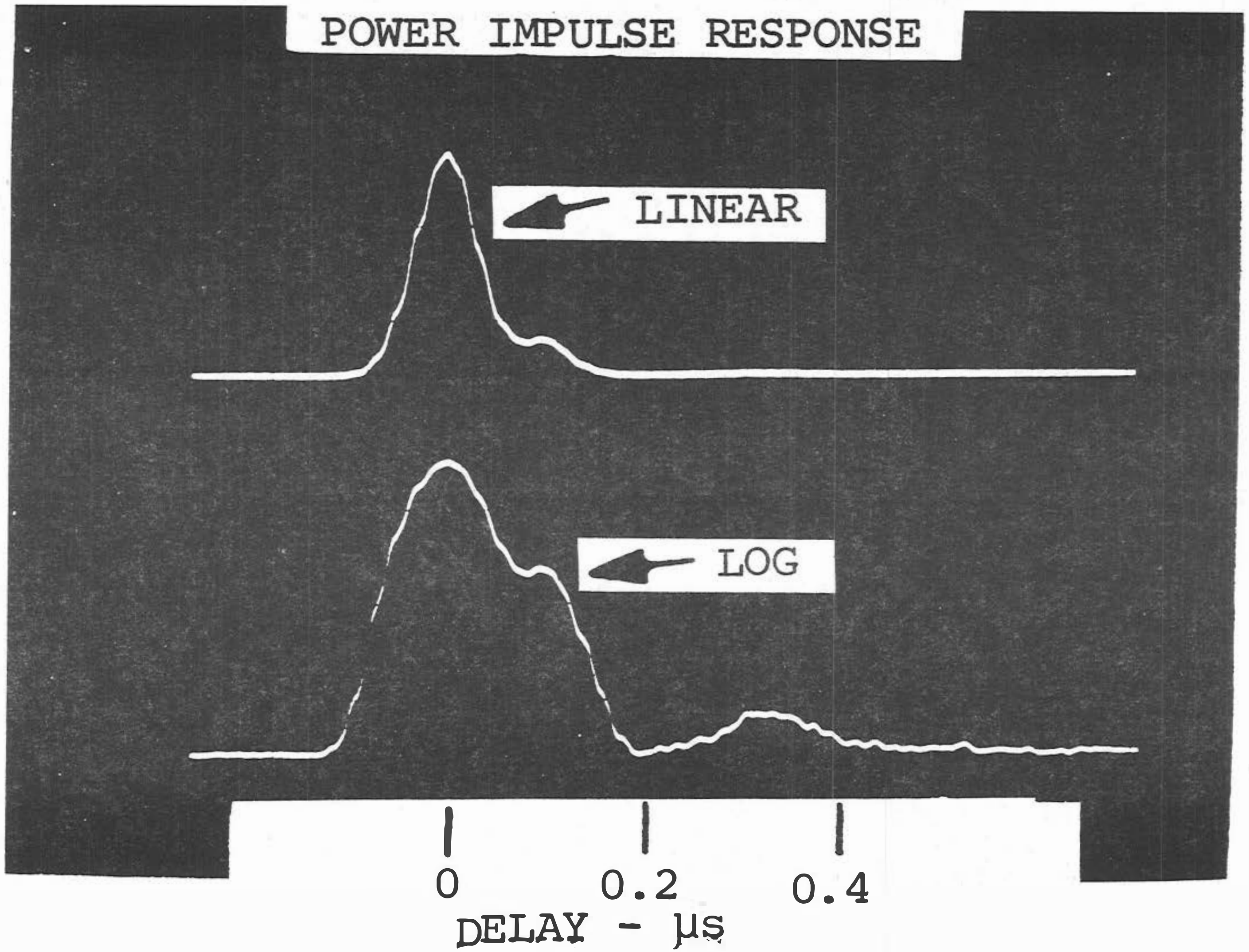


Figure 3-6. An example of the power impulse response measured over a 100 mile troposcatter path in southern Arizona. The log response function shows received power spread to delays of 0.4 μs beyond the initial response.

The objective of the present project is to examine the feasibility of maintaining useful accuracy in a system where one terminal is mounted on a small aircraft or helicopter. The immediate application would be to calibrate millimeter-wave radiometers used in earth strain measurements. The principal problems appear to be engineering problems associated with maintaining adequate optical alignment between the airborne and ground terminals. Results to date indicate that the technical problems can be solved, but the question of cost is not yet answered.

Navy Refractivity Study. Anomalous features in the vertical profile of atmospheric refractivity can have profound effects on the performance of airborne radars and other microwave systems. The purpose of this project, sponsored by the U. S. Naval Research Laboratory, was to develop and demonstrate an airborne refractivity measurement system that can provide the aircraft crew with real-time graphical and tabular output of the refractivity profile, and nearly real-time information on the probable effect of this profile on the performance of their microwave systems.

The system was designed to be used in the P-3 naval aircraft and consists of a Model 7 microwave refractometer developed at ITS, a commercial desktop computer, and a comprehensive computer program to control the refractivity measurements. The program provides the options of displaying the refractivity, air temperature, and altitude data in tabular format on a cathode ray tube (CRT) display, or producing a graph of refractivity vs. altitude on the CRT. The latter can also be reproduced on paper using the computer's hardcopy feature. All of these data are also stored on cassette tapes for subsequent analysis.

After the refractivity profile has been measured, the program can produce ray-trace graphs on the CRT display and, if desired, on hard copy. The ray-trace graph shows the path which a radio signal would be expected to follow when transmitted through a horizontally-stratified atmosphere characterized by that refractivity profile. The operator simply specifies the altitude, beamwidth, and elevation angle of the transmitting antenna.

The profile and/or ray-trace graphs can be used to predict altitudes at which the performance of a given microwave system may be adversely effected by the atmospheric structure.

The system was flight-tested in naval aircraft in the Mediterranean area during the summer of 1979. Preliminary evaluation of the tests indicated that the system performance equaled or exceeded the sponsor's expectations.

Intervisibility Propagation Loss Measurements. A study was conducted to determine what the limiting propagation effects are on the performance of a microwave system that could be used to detect when two vehicles, separated by up to 10 km, are optically visible to one another in irregular, obstructed terrain. The study objectives were to: 1) demonstrate what effects signal variability has on the intervisibility decision process; 2) identify the possible sources of the signal variability and to estimate the magnitude of each source's contribution to the total variability; 3) obtain propagation loss data, over various types of terrain and obstructed paths, which could be used to predict received signal variability due to propagation over similar paths; and 4) use the measured data to determine the performance of a simulated intervisibility measurement system.

A measurement system was prepared and sent to Ft. Hunter Liggett, California, where propagation path loss was measured over several selected paths of varying lengths, varying path geometrics, and varying amounts of vegetation and rock outcroppings. A photograph of the transmitting terminal is shown in Figure 3-7, on top of a telescoping tower which allows a height adjustment of about 7 meters. Two frequency sources are provided, 9.6 and 28.8 GHz, both very stable in frequency and power level in the outdoor environment. The tower and transmitter are attached to a four-wheel-drive van, as shown, for travel into rough terrain. The receiver terminal (Figure 3-8) is also attached to a four-wheel-drive van and mounted on tracks to permit a vertical adjustment of 6 meters. A milling head platform is used for the base of the terminal to permit precision travel in-line and transverse to the path to be measured. Gain determining stages are also carefully stabilized with an overall long term stability of the combined link of $\pm$ 0.25 dB.

For most of the measured paths, the propagation loss showed characteristics of a theoretical Fresnel knife-edge obstacle. These data were used to establish a decision threshold for an idealized computer simulated intervisibility measurement system. The simulation system showed that correct intervisibility decisions could be made for 80 percent of the cases when the two end points were at least 1 meter above or below the grazing path. Whether this performance level of the simulated system would be acceptable for an actual system depends upon its application; however, by "calibrating" the terrain where the system is to operate, an optimum decision threshold can be computed which would improve the performance results over that which general propagation experience would predict.

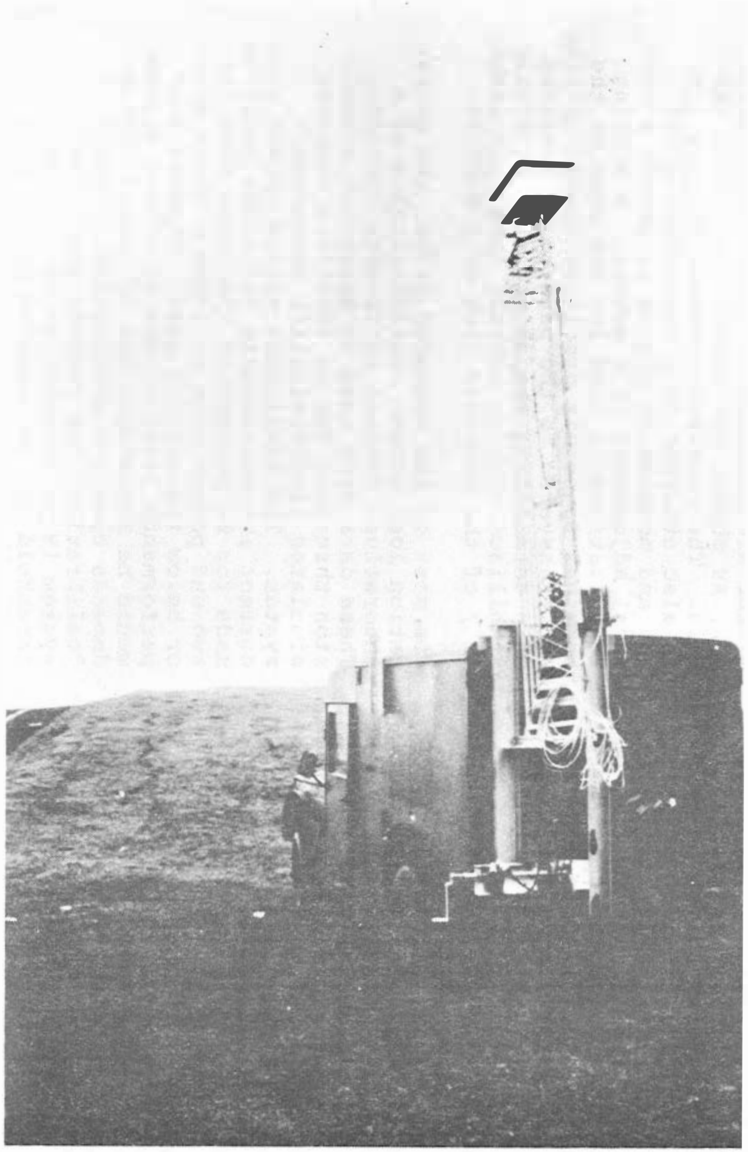


Figure 3-7. Photograph of measurement path from transmitter to crest (about 60 meters).

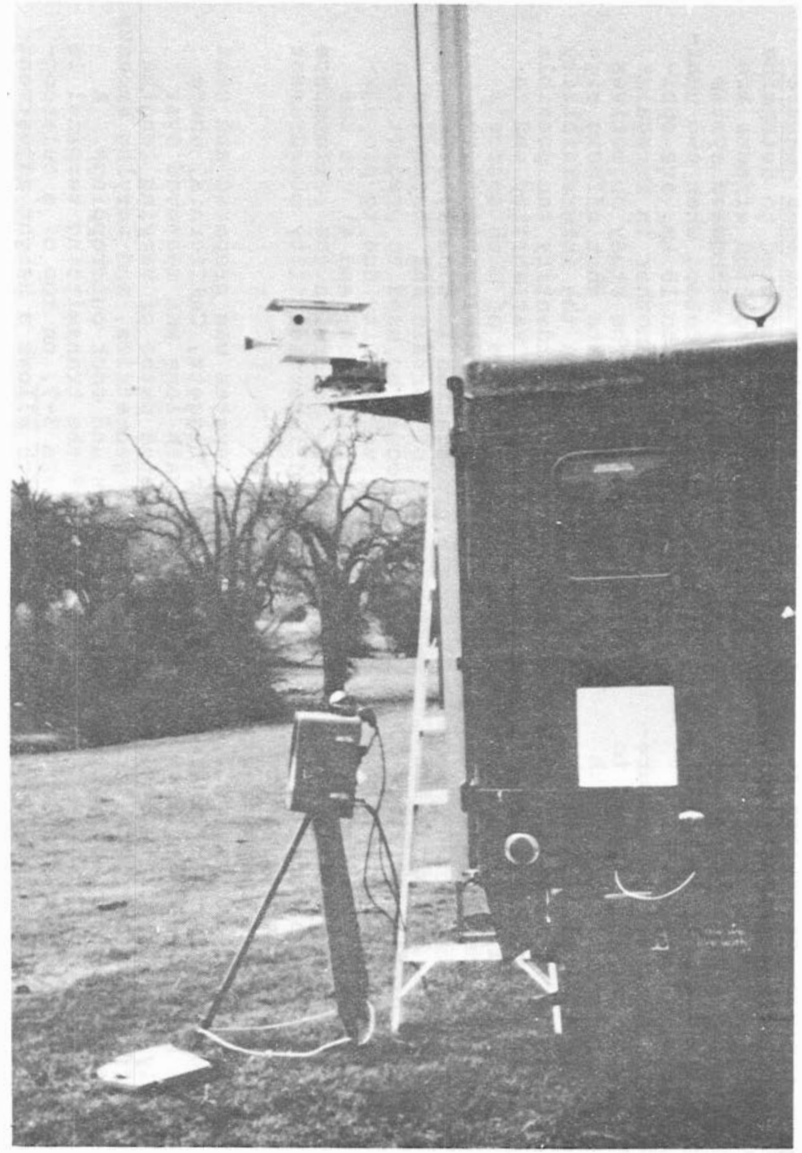


Figure 3-8. Photograph of receiving terminal.

Figure 3-9 shows examples of the path geometry used in the measurements. The transmitter was located on one side of the obstacle and the receiver on the other side; the antennas were positioned so that raising (lowering) one antenna could cause the path to be just above (below) the grazing path. Path-loss measurements were made as the antenna was moved from above grazing to below grazing.

Figure 3-10 shows a family of curves giving the expected diffraction gain due to the path obstacle for four different obstacle radii of curvature.

Figures 3-11 and 3-12 compare the measured data with the theoretical diffraction gain caused by a knife-edge ridge.

A computer-simulated intervisibility detection system was developed to test its performance using the measured data. Figure 3-13 shows the performance results of the idealized measurement system operating on the measured data versus what would be expected if the propagation data had more signal level variability (i.e., signal variability, $\sigma = 5$ dB and $\sigma = 10$ dB). Past propagation experience would have predicted the signal variability to be at least 5 to 10 dB and possibly as great as 25 dB.

Results of the two measured paths are shown in Figure 3-14 as an example of the data recorded. The vertical axis is the diffraction gain adjusted so that 0 dB represents the calculated free space loss values for the path. The horizontal axis is labeled in feet and meters and represents the distance the transmitter terminal is above or below the crest of an obstacle, which in this case is a hill along the path. Represented are two paths, #4 and #6, which show sharply contrasting results. Path 6 was recorded from a path with no prominence except the crest of the hill, while path 4 had many trees surrounding the path but not in direct line. It is obvious that signal scattering from the trees greatly influenced the propagated signal. A total of nine paths were measured, each representing a different terrain feature.

Propagation Model for Terrestrial Microwave Systems. Performance predictions of a digital radio system on a line-of-sight microwave path requires an accurate statistical model of the random parameters of the channel. Because different digital radio systems may have different sensitivities to the various channel impairments, the model must be complete to the extent that it must be capable of duplicating the amplitude and delay of the transmitted signal under all possible path conditions. To facilitate the understanding of the role of the random parameter which has the most significant effect on line-of-sight digital systems (i.e., the refractive index), a group in Division 3 is presently observing the fading and delay statistics along a 22.8 km path from the Radio Building to the BAO observatory at Erie, Colorado. The profile of the path together with the locations of the transmitter and receiver are shown in Figure 3-15. The transmitter is shown at a height of about 110 m above the ground on the movable elevator on the Erie tower. The profile of the terrain is drawn assuming an effective earth's radius of 4/3. This effective earth's radius is important because of the relative curvature of the earth and the direction a microwave beam travels. The beam is normally bent downward a slight amount by atmospheric refraction. The amount of bending varies with atmospheric conditions. The degree and direction of bending can be conveniently described by an effective earth's radius. Any change in the amount of beam bending caused by atmospheric conditions can then be expressed as a change in this effective earth's radius. This factor is one of the parameters under investigation on the path shown in the figure. Also shown in the figure is the straight line the microwave energy travels in going from the transmitter to the receiver. As shown in the figure, the energy travels near the top of a ridge (Hoover Hill), and this ridge also has a bearing on the propagation of energy. Since the ridge in the figure resembles a knife-edge, the theory of knife-edge diffraction will be used to predict the variation in the signal as a function of height as the transmitter is raised and lowered on the tower. When a portion of the radio energy strikes the top of the ridge, it can interfere with the direct signal either constructively or destructively, depending upon the relative phase of the ground reflected signal. In general, there is a point where the direct and reflected signals are in phase opposition. This first occurs when the path from the transmitting antenna to the reflection path is one half wavelength longer than the direct signal to the receiving antenna path. The first point of phase addition is a point on an ellipse of revolution with imaginary foci at the transmitter and receiver, and this ellipsoid is referred to as the first Fresnel zone ellipsoid. In the figure, the lower portion of the first Fresnel ellipse is drawn at a height of the transmitting antenna such that the ellipse just grazes the ridge. The effect of first Fresnel zone clearance is under investigation by observing the fading and delay characteristics of a radio signal at 9.6 or 28.8 GHz over the path shown in the figure.

The work on this problem is intended to assemble usable and efficient information for the planning and engineering of line-of-sight micro/millimeter wave paths for communication systems.

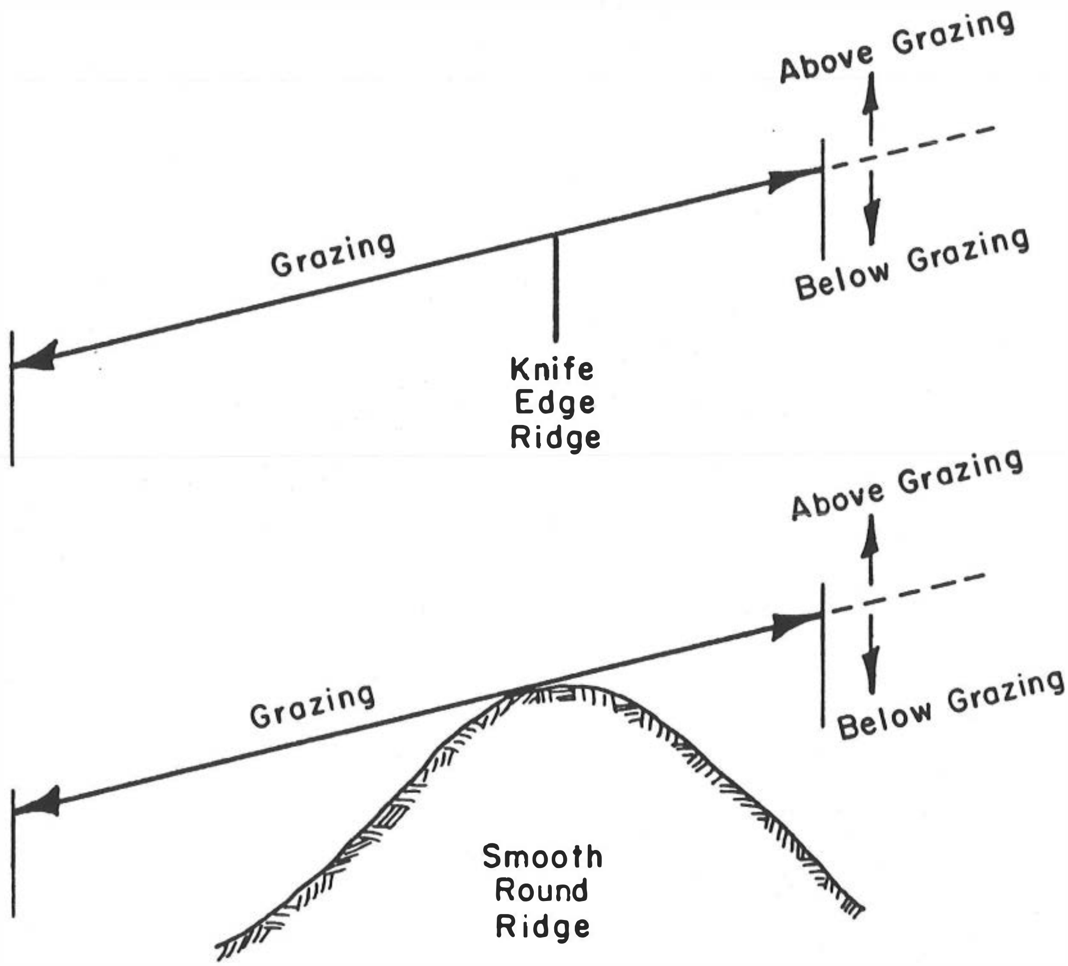


Figure 3-9. Examples of clear, well-defined paths.

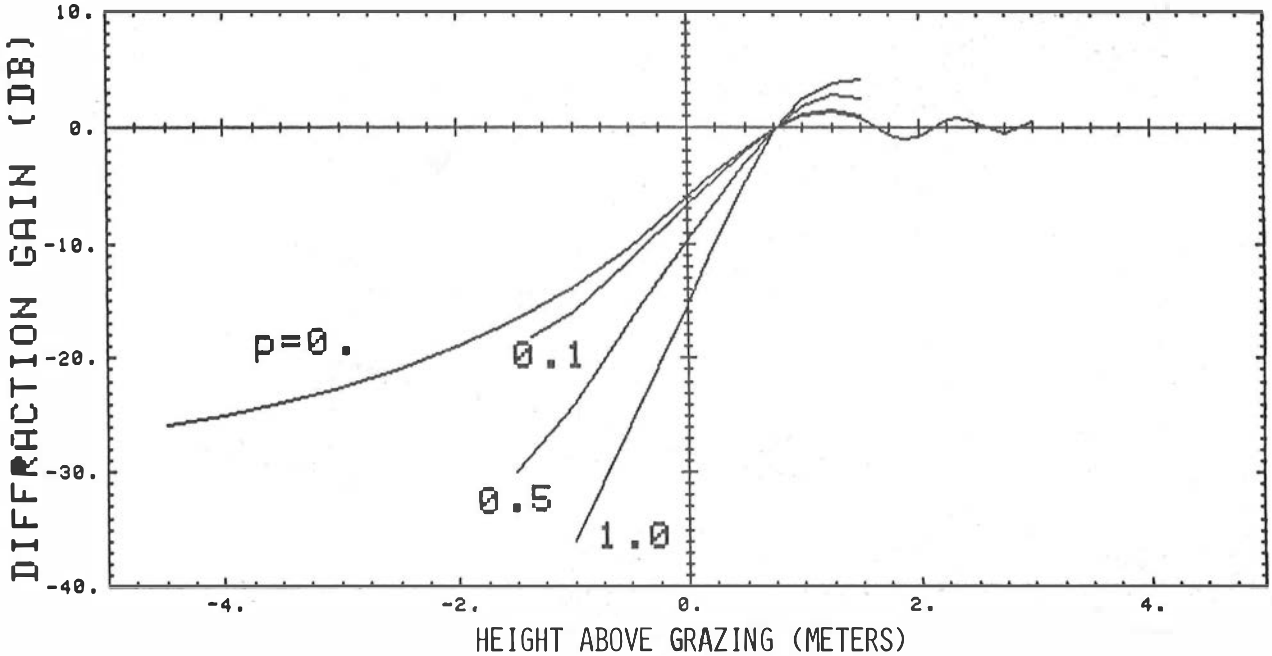


Figure 3-10. Results for an obstacle having a radius of curvature from 0 to 1.0.

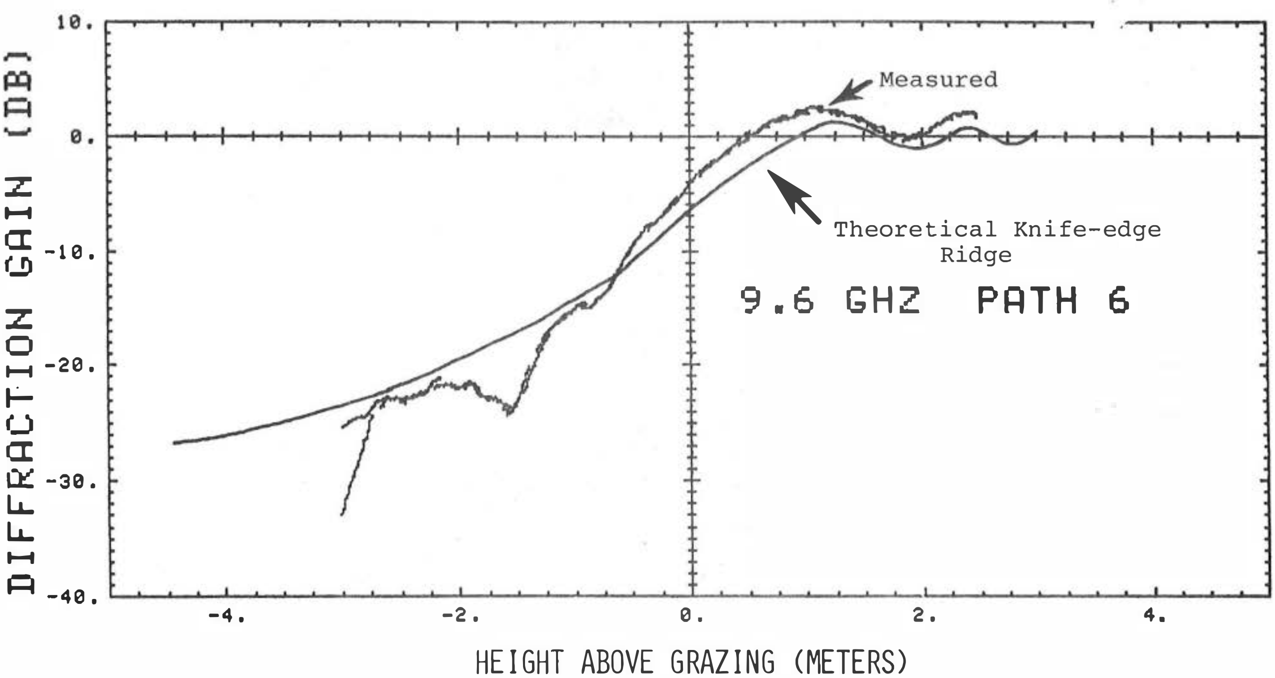


Figure 3-11. Normalized results for path 6, 9.6 GHz.

