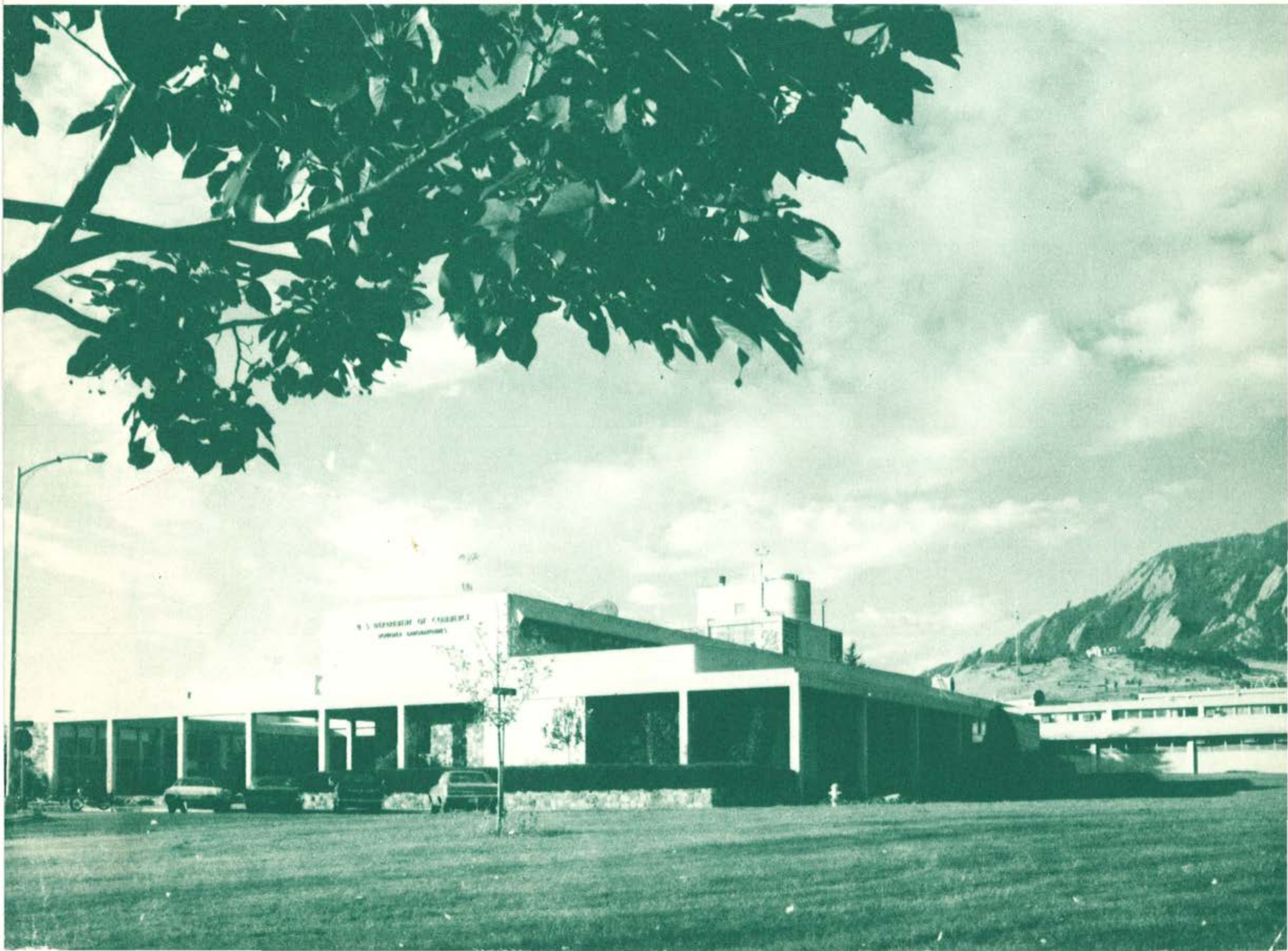
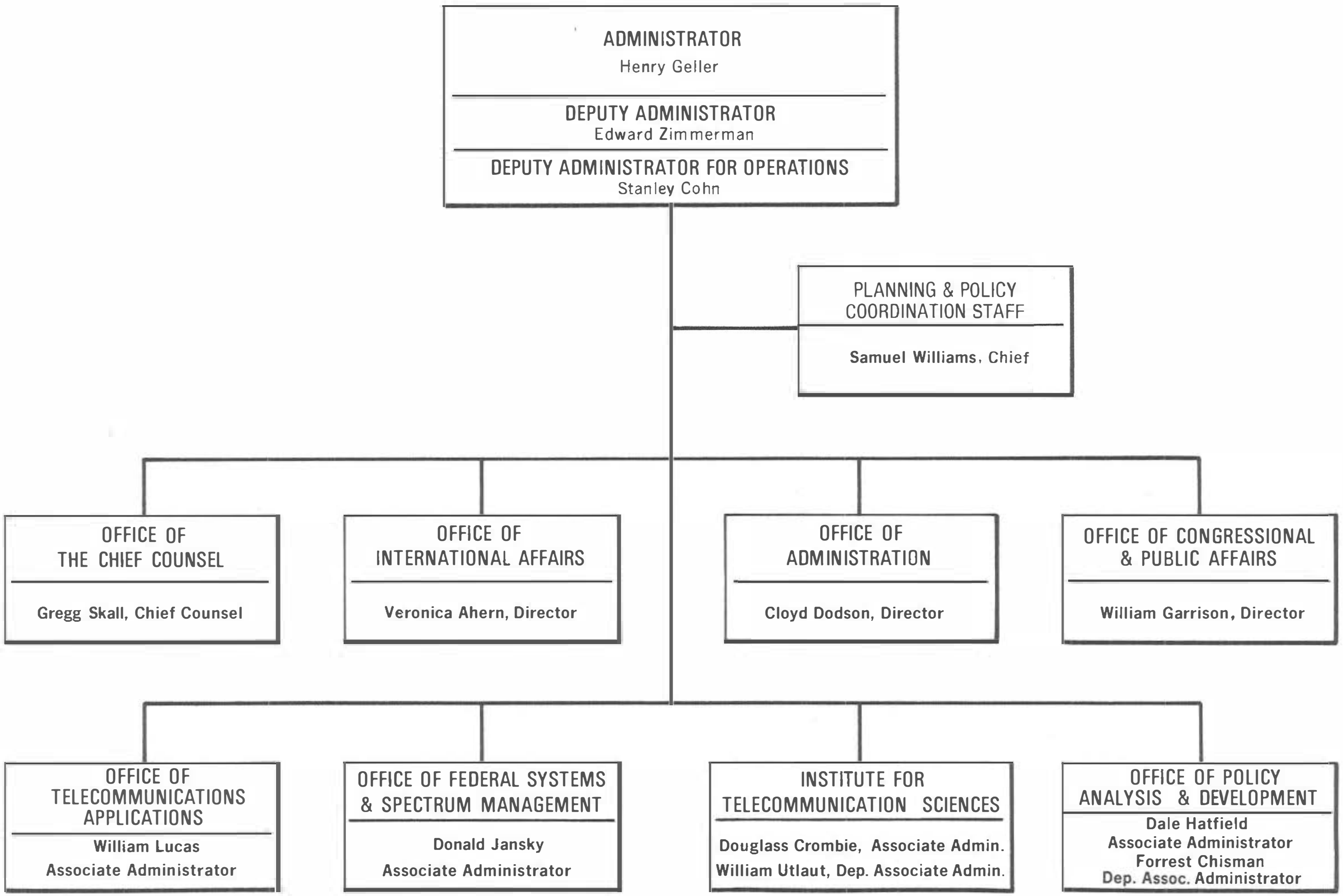
INSTITUTE FOR TELECOMMUNICATION SCIENCES
OF THE
NATIONAL TELECOMMUNICATIONS AND
INFORMATION ADMINISTRATION