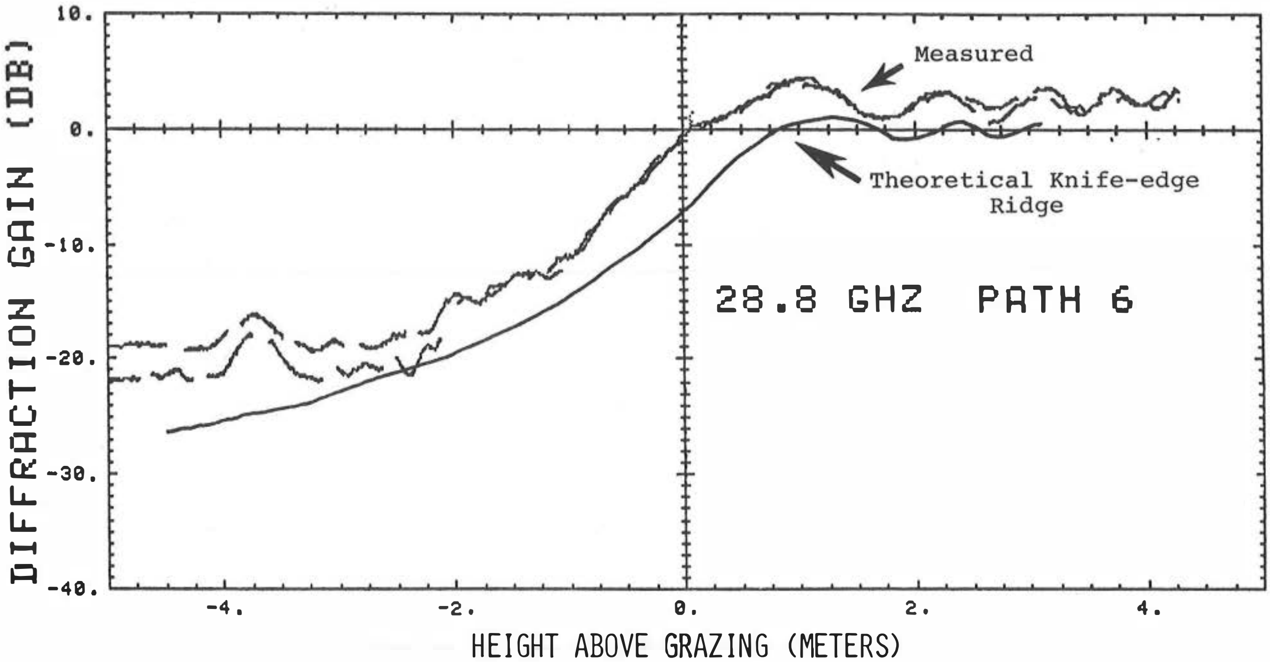


Figure 3-12. Results for path 6, 28.8 GHz.

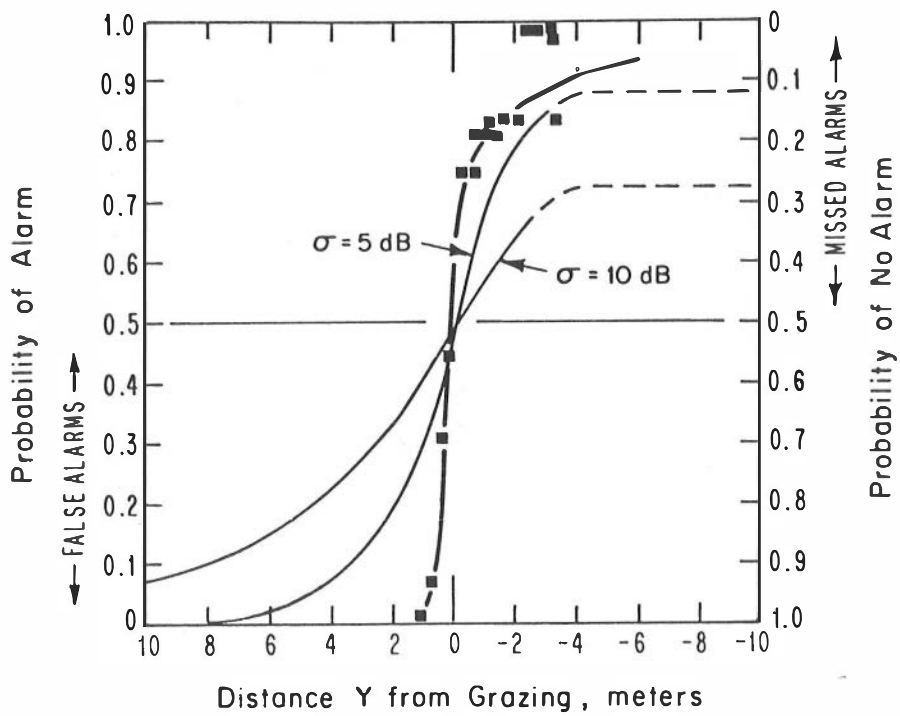


Figure 3-13. Comparison of measured alarm probability (9.6 GHz, decision threshold at optimum) with two theoretical alarm probabilities.

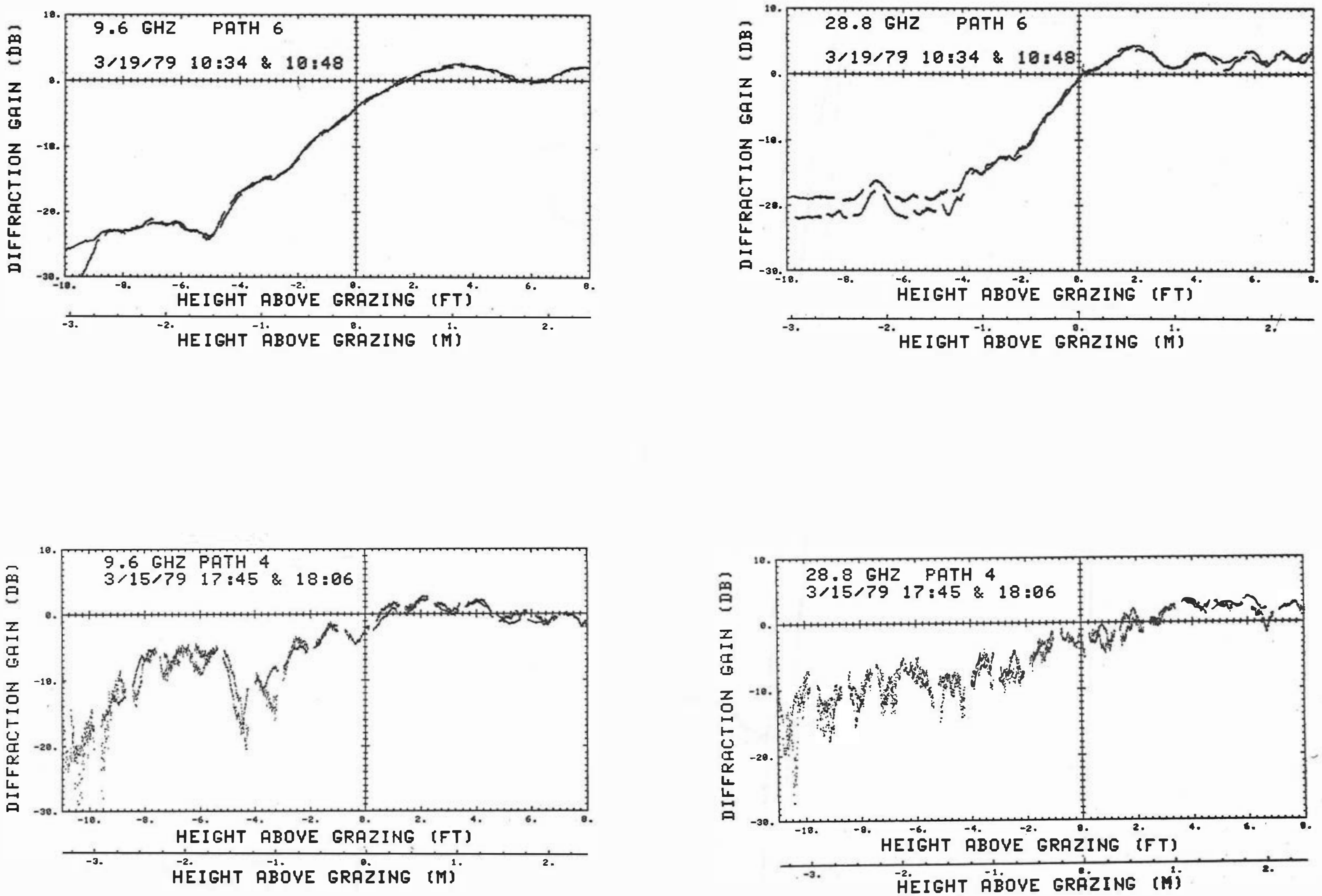
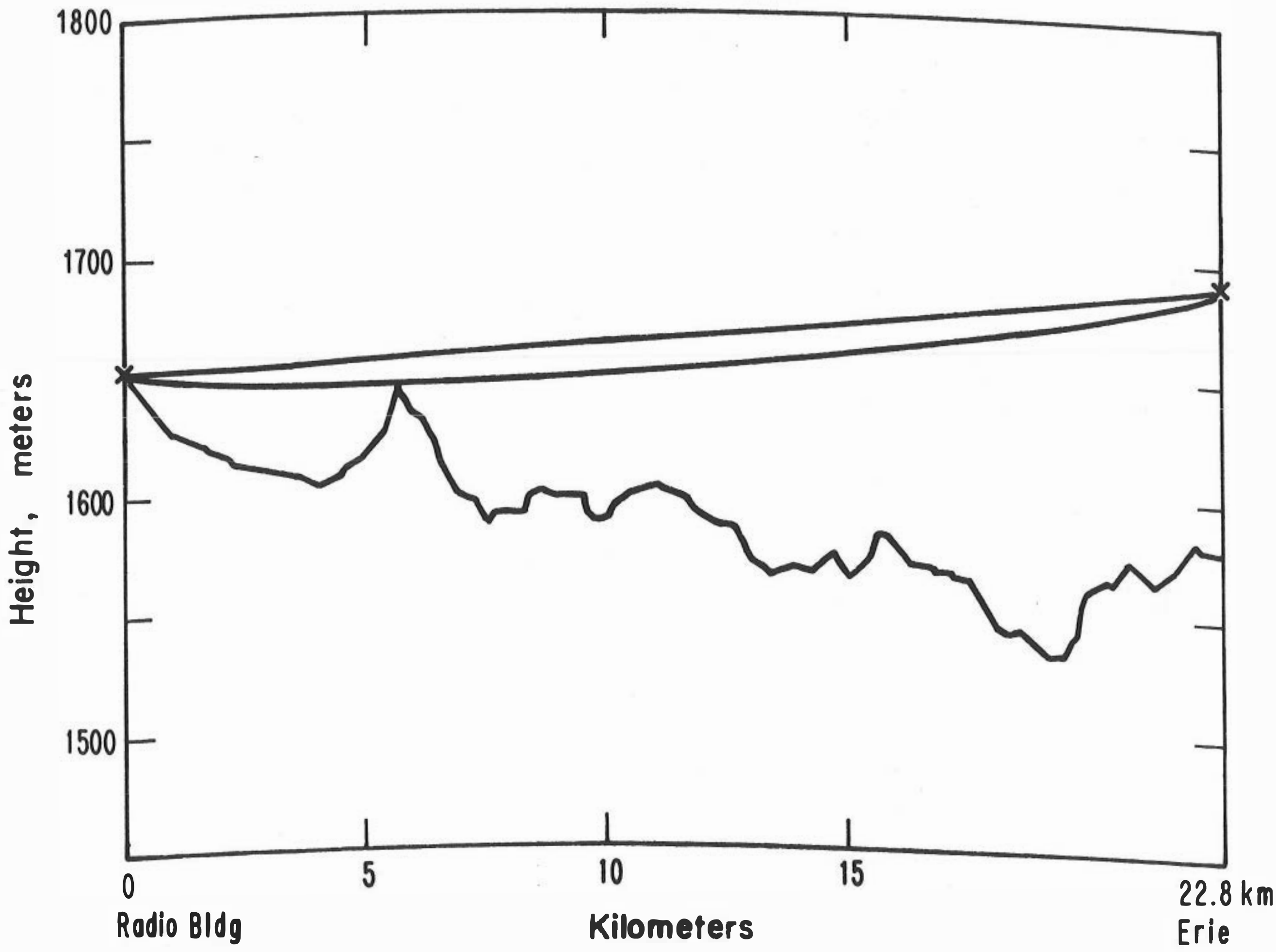


Figure 3-14. Diffraction results.


1800
1700
1600
1500
Height, meters
0
Radio Bldg
5
10
15
22.8 km
Erie
Kilometers

3.2.2. Ionospheric Characteristics and Effects

High Frequency Ionospheric Scattering Study. Efforts to recover high-frequency (HF) radio signals trapped between layers of ionization which surround the earth at heights of 150 to 250 km have been successful. This work (performed under the sponsorship of the Rome Air Development Center located at Hanscom AFB, Massachusetts) is directed toward determining if there are low-loss trapped propagation modes which could extend the useful range of surveillance systems well beyond the normal over-the-horizon distances (~ 2000 miles). It is well known that, for periods of time near local sunrise or sunset, HF signals can be transmitted into the nighttime part of the day/night terminator and that the same signal can be detected arriving from the day side of the terminator, after traveling around the world, approximately 135 ms later. A delay of this magnitude is appropriate for the propagation time required to circle the earth at a height within the ionosphere. Evidence indicates that, when the transmitter and receiver are located at the day/night terminator, ionospheric layer gradients and irregularities in electron density can result in the launching of a propagation mode which can be guided by ionospheric boundary gradients, much like a waveguide, around the world (RTW). The same mechanisms (i.e., geometry of ionospheric gradients and irregularities) can also result in the ability to recover a (RTW) signal from ionospheric heights. This mechanism for launching and recovery is likely to reduce the signal level for each transition by several tens of dB. It is believed that, once launched, the propagation loss is comparatively small.

Experiments using a very-high-powered HF transmitter to excite the electrons in the ionosphere and create a scattering volume were conducted from 1970 to 1974 (Radio Science, November 1974). The artificially created scatterers are composed of numerous very elongated bubbles of increased electron density with their longitudal axis aligned along the earth's magnetic field lines. These bubbles in the ionosphere approximate slender cylinders and are aligned along the earth's magnetic field because the flow of charged particles transverse to the field lines are greatly impeded.

The NTIA/ITS high-powered transmitter facility located near Platteville, Colorado, can produce about 1.6 megawatts of average power, which is used to excite a 10 element ring-array antenna. Observations made prior to 1974 showed that the field-aligned scatterers acted like a large reflector of radio signals at ionospheric heights for frequencies in excess of 400 MHz. Regular propagation modes would not have exceeded 30 MHz for the same paths traveling via the unmodified ionosphere. Because there is little known about how the characteristics of propagation modes that are presumed trapped by ionospheric gradients such as the RTW, it was speculated that an artificial reflector produced by the Platteville high-powered transmitter would test the argument that ionospheric trapped modes do exist.

Receiving sites to test this speculation were located at Alamosa, Colorado, and Los Alamos, New Mexico, about 250 km and 500 km south of Platteville, respectively. An eight-element beverage antenna array was constructed at both sites and aimed towards the region in the ionosphere where the scattering volume produced by the Platteville transmitter would occur. SRI, International, also under contract with the Rome Air Development Center, installed a swept-frequency FM/CW transmitter and log periodic antenna at Salisbury, Australia, 14,500 km from Platteville. The FM/CW transmitter was programmed to sweep in frequency from 12 to 30 MHz at a 100 kHz/second rate. During the first experiment conducted in the last week in April of this year, significant results were obtained to show that trapped modes could be recovered from the ionosphere. The tests took place between 0700 and 0900 UT (0000 to 0200 MST). The highest frequency propagated by conventional multi-hop modes was about 23 MHz. When the Platteville transmitter was turned on with the modifier, signals were detected up to the limit of the frequency range employed (30 MHz). The signal level of the trapped modes exceeded by 10 dB or more that of the multi-hop mode measured at the same frequency. Computer simulation employing realistic ionospheric structures was used to verify that the extended frequency signal recorded was an ionospherically trapped (not reflecting from the earth's surface) mode of propagation.

A second experiment was conducted on the 5th of June with substantially the same results between 0620 to 0820 UT. Observations were made at other times of day without success, presumably because of the inability to launch an elevated mode except at local sunset, which does correlate with the times above.

As the data processing progresses, more will become known about signal losses and height of reflections from the transmitter-induced artificial scatterers. A test series is planned under Air Force sponsorship with a transmitter aboard the space shuttle and located at ducting heights in the ionosphere.

Figure 3-16 shows a processed ionogram of the Salisbury FM/CW transmitter as received at Alamosa, Colorado, on 5 June 1979. The ionogram starts at 12 MHz on the left and

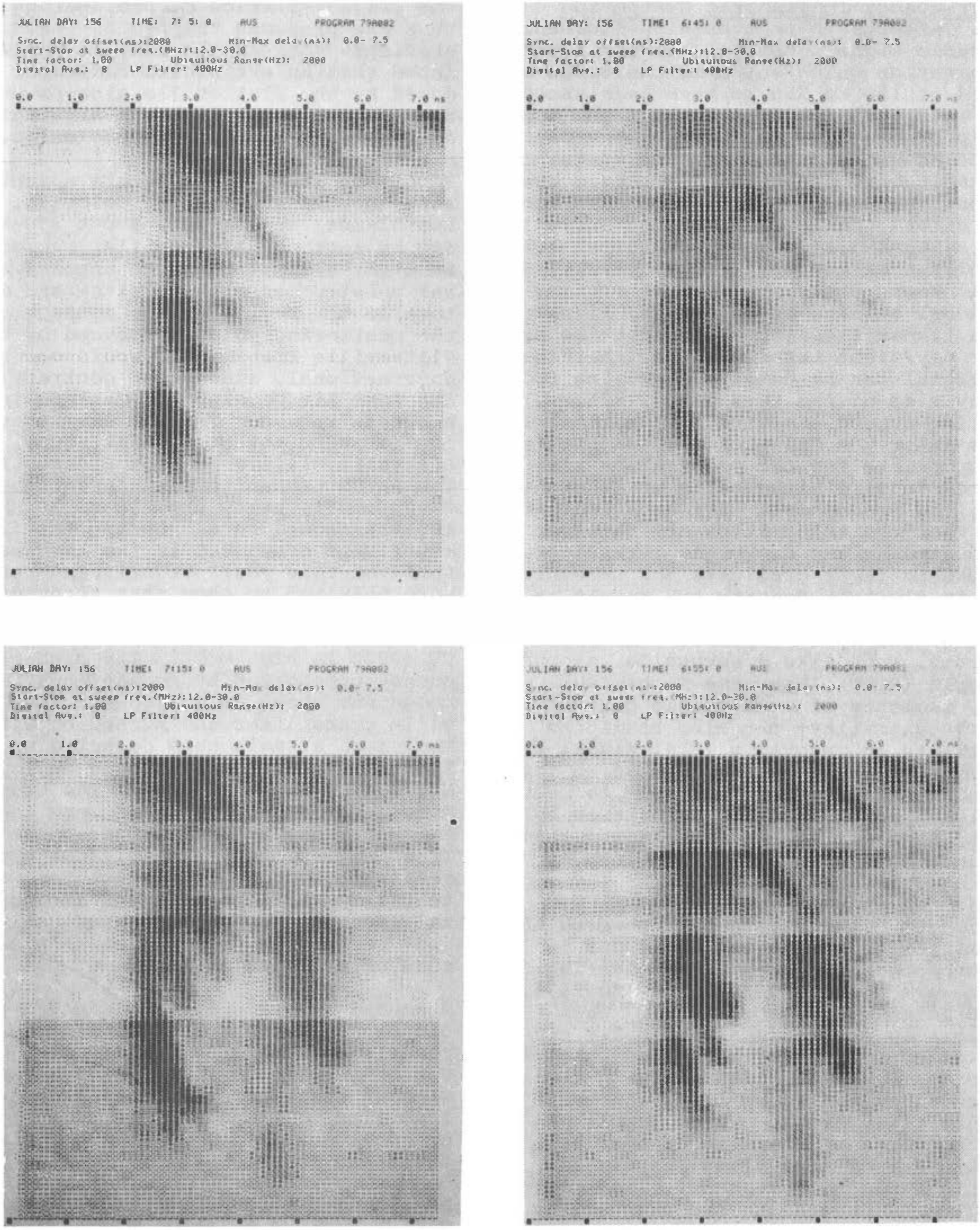


Figure 3-16. Examples of ionograms for the Salisbury, Australia, to Alamosa, Colorado, path with (right side) and without (left side) the artificial ionospheric scatterer.

increases linearly to 30 MHz. Signal delay is preset to 48 milliseconds (ms) and the scale of 0 to 7 ms (bottom to top of ionogram) adds to obtain the overall path delay. The ionogram on the left (0645 and 0705 UT) was recorded with the Platteville transmitter "off" and no artificial scatter present in the ionosphere, and the ionograms at the right were taken with the Platteville transmitter "on" and the scatter present. It is quite apparent totally new rays appeared at about 5 ms delay extending in frequency from about 18 to 28 MHz. The darkness of the ionogram is portional to the received signal level, and it seems likely that a small contribution from the artificial scatter appears on the first ray, which is the 4-hop signal between earth and ionosphere enroute from Australia to Alamosa. The delay analysis of the elevated mode signal is quite complex and ray paths must be mapped to evaluate these delays, but it is obvious that the scattered signals travel an extra distance of about 500 km, twice the distance from Alamosa to Platteville, further than a signal which is not reflected from the scatter.

Topside HF Noise. In order to assess the HF environment in the topside ionosphere, ITS has investigated the data observed by the Defense Meteorological Satellite. This satellite is equipped with an HF radio receiver that provides measurements of the intensity of HF noise at the satellite orbit (almost circular at 840 km). The data have been analyzed according to local time and location on the globe.

Global maps of the intensity of the HF noise in the topside ionosphere have been produced for various frequencies between 4 and 13.5 MHz. An example of one such map is shown in Figure 3-17. The map provides contours of the receiver terminal voltage as observed by the satellite over a three-month period from September through November 1977, for the frequency of 12.0 MHz. By producing and analyzing maps such as these, it has been found that the data observed by the satellite appear to emanate from discrete transmissions at the surface of the earth. Further study has revealed that the HF environment in the topside ionosphere is in concert with the manner in which the HF spectrum is utilized for terrestrial point-to-point or point-to-area services. The most intense signals in the topside ionosphere are observed in those bands assigned to the broadcasting service, followed by those assigned to the fixed, maritime mobile, and aeronautical mobile services, respectively.

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

Atmospheric Transmission Models. This program is a continuation of the effort to create and maintain an information system of computer propagation models and data bases. These models and data bases represent a consolidation of the results in telecommunications research to be accessible nationwide to support the design and evaluation of telecommunications systems. Two Reports have been published thus far. The first is entitled "A Preliminary Catalog of Programs and Data for 10 - 100 GHz Radio System Predictions" and is OT Report 78-141. The second is entitled "An Additional Catalog of Programs and Data for 100 MHz to 100 GHz Radio System Predictions" and is NTIA Report 79-15.

Computer programs and data bases under the following categories now exist in the catalogs.

Category	Title
1.	Computations of Transmission Loss and Radio Returned Power
2.	Computations of Desired/Undesired Signal
3.	Computations of Atmospheric and Precipitation Parameters
4.	Data Bases and Associated Programs
5.	Performance of Digital Communication Systems
6.	Miscellaneous Programs

Additional entries to the information system are being solicited and evaluated on a systematic basis, and a new catalog is anticipated to keep those interested abreast of this valuable information.

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.

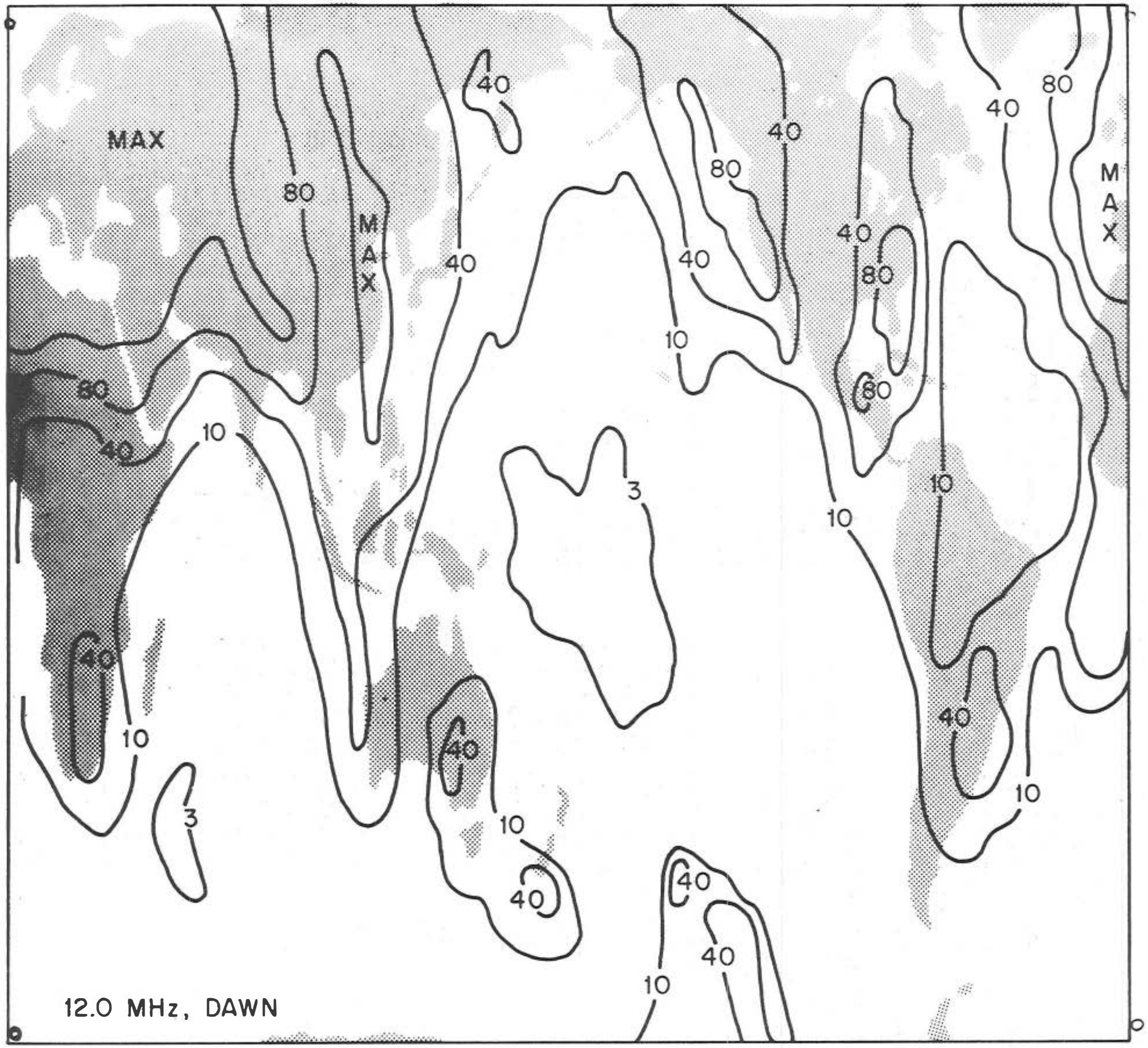


Figure 3-17. Average global behavior in the topside ionosphere of the HF radio environment at local dawn for 12 MHz during the period September-November 1977. Contours are given in millivolts x 10^{-1} 288^{0}K.

Data acquired on this project are being obtained using carrier frequencies near 15 GHz. The data are acquired on three long paths (90 km, 93 km, and 132 km) which converge at Mt. Corna, Italy (see Figure 3-18). The 93 km path is primarily over water. The data acquisition period will be one year beginning April 1979. 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 is 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 response to increased pressure to change military radio systems to operate in the 15-GHz band within areas of high microwave spectrum usage.

Fading on Long LOS 8-GHz Paths in Europe. This project is being done in conjunction with the 15 GHz Long Path Project. The objective of the project is to assess the performance of specific long line-of-sight microwave paths operating at carrier frequencies near 8 GHz in concert with a 15 GHz ITS project now in progress. The results of these tests will be used to calculate the reliability and assess the potential for upgrading these and other long links in Europe where military microwave systems are currently operating at 7 - 8 GHz.

Received signal levels will be monitored at 8 GHz on five links (Figure 3-18). The three links terminating at Mt. Corna will be monitored on both 8 and 15 GHz for one year. The two links terminating will be monitored at 8 GHz for one year. Recording and processing of data will be done using the same techniques used for the 15 GHz project.

The type of meteorological parameters that are used in the prediction models are ones that are readily available from past meteorological records. For example, average annual temperature is used in the multipath and atmospheric absorption models. Average annual absolute humidity and air pressure are used in the atmospheric absorption models. The rain attenuation model uses average annual rainfall, the ratio of thunderstorm to stratiform rain and the average number of thunderstorm days per year.

To compare these prediction models with the data from this experiment, it is important that we know what these meteorological parameters are doing on a daily basis. The daily information is necessary for helping to identify radio propagation mechanisims and also to compare models on the basis of the statistics for the year of the testing. Daily reports of meteorological data are being obtained from the U. S. Air Force Environmental Technical Applications Center (MAC), Scott Air Force Base, Illinois.

The USAF organizations sponsoring this project are the Air Force Communications Service, Scott Air Force Base, Illinois and Headquarter Electronic Systems Division, Hanscom Air Force Base, Massachusetts.

Propagation Measurements Guidelines. Sponsored by the Communications R&D Command (CORADCOM) of the Army, this project was originally planned to provide generalized guidelines for designing measurement programs where the major purpose is to examine some aspect of radio propagation. But it soon became apparent that a more immediate concern had to do with the very special problem of wide-band propagation through forests. In response, we have fashioned guidelines and suggested possible equipment to effect such measurements. These guidelines are incorporated into plans for a beginning phase of what the Army expects to be a long, multi-phase effort, eventually collecting statistics in many parts of the world including forested regions of Europe.

Indeed, ITS has already begun the first of these phases in a project entitled Wide-Band Measurements. Although this first phase is restricted to assembling and testing equipment, we do hope to make a modest number of field measurements in south-central Tennessee. The principal tool to be used is the pseudo-noise probe owned by ITS. It has a bandwidth of 300 MHz and provides an effective impulse signal of about 6.7 ns resolution. It will be operated with center frequencies at 600, 1200, and 1800 MHz. The transmitter is to be mobile and the receiver semi-mobile. We plan to record the data in a digital format which can be made available to interested parties. Even in this first phase we hope to be able to address and answer some outstanding questions concerning multi-path and pulse spread when propagation is through forests or near stands of trees.

Wide-Band Radio Propagation Measurements. This project has developed a computer controlled system for digitally recording the output from the ITS psuedo-random channel probe. The digitized output from the probe will be analyzed on a large computer to determine the wide-band characteristics of propagation in the 400 to 2000 MHz frequency range.

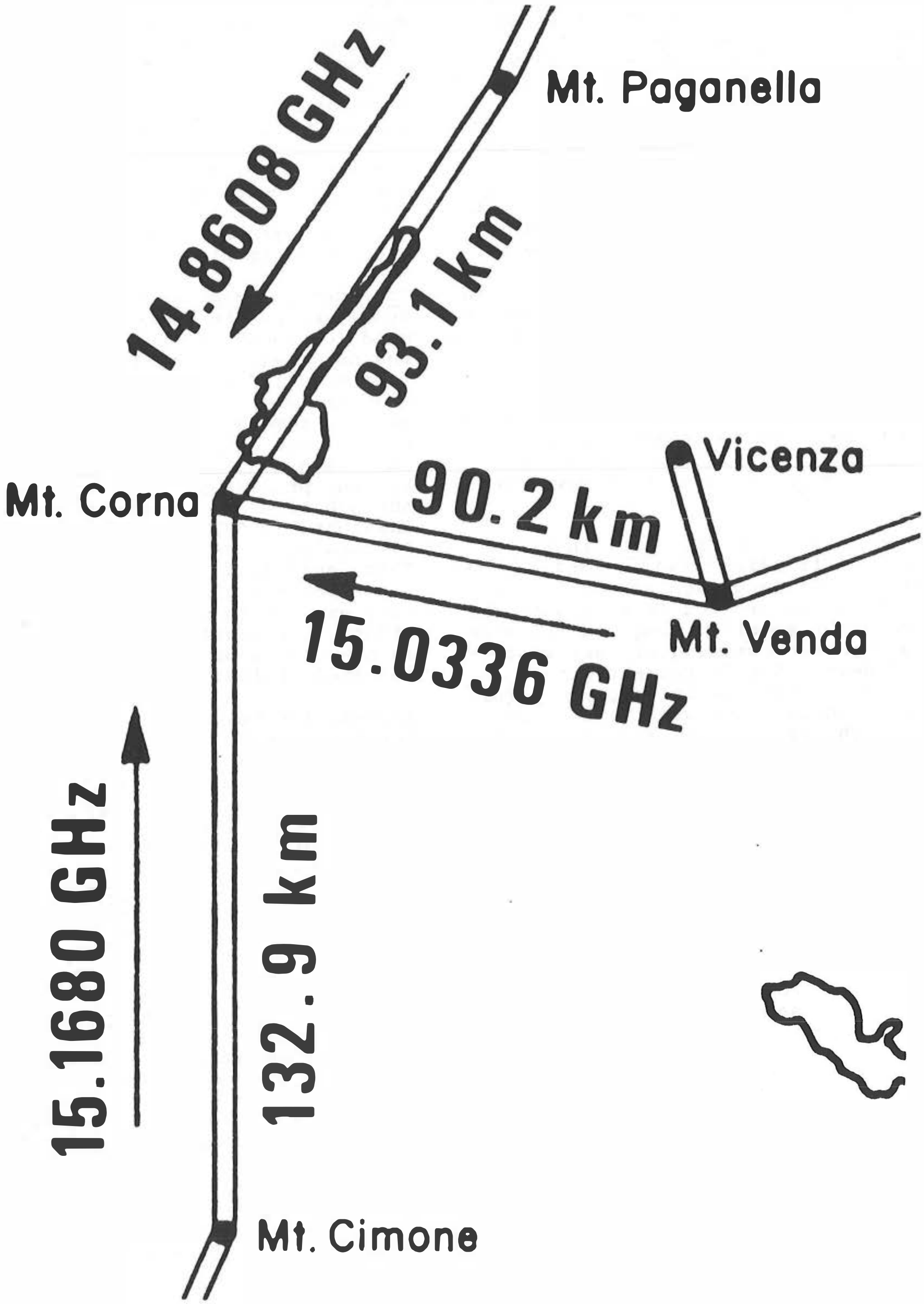


Figure 3-18. Path locations for the long path 15 GHz multipath fading tests.

This digitizing system is controlled by a commercially available 8-bit microprocessor system as shown in Figure 3-19. The six outputs from the receivers are digitized and stored in buffers at a rate determined by the operator. The receiving antenna height is measured with the electronic distance meter, and recorded along with the propagation data. These data are then written on digital tape for later analysis. The software has been designed to be flexible and yet easy to use. The operator communicates to the system through the printing terminal, which asks for his input. A sample of the questions and answers is shown in Figure 3-20. A provision was made to store all of the housekeeping information on a header record at the beginning and end of each file of data so that the system is self documenting of the measurements that have been recorded. A sample of the information in the header, data, and trailer records is shown in Figure 3-21.

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.

The Ionospheric Communications Analysis Prediction Program (IONCAP) is the most recent of the HF prediction programs developed at the Institute for Telecommunication Sciences (ITS). The computer program is an integrated system of subroutines designed to predict high-frequency (HF) skywave system performance and analyze ionospheric parameters. These computer-aided predictions may be used in the planning and operation of high frequency communication systems using skywaves.

In the initial planning or in the modification of many communication systems there may be an appreciable delay between the circuit planning and the actual circuit construction or modification. This is of particular importance for high frequency (HF) circuits which have marked time and geographic variations in optimum frequency, required power, and system performance.

Predictions of ionospheric characteristics and techniques for using these characteristics are available and may be used to anticipate the performance of HF communication circuits and thereby provide the lead time for necessary equipment selection, frequency selection, and frequency and time-sharing arrangements.

The IONCAP program or calculations using the program are available from the Propagation Predictions and Model Development Group of the Applied Electromagnetic Science Division of ITS. The program has been supplied to several foreign and domestic government agencies and to the private sector.

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.

HF Sharing and Power Studies. Another example of the use of EM ionospheric transmission models is the work for NTIA and FCC in development of technical material to support the U. S. position at the 1979 WARC. The use of these models to support the U. S. position was provided in a technical report "Theoretical Compatibility Between High Frequency Broadcasting and High Frequency Fixed Services" which is currently in editorial review.

This report considers the propagation aspects of frequency sharing especially as related to the short and medium distance, lower power operations of the fixed service as compared to high-power international broadcast. Published international high-frequency broadcast schedules as directed toward selected areas were compared to the expected times of successful low-power operations within those areas and comparisons were made of the relative signal strengths expected from the high-power transmitters relative to the expected signal strength of the low-power operations. These comparisons were made with recently improved skywave field-strength prediction methods developed at the Institute for Telecommunication Sciences, and field strengths as predicted by these methods were compared with observed fields on short and long distance circuits.

It was concluded that appreciable opportunity for frequency sharing exists, and examples were shown as to how this opportunity may be predicted and used in the

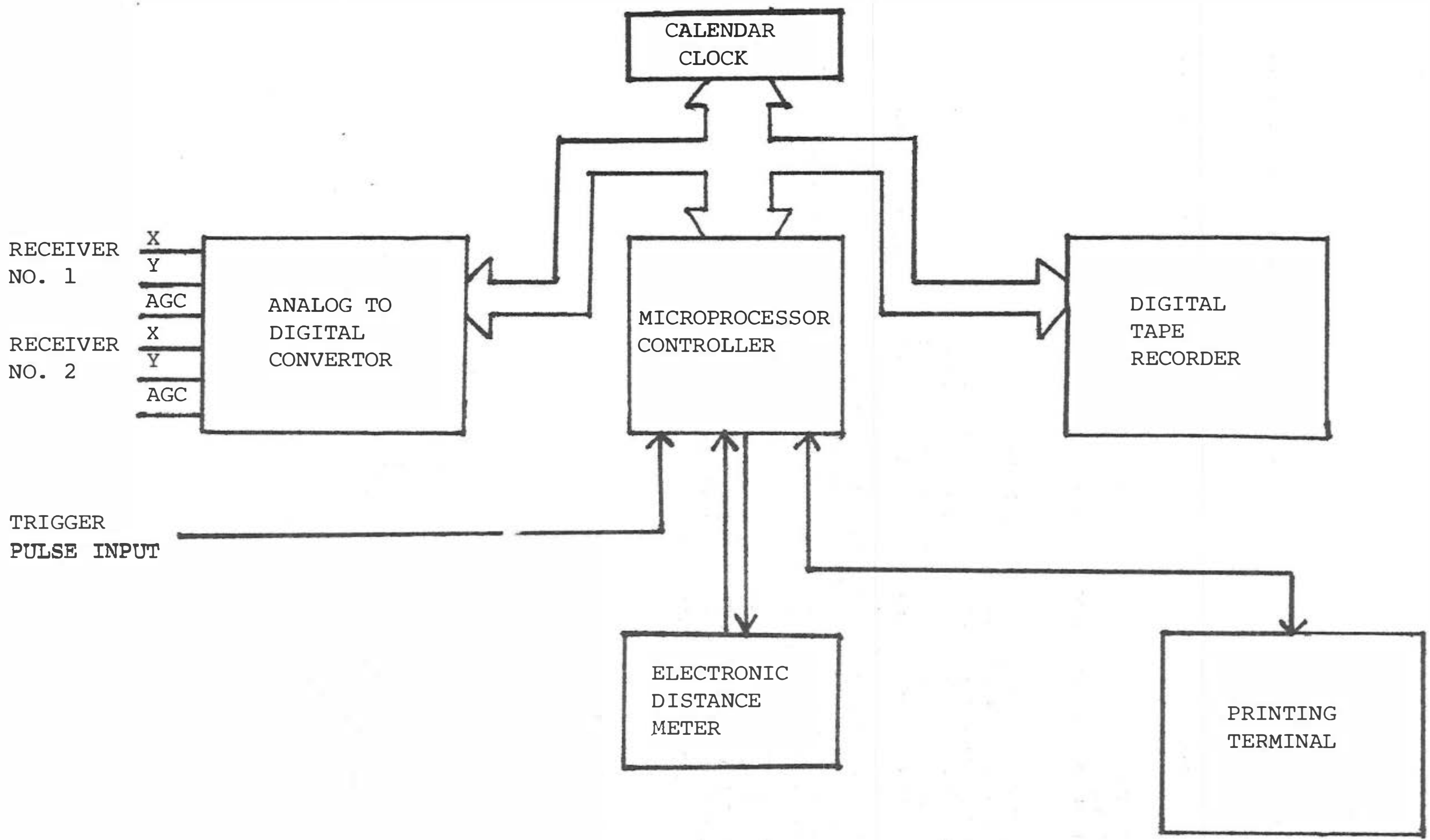


Figure 3-19. A block diagram of the data recording system used in the wide-band measurements.

```
*****************************************************************************

                    WIDEBAND PROPAGATION MEASUREMENT SYSTEM

*****************************************************************************


DATE:    8/27/79
TIME:   16:20:36
DO YOU WANT TO RESET THE CLOCK (Y/N)?   ?N


1)   ENTER LOCATION (<= 20 CHRS): ?BOULDER
2)   ENTER PATH ID (<= 20 CHRS): ?TEST
3)   ENTER FREQUENCY (MHZ) FOR RECEIVER 1:  ?400.0
3)   ENTER FREQUENCY (MHZ) FOR RECEIVER 2:  ?800
4)   ENTER NUMBER OF FRAMES TO AVERAGE (1-10):  ?10
5)   ENTER NUMBER OF FRAMES OF DATA TO BE RECORDED (10-4500):  ?100
6)   ENTER FRAME RATE (1,2,5,10/SEC):  ?10
7)   ENTER SAMPLE RATE (10-10000/SEC):  ?10000
8)   ENTER NUMBER OF SAMPLES/FRAME(10-1000):  ?1000
9)   ENTER NUMBER OF FRAMES TO SKIP BETWEEN SAMPLE SETS (0-100):  ?0
10)  ENTER COMMENTS (1 LINE): ?TEST
DO YOU WISH TO CHANGE ANY ANSWERS (Y/N)?  ?Y
ENTER QUESTION NO. OR CR WHEN DONE:  ?3
3)   ENTER FREQUENCY (MHZ) FOR RECEIVER 1:  ?600
3)   ENTER FREQUENCY (MHZ) FOR RECEIVER 2:  ?1200
ENTER QUESTION NO. OR CR WHEN DONE:  ?


WBPMS HEADER INPUT DATA SUMMARY:

DATE:    8/27/79
TIME:   16:24:18

1)   LOCATION:  BOULDER
2)   PATH ID:  TEST
3)   FREQUENCY (MHZ) FOR RECEIVER 1:    600.
     FREQUENCY (MHZ) FOR RECEIVER 2:   1200.
4)   NUMBER OF FRAMES OF DATA TO AVERAGE:    10
5)   NUMBER OF FRAMES OF DATA TO BE RECORDED:    100
6)   FRAME RATE:    10
7)   SAMPLE RATE:   10000
8)   NUMBER OF SAMPLES/FRAME:  1000
9)   NUMBER OF FRAMES TO SKIP BETWEEN SAMPLE SETS:     0
10)  COMMENTS:  TEST
```

Figure 3-20. A sample of the questions and answers.

WIDEBAND PROPAGATION MEASUREMENT SYSTEM
DATA ACQUISITION RECORD DESCRIPTION

<u>Header Record</u>

Date
Time
Location
Path ID
Frequency for receivers 1 and 2
Number of frames of data to be averaged
Number of frames to be recorded to tape
Frame rate/sec
Sample rate/sec
Number of sample sets to be taken/fram
Number of frames to ship between sampled frames
Comments

<u>Data Record</u>

Up to 1000 12-bit A/D sample sets (X & Y components for receivers 1 and 2)
AGC A/D samples for receivers 1 and 2
Distance meter reading
Date
Time

<u>Trailer Record</u>

Flag to indicate if preceding measurement set is good or not
Up to 10 lines of comments describing any unusual conditions occurring during the preceding measurement set

Figure 3-21. A sample of the information in the header, data, and trailer records.

development of operational schedules so that the fixed and broadcast services may take advantage of time sharing or geographic sharing (simultaneous co-channel use) of frequencies in the high-frequency band.

Figure 3-22 is a sample chart illustrating how EM ionospheric transmission models may be used to develop geographic area sharing plans for high frequency services.

Another use of skywave field strength predictions to support U. S. WARC positions was in the area of deducing the optimum power for international broadcast transmitters to maintain a given quality of service. The results of this study show that, under most circumstances, coverage by the broadcast can be effected at distances less than 5000 km by using powers less than 100 kW.

Prediction of Transmissions Parameters and System Performance. Models for EM transmission via the ionospheric mode of propagation were used to conduct feasibility studies for new applications for high frequencies in the long range planning of Federal agencies. The use of these models to assist the Department of Transportation in the updating of their aeronautical communication systems was provided in a technical report "Theoretical Feasibility of Digital Communication over Ocean Areas by High Frequency Radio" NTIA TM 79-17. This report examines the theoretical reliability of digital data transmission via high-frequency radio for typical air traffic routes in the Atlantic and Pacific areas in an evaluation of a system for improving air traffic control over ocean areas. The expected performance of a reference high-frequency data transmission system of 1200 bits per second with a permissible error rate of one-in-a-thousand binary error was expressed as a percentage of time that a given theoretical reliability will be equaled or exceeded.

Transmission models permitted the determination of optimum high frequency for digital communication from aircraft and also the optimum ground locations for reception. These bands and ground locations were found to vary with aircraft location and time of day. Figure 3-23 is an example of the determination of these optimum bands and receiver sites.

Polar Ionospheric Propagation. As part of the program to assess the performance of the CONUS over-the-horizon backscatter radar system, the Air Force Geophysics Laboratory and the Electronic Systems Division are supporting a development effort at ITS to assist in this assessment. The ITS is developing optimum models of the polar ionospheric electron density that represent the structure of the ionosphere during the time periods that the radar will be operating. The models will permit actual ionospheric data to be incorporated into them and will be used in propagation simulation programs to reproduce the actual radar characteristics. The ionospheric absorption suffered by the radar signals and the impact of irregularities in electron density will also be modeled and compared against actual radar data.

In addition to modeling, the polar ionospheric structure and other parameters of importance to the performance of an HF backscatter radar, the ITS will be developing optimum methods to store and retrieve the polar ionospheric data. The types of data and the locations at which they will be observed are given in Figure 3-24.

VHF/UHF Measurements in Urban Areas. The objective of this program is to provide measurements of the signal strengths of VHF/UHF broadcasts in an urban area which can be used as a basis for implementing improved techniques for predicting the coverage of UHF-TV and mobile radio systems. During this year, a measurement program was designed and carried out for gathering data on the statistical variability of signals from existing transmitters in the VHF/UHF band in the Denver metropolitan area.

Measurements were made using the TV transmitters located on top of Lookout Mountain near Golden, Colorado. The signals monitored were KBTV (189 MHz), KMGH (177 MHz), KOA (69 MHz), and KWGN (57 MHz). Mobile measurements of these signals were made at several vehicle speeds along 44th Avenue in Golden, Colorado. The antenna used was a modified version of a miniature VHF directional antenna system originally designed to provide continous coverage of the 30-200 MHz frequency range. The modified antenna was converted to an isotropic antenna using a hybrid network with a 90° phase shift. The receiver system was installed in a mobile van.

Typical received signal variations of Channel 9 (KBTV) at 187.24 MHz (video) and 191.74 MHz (audio) measured at a mobile speed of 20 mph are displayed in Figure 3-25. These measurements were obtained over a test course of approximately .7 mile (1200 meters), which simulated the urban environment of large steel and concrete buildings. The correlation coefficient was less than 0.5 for the multipath scattering on the video and audio signals. Inspection of Figure 3-25 suggests that the fading mechanism may be similar to that involved in tropospheric scatter, i.e., a random multipath effect. It can be shown that this type of transmission produces a received signal whose cumulative distribution function (CDF) is a Rayleigh distribution. The data in Figure 3-25 was analyzed and processed to obtain the CDF's, and the results are plotted in Figure 3-26 on Rayleigh Distribution Function paper. On this coordinate scale, a Rayleigh

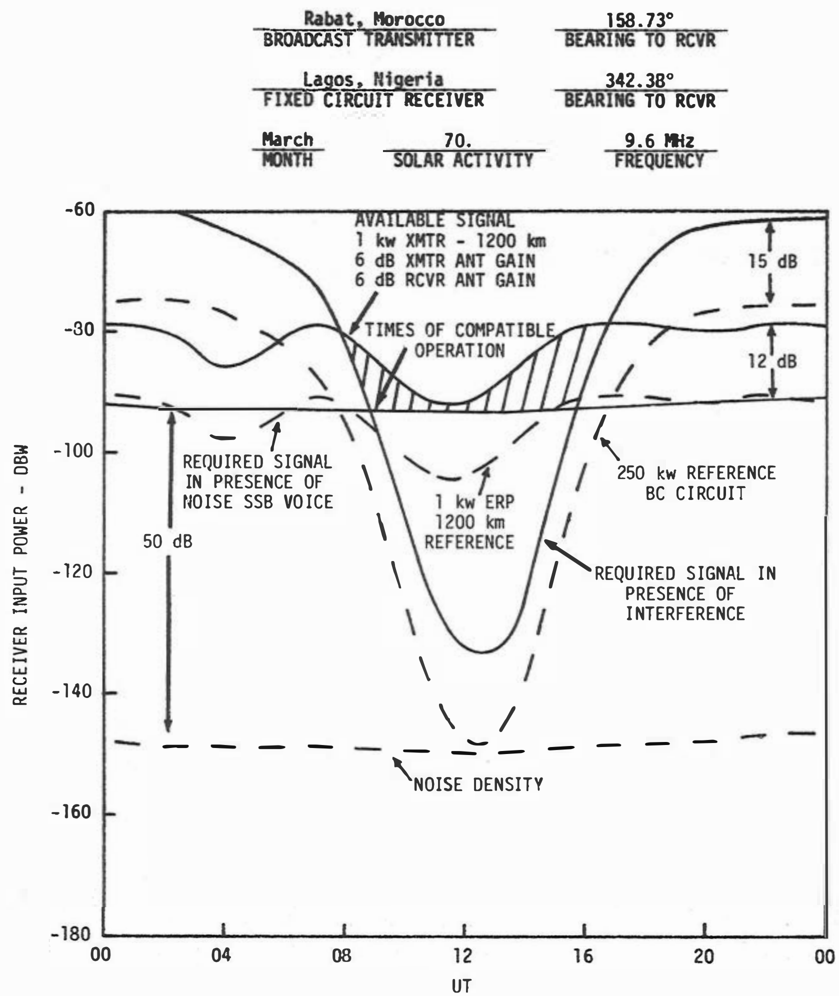


Figure 3-22. Chart to estimate time of compatible operation between the fixed service and a broadcast transmitter operating at 9.6 MHz.

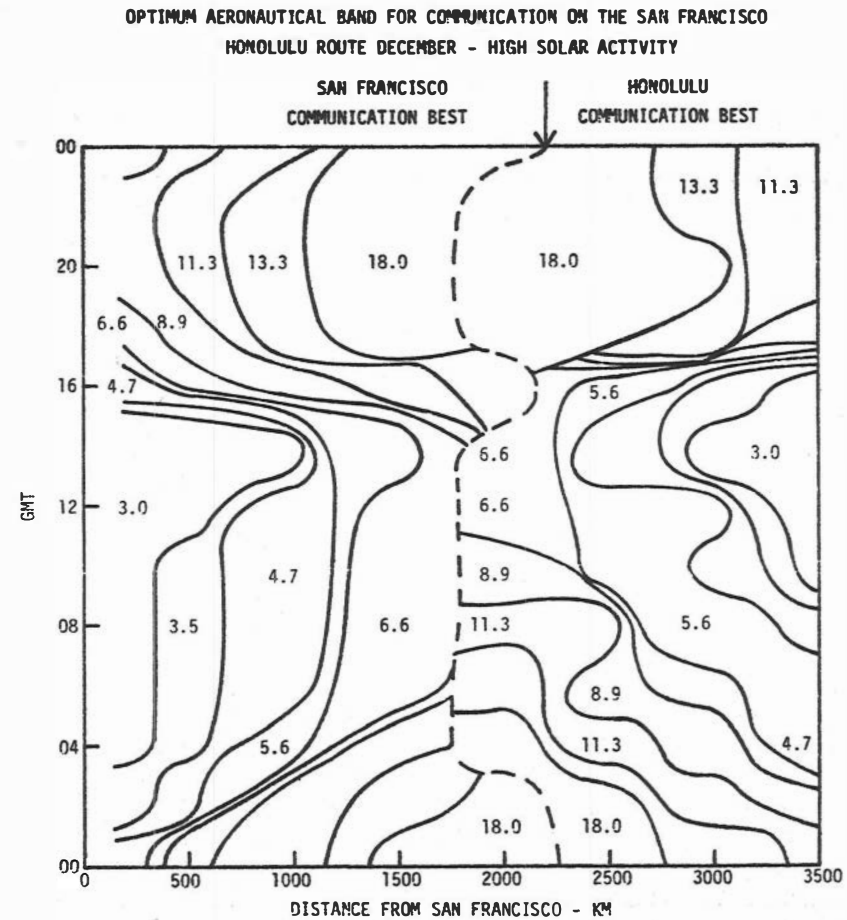


Figure 3-23. Sample graph which could be used to assist in the selection of a theoretically optimum aeronautical channel.