ANNUAL TECHNICAL PROGRESS REPORT 1980

For the period from Oct. 1, 1979 through Sept. 30, 1980



National Telecommunications and Information Administration



ITS

ANNUAL TECHNICAL PROGRESS REPORT 1980

For the period
October 1, 1979 through Sept. 30, 1980

U.S. DEPARTMENT OF COMMERCE
Philip M. Klutznick, Secretary

Henry Geller, Assistant Secretary
for Communications and Information

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INTRODUCTION

This annual report reviews the activities and accomplishments of the Institute for Telecommunication Sciences for the fiscal year ending September 30, 1980. It is intended to serve as a reporting mechanism to the agency management, to our other agency sponsors, and to interested members of the public.

The Institute for Telecommunication Sciences (ITS) is the chief research and engineering arm of the National Telecommunications and Information Administration (NTIA), U.S. Department of Commerce. Its mission may be divided into two major elements: 1) to provide direct support to the NTIA Administrator and the Secretary of Commerce and 2) to serve as a central Federal resource to assist other agencies of the Government in the planning, design, maintenance, and improvement of their telecommunications activities. The work performed in carrying out the latter responsibility is reimbursable, is relevant to national goals and commitments, cannot be readily performed by the private sector, and contributes to NTIA's goals.

In order to meet the responsibilities assigned to it by the Department and requests from other agencies, the Institute is divided into four technical divisions, each of which has specifically assigned roles as outlined below:

Division 1 - Spectrum Utilization
John P. Murray, Associate Director

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.

Highlights for FY 80:

- Potentially increased broadcast capacity in congested markets was defined for FM and TV services.
- Automated procedures for processing FM license applications were developed and provided for use by the FCC.
- Optimum techniques for the selection of broadcast frequencies were developed.

Division 2 - Systems Technology and Standards
Joseph A. Hull, Associate Director

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.

Highlights for FY 80:

- Defined end-to-end performance requirements for the future digital Defense Communications System (AUTODIN II), using Federal Standard 1033.
- Prepared an assessment of computer and telecommunication needs of the Northern Region (Region 1) of the National Forest System.
- Developed procedures by which design engineering work for line-of-sight microwave systems may be performed on desktop calculators.
- Developed proposed Federal Standard 1043, "Standard Measurement Methods," which defines a performance measurement system capable of determining values for the parameters defined in Federal Standard 1033.

Division 3 - Applied Electromagnetic Science
Donald L. Lucas, Associate Director

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.

Highlights for FY 80:

- Completed electromagnetic compatibility study of Solar Power Satellite effects on other satellite systems.
- Characterized the power density distribution of VHF signals in an urban area to assist in predicting VHF/UHF signals in urban congestion.
- Completed the final design package for the U.S. Air Force to procure a number of multiple receiver systems prototyped by ITS.
- Concluded the Ionospheric Heating portion of the SPS Environmental Assessment and the electromagnetic compatibility analysis of SPS effects on other satellite systems for the Department of Energy.
- Conducted research into the propagation characteristics of millimeter waves under a variety of practical environments to help meet growing demand for communication capacity.

Division 4 - Advanced Communication Networks
Dr. Peter M. McManamon, Associate Director

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.

Highlights for FY 80:

- Completed the first assessment of the technical requirements protection applications of unclassified information in nondefense agencies.
- In cooperation with the FCC and other NTIA elements, developed and coordinated the U.S. recommended changes to the ITU frequency allocations from 11.7 to 12.7 GHz.
- Approval of the U.S. Postal Service electronic mail program ECOM for which the Division had provided technical assistance.

International Telecommunications

Continuing a long history of involvement in international telecommunications activities, the Institute staff has been actively involved in work for the International Telecommunication Union and its major subdivisions such as the CCIR and the CCITT. Accomplishments during the fiscal year in support of these international commitments are reported within the succeeding chapters. Specific mention should be made of the Institute's contributions to the technical preparation for WARC '79, CCIR Interim Meetings for Study Groups 1, 5, and 6, and the Region 2 conferences on MF broadcasting.