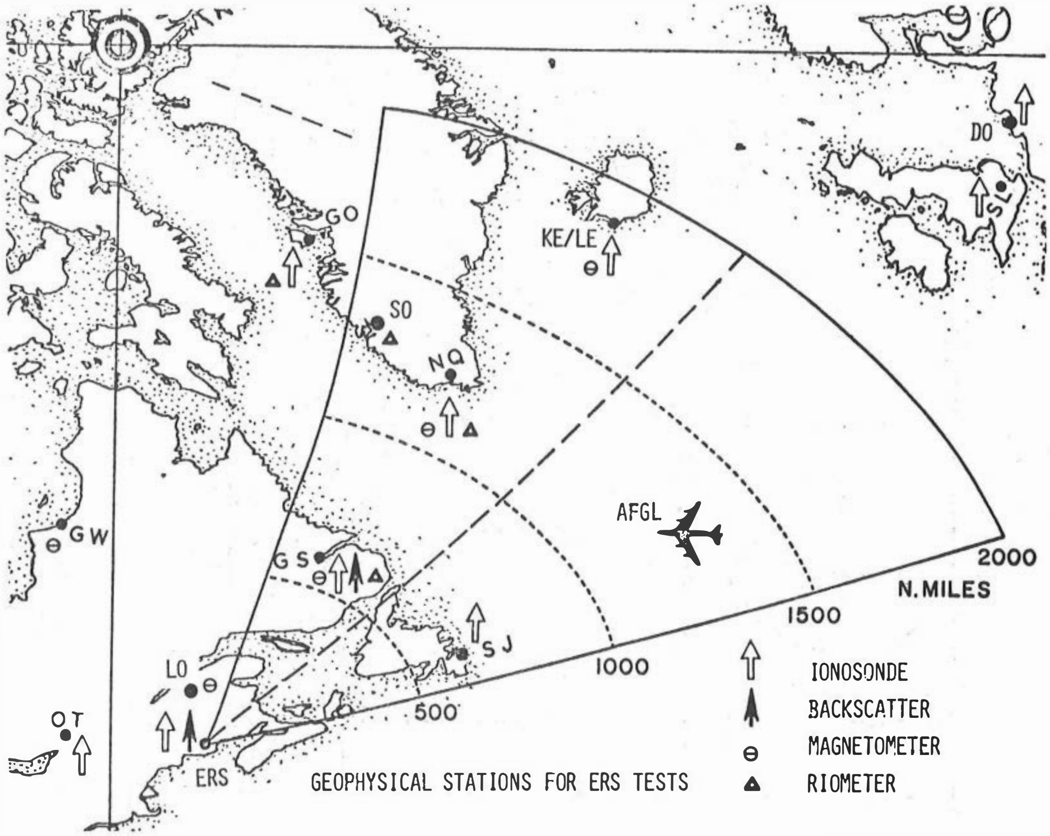


Figure 3-24. Coverage area of the CONUS OTH-B radar system.

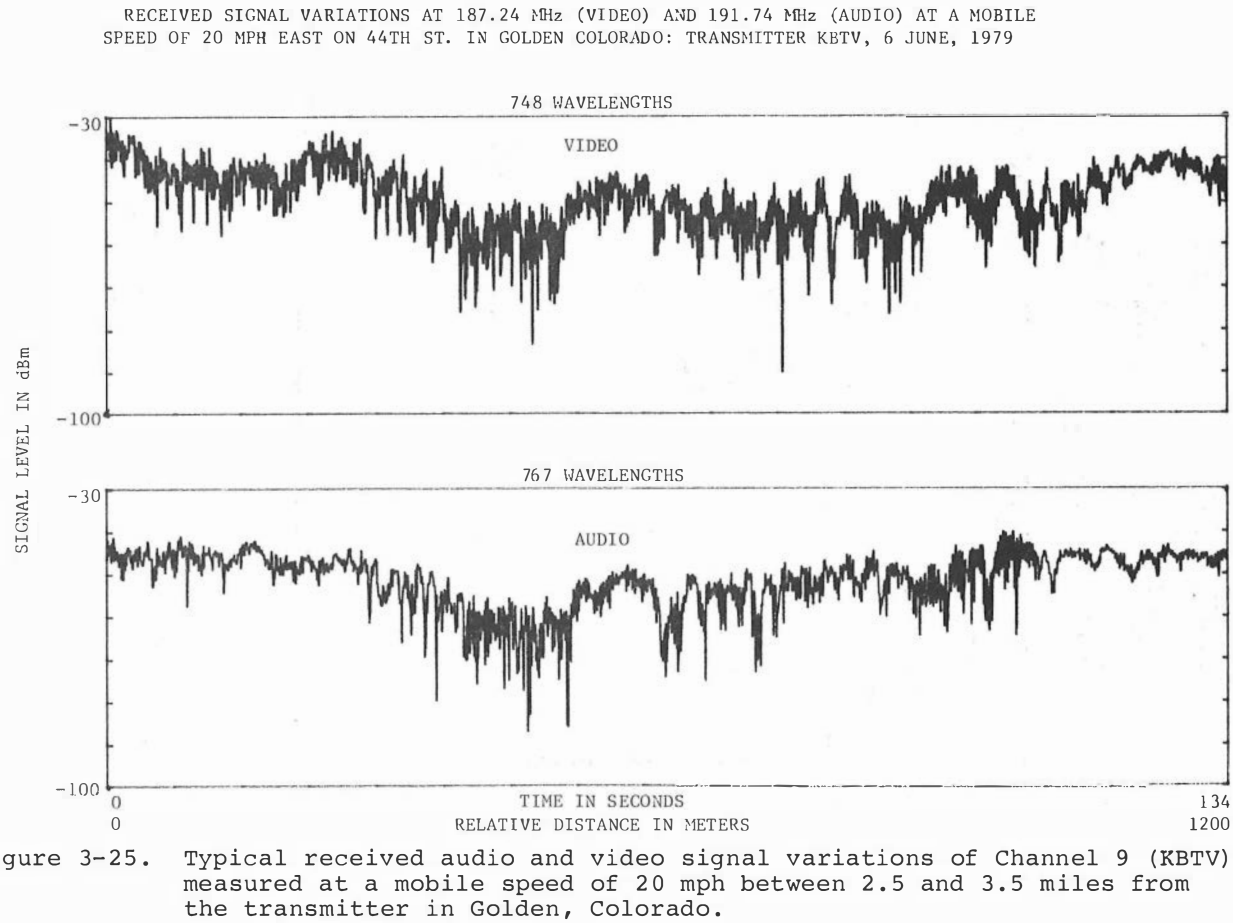


Figure 3-25. Typical received audio and video signal variations of Channel 9 (KBTV) measured at a mobile speed of 20 mph between 2.5 and 3.5 miles from the transmitter in Golden, Colorado.

RUN NO. 15 EAST ON 44TH ST. AT 20 MPH 6 JUNE, 1979

CUMULATIVE PROBABILITY DISTRIBUTIONS FOR 187.24 MHz (VIDEO)
AND 191.74 MHz (AUDIO) RAYLEIGH DISTRIBUTION FUNCTION SCALE

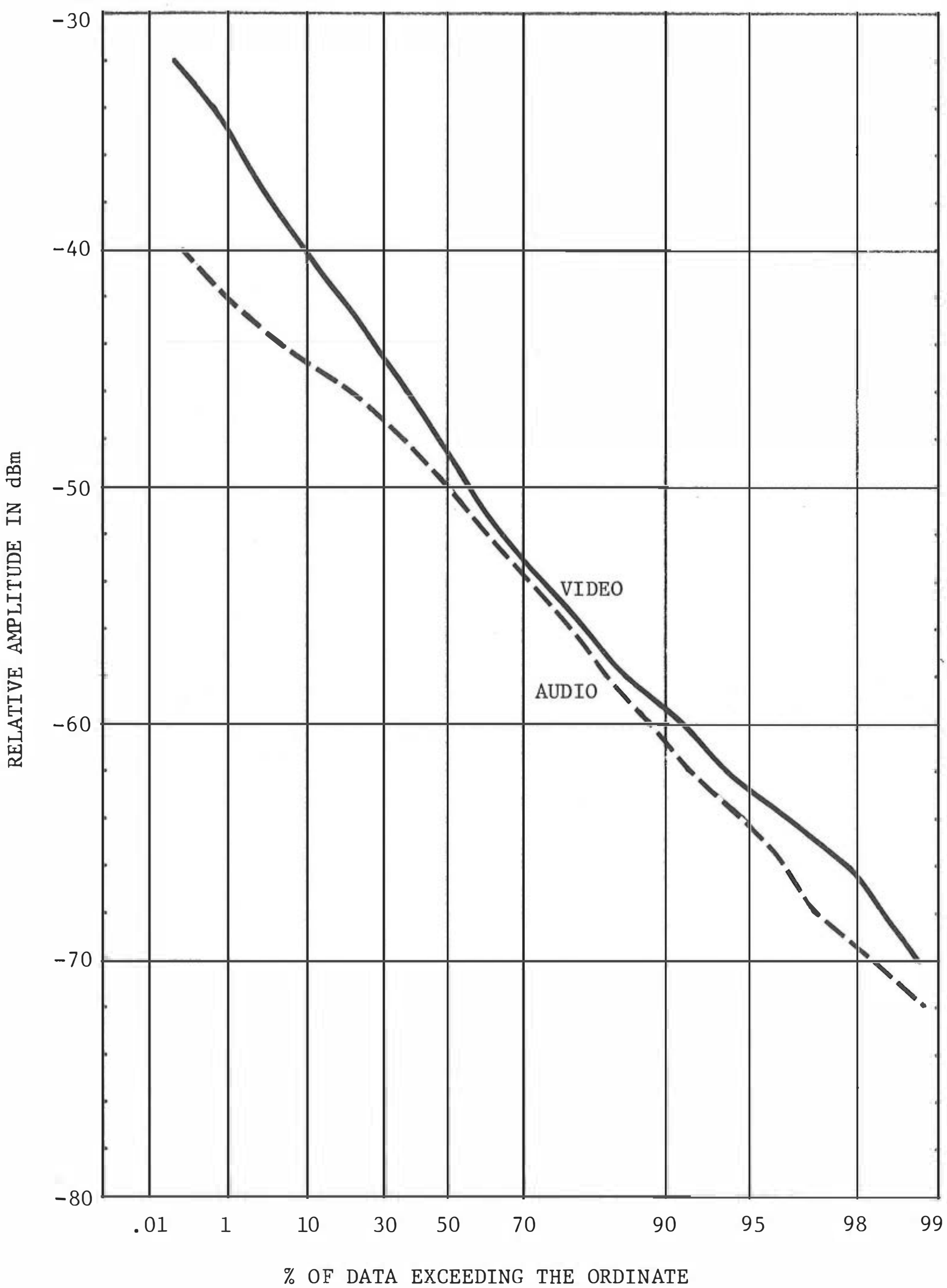


Figure 3-26. Cumulative probability distributions for the Channel 9 (KBTV) signal on a Rayleigh scale.

distribution would plot as a straight line, and one can see that the observed CDF's are very nearly "Rayleigh." For purposes of comparison, the same CDF's were plotted on so-called "Gaussian" paper (Figure 3-27). On these coordinates, if the distribution were a Gaussian (or normal) probability function, the CDF's would also plot as a straight line. It would appear that the observed distribution is more nearly "Rayleigh" than "normal." However, additional analysis of all the data will be necessary to verify this rather tentative conclusion.

Ionospheric Mapping Study. Numerical models of median ionospheric characteristics have been developed by ITS and are widely used for predicting radio wave propagation either via the ionosphere or through the ionosphere.

The models for the F2-layer critical frequencies, foF2, and the transmission factor for a 3,000 km path, M(3000)F2, were derived from observations made between 1954 and 1958. A study for the Department of Defense is underway to determine if there are any systematic differences with either solar cycle activity or season, between the predictions and observations for the years of 1968, 1970, 1972, and 1974. Based on these results, ITS will develop a program to improve the numerical maps in those areas of the world where substantial improvement is indicated. Theoretical numerical techniques, as well as other sources of additional measurements, (e.g., satellites) will be considered.

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, Woofer-ton, Monrovia, Munich, and Tangier), the predictions include selection of optimum transmitting antenna. In the past, the predictions program, HFMUFES, has been used. With the development of IONCAP, however, HFMUFES will gradually be replaced. For the VOA, a set of predictions made with both programs have been submitted for comparison. In addition, maps of "broadcast coverage" for representative VOA transmitter sites have been prepared as an alternative output for study by VOA personnel.

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 access from a remote TELEX terminal. 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 provided routinely to ITT World Communications, Associated Press, NOAA/SEL, and the American Radio Relay League (for publication in (QST). ITS made predictions for Gulf Oil Communications, Radio Netherlands, McPhee Consultants, Sabre Communications, Scientific Radio Systems, USDA Forest Service, Atlantic Research Corporation, Barry Research Communications, Page Iberica, TRT Telecommunications, Federal Electric Corporation (Vandenberg AFB), and Adventist World Radio. Radio Netherlands is now engineering a new broadcast operation at Hilversum, Holland, and has requested extensive predictions for this site. ITS has received two requests for atmospheric noise data "numerical maps" which have been filled according to detailed instructions from those requesting them: RD Associates, and CNET in Lannion, France. 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 Telecommunication 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.

Saudi Arabia HF Predictions. The Propagation Prediction and Model Development Group of ITS has undertaken a project to develop high-frequency (HF) radio propagation predictions for the Kingdom of

RUN NO. 15 EAST ON 44TH ST. AT 20 MPH 6 JUNE, 1979

CUMULATIVE PROBABILITY DISTRIBUTIONS FOR 187.24 MHz (VIDEO)
AND 191.74 MHz (AUDIO) GAUSSIAN DISTRIBUTION FUNCTION SCALE

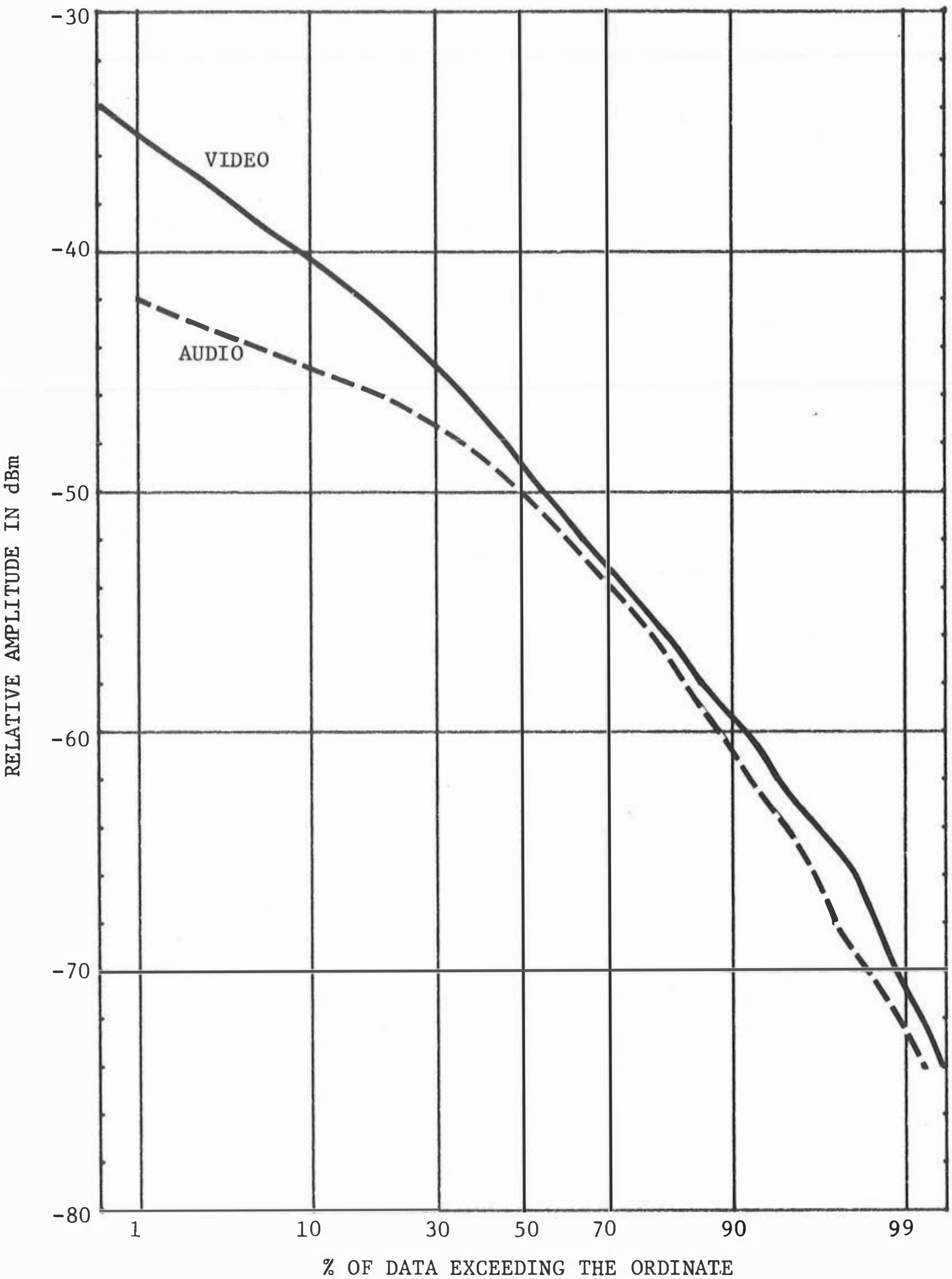


Figure 3-27. Cumulative probability distributions for the Channel 9 (KBTV) signal on a Gaussian scale.

Saudi Arabia as an aid in broadcast scheduling. These predictions were intended to assist the Minister of Information in Saudi Arabia to more effectively determine an optimum assignment of frequency for their broadcast circuits.

A total of seventy-nine worldwide receiving sites were specified by the Director of Frequency Management of Saudi Arabia with the transmitter location at Riyadh, Saudi Arabia. Four antenna types with appropriate bearings were requested for a total of thirty-one antenna configurations (see Table 3-1).

Table 3-1. Transmitter Antenna Configurations

Type	Number of Bearings
Curtain Antenna (one band)	14
Curtain Antenna (two band)	14
Fixed Log Periodic	2
Rotable Log Periodic	1*

*Rotable to main beam.

The predictions were prepared using the Ionospheric Communications Analysis and Prediction Program (IONCAP) developed at ITS and constituted a significant utilization of the flexability and optimization of IONCAP. Both tabular and graphical presentations of the various prediction parameters were presented that included graphs of the expected diurnal variation of Maximum Useful Frequency (MUF), Optimum Traffic Frequency (FOT), and Lowest Usable Frequency (or Lowest Usable Broadcast Band). LUF were produced for each antenna and its associated bearings and broadcast reception location for each month at the two solar activity levels. A tabular presentation of predicted parameters included the circuit reliability (REL), defined as the percentage of days within the month that an adequate signal-to-noise ratio is expected, the expected monthly median of the hourly median field strength at the receiver location (DBU), and the monthly median of the hourly median signal-to-noise ratios at the receiver inputs (S/N). These parameters were determined as important in the development of frequency schedules, the selection of antennas to estimate if broadcast signals would be adequate in the presence of interference, and to measure circuit quality. The reliability parameter was also presented in a format designed to simplify the determination of geographic coverage at a given time for a given frequency and antenna. Another format of circuit reliability was developed to estimate the portion of the day a given frequency would provide satisfactory reception in a given area.

HF/UHF Propagation Evaluation. The Institute for Telecommunication Sciences has been involved in an HF/VHF propagation valuation program for representation of the United States intelligence community to enhance their operational capabilities. This included tasks to supply technical consultation on HF/VHF propagation-related problems and provide comparison of observed and predicted HF propagation parameters. This included numerical simulation of long-distance high-frequency radio propagation system performance and HF performance predictions utilizing the Ionospheric Communications Analysis and Prediction Program (IONCAP) developed at ITS.

The IONCAP program was used to predict specific circuit parameters. These predictions were then compared against observations of HF field strength, maximum usable frequencies, and lowest observable frequencies. The source of observed data was primarily CCIR documents. Particular emphasis was placed on the extension of the IONCAP program to frequencies from 3055 MHz. As part of this task, it was necessary to develop specific antenna model routines for antenna designs specified by the sponsor.

3.4.2. Medium Frequencies Transmission Studies

AM Band Coverage Prediction Techniques. Propagation by skywaves in the medium frequency (MF) portion of the spectrum significantly impacts the performance of AM broadcasting service, especially at night. Standards of performance and quality of service during nighttime hours are determined using methods to deduce field strengths due to MF skywaves that are less than optimum. The ITS has been supporting an NTIA initiative to the Federal Communications Commission that the channel spacing for AM broadcasting be reduced from 10 kHz to 9 kHz in keeping with a European and Asian decision to adopt the 9 kHz channel spacing. As part of this support, the Propagation Predictions and Model Development Group has investigated and summarized the various methods of computing MF skywave field strength. The methods include those developed by the FCC, the CCIR, and the European Broadcasting Union. This investigation and the results derived therefrom have been documented in a report that is presently in the draft form.

The results of this investigation are being used to determine methods that can improve the prediction and specification of nighttime MF skywave field strength.

MF Adjacent Channel Interference Project. This project's objective was to determine the adjacent channel interference potential resulting from a reduction in the MF frequency channel spacing from 10 kHz to 9 kHz. Four elements were needed to achieve this objective. First, industry-acceptable standard measurement techniques for the performance of commercial AM receivers had to be identified. Secondly, approximately 50 commercial receivers were subjected to performance measurements and the measurements summarized. Thirdly, the number of adjacent channel stations where groundwave service area might possibly be adversely affected by a 9 kHz MF channel space, was summarized. Lastly, the overall potential impact of 9 kHz channel spacing was determined on the AM service area and reported.

Radio Performance Tests. With respect to the time constraints on the project, three tests were deemed germane in evaluating potential receiver interference from the proposed channel spacing reduction. The first was the objective two-signal measuring method for the determination of radio frequency protection ratios. This method of testing is found in CCIR Report 399-2 "AM Sound Broadcasting." This is essentially a two-signal method consisting of modulating successively with a given modulation depth, the wanted and the interfering signal by a standard shaped noise signal, the spectral amplitude of which corresponds to modern dance music. The second tests were called SINAD measurements as described in the EIA Standard RS-204-A. SINAD is defined as

$$\frac{\text{signal + noise + distortion}}{\text{noise + distortion}}$$

and is a meaningful measure of a receiver's usable sensitivity, although the SINAD data does not directly relate to the interference problems associated with a reduction in channel spacing.

The third set of tests was to determine the selectivity of the test receivers. The selectivity of a receiver is a measure of its ability to discriminate between a wanted signal, to which the receiver is tuned, and unwanted signals. The single signal-selectivity measurement which was used in this test is referred to as a receiver bandwidth test. The selectivity curve associated with a particular radio has a definite effect upon the interference problems associated with reduced channel spacing.

Test Receiver Selection. Approximately 50 radios were purchased from local retailers for use in this testing program and were tested in an "off the shelf" condition. No attempts were made to optimize the receiver performance with the exception of the car radios where the trimmer capacitor was adjusted for optimum high frequency performance. The price of these radios varied from $5.00 to about $100.00. These receivers are considered typical of what the average consumer might purchase, and hence our test data reproduces the potential interference problems faced by consumers.

Adjacent Channel Stations. 5337 AM Broadcast stations were analyzed for geographic proximity to other stations broadcasting on adjacent channels. Cumulative distributions were made parametric in nighttime and daytime transmitting powers.

Overall Potential Interference of 9 kHz Channel Spacing. From the tests on AM receivers, it appears that, to maintain the same audio frequency protection ratio as enjoyed on the present channel spacing, the radio frequency protection ratio needs to be increased by 2 or 3 dB on the average.

Directional Antenna Studies. The proposed change in the allocation bandwidth (from 10 kHz to 9 kHz) in the medium-frequency broadcast band would require that a large number of broadcast stations change their operating frequencies. One plan that has been proposed would require changes in frequency allocations of 1 kHz to 4 kHz depending upon the present operating frequency of the broadcast station. This listing, showing the proposed new operating frequencies, is shown in Table 3-2.

A part of the study being conducted by the Institute for Telecommunication Sciences is concerned with the dollar cost to broadcasters for changing their operating frequencies in accordance with the proposed plan. In the case of broadcast stations without directional antennas, this cost can be easily determined as being the cost of new crystals for transmitters and monitoring equipment plus the cost of installing them in the equipment. New antenna impedance measurements should not be necessary since antenna impedance curves for the present frequency should span the new operating frequency.

In the United States, because of the need for many broadcast stations to serve the needs of the many communities and ethnic groups, the medium-frequency broadcast band is very crowded and the use of directional antennas which protect other stations on the same frequency from interference while making it possible to serve a community has become prevalent. Originally directional antennas were utilized for nighttime operation when skywave interference between stations on the same or adjacent channels became a problem, but the use of these antenna systems has been greatly extended to permit daytime stations to operate in local areas. The result of this practice is the existence of a very large number of stations using directional antennas.

The determination of the cost to the broadcaster of making small (1 kHz to 4 kHz)

Table 3-2. Proposed 9 kHz Frequency Allocation Plan

Present f kHz	Nearest New * f kHz	Δf kHz	Present f kHz	Nearest New * f kHz	Δf kHz	Present f kHz	Nearest New * f kHz	Δf kHz
540	540	0	900	900	0	1260	1260	0
550	549	-1	910	909	-1	1270	1269	-1
560	558	-2	920	918	-2	1280	1278	-2
570	567	-3	930	927	-3	1290	1287	-3
580	576	-4	940	936	-4	1300	1296	-4
	585			945			1305	
590	594	+4	950	954	+4	1310	1314	+4
600	603	+3	960	963	+3	1320	1323	+3
610	612	+2	970	972	+2	1330	1332	+2
620	621	+1	980	981	+1	1340	1341	+1
630	630	0	990	990	0	1350	1350	0
640	639	-1	1000	999	-1	1360	1359	-1
650	648	-2	1010	1008	-2	1370	1368	-2
660	657	-3	1020	1017	-3	1380	1377	-3
670	666	-4	1030	1026	-4	1390	1386	-4
	675			1035			1395	
680	684	+4	1040	1044	+4	1400	1404	+4
690	693	+3	1050	1053	+3	1410	1413	+3
700	702	+2	1060	1062	+2	1420	1422	+2
710	711	+1	1070	1071	+1	1430	1431	+1
720	720	0	1080	1080	0	1440	1440	0
730	729	-1	1090	1089	-1	1450	1449	-1
740	738	-2	1100	1098	-2	1460	1458	-2
750	747	-3	1110	1107	-3	1470	1467	-3
760	756	-4	1120	1116	-4	1480	1476	-4
	765			1125			1485	
770	774	+4	1130	1134	+4	1490	1494	+4
780	783	+3	1140	1143	+3	1500	1503	+3
790	792	+2	1150	1152	+2	1510	1512	+2
800	801	+1	1160	1161	+1	1520	1521	+1
810	810	0	1170	1170	0	1530	1530	0
820	819	-1	1180	1179	-1	1540	1539	-1
830	828	-2	1190	1188	-2	1550	1548	-2
840	837	-3	1200	1197	-3	1560	1557	-3
850	846	-4	1210	1206	-4	1570	1566	-4
	855			1215			1575	
860	864	+4	1220	1224	+4	1580	1584	+4
870	873	+3	1230	1233	+3	1590	1593	+3
880	882	+2	1240	1242	+2	1600	1602	+2
890	891	+1	1250	1251	+1			

* According to the 9 kHz spacing plan used in Regions 1 and 3.

frequency changes in accordance with the proposed plan is not as simple with directional arrays. These antenna arrays range from simple two-element arrays to arrays with as many as twelve elements and from linear arrays to arrays with more complicated physical arrangements. Changes in operating frequency alter the electrical heights of the antennas, the electrical spacing between elements of the array, and the phase shifts in transmission lines and in phasing and matching networks. The costs of frequency changes are determined to a large extent by the engineering costs of realigning these arrays and the complexity of requirements imposed by the Federal Communications Commission.

Theoretical computations of the change in the radiation patterns of a large number of broadcast stations have been made for frequency changes of 1 to 4 kHz and have shown the pattern changes to be minor.

To provide experimental verification of the theoretical findings, the operating frequency of radio station WLBH in Mattoon, Illinois, was changed from 1170 kHz to 1166 kHz and to 1174 kHz during the test period from 1 to 5 am on two nights. WLBH uses a 4 tower linear directional antenna array. The licensed operating parameters for the directional were used at each of the test frequencies. A Delta in-line bridge was used at the common point to assure that the licensed input power was obtained at each frequency. Measurements were made at three points on each of twelve radials for each of the three frequencies.

It is interesting to note that the directional was realigned on each of the frequencies in less than 1.5 hours by engineering personnel of the station for the most part using the front of the panel controls of the phasing gear.

The field strengths measured on the radials varied more than the predicted values. It is felt that the deviations can be explained as being due to the fact that phases and current ratios were not exactly the same on the three frequencies and that sampling for the monitoring equipment was located at the tower bases. It was felt that the original values of field strength could have been restored with further minor adjustment of the array. This was not possible because of the limited authorization of two four hour periods in which to perform the tests.

A full report on the project and a discussion of the alternative procedures for implementation of the proposed frequency change with trade-offs which will greatly influence the cost to broadcasters is planned.

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

San Clemente Over-the-Horizon Radar. Some years ago ITS built a new phased array, over-the-horizon radar on San Clemente Island off the coast of California. This used a new concept where each antenna was fed at the base of the antenna tower by its own transmitter as shown in Figure 3-28. The hostile environment of San Clemente Island (mainly the salty sea breeze) had caused major corrosion of the antenna and transmitter system. On-site repairs of the transmitters were deemed impossible due to lack of facility, so the 25 transmitters were returned to Boulder for refurbishment and design update.

The transmitters were returned to the Island in June of 1979. The systems were installed, phased, and calibrated and successful experiments having to do with ocean surveillance were conducted in July 1979 under the direction of the Naval Research Laboratories, Washington, D. C.

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 Mutual - Assistance Vessel Rescue) 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.

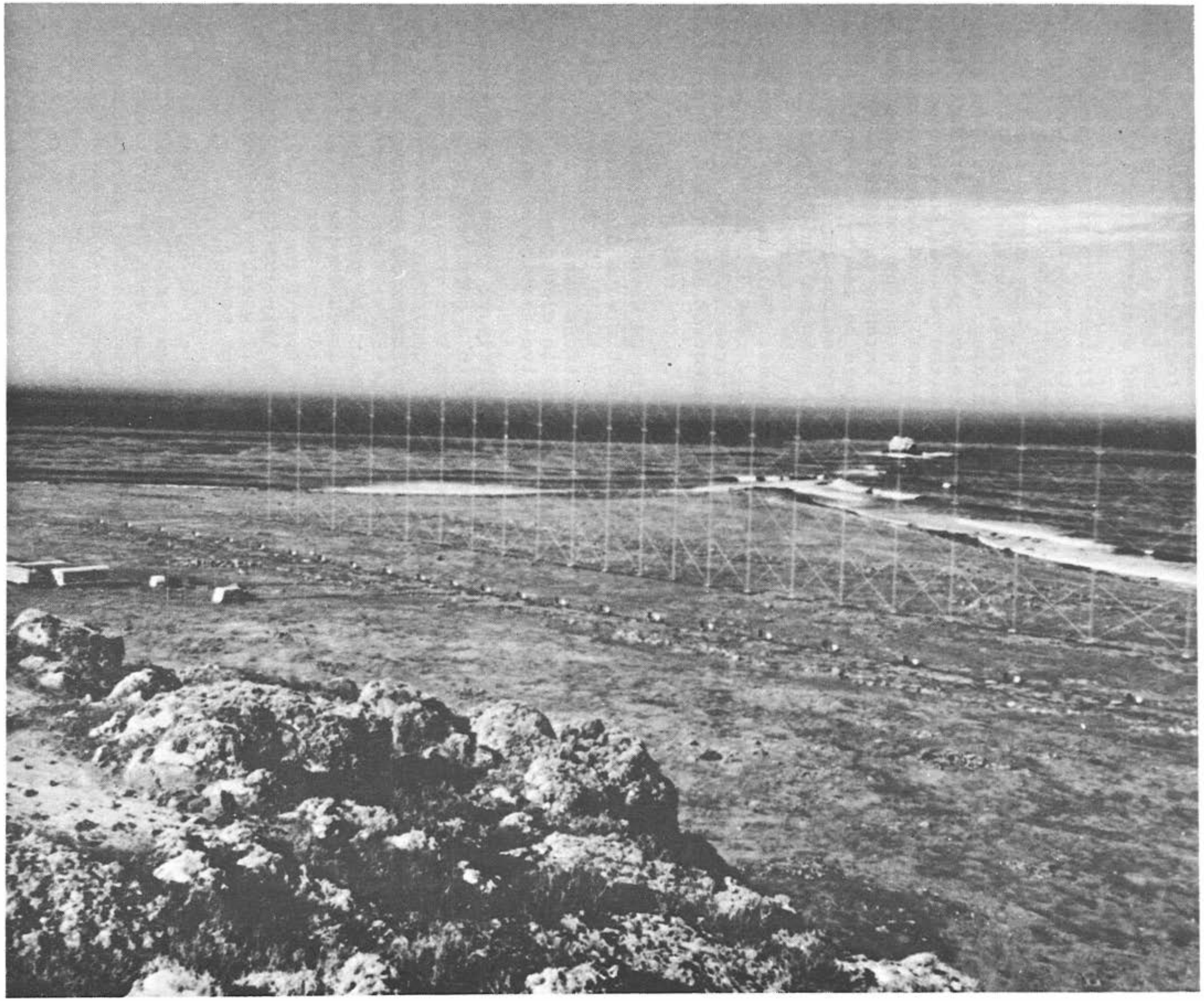


Figure 3-28. San Clemente Island over-the-horizon radar antenna.

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. 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 regard to the ocean areas and the topography of Kodiak Island. Surface-wave propagation predictions were made for the MF frequencies and were described in previous ITS annual reports.

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. These predictions also were described in a previous annual report.

Predictions such as those just described are used in determining the required 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. The following recommendations were presented in a final report.

Operational Configuration - The proposed operational configuration is considered to be efficient and more versatile than the current one (see Figures 3-29 and 3-30). The new configuration should be capable of handling the expected traffic. The proposed "quick-tune" transmitters that need to be acquired should be remotely controllable. The AN/FRT-39's could be used as the "slow-tune" transmitters in the proposed transmitter upgrading program.

Transmitter Power - The 10 kW (AN/FRT-39) currently used is indeed a factor in dealing with the poor site location, although 1 kW may be sufficient for the shorter range circuits that involve the higher elevation angles. Since this is difficult to predict, it is suggested that lower power be tried for a time to determine where and when it can be used. It would be good to retain one or more of the 40 kW (AN/FRT-40) transmitters for emergency situations.

Poor Coverage Areas - The few cases of spotty, poor communications currently experienced (southeast Alaska, the Aleutian chain) may be due to the terrain in the vicinity of the ship. The use of a horizontally polarized antenna aboard ship may alleviate the problem.

Antenna Polarization - The simplest and most effective way of dealing with the poor site location is to use horizontal polarization for all but the lowest frequencies and shorter circuits.

Antenna Matrices - It is recommended that two new antenna matrices be installed at the transmitter site to replace the current "patch-panel". One matrix should be of the manual type, switchable at the transmitter building, and it should be used to couple the slow-tune (ST) transmitters to some of the general purpose or fixed-tuned antennas. This matrix is shown in Figure 3-31 with the recommended transmitter and antenna ensembles. The second matrix should be remotely controllable from the operations building. It would couple the proposed quick-tune (QT) transmitters and the special-purpose or high gain antennas. This matrix is shown in Figure 3-32. The 3 x 3 matrix currently used with three AN/FRT-89 MF transmitters is quite adequate and should be retained as is.

BOM Analytic EM Waves. Various subsurface electromagnetic wave problems have been analyzed for the U. S. Bureau of Mines. The applications have been in mine communications and in electromagnetic methods for nondestructive testing of mine hoist ropes.

The possibility of transmitting signals from depth in a bore hole to a drill operator has been studied. A toroidal coil which completely encircles the drill rod will excite axial currents on the drill rod which will propagate to the surface. Both the propagation along the rod and the input impedance of the transmitting toroid have been analyzed for frequencies from 1 to 3000 Hz. It was found that a thin insulating layer on the drill rod will greatly decrease the required input power.

Nondestructive testing of mine hoist ropes is an important problem in mine safety. Electromagnetic methods involving both solenoidal and toroidal excitation of wire ropes have been analyzed extensively. A system involving solenoidal excitation and multiple sensing coils appears to be most promising. The effect of rope velocity has also been analyzed and is found to be relatively unimportant except for extreme cases of high velocity or very thick ropes.

Hydro-Quebec, the province-owned distributor of electric power to almost all of

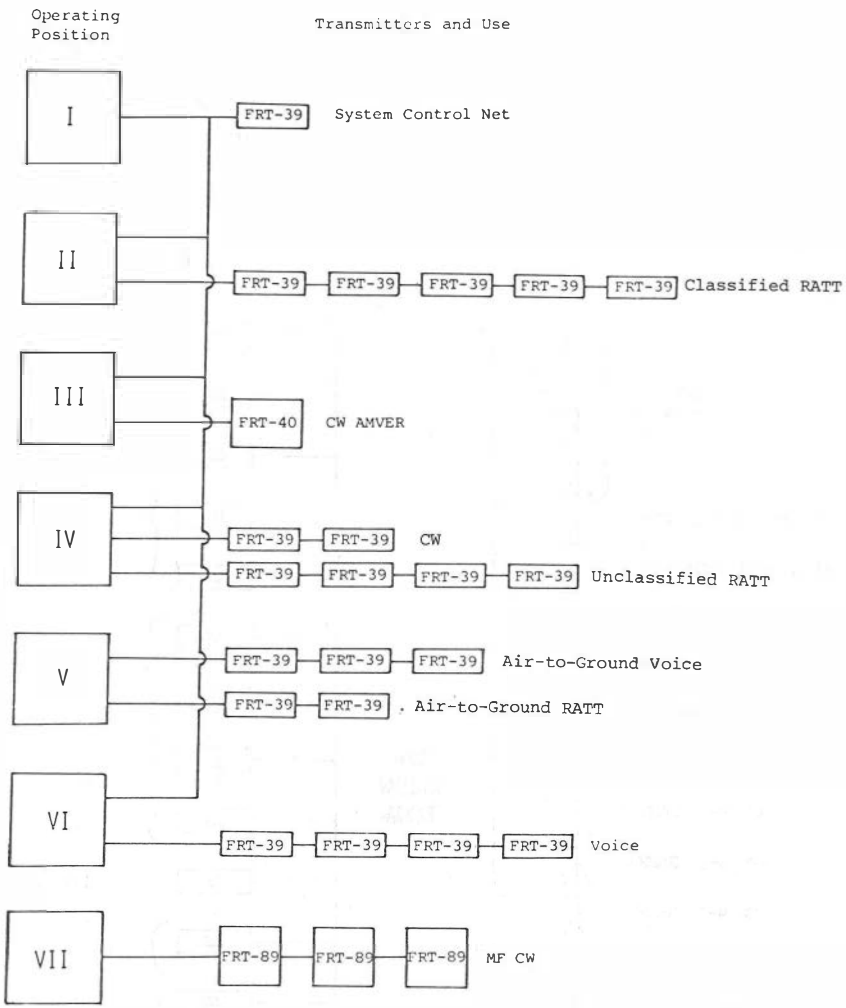


Figure 3-29. Current operating position/transmitter relationships.

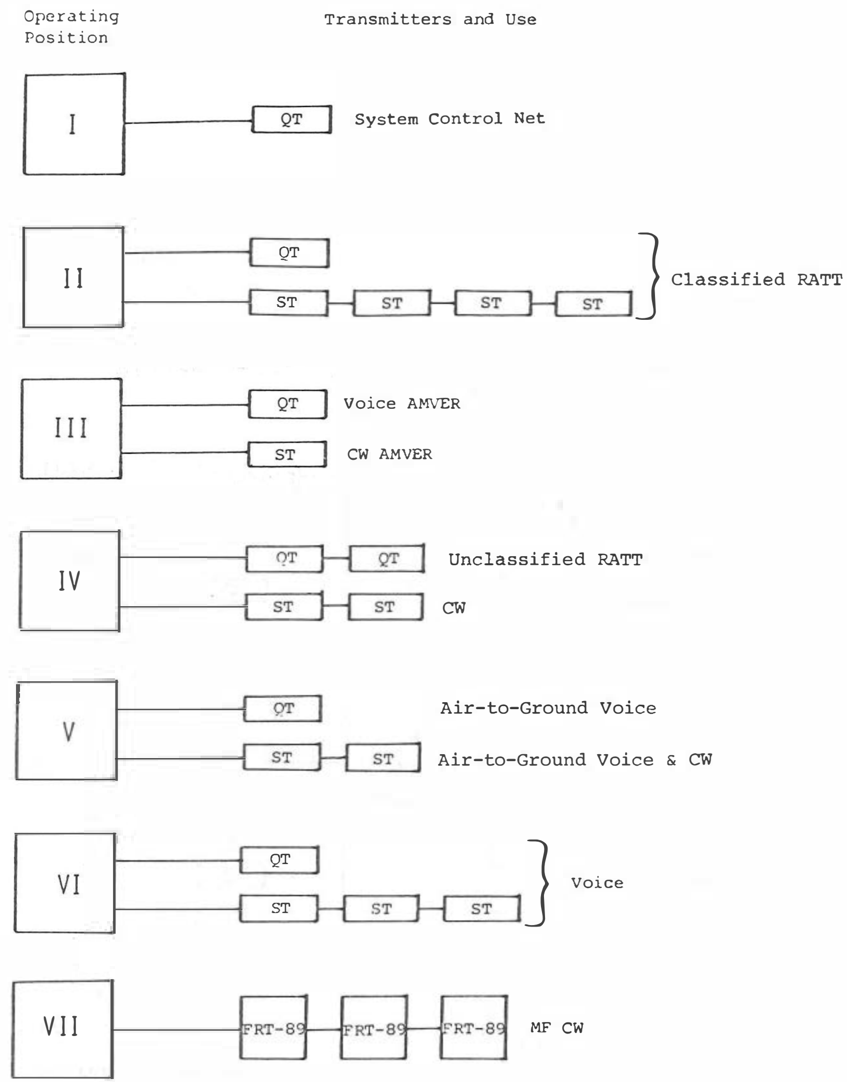


Figure 3-30. Proposed operating position/transmitter relationships showing the use of slow-tune (ST) and quick tune (QT) transmitters.

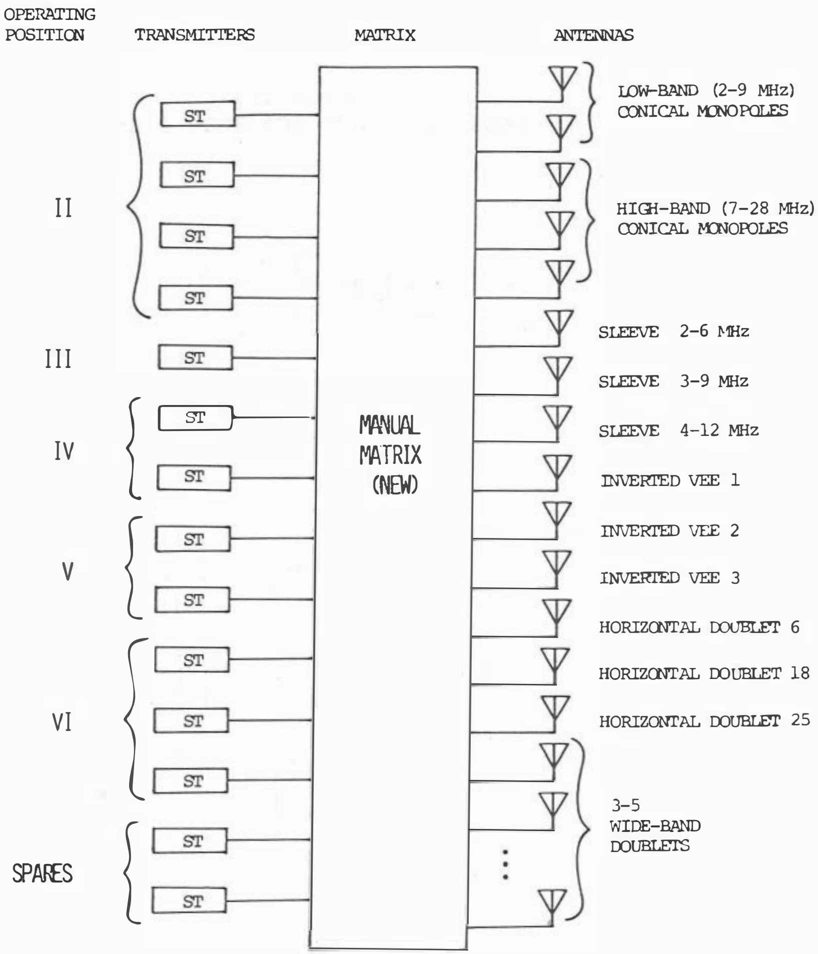


Figure 3-31. Recommended manual matrix.

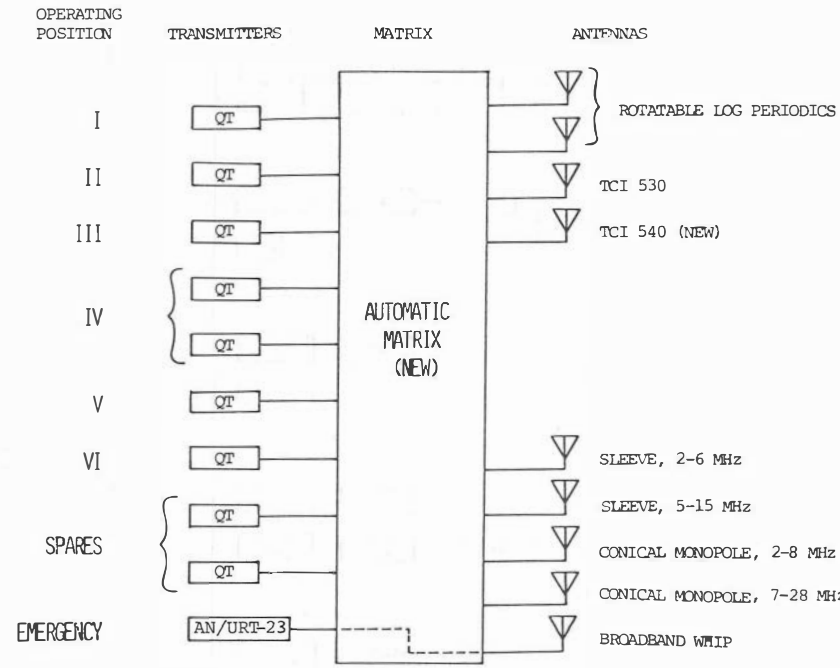


Figure 3-32. Recommended automatic matrix.

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

The project is now complete. The sponsor now has operating programs which store and retrieve large amounts of data in a variety of formats and others which use a digitized topographic file to estimate received signal levels on point-to-point links and on roads and areas serviced by mobile base stations.

3.5.2. Transmission Through the Atmosphere: Applications

Consolidated Model for Earth-Satellite Links. The allocation of frequency assignments is one aspect of radio spectrum management which is very much concerned with the problem of determining coordination distance (the minimum permissible geographical separation between co-channel stations without formal coordination). Determination of this distance requires prediction of the occurrence of propagation conditions which support interference fields. NTIA has initiated a study to develop engineering methods for the prediction of the potential for interference fields. A recent report ("Recent Progress in Duct Propagation Prediction" by Dougherty and Hart, IEEE Trans. AP-27, July 1979) reviews the available meteorological data on ducts, propagation prediction methods, and preliminary estimates of expected interference fields.

Figure 3-33 illustrates the type of unusually strong fields (to within 20 dB of the free-space level) that can occur in the presence of elevated atmospheric layers over transhorizon paths which normally produce rapidly fluctuating fields attenuated by an additional 40 to 60 dB.

Previous years' activities have extended the Dutton-Dougherty (modified Rice-Holmberg) rainfall prediction model by detailed mappings of the prediction parameters (total rainfall, M, ratio of thunderstorm days to total rainy days, β, etc.). Last year's efforts produced estimates of average-year rainfall and the year-to-year variation in Europe. This year, a report ("Year-to-Year" Variability of Rainfall for Microwave Applications in the U.S.A." by Dutton and Dougherty, IEEE Trans. COM-27, June 1979) presents similar estimates for the U.S.A. For example, Figures 3-34 and 3-35 show the contour mapping of the U.S.A. for the one-minute rainfall rate expected for 0.1% of an average year, $R_1(0.1\%)$--expected for a cumulative total of 8.75 min during the year--and the contour mapping of the year-to-year variability in this 0.1% rainfall rate, $S_1(0.1\%)$. A computer program that makes the corresponding earth-space predictions of attenuation due to rainfall is entitled DEGP77, and has recently been user-oriented through the addition of comment cards and the preparation of a special deck of cards for general access by potential users.

Solar Power Satellite Ionosphere Modification. As part of its program in seeking alternative energy sources to meet the needs of the United States, the Department of Energy is undertaking a program to assess the impact of the operation of a Satellite Power System (SPS) upon the atmosphere and ionosphere. The SPS is configured as 60 satellites in geostationary orbit collecting radiant solar energy. This radiant energy is to be converted at the satellite into microwave energy and down-linked to antennas at the surface of the earth which will rectify the microwave energy and convert it into DC for inclusion into power grids. As the microwave energy passes through the ionosphere from the satellite, there exists the possibility that the ionosphere will be heated by ohmic processes by the microwave energy. This heating could result in the formation of electron density irregularities in the F region and in enhanced absorption of radio waves in the D region. The effects of such heating upon telecommunications systems are illustrated in an artist's concept in Figure 3-36.

The Propagation Predictions and Model Development Group is responsible for coordinating and managing the DoE program addressing the potential effects of SPS operation on the ionosphere and ionospheric-dependent telecommunications systems. A program of research and exploratory development has been developed and coordinated with scientists and policy-makers throughout the United States. Current activities are directed toward three specific areas of investigation. First, the impact of the SPS operation upon telecommunication systems that rely on the D region of the ionosphere will be studied. This is being accomplished by simulating the SPS ionospheric heating effects using the HF Platteville Ionospheric Heating Facility and measuring the performance of the telecommunication systems whose energy passes through the heated ionosphere. Telecommunication systems such as OMEGA, LORAN-C, WWVB, WWV, and AM Broadcasting signals will be monitored when the Platteville heater is turned on and off in an effort to deduce what, if any, heating-related effects are observed.

A second effort is directed toward gathering experimental data to aid in determining the physical mechanisms responsible for the heating of the ionosphere. This effort relies heavily upon the use of the Incoherent Scatter Radar at Arecibo, P.R., in order to determine the changes in electron

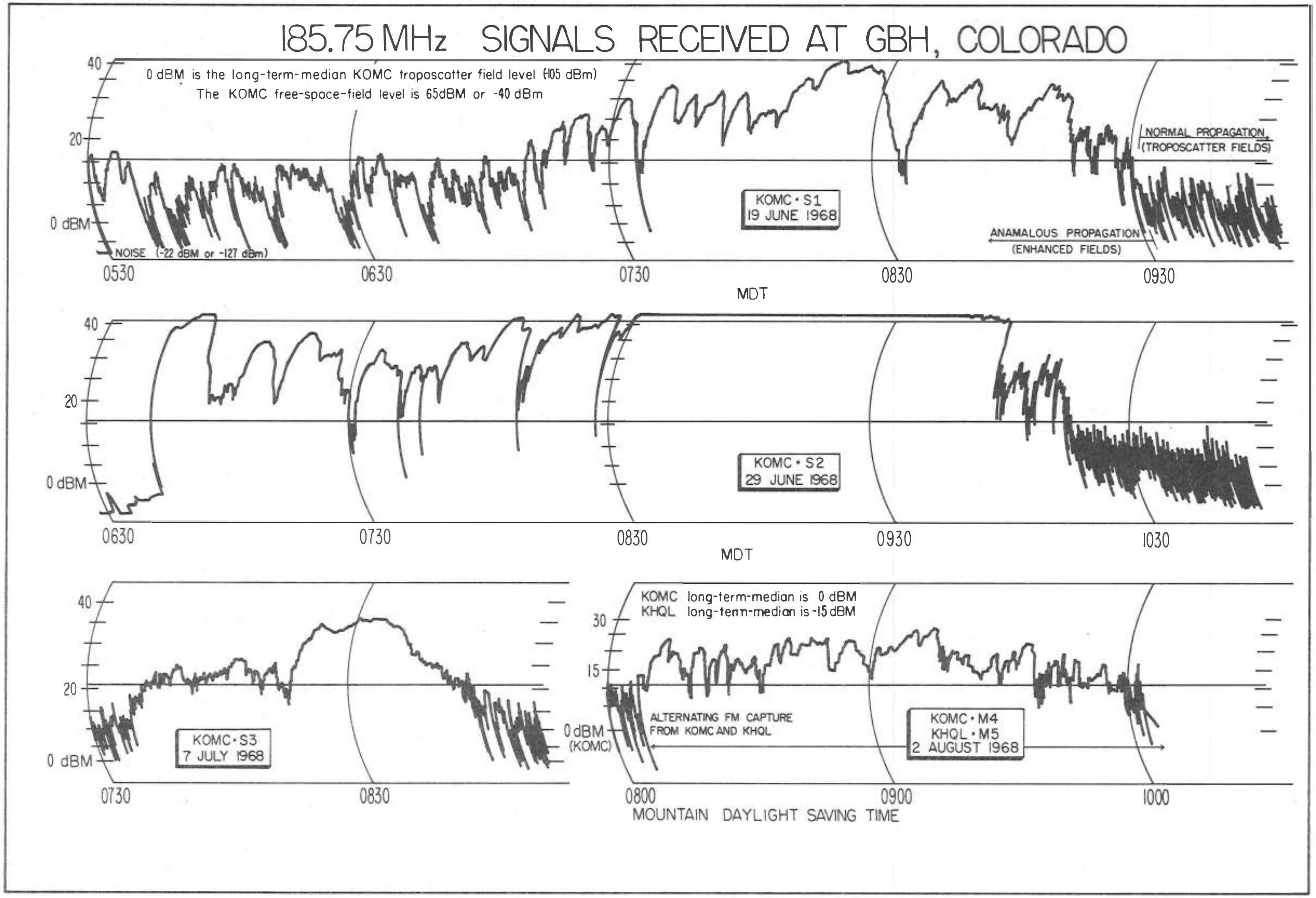


Figure 3-33. Strong fields (40 dB and more above the long-term median of 0 dBm) that occur on transhorizon paths in association with elevated atmospheric (refractivity) layers as potential interference fields.