Additional copies of this annual report may be obtained by contacting the Publications and Technical Information Office, NTIA/ITS, Rm. 3011, 325 Broadway, Boulder, CO 80303.

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. 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 Chapter 3 of this report, Electromagnetic Wave Transmission. 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 of the natural environment. 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 users to be as liberal or conservative as they choose.

For over a decade, government, academic, and industrial groups have advocated development of methods for improving the overall effectiveness of spectrum use (as opposed to the optimization of individual system performance). 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, and the design of interactive computer programs that make it easy to ask "what if?" questions are indicative of our continuing effort to bridge the gap between technology and the planners and policy makers.

In previous years we have developed a computer program, COMAP, which looks at the television broadcast stations of the United States and estimates the total population served. The program is flexible and allows a variety of choices of what stations are to be considered and what definition of "service" is used. In addition, the program will provide a graphical display showing the United States and the areas that receive the indicated service. In this year's project, TV Coverage Maps, we increased the program's flexibility even further. For example, to help in the study of

UHF comparability (of great concern to the FCC), we have provided the map reproduced in Figure 1-1. This shows those areas of the country that are "UHF only"--i.e., that can receive UHF stations but that cannot receive any VHF stations. We compute that there are 4,489,000 ± 69,000 people who live in these areas. We have also found that 47,570,000 ± 200,000 people can receive only VHF stations, while 144,700,000 ± 200,000 people can receive stations in both bands.

The objective of the TV Broadcast Spectrum Strategies project is to define optimum strategies for TV channel assignment and determine the influence of existing and alternative taboos on the number of stations that can be assigned. A technical goal of frequency assignment in general is to provide for as many stations as possible arranged so that there is no interference between stations. The objectives of "maximum number of stations" and "no interference" are mutually exclusive; these ideals must be traded off at the margins to reach a practical compromise.

The licensing authority often formalizes the compromise in a set of frequency-distance rules, which in UHF television are called "taboos." Table 1-1 shows the UHF taboos, where frequency separation is shown as channel separation and the required distance separations are given in miles. Notice that the assignment of one channel in a specific location denies the assignment of 18 other channels within a radius of 20 miles--and some of the channels are taboo for even greater distances. Such sets of taboos are used in assigning frequencies in many different radio services, although the UHF-TV taboos are perhaps the most elaborate.

Table 1-1. UHF TV Taboos

Channel Separation	Required Distance Separation
0 (co-channel)	155 miles
1	55 miles
2	20 miles
3	20 miles
4	20 miles
5	20 miles
7	60 miles
8	20 miles
14	60 miles
15	75 miles

Once the taboos are determined and the likely (or actual) station locations are known, two problems remain:

1. How many channels are necessary to satisfy the requirements?

2. How do we assign specific channels to specific stations using the minimum bandwidth without violating any taboos?

Although these are fundamental problems of spectrum management, no practical method of solution has heretofore existed, except for very small numbers of stations.

In the TV Broadcast Spectrum Strategies project, it has been established that many frequency assignment problems (including the UHF-TV case) are equivalent to generalized graph coloring problems. This identification is important because there is an extensive literature on this famous problem. One result of the identification is that we know that many frequency assignment problems are "NP-hard." This means that the computer time required by exact algorithms for solving the problems increases exponentially with the number of stations, so that large problems (like UHF-TV assignments) cannot be solved exactly. However, efficient (fast) heueristic algorithms which produce almost-optimum solutions have been developed by the graph-coloring mathematicians. The best of these have been extended to apply to frequency assignment problems and have been implemented on our HP-1000 computer. A paper describing the research, "Frequency Assignment: Theory and Applications," by W.K. Hale will be published in the December 1980 Proceedings of the IEEE.