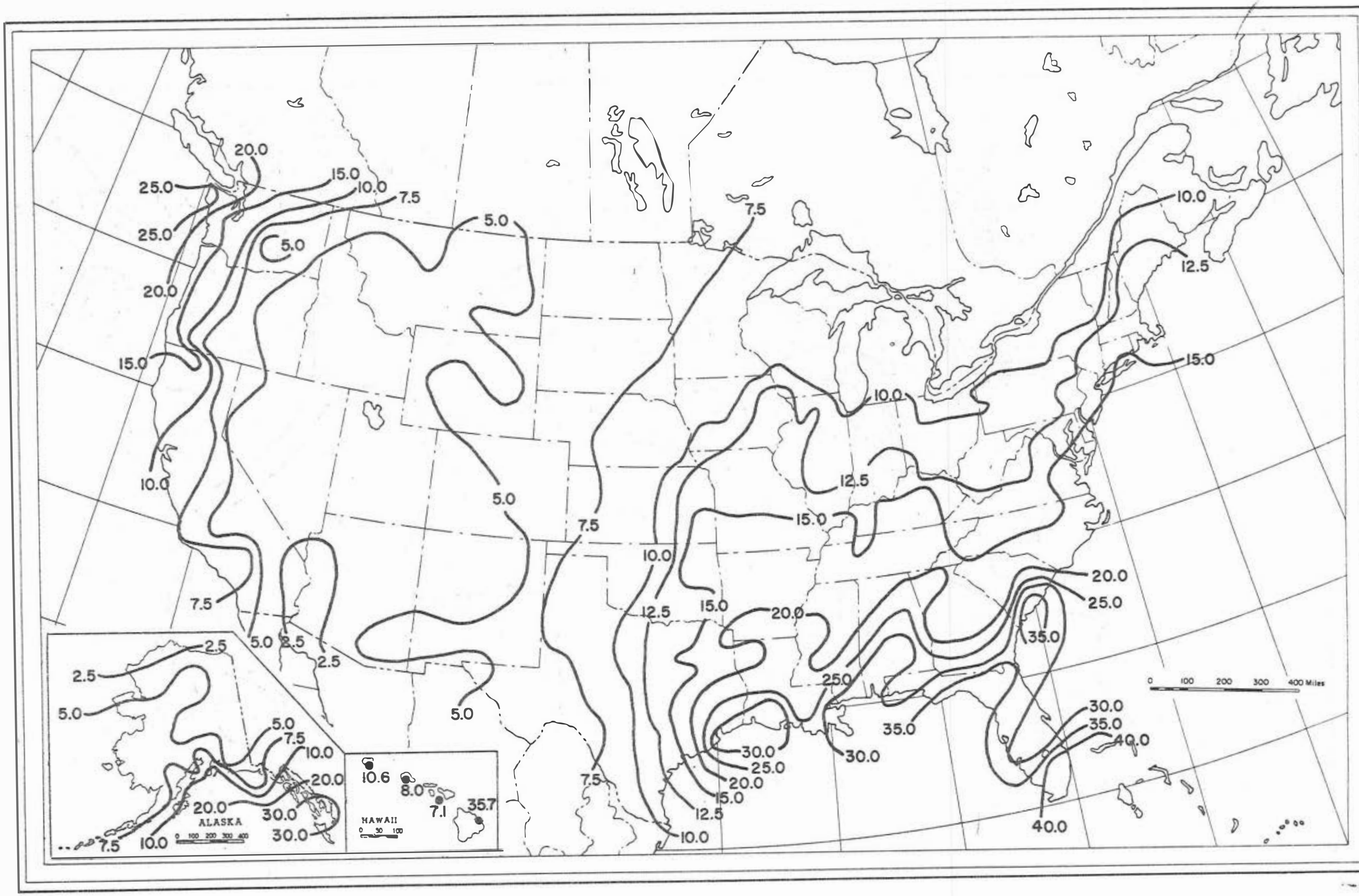


Figure 3-34. Contours of R_1(0.1%), the t = 1 min rainfall rates in mm/hr predicted for 0.1 percent of an average year in the U.S.A.

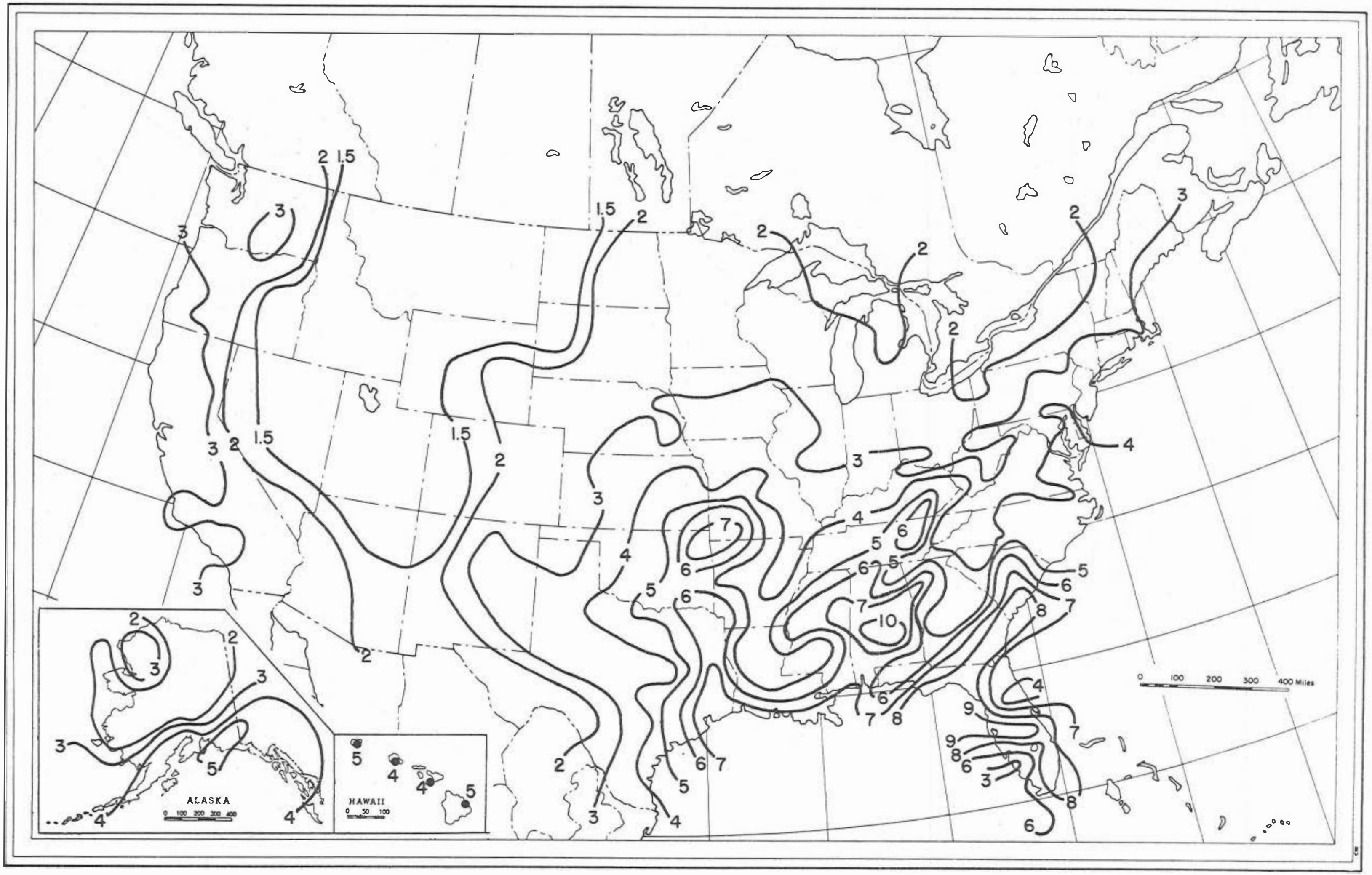


Figure 3-35. Contours of S_{R1}(0.1%), the standard deviation in mm/hr of the year-to-year variation in the t = 1 min rainfall rate, R_1(0.1%), for 0.1 percent of all hours of a year.

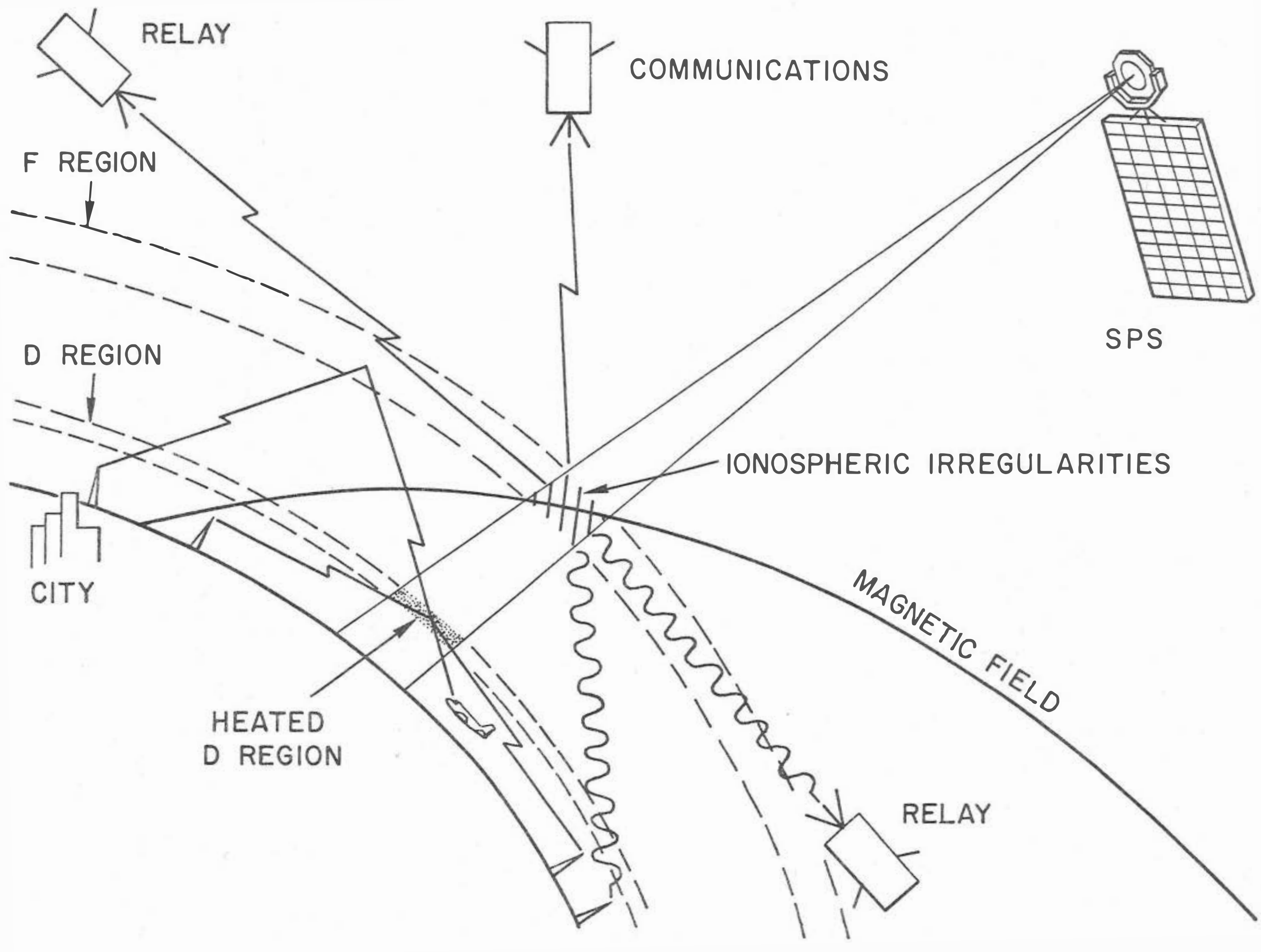


Figure 3-36. Illustration of the possible effects of the operation of the SPS on the ionosphere and telecommunications systems.

density and electron temperature due to ohmic heating. A final effort is directed toward the development of theoretically valid models of the SPS-induced ionospheric heating effects. The theoretical models are needed in order to extrapolate the experimental results obtained at heating frequencies in the HF portion of the spectrum to those anticipated at the SPS operational frequency of 2.45 GHz.

Solar Power Station EMC Analysis. This is a continuing program sponsored by the Department of Energy to study the potential RFI/EMI effects of a proposed Solar Power Station (SPS). These satellites would convert solar energy into DC voltage which would drive high power microwave sources to produce a high energy microwave beam at 2.45 GHz. The satellite in geostationary orbit would beam the energy to a given receiving antenna (rectenna) on earth where the microwave energy would be converted to electrical energy for consumer use. One satellite is capable of producing 5000 megawatts of electrical power on the earth.

One of the first tasks was to calculate the radiation pattern for the space antenna. The antenna is a phased array 1 kilometer in diameter with a 10 dB Gaussian amplitude taper across the aperture. It beams 6.85 GW of power using more than a hundred thousand microwave klystrons each producing about 50-70 kW each. The pattern analysis is given in NTIA Technical Memorandum TM-79-5. Figure 3-37 shows a computer plot of gain versus angle from boresight for the proposed spacetenna. Field intensity plots for the continental United States were calculated for a various number of SPS satellites. Figures 3-38 through 3-40 show a 1, 5, and 10 satellite distribution. Figure 3-41 shows a hemisphere distribution for a 10 satellite case.

From the field intensity maps came an estimate of the range of microwave energy that other electronic equipment and systems would be exposed to. This led to exposure levels that would be used in the determination of the functional and operational degradation of electromagnetic systems (communications, radars, navigation aids, etc.) and other environmental sensitive equipments and systems (computers, sensors, electronic medical instruments and devices, etc.). Subsequent tasks addressed mitigation techniques for degraded systems with some actual measurements to validate estimated operational degradation.

Figures 3-42 through 3-44 show: normal error limits on some candidate systems with no SPS illumination; the percent loss in efficiency in an SPS environment as a function of distance from the rectenna site; and the reduction of effect when certain mitigation techniques were used. Figure 3-42 shows the normal efficiency range for a variety of microwave communication links. The cross-hatch area represents the range of errors measured for the systems tested. The area labeled "mitigated" shows the reduction in degradation due to the following techniques.

1. The receiving antennas of the microwave systems were changed to reduce their vertical gain and thus reduce the amount of interaction with the SPS power beam.

2. Notch filters for the SPS center frequency at 2.45 GHz and second harmonic at 4.96 HZ were used to reduce signal coupling to the input signal amplitudes.

3. Shielding of modules within the systems were accomplished to eliminate physical apertures (slots or holes) through which SPS microwave energy could be coupled.

4. Signal and control cables were either shielded if energy coupling was taking place or double shielded cables were used if normal shielded cables showed SPS coupling effects.

Figure 3-43 shows the imaging efficiency of high resolution TV and infrared sensors used in security monitor applications as a function of SPS illumination and mitigation. The cross hatch again shows a range of degradation representing a variety of systems tested and a variety of configurations of sensor systems. The mitigation techniques used included an optical aperature grid shield placed in front of the receiving optics in an optical defocus location with a mesh size of 1/2" x 1/2"; an aluminum shield was used over other sensitive areas with no openings larger than 1/4" in diameter; dual coax was again used to keep cable coupling at a minimum.

Figure 3-44 shows the effects of SPS beam coupling into microprocessors and mini computers. A large variety of systems were tested giving a wide range of degradation responses to SPS energy coupling represented by the cross-hatch area. However, the measured errors were reduced to an acceptable level by the use of wire grid shielding over physical slots and holes larger than 1/2" x 1/2"; using single point ground system for all modules; the use of dual coax in all message and connecting cables; using single point ground for cable system; and using power and bias supply filters for source and functional module ends to eliminate SPS EM energy from coupling through supply voltages.

These are only a few representative types of systems under study, and a complete report will be written to show the coupling modes and mitigating strategies for a wide variety of systems.

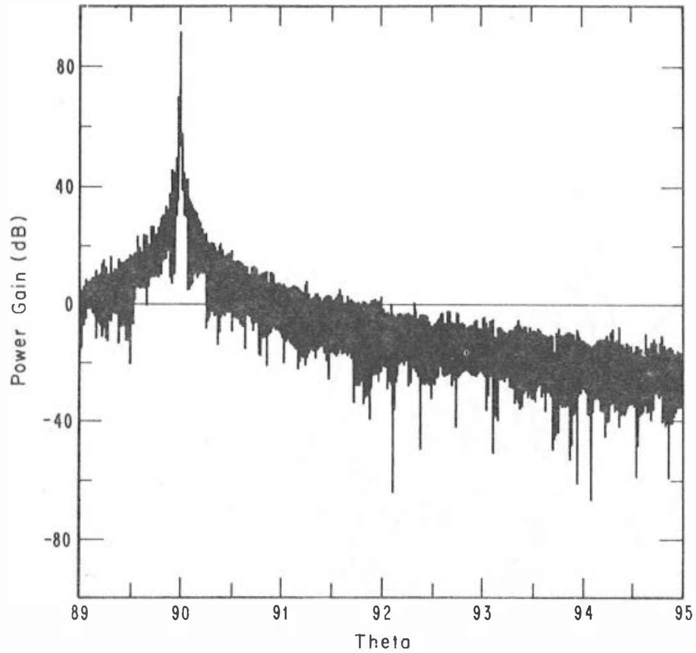


Figure 3-37. Gain versus angle from boresight. On-axis gain is about 87.65 dB.

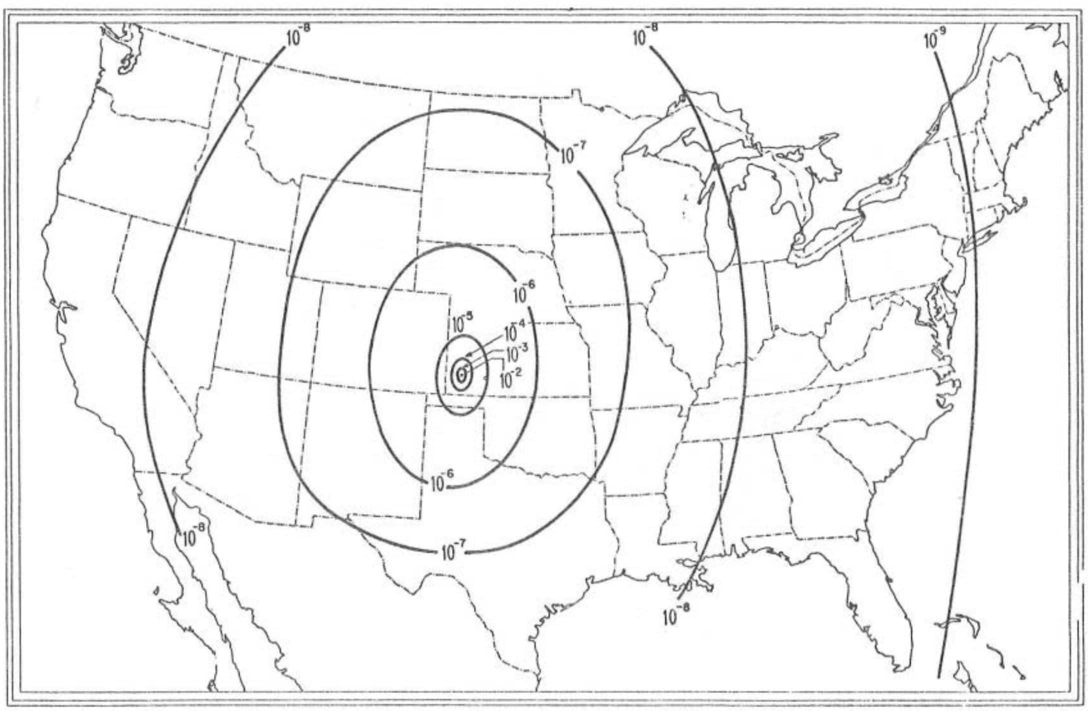


Figure 3-38. SPS single satellite power density distribution, mw/cm^2.

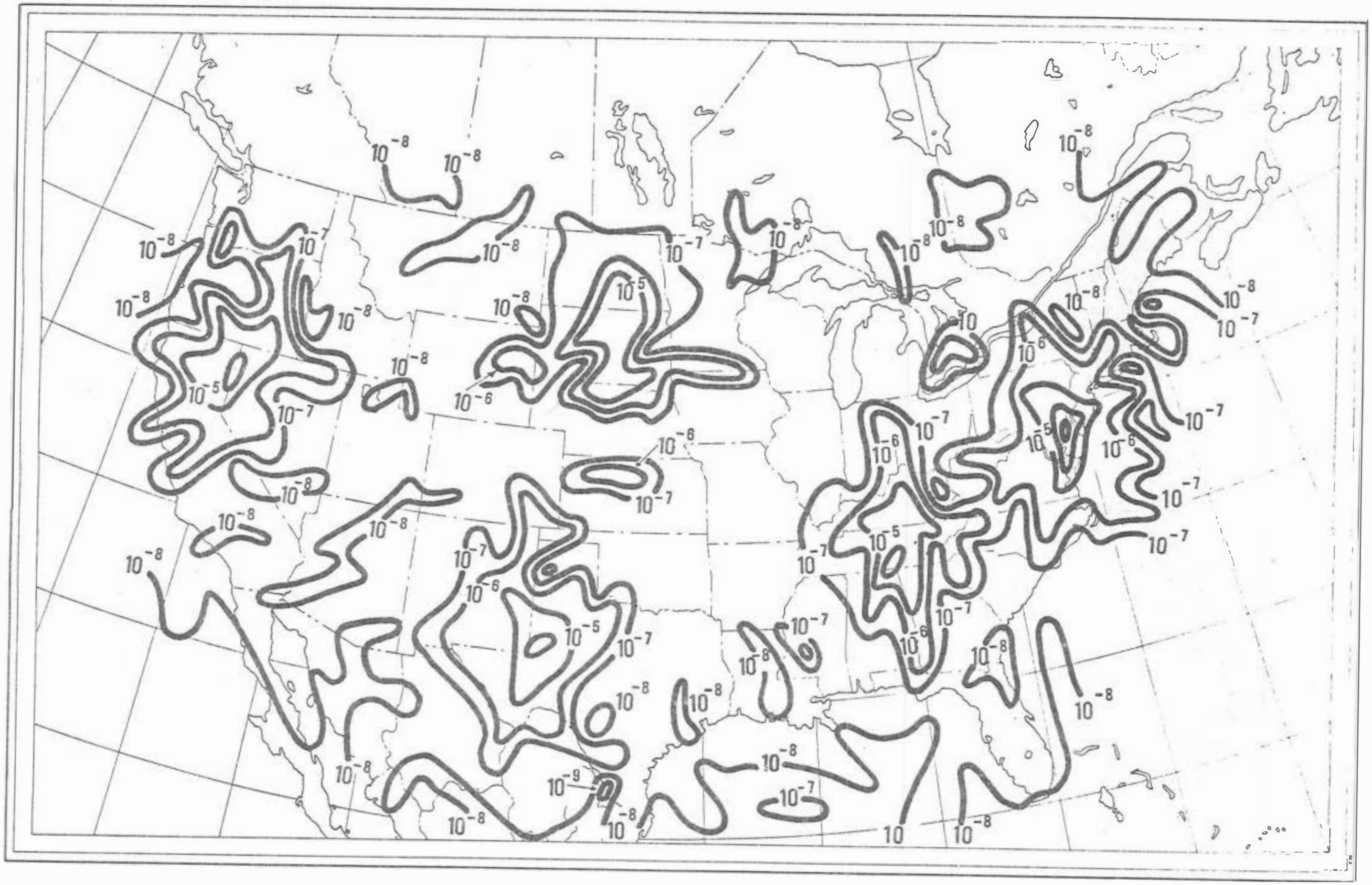


Figure 3-39. Field intensity distribution, mw/cm^2, 5 receiver sites.

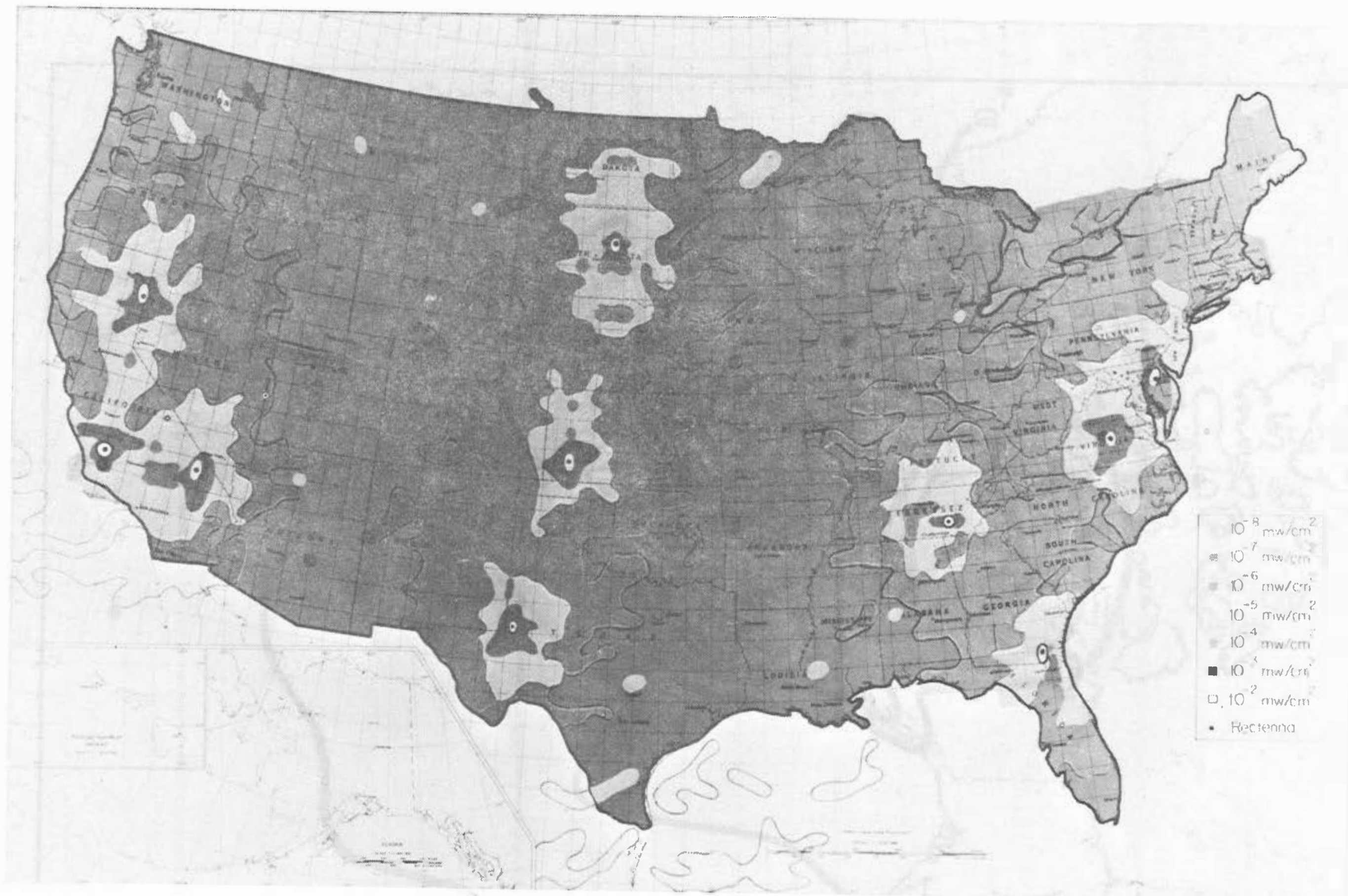


Figure 3-40. Field intensity distribution for 10 SPS receiving sites.