In a set of taboos, the co-channel separation distance results from the type and quality of service desired and uncontrollable factors like propagation loss and variability. The rest of the taboos are initially descriptions (later specifications) of receivers. Each non-co-channel taboo is intended to prevent some kind of interference that would not exist in a theoretically-ideal receiver. Each taboo is a concession to either the state-of-the-engineering-art or to economics. That is, some taboos may result from the inability to manufacture hardware that rejects the relevant kind of interference. However, most taboos are economic tradeoffs. The additional filters, or quality control, or whatever is required to reduce or eliminate the distance separation at a particular channel separation raises the price of the receiver. Small price increases in items as ubiquitous as TV receivers can represent a large national cost.

The algorithm developed for optimum frequency assignment is now being used to determine the spectrum cost of various taboos. By running the program with the existing taboos, and with some taboos relaxed or eliminated, we can discover how many more stations could be assigned in the same bandwidth--or how much bandwidth could be released while still licensing all stations. This information will be valuable for directing research on improved receivers.

The project goal of FM/UHF TV Increased Capacity has been to establish the basis for more spectrum-efficient and service-oriented broadcast spectrum assignment criteria. For Broadcast FM, we believe more assignments are possible, even in the large markets, if some or all of the following recommendations are adopted: 1) protection is granted to existing facilities rather than to legally maximum facilities, 2) the effects of terrain on signal coverage and interference are considered, 3) directional antennas are used to control both coverage and interference, 4) reasonable changes to the signal-to-interference protection ratios for co-channel and adjacent-channel operation are adopted, and 5) co-siting of second- and third-adjacent channel transmitters with existing