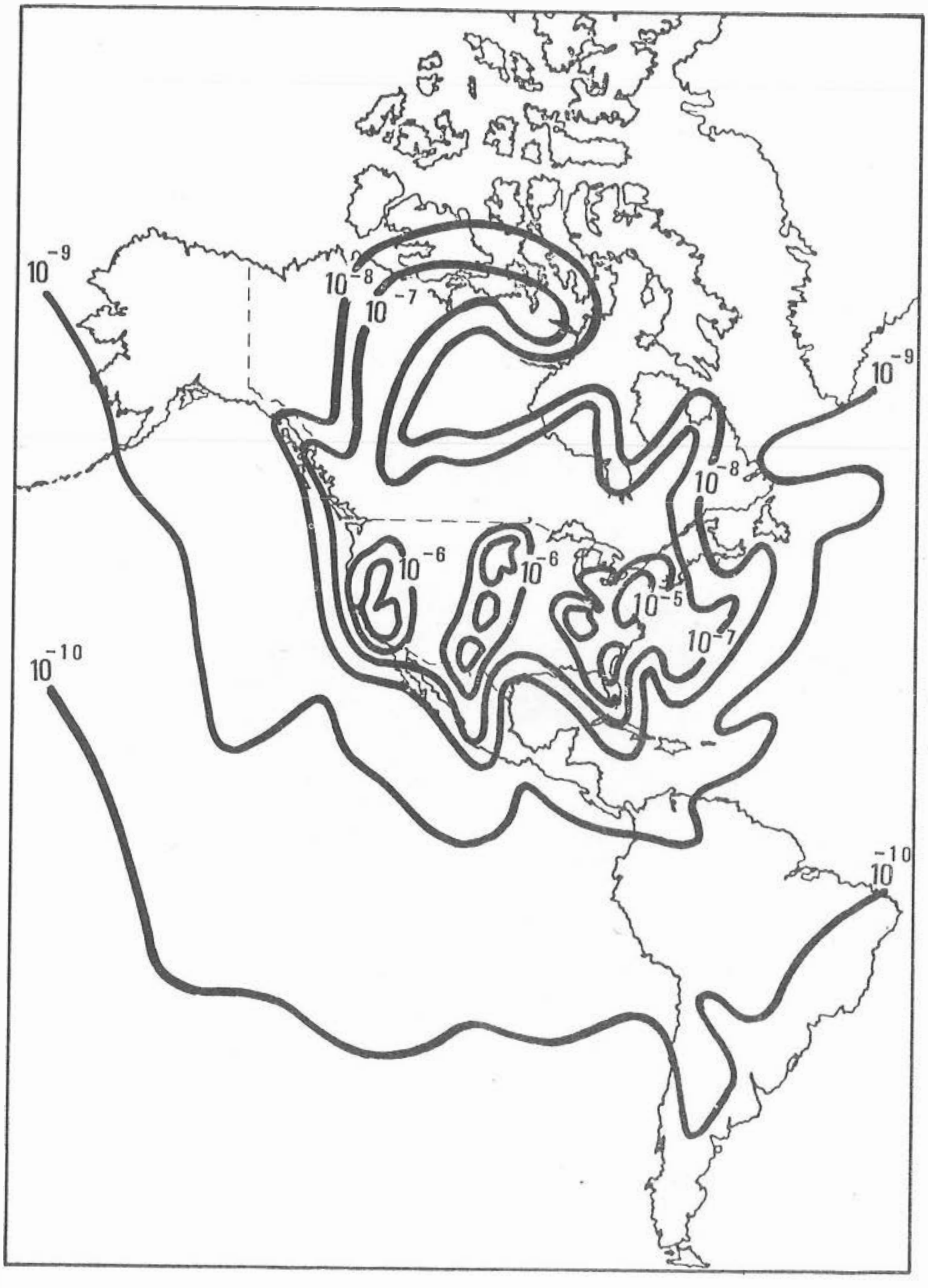


Figure 3-41. Field intensity distribution, mw/cm^2, 10 receiver sites.

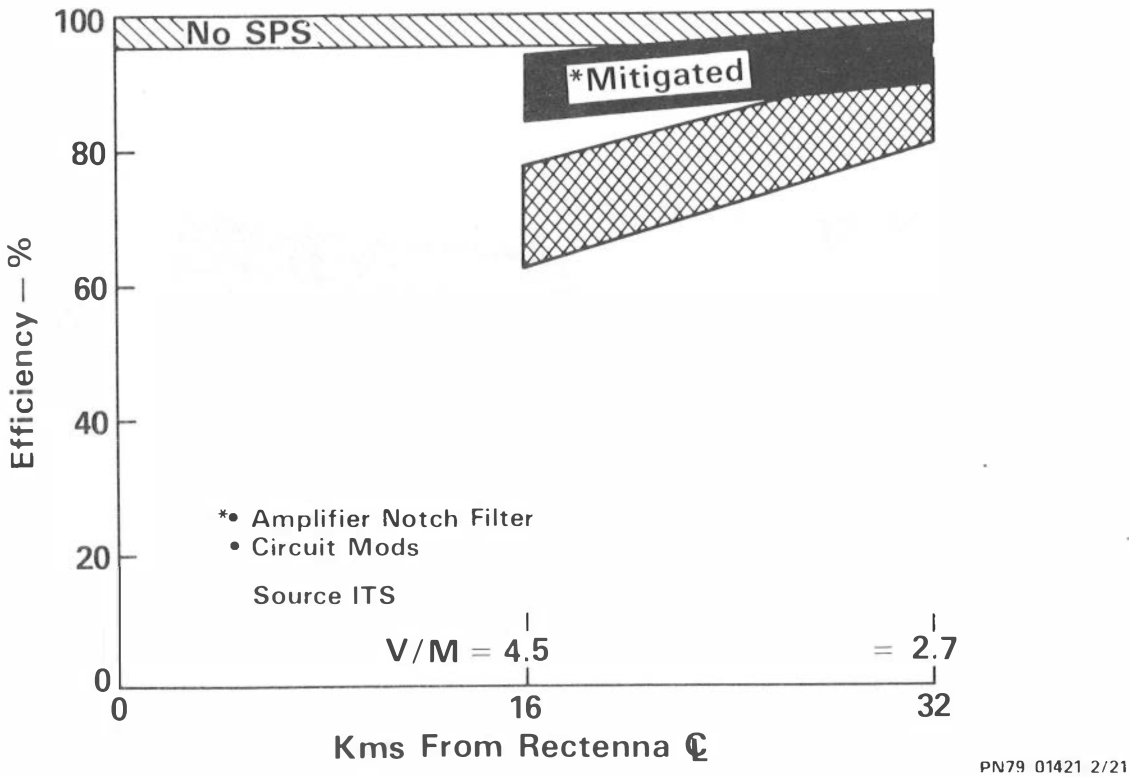


Figure 3-42. SPS results - electromagnetic compatibility effect of MPTS beam on M-W communications links.

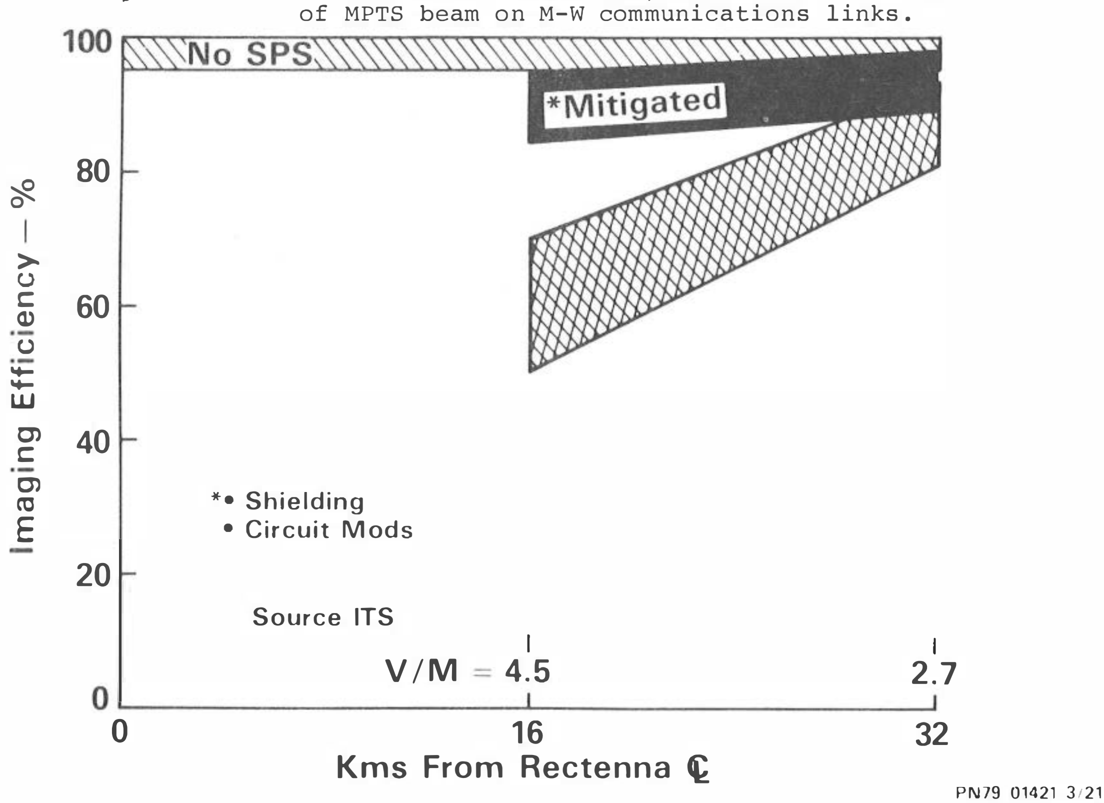


Figure 3-43. SPS results - electromagnetic compatibility effect of MPTS beam on security systems (hi-resolution TV & IR sensors).

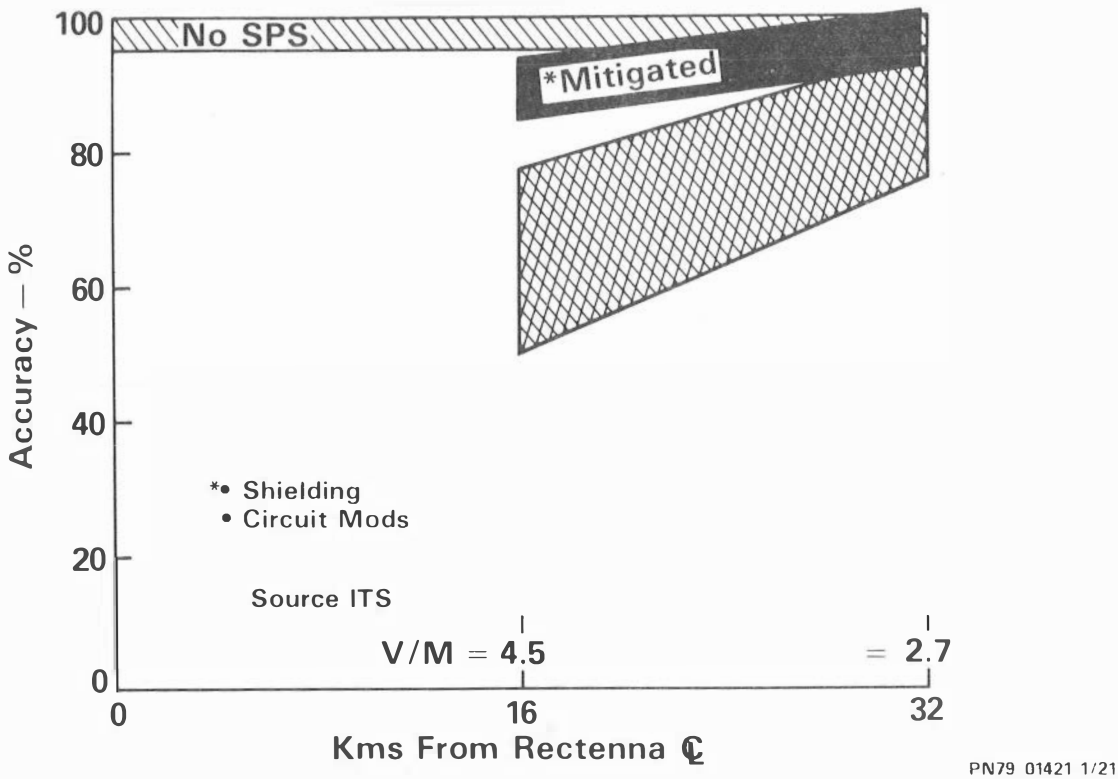


Figure 3-44. SPS results - electromagnetic compatibility effect of MPTS beam on microprocessor accuracy.

Another area of concern was the potential degradation in operation of existing and planned satellites both in Geostationary Earth Orbit (GEO) and Low Earth Orbit (LEO). The GEO satellites investigated are given in Figure 3-45 and the SPS amplitude thresholds where problems start to occur are given in Figure 3-46.

A detailed analysis of potential effects on an INTELSAT communication satellite is given in NTIA Technical Memorandum 79-5. The conclusions drawn from these analyses appear to indicate that the SPS spacetenna's extremely narrow beamwidth will not cause potential interference problems with neighboring satellites.

The LEO satellites such as LANDSAT and GPS have a much higher potential for SPS effects since they have a high probability of passing through the power beam of an SPS from time to time. Figure 3-47 shows the SPS microwave beam geometry at a GPS satellite orbit altitude. The times shown are the times the satellite will be subjected to the level of intensity indicated or higher. That is, the satellite will be subjected to fields greater than 4 mw/cm^2 for 1.35 seconds. The potential problems could effect S band receivers, on board signal processing, altitude control circuits, and EED circuits. The main signal coupling would come through the S band antenna that looks away from earth and toward an SPS, and through cooling louvers as they open to cool electronic circuits behind them. A GPS functional impact modes diagram is shown in Figure 3-48. There are a number of mitigating techniques such as power supply filtering, wire mesh behind open louvers, filtering ahead of the receivers, etc., that can be used to allow acceptable performance of most satellites for the few seconds they would be in the power beam.

This is an ongoing project which will look at other satellites in an SPS environment, analyze the possible use of higher operating frequencies for the Microwave Power Transmission System (MPTS), continue to study effects and mitigation techniques for many types of EM and electronic systems and devices, compute emissions expected from the MPTS including noise and harmonics, and other tasks involved in understanding the SPS EM environment and how compatibility can be achieved.

3.5.3. CCIR Participation

Support to the International Telecommunication 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.

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.

In addition, ITS personnel actively participated in the CCIR Special Preparatory Meeting held in Geneva, Switzerland, during October and November 1978, and participated in a Region 2 telecommunications meeting held in Panama in March 1979. These meetings were held to develop reports to be used by Administrations preparing for the General World Administrative Radio Conference.

1. SATCOM - 119 W, 135 W, 132 W
2. COMSTAR - 128 W, 95 W
3. WESTAR - 99 W, 123.5 W, 91 W
4. TDRSS - 171 W, 41 W
5. MARISAT - 15 W, 176.5 E, 73 E
6. SBS - 122 W, 106 E
7. INTELSAT - 16.5 E
8. ANIK - 108.5 W, 114 W

Figure 3-45. Potential victim satellites.

1. SATCOM: -62 dBm - f_0; -77 dBm - f_2
2. COMSTAR: -60 dBm - f_0; -74 dBm - f_2
3. WESTAR: -58 dBm - f_0; -74 dBm - f_2
4. MARISAT: -62 dBm - f_0; -76 dBm - f_2
5. SBS: -62 dBm - f_0; -78 dBm - f_2
6. ANIK: -62 dBm - f_0; -78 dBm - f_2
7. TDRSS: -54 dBm - f_0; -68 dBm - f_2

Figure 3-46. The SPS amplitude thresholds for GEO satellites.

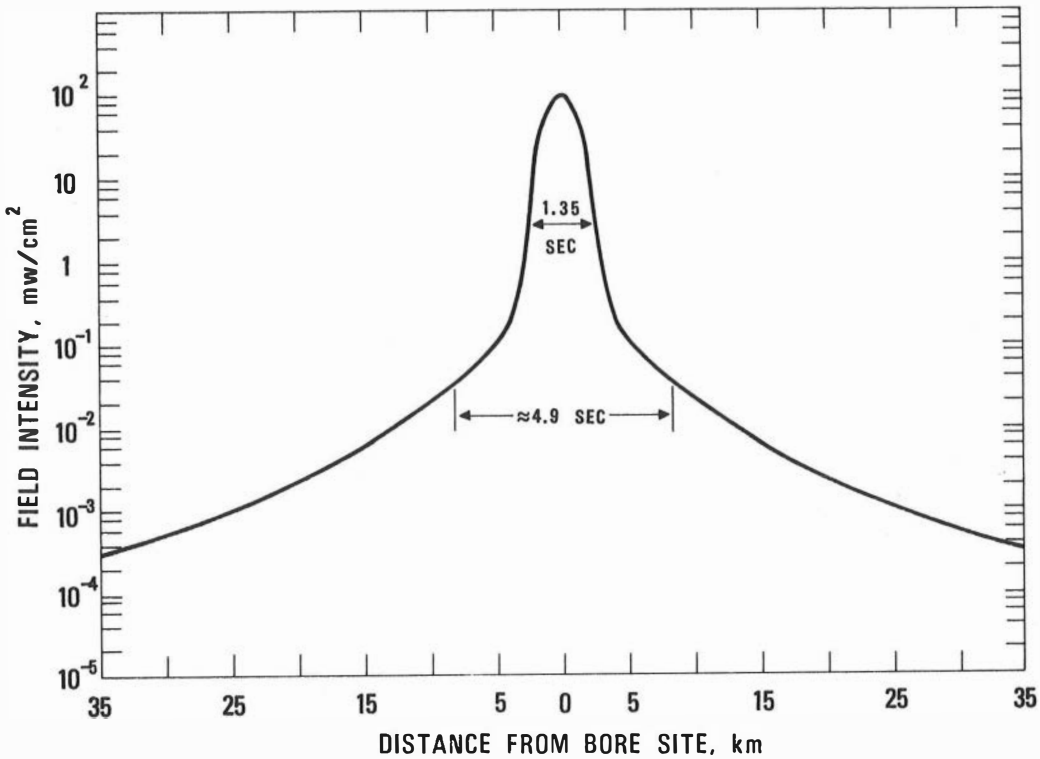


Figure 3-47. SPS microwave beam geometry at Navstar orbit amplitude.

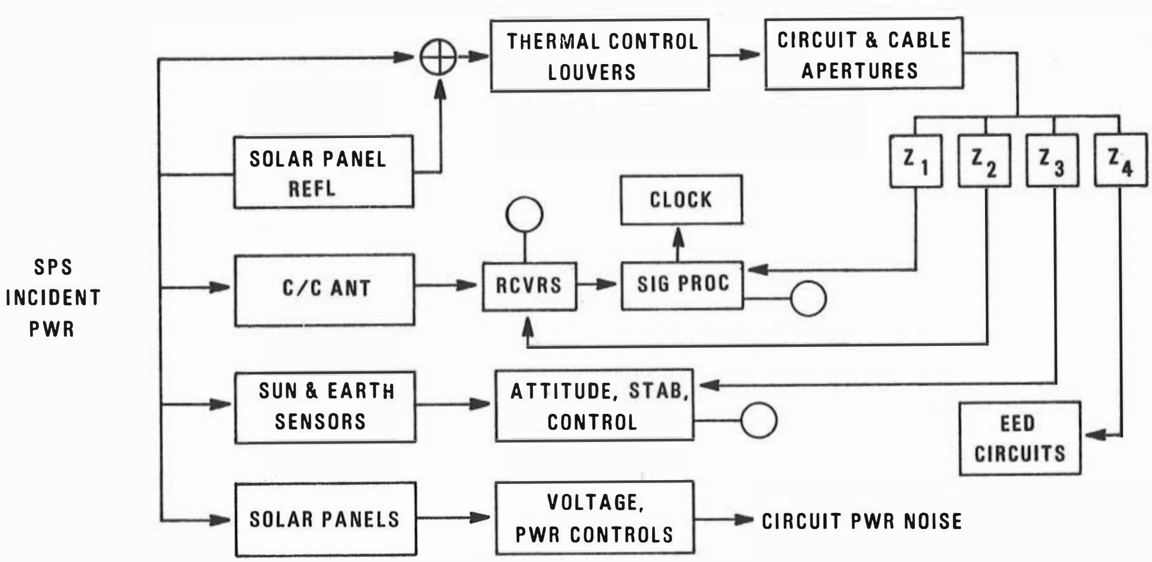


Figure 3-48. SPS functional impact modes.

ANNEX I
ITS PROJECTS FOR FY 79
ORGANIZED BY DEPARTMENT AND AGENCY

Project	Title	Leader
AGRICULTURE, DEPARTMENT OF		
9104384	Communication Support Program	McQuate
COMMERCE, DEPARTMENT OF (DoC)		
	Maritime Administration (MARAD)	
9102419	MARAD Assistance	deHaas
	National Bureau of Standards (NBS)	
9103551	IACP/NBS Test Program	Bolton
	National Oceanic & Atmospheric Administration (NOAA)	
9103417	Weather Radar RFI Surveys	Tary
9103537	SPS Ionospheric Modification	Rush
	National Telecommunications and Information Administration (NTIA)	
9101111	FM Frequency Assignment & Criteria Evaluation	Haakinson
9101112	Spectrum Tradeoffs - Mobile	Berry
9101113	Spectrum Consuming Property of TV-FM Receiving Antennas	Matheson
9101114	Evaluation of UHF TV Receivers	Adams
9101115	Spread Spectrum Application of LMR	Juroshek
9101116	Multiple Interference Effects of LMR Receivers	Juroshek
9101117	TV Spectrum Planning Techniques	Hufford
9101118	Theoretical FM Performance/ Interference	Spaulding
9101119	Adjacent Channel Interference	Washburn
9101120	Directional Antenna Study	Stewart
9104151	Data Communications	Seitz
9104152	Guided Wave Communications	Bloom
9104153	EMS Communications	Hull
9104154	Rural Telecommunications	Hull
9104156	Regular Impact on Direct Satellite Communications	Wells
9104157	Technical & Economic Aspects of Small Earth Station Development	Wells
9105179	Engineering/Technical Evaluation	McManamon
9105180	Characterization of Protection Contract	Lemp
9105195	Technical Assessment of Green Thumb	Wortendyke
9105196	Local Loop Telephone Distribution Technology	Bloom
9106209	HF Sharing & Power Studies	Rush
9106210	Satellite Spectrum Sharing Study	Wells
9107219	Technical Subcommittee Support	Hull
9107226	Spectrum Analysis Techniques & Support	Murray
9107235	RSMS Operations	Matheson
9107236	RSMS Development	Matheson
9108240	VHF/UHF Measurements in Urban Areas	Grant
9108241	Review of Present AM Band Coverage Prediction Technique	Rush
9108242	Expansion of Model & Data Bank	Washburn
9108243	Propagation Model Terrain Microwave System	Ott
9108244	Model Satellite-Earth Microwave Links	Dougherty
9108245	Measurement of Fading Statistics & Error Rates	Lucas

Project	Title	Leader
COMMERCE, DEPARTMENT OF (DoC) (Continued)		
	National Telecommunications and Information Administration (NTIA) (Continued)	
9108246	MF Long Distance Interference	Lloyd
9108247	Platteville Repairs	Lucas
9108249	Directional Antenna Study	Stewart
9108250	Adjacent Channel Interference	Washburn
9108260	FCC Proceedings	Williams
9108265	Public Broadcasting	Hufford
DEFENSE, DEPARTMENT OF (DoD)		
	Air Force Communications System (AFCS)	
9103484	Automatic Measurement System Upgrade	Wortendyke
9104380	LOS Fade 8-GHz System	Hause
	Air Force Systems Command (ESD)	
9103479	EFAS/PEP II Program	Skerjanec
9103528	HF Ionospheric Scattering Study	Violette
9103564	CONUS OTH-B Propagation	Rosich
9104371	TRC Tropographic Tests	Hubbard
9104373	EFAS/PEP II Program Analysis	Skerjanec
	Air Force Systems Command (RADC)	
9103530	RADC Technical Support	Hubbard
9103562	HF Ground Wave	Wait
	Air Force Space & Missile Systems (SAMSO)	
9101463	Buried Antenna Studies - MX Phase II	FitzGerrell
	Air Force Miscellaneous	
9103441	MSR-T1 Multiple Receiver System	Barghausen
9103492	TAC-Signal Analysis System	Barghausen
9103563	Polar Ionospheric Propagation	Rosich
9103565	Topside HF Noise	Rush
9103569	OHD Target Detection	Ott
9104393	LF Radio Propagation Measurement	Kissick
	Army Communication Command (USA/CC)	
9103382	Army Mobile Automatic Receiver System	Carroll
9103427	EMC Van, Part II	Carroll
9103434	Access Area Digital Switching Program	Linfield
9103446	Applications Software	McLean
9103470	EMC Remote Extension	Diede
9103474	Automated Digital Topographic Data Techniques	Spies
9103478	EMC Van, Part III	Carroll
9103491	Follow-on Maintenance	Stewart
9103499	TAEMS Training 3	McLean
9103501	Application Enhancements	Stewart
9103505	Automated Field Intensity Measurement System	Haakinson
9103507	TAEMS Noise Measurement	Spaulding
9103511	Voltage Tuned Filter	Carroll
9103513	TAEMS Repair Parts	Stewart
9103531	ADRES System Upgrade	Harr
9103532	15-GHz LOS Fading	Hause
9103533	Aircraft Effects	Skerjanec
9103534	Channel Probe Measurement/MW Links	Hubbard
9103538	Verification Test Set	Smith
9103547	Digital System Performance Verification	McQuate

DEFENSE, DEPARTMENT OF (DoD) (Continued)

Army Communication Command (USA/CC) (Continued)

Project	Title	Leader
9103557	TAEMS Field Measurement Consultation	Matheson
9103559	Technical Concept Papers	Gallawa
9103560	HF Communications	Watterson
9103561	Command Post/SIG CTR Bus	Linfield
9104390	NBS Antenna Interface	Grant
9104407	Army Communication Network Analysis	Lloyd

Army Research Office (ARO)

Project	Title	Leader
9103550	DM-4/Calculator Software	Matheson
9104405	MM Wave Attenuation in Moist Air	Liebe

Army Miscellaneous

Project	Title	Leader
9103525	Spectrum Monitoring Unit	Adams
9103527	Frequency Extension of Spectrum Monitoring Capability	Adams
9103544	Intervisibility Propagation Loss Measurement	Haakinson
9103545	Intervisibility Propagation Loss Measurements	Thompson
9103555	30-300 GHz Communication Links	Thompson
9103558	Large Earth Terminal Antenna Measurement	Matheson
9103568	Propagation Measurement Guidelines	Hufford
9104375	MM Workshop	Thompson
9104377	Jammer S/I Ratios	Paulson
9104378	Short-Term Ionospheric Predictions	Rush
9104396	Wide-Band Measurement DDAS	Adams
9104397	Wide-Band Measurement Data Analysis	Hufford
9104398	Wide-Band Data Collection	Hubbard

Naval Research Laboratory (NRL)

Project	Title	Leader
9102370	Project NONESUCH	Warner
9103508	Navy Optimum Communications	Spaulding
9103556	Navy Refractivity Study	Marler

Office of Naval Research (ONR)

Project	Title	Leader
9104406	EHF Attenuation of Air	Liebe

Pacific Missile Range

Project	Title	Leader
9103497	Ground/Air Propagation Predictions	Gierhart
9103543	PMR Microwave Link Tests	Hubbard

Navy Miscellaneous

Project	Title	Leader
9103553	EHF Prediction Model	Liebe

Defense Communications Agency (DCA)

Project	Title	Leader
9101534	MEECN Simulation	Watterson
9103512	Glossary Update	Hanson
9103566	DCS II Standards Development	deHaas
9104399	DCS II Operating Performance Criteria	Linfield

National Security Agency (NSA)

Project	Title	Leader
9101518	NSA Consulting	Spaulding
9103567	HF/VHF Propagation Validation	Teters
9104372	Ionospheric Mapping Study	PoKempner
9104401	High Altitude Topside Noise	Rush
9104403	Computer Model Extension	Hufford

ENERGY RESEARCH & DEVELOPMENT ADMINISTRATION (ERDA)

Project	Title	Leader
9103536	SPS RFI/EMI Analysis	Grant
9104379	SPS Ionospheric Effects	Rush
9104388	DOE Platteville Heating	Violette
9104404	SECOM System Enhancement	deHaas

FEDERAL COMMUNICATIONS COMMISSION (FCC)

Project	Title	Leader
9103539	CATV/ATC Interference	Adams
9104381	CB Intermodulation Interference	Berry
9104382	HF Sharing Tests	Lucas
9104385	TV Antenna Performance	Matheson
9104386	TV Antenna System Performance	Matheson
9104394	FCC Channel Simulation	Watterson

INTERNATIONAL COMMUNICATION AGENCY (ICA)

Project	Title	Leader
9101499	Radio Propagation Predictions	Agy
9101501	Improved Prediction Formats	Agy
9103524	Revision of HF Broadcast Methods	Agy
9103540	VOA Consulting	Agy
9103542	Remote Access Computer	Agy

NATIONAL AERONAUTICS & SPACE ADMINISTRATION (NASA)

Project	Title	Leader
9104391	Radio-Optical Refractometer	Thompson

TRANSPORTATION, DEPARTMENT OF (DoT)

Federal Aviation Administration (FAA)

Project	Title	Leader
9103489	Technical Support in Propagation and Spectrum Engineering	Hubbard
9103526	Air Navigation Aids	Johnson
9104370	LPC Evaluation of Voice Channel	Pratt
9104374	ADF/PLC Interference	Kissick

U.S. Coast Guard (USCG)

Project	Title	Leader
9101532	Consulting USCG	Kissick
9103488	KODIAK Antenna Improvement	Kissick
9103548	San Juan/ADAK Trade-off	Kissick
9104395	Puget Sound Coverage	Kissick

U.S. POSTAL SERVICE

Project	Title	Leader
9103529	U.S.P.S. Electronic Message Service	McManamon
9104389	U.S.P.S. Electronic Message Service	McManamon

OTHER

Project	Title	Leader
9101583	LF Models	Berry
9101585	GOES Equipment Certification	Bolton
9101586	Tropospheric Predictions	Johnson
9101587	Numerical Prediction Services MFA	Agy
9102580	Analysis Services	Adams
9102586	IONCAP Requests	Tveten

Miscellaneous Federal Agencies

Project	Title	Leader
9101504	HF Consulting	Haydon
9103466	Saudi Arabia HF Predictions	Teters
9103482	SECOM Communications Analysis	deHaas

Miscellaneous Non-Federal Agencies

Project	Title	Leader
9102378	Mobile Aids	Hufford
9103521	Bell Consulting	Spaulding
9104376	Canal Zone RFI Survey	Tary
9104383	IONCAP Goes International	Lloyd
9104387	Voice Performance Measurement	Hartman
9104392	Channel Simulator Tests	Watterson
9104402	TADIRAN Channel Simulation	Watterson

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)
DIVISION 1 - SPECTRUM UTILIZATION		
MURRAY, John P. - Associate Director	4162	4533
1.1 Spectrum Analysis, Modeling & Services ADAMS, Jean E.	4301	4517
1.2 EM Environment Characterization MATHESON, Robert J.	3293	2221
1.3 Spectrum Planning Methodology HUFFORD, George A.	3457	4523
DIVISION 2 - SYSTEMS TECHNOLOGY AND STANDARDS		
HULL, Joseph A. - Associate Director	4136	2034
2.1 Evaluation of New Technology Developments BLOOM, Louis R.	3485	2245A
2.2 Systems Requirements Definition MORRISON, Ernest L., Jr.	4215	3013
2.3 System Performance Criteria GATES, Harvey M.	3589	2213A
DIVISION 3 - APPLIED ELECTROMAGNETIC SCIENCE		
LUCAS, Donald L. - Associate Director	3821	3421
3.1 EM Propagation Research and Analysis THOMPSON, Moody C., Jr.	3508	3442A
3.2 Advanced Communication Technology & Applications GRANT, William B.	3729	3447
3.3 Propagation Predictions & Model Development RUSH, Charles M.	3460	3411
DIVISION 4 - ADVANCED COMMUNICATION NETWORKS		
McMANAMON, Peter M. - Associate Director	3570	2-0323
4.1 Communications Protection McMANAMON, Peter M. - Acting	3570	2-0323
4.2 Switched Networks McMANAMON, Peter M. - Acting	3570	2-0323
4.3 Specialized Networks McMANAMON, Peter M. - Acting	3570	2-0323

ANNEX III
INSTITUTE FOR TELECOMMUNICATION SCIENCES
NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION
DEPARTMENT OF COMMERCE
Alphabetical Listing of ITS Employees
August 15, 1979

Name	Ext.	Room
ADAMS, Jean E.	4301	4517
AGY, Vaughn L.	3659	3441
AKIMA, Hiroshi	3392	2-0324
ANDERSON, David P.	3506	2246
ARCHULETA, Stephanie L.	4136	2030
AX, Carole J.	3748	2218
BARGHAUSEN, Alfred F.	3384	3443
BEASLEY, Keith R.	3731	4528A
BEERY, Wesley M.	3501	3463
BERRY, Janet S.	4129	4516B
BERRY, Leslie A.	4474	4528D
BLOOM, Louis R.	3485	2245A
BOGLE, Robert W.	3130	2-0120
BOLTON, Earl C.	3104	2236M
BROOKS, Minnie	4281	2245
BYERS, John D.	4125	4520B
CANADAY, Lois S.	3562	3413
CARROLL, John C.	3601	3459
CHAVEZ, Richard	3584	3430
CHILTON, Charles J.	3815	3420
COLEMAN, Susan J.	3883	3450
CROMBIE, Douglass D.	4215	3020
CROW, Edwin L.	3452	2-0324
deHAAS, Thijs	3728	2030
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
FLETCHER, Christopher M.	4162	4524
FRITZ, Olive M.	3778	2213
GALLAWA, Robert L.	3761	2217
GAMAUF, Kenneth J.	3677	3430
GATES, Harvey M.	3589	2213A
GEISSINGER, Marcia L.	3500	3020
GIBSON, Beverle J.	4215	3020
GIERHART, Gary D.	3292	2222M
GLEN, Donald V.	3893	2-0118
GODWIN, John R.	4122	4520D
GOODKNIGHT, Frank A.	3998	3419
GOULD, Beverly A.	3291	2219
GRANT, William B.	3729	3447
GRAY, Evelyn M.	3307	2223
GREEN, Robert F.	3778	2213
HAAKINSON, Eldon J.	4304	4511
HAIDLE, Leroy L.	3233	4524B
HALE, William K.	4474	4528F
HANSEN, Ruth B.	3513	3442C
HANSON, A. Glenn	4449	2223
HANSON, D. Wayne	3573	2246
HARMAN, John M.	3655	2030
HARTMAN, William J.	3606	2210D
HAUSE, Laurance G.	3945	2230B
HAYDON, George W.	3583	3420C
HERSHEY, John E.	3748	2246
HILDEBRANDT, Thomas H.	3175	2230
HILL, David A.	3472	2209
HOROWITZ, Renee B.	4162	4529
HUBBARD, Robert W.	3414	2243
HUFFORD, George A.	3457	4523
HULL, Joseph A.	4136	2034
HUNT, Howard D.	3730	2236M
HYOVALTI, Duane C.	3447	3450A
JEFFREYS, Charlene E.	4414	3021
JENNINGS, Raymond D.	3233	4528H
JOHNSON, Mary Ellen	3587	4522C
JUNEAU, Robert I.	4202	2222
JUROSHEK, John R.	4362	4528E
KISSICK, William A.	4258	4520E
LANGER, Susan K.	4162	4527
LAWRENCE, Vincent S.	3211	2222
LAYTON, Donald H.	3584	3430
LEMP, John	3713	2246
LIEBE, Hans J.	3310	3426
LINFIELD, Robert F.	4243	2237
LLOYD, John L.	3701	3419M
LONGLEY, Anita G.	3470	4521
LUCAS, Donald L.	3821	3425
MADONNA, Nancy	3821	3421
MAJOR, Jeanne C.	4122	4520D
MARLER, F. Gene	4321	3458A
MARLOW, Michael M.	3175	2230
MARTIN, William L.	3195	3426
MATHESON, Robert J.	3293	2221
MAYEDA, Kathy E.	3998	3420
McCARROLL, Patricia A.	3883	3449
McCOY, Elizabeth L.	4162	4527
McLEAN Robert A.	3262	3462
McMANAMON, Peter M.	3570	2-0323
McQUATE, Paul L.	3945	2230
MELLECKER, Carlene M.	3330	3458A
MILES, Martin J.	3567	2-0118
MILLER, Charles M.	4496	3454A
MITZ, Albert R.	3513	3442
MIZE, James W., Jr.	4166	2218
MOLLARD, Jean R.	3821	3421
MORRISON, Ernest L.	4215	3013
MURRAY, John P.	4162	4533
NESENBERGS, Martin	3337	2210M
NEY, Linda	4125	4520B

Name	Ext.	Room
OLSON, Marylyn N.	4136	2030
OTT, Randolph H.	3353	3467
PATTERSON, James E.	3883	3458A
PAULSON, S. Jean	3874	4519
PAYNE, Judd A.	3200	2214A
PIETRASIEWICZ, Val J.	3723	2236M
POKEMPNER, Margo	3825	3422M
POMPER, William J.	3730	2236M
PRATT, Lauren E.	3826	2234B
RANDELL, Holly L.	3786	4515
REASONER, Rita K.	3184	4522A
REHM, Eric C.	3364	4516E
ROSICH, Rayner K.	3109	3415
RUSH, Charles M.	3460	3411
RUSSELL, Deborah J.	3358	3450
RUSSELL, Jane L.	3588	4525
SANCHEZ, Patricia A.	4166	2-0321
SANDERS, Frank H.	3211	2222
SARRAZIN, David B.	3562	3413
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	2237
SPAULDING, Arthur D.	4201	2222A

Name	Ext.	Room
SPIES, Kenneth P.	3839	2234B
STEARNS, Charles O.	3749	3450
STEELE, Francis K.	3815	3458C
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
TEITELBAUM, Jeremy T.	4302	4516C
TETERS, Larry R.	4430	3419M
THOMPSON, Moody C., Jr.	3508	3442A
THOMPSON, Ray E.	3352	2-0123
TVETEN, Lowell H.	3621	3445
UTLAUT, William F.	3500	3020
VAN STORY, Carol B.	3267	3017
VAUGHAN, Margo S.	4129	4516B
VIOLETTE, Edmond J.	3703	3446A
VOGLER, Lewis E.	3668	3450
WALLER, Freda L.	3618	2223
WALTERS, William D.	4414	3019
WARNER, Billie D.	4496	3454B
WASHBURN, James S.	3798	3413M
WASSON, Gene E.	3584	3430
WATTERSON, Clark C.	3536	2241
WELLS, Paul I.	4368	2235
WIEDER, Bernard	3484	3014
WILLIAMS, John G.	3594	2210
WILSON, Debra R.	3634	3419
WORTENDYKE, David R.	4241	2233

ANNEX IV
ITS PUBLICATIONS - FISCAL YEAR 1979

Agy, V. L. (1979), Perspective on the prediction of auroral absorption, Proc. of AGARD Symposium of the Electromagnetic Wave Propagation Panel, Lisbon, Portugal, May 28-June 1, pp. 19-1 - 19-15.

Agy, V. L., G. W. Haydon, C. M. Mellecker, and C. M. Rush (1979), FY 78 progress report to International Communications Agency, Voice of America, Contract IA-18212-23, NTIA Technical Memorandum 79-8, January, 20 pp.

Agy, V. L., G. W. Haydon, C. M. Mellecker, and C. M. Rush (1979), Annex to FY 78 progress report to International Communications Agency, Voice of America, Contract IA-18212-23, NTIA Technical Memorandum 79-10, February, 60 pp.

Akima, H. (1978), A note on measures of voice transmission performance used by the CCIR, IEEE Trans. Commun. COM-26, No. 10, October, pp. 1478-1480.

Akima, H. (1979), Remark on Algorithm 526, Bivariate interpolation and smooth surface fitting for irregularly distributed data points {E1}, ACM Trans. Math. Software 5, No. 2, June, pp. 242-243.

Akima, H., P. M. McManamon, and P. I. Wells (1978), Fixed-satellite and broadcasting-satellite service considerations for 1979 GWARC planning, NTIA Special Publication 78-2, October, 102 pp.

Berry, L. A. (1978), Measuring spectrum use, Wireless World, December, pp. 43-46.

Berry, L. A. (1979), Probability of intermodulation interference in an expanded CB service, NTIA Technical Memorandum 79-15, July, 20 pp.

Berry, L. A., and E. J. Haakinson (1978), Spectrum efficiency for multiple independent spread-spectrum land mobile radio systems, NTIA Report 78-11, November, 65 pp. (NTIS Access. No. PB 291539/AS).

Chilton, C. J. (1979), Wave interaction observations of ionospheric modification in the D-region, NTIA Technical Memorandum 79-4, January, 35 pp.

Cho, S. H., and J. R. Wait (1978), Analysis of microwave ducting in an inhomogeneous troposphere, Pure Appl. Geophys. 116, No. 6, pp. 1118-1142.

Collins, J. T., and F. K. Steele (1979), An additional catalog of programs and data for 100 MHz - 100 GHz radio system predictions, NTIA Report 79-15, January, 48 pp. (NTIS Access. No. PB 293366/AS).

Crombie, D. D. (1979), Comparison of measured and predicted signal strengths of nighttime medium frequency signals in the USA, IEEE Trans. Broadcasting BC-25, No. 3, September, pp. 86-89.

Crow, E. L. (1979), Approximate confidence intervals for a proportion from Markov dependent trials, Commun. Statist.-Simula. Computa., B8(1), pp. 1-24.

Crow, E. L. (1979), Statistical methods for estimating time and rate parameters of digital communication systems, NTIA Report 79-21, June, 41 pp. (NTIS Access. No. Not Yet Available).

Crow, E. L., and M. J. Miles (1979), Validation of estimators of a proportion from Markov dependent trials, Commun. Statist.-Simula. Computa., B8(1), pp. 25-52.

Dougherty, H. T. (1978), Atmospheric limitations on telecommunication system performance - recent advances, Proc. National Telecommunications Conference, Birmingham, Alabama, December 4 & 5, 2, pp. 18.1.1 - 18.1.5.

Dougherty, H. T., and C. M. Rush (1979), Propagational aspects of allocation and frequency sharing, Proc. of ITU Regional Seminar Preparatory to WARC 1979, Panama, March 12-23, pp. 1-17.

Dutton, E. J. (1978), Earth-space attenuation predictions for geostationary satellite links in the U.S.A., NTIA Report 78-10, October, 48 pp. (NTIS Access. No. PB 289841/AS).

Dutton, E. J., and H. T. Dougherty (1979), Year-to-year variability of rainfall for microwave applications in the U.S.A., IEEE Trans. Commun. COM-27, No. 5, May, pp. 829-832.

Espeland, R. H., E. J. Violette, and M. C. Thompson, Jr. (1979), An assessment of government radio frequency assignments in the 3.0-10.0 GHz band with considerations for applications above 10 GHz, NTIA Technical Memorandum 79-13, May, 51 pp.

FitzGerrell, R.G., R.D. Jennings, and J.R. Juroshek (1979), Television receiving antenna system component measurements, NTIA Report 79-22, June, 115 pp. (NTIS Access. No. Not Yet Available).

Gallawa, R. L. (1978), Dispersion characteristics of fiber systems at long wavelengths, Proc. of First Fiber Optics and Communications Exposition, Chicago, IL, Sept. 6-8, pp. 159-161.

Gallawa, R. L. (1979), Recent developments in optical waveguide communications, Pt. I: Optimum refractive index profiles for multimode fibers, Electro-Optical Systems Design, July, pp. 42-44; Pt. II: Renewed interest in monomode fibers, Sept.

Gallawa, R. L. (1979), Problems, results, and availability of a recent interlaboratory effort on an optical waveguide communications glossary, Proc. of Second Fiber Optics and Communications Exposition, Chicago, IL, Sept. 5-7.

Hause, L. G., and D. R. Wortendyke (1979), Automated digital system engineering model, NTIA Report 79-18, March, 98 pp. (NTIS Access No. PB 294960/AS).

Haydon, G. W., C. M. Rush, and L. R. Teters (1979), Theoretical feasibility of digital communication over ocean areas by high frequency radio, NTIA Technical Memorandum 79-17, July, 46 pp.

Hildebrandt, T. H. (1979), A flowchart drafting tool using a calculator-controlled plotter, NTIA Technical Memorandum 79-3, January, 24 pp.

Hill, D. A. (1979), Electromagnetic wave propagation along a pair of rectangular bonded wire meshes, IEEE Trans. Electromagnetic Compatibility EMC-21, No. 2, May, pp. 114-122.

Hill, D. A., and J. R. Wait (1978), Electromagnetic basis of drill-rod telemetry, Electron. Letters 14, No. 17, August, pp. 532-533.

Hill, D. A., and J. R. Wait (1978), Theory of electromagnetic methods for nondestructive testing of wire ropes, Proc. of Fourth West Virginia University Conf. on Coal Mine Electrotechnology, August 2-4, pp. 16-1 - 16-13.

Hill, D. A., and J. R. Wait (1978), Bandwidth of a leaky coaxial cable in a circular tunnel, IEEE Trans. Commun. COM-26, No. 11, November, pp. 1765-1771.

Hill, D. A., and J. R. Wait (1978), Electromagnetic surface-wave propagation over a rectangular-bonded wire mesh, IEEE Trans. Electromagnetic Compatibility EMC-20, No. 4, November, pp. 488-494.

Hill, D. A., and J. R. Wait (1978), Excitation of the Zenneck surface wave by a vertical aperture, Radio Sci. 13, No. 6, November-December, pp. 969-977.

Hill, D. A., and J. R. Wait (1979), Electromagnetic field perturbation by an internal void in a conducting cylinder excited by a wire loop, Appl. Phys. 18, pp. 141-147.

Hill, D. A., and J. R. Wait (1979), Comparison of loop and dipole antennas in leaky feeder communication systems, Proc. of AGARD Symposium of the Electromagnetic Wave Propagation Panel, Lisbon, Portugal, May 28-June 1, pp. 44-1 - 44-9.

Hubbard, R. W. (1979), Investigation of digital microwave communications in a strong meteorological ducting environment, NTIA Report 79-24, August, 96 pp. (NTIS Access. No. Not Yet Available).

Hubbard, R. W., and R. L. Gallawa (1978), Design handbook for optical fiber systems, U.S. Army Communications-Electronics Engineering Installation Agency report CCC-CED-XES-78-01, August, 265 pp.

Hull, J. A. (1979), Fiber optic communications and the Federal government, Proc. of Second Fiber Optics and Communications Exposition, Chicago, IL, Sept. 5-7.

Hull, J. A., R. L. Gallawa, and L. R. Bloom (1979), The development of fiber optic communications, Proc. of ICC '79, Boston, MA, June 10-13, pp. 10.3.1 - 10.3.3.

Hull, J. A., J. M. Harman, M. N. Olson, and H. D. Hunt (1979), Emergency Medical Services communications system technical planning guide, NTIA Special Publication 79-3, March, 214 pp. (SupDocs Order No. 003-000-00547-0).

Johnson, M. E., and G. D. Gierhart (1979), Comparison of measured data with IF-77 propagation model predictions, U.S. Dept. of Transportation Report FAA-RD-79-9, August, 444 pp.

Juroshek, J. R. (1979), A compatibility analysis of spread-spectrum and FM land mobile radio systems, NTIA Report 79-23, August, 80 pp. (NTIS Access. No. Not Yet Available).

Kissick, W. A., and J. E. Adams (1979), The Kodiak site study, NTIA Technical Memorandum 79-11, March, 83 pp.

Kissick, W. A., E. J. Haakinson, and G. H. Stonehocker (1978), Measurements of LF and MF radio propagation over irregular, inhomogeneous terrain, NTIA Report 78-12, November, 171 pp. (NTIS Access. No. PB 291732/AS).

Kissick, W. A., and K. P. Spies (1979), Alternatives to the AMVER guards on 8, 12, & 16 MHz at San Juan and 8 MHz at Kodiak, NTIA Technical Memorandum 79-12, May, 108 pp.

Liebe, H. J. (1979), Millimeter wave attenuation in moist air, Proc. of Army Conf. on Millimeter Wave Propagation, Huntsville, AL, March 20-22.

Liebe, H. J., and D. D. Crombie (1979), Estimates of maximum electric field strengths in the automobile environment, NTIA Report 79-16, February, 29 pp. (NTIS Access. No. PB 294819/AS).

Liebe, H. J., and J. D. Hopponen (1978), Atmospheric medium characterization and modelling of EHF propagation in air, AGARD Conf. Proc. 238, December, pp. 45-1 - 45-18.

Liebe, H. J., and R. K. Rosich (1979), Modelling of EHF propagation in clear air, Proc. of 1979 IEEE Region V Annual Conference on Space Instrumentation for Atmospheric Observation, El Paso, TX, April 3-5, pp. 6-20.

Linfield, R. F. (1979), Control signaling in a military switching environment, NTIA Report 79-13, January, 250 pp. (NTIS Access. No. PB 292377/AS).

McManamon, P. M. (1979), A hybrid satellite for Pacific nations using small earth stations, Proc. of Pacific Telecommunications Conference, Honolulu, Hawaii, January 8 & 9, pp. 4B-24 - 4B-33.

Nesenbergs, M. (1979), A hybrid of Erlang B and C formulas and its applications, IEEE Trans. Commun. COM-27, No. 1, January, pp. 59-68.

Nesenbergs, M. (1979), Potential use of HF data transmission for oceanic ATC improvement, NTIA Technical Memorandum 79-14, May, 41 pp.

Ott, R. H. (1979), Ground wave propagation over irregular, inhomogeneous terrain: Comparisons of calculations and measurements at frequencies from 121 kHz to 50 MHz, Proc. of AGARD Specialists Mtg. on Terrain Profiles and Contours in EM Propagation, Spatind, Norway, Sept. 10-14, pp. 6-1 - 6-8.

Ott, R. H. (1979), Theories of ground wave propagation over mixed paths, Proc. of AGARD Specialists Mtg. on Terrain Profiles and Contours in EM Propagation, Spatind, Norway, Sept. 10-14, pp. 8-1 - 8-7.

Ott, R. H., E. L. Morrison, and W. B. Grant (1979), Antenna patterns for the solar power satellite, NTIA Technical Memorandum 79-5, January, 24 pp.

Ott, R. H., M. C. Thompson, Jr., E. J. Violette, and K. C. Allen (1978), Experimental and theoretical assessment of multipath effects on QPSK, IEEE Trans. Commun. COM-26, No. 10, October, pp. 1475-1477.

Ott, R. H., L. E. Vogler, and G. A. Hufford (1979), Groundwave propagation over irregular inhomogeneous terrain: Comparisons of calculations and measurements, IEEE Trans. Ant. Prop. AP-27, No. 2, March, pp. 284-286.

Ott, R. H., L. E. Vogler, and G. A. Hufford (1979), Ground wave propagation over irregular, inhomogeneous terrain: Comparisons of calculations and measurements, NTIA Report 79-20, May, 137 pp. (NTIS Access. No. Not Yet Available).

Rush, C. M. (1979), Transionospheric radio propagation, NATO AGARD Lecture Series No. 99: Aerospace Propagation Media Modelling and Prediction Schemes for Modern Communications, Navigation, and Surveillance Systems, May; Presented June 4-5 in London, UK, and June 14-15 in Boulder, CO; pp. 4-1 - 4-28.

Schlafly, H. J., R. E. Button, and B. L. Wormington (1979), The initial growth and expanding opportunities of U.S. domestic satellite service, NTIA Contractor Report 79-3, February, 158 pp.

Skerjanec, R. E., and R. W. Hubbard (1979), Aircraft obstruction of microwave links, NTIA Report 79-14, January, 68 pp. (NTIS Access. No. PB 292372/AS).

Spaulding, A. D. (1979), Optimum threshold signal detection in broadband impulsive noise employing both time and spatial sampling, Proc. of 3rd Symposium and Technical Exposition on Electromagnetic Compatibility, Rotterdam, Netherlands, May 1-3, pp. 377-385.

Violette, E. J., R. H. Espeland, M.C. Thompson, Jr. (1979), An economic evaluation of systems and components for short path communication links above 10 GHz, NTIA Technical Memorandum 79-16, July, 31 pp.

Wait, J. R., and D. A. Hill (1979), Theory of transmission of electromagnetic waves along a drill rod in conducting rock, IEEE Trans. Geosci. Electron. GE-17, No. 2, April, pp. 21-24.

Wait, J. R., and D. A. Hill (1979), Excitation of the H.F. surface wave by vertical and horizontal apertures, Proc. of AGARD/NATO Conference "Special Topics in H.F. Propagation," Lisbon, Portugal, May, pp. 41-1 - 41-10.

Washburn, J. S., R. A. McLean, S. J. Coleman, W. M. Welch, and D. C. Hyovalti (1979), Operator's guide to the Electromagnetic Radiation Hazards Scenario, NTIA Technical Memorandum 79-7, January, 127 pp.

Watterson, C. C. (1979), An adaptive receiver filter for interference suppression in digital spread-spectrum radio systems(U), NTIA Technical Memorandum 79-9C, February, 142 pp.

Wieder, B., R. H. Espeland, L. R. Teters, and J. S. Washburn (1978), An application of holographic principles to locating multipath scatterers in LF navigation systems, Proc. of Seventh Annual Technical Symposium of The Wild Goose Association, New Orleans, LA, October 18-20, pp. 170-175.

Wortendyke, D. R., and T. H. Hildebrandt (1979), Received signal level (RSL) measurements and analysis with a desk-top computer, NTIA Report 79-17, February, 160 pp. (NTIS Access. No. PB 294820/AS).

Wortendyke, D. R. (1979), Project Green Thumb, Proc. of Fourth West Coast Computer Faire, San Francisco, CA, May 11-13, pp. 90-91.

ADDENDUM:

Dougherty, H. T., and C. M. Rush (1979), Propagational aspects of frequency allocation and frequency sharing, NTIA Technical Memorandum 79-19, September, 24 pp.

Hanson, A. G., L. R. Bloom, G. W. Day, R. L. Gallawa, E. M. Gray, and M. Young (1979), Optical waveguide communications glossary, NTIA Special Publication 79-4, September, 73 pp. (NTIS Access. No. Not Yet Available).

AVAILABILITY OF PUBLICATIONS -

NTIA Reports, Special Publications, and Contractor Reports are available from the National Technical Information Service. Order by accession number shown in publications listing. Technical Memoranda are not generally available, but additional information may be secured by contacting the author. Requests for copies of journal articles should be addressed to the journal.

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 the 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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