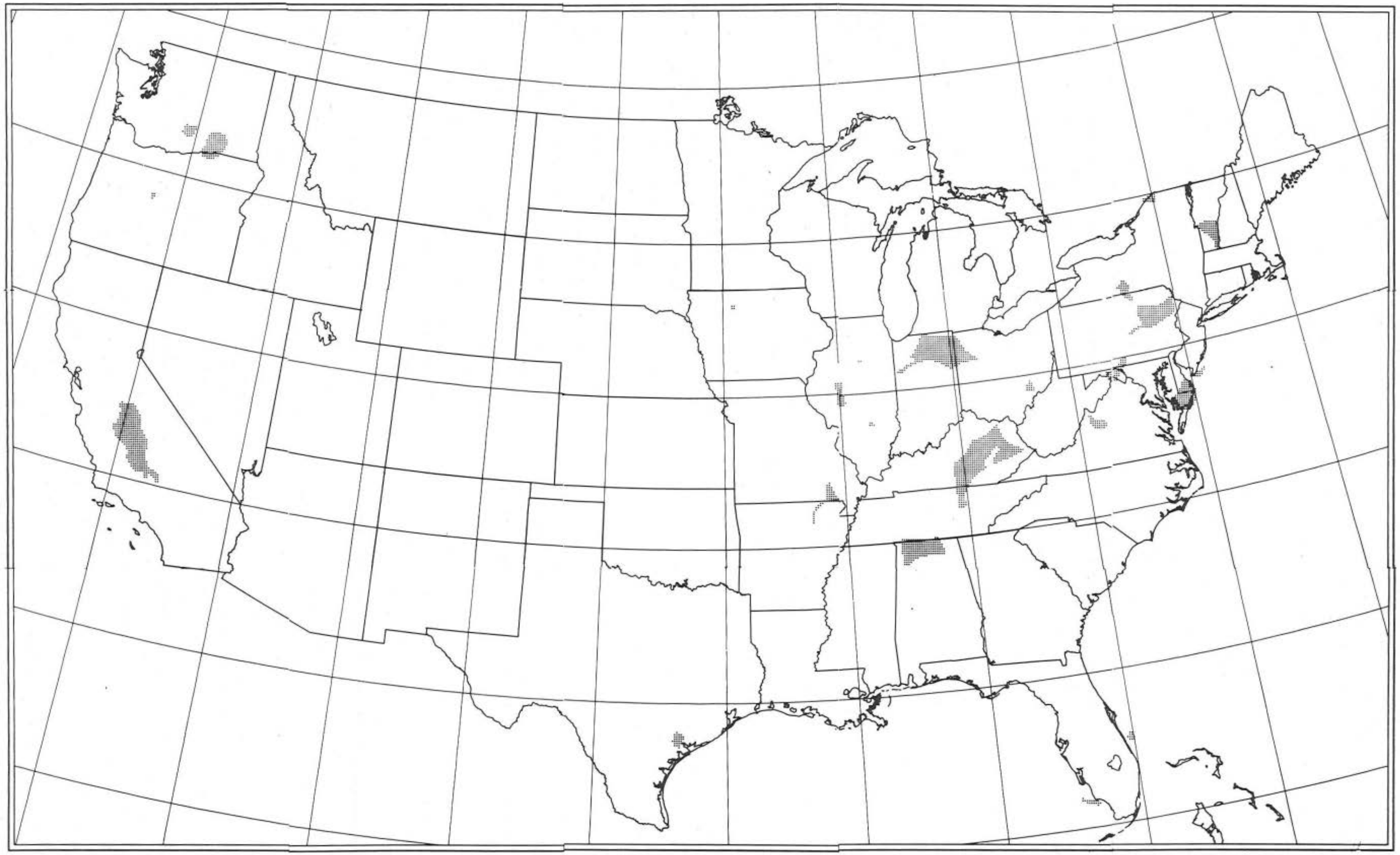


Figure 1-1. Areas in the United States with "UHF-only" television service.

transmitters is permitted. To demonstrate the approach of adding new assignments to a saturated major market, an NTIA report (NTIA-R-80-44) shows how the number of FM broadcast stations in the Dallas-Ft. Worth region (the fifth densest market) could be increased from the present 21 stations to 38 stations. Figure 1-2 shows an example of the 59 dBuV/m service contour from a proposed facility on channel 209 in Dallas-Ft. Worth. Figure 1-3 shows the predicted service coverage from a co-channel station (KGCC) and a second-adjacent channel station (KERAFM) that are near our proposed facility. The solid contours are the service contours and the dashed lines are the predicted interference contours of S/I = 20 dB for the co-channel station and S/I = -20 dB for the second-adjacent-channel station. The cross-hatched area shows the region that is within the service contour but also receives unacceptable interference from the proposed facility. Figure 1-4 shows the interference region if more realistic interference criteria were adopted; i.e., S/I = 14 dB for co-channel stations and S/I = -50 dB for second-adjacent channel stations. (These revised criteria are based upon interference protection measurements as described in popular audio magazines and as made for an FCC filing.) Note that there still exists a region of unacceptable interference within KGCC's service contour. We could reduce the proposed station's power and/or antenna height to eliminate the interference region. Instead, we choose to use a directional antenna for proposed facility. Figure 1-5 shows the area and population that are within the new service contour. Figure 1-6 shows the interference area using the present interference criteria, and Figure 1-7 shows the interference area using the proposed interference criteria; in both cases, the proposed facility uses a directional antenna. In the final figure, note that no unacceptable interference is predicted to occur within the existing stations' service contours. We believe these techniques could be used in most other major markets with a similar increase in the number of compatible FM assignments.

One example of the techniques designed to assist operational frequency management is provided by the FM License Processing project in support of the FCC. Applications for licenses in the non-commercial FM band from 88 to 90 MHz are handled differently from other applications. In that band there is no table of allocations, but instead, a rule that computations should show no interference (90% of the time) to or from any existing station. Done by hand, the necessary computations are long and tedious. This is one reason why there is a large backlog in the processing of this set of applications. We have devised a computer program which can be operated by FCC personnel using remote terminals. The program produces tabulated and graphical displays describing the service contours and the "interference contours" of the applicant station and of those existing stations which are co-channel, or first, second, or third adjacent channel. The idea is that no interference contour should intersect a service contour. In Figure 1-8, we reproduce a simulated and annotated sample of the graphical output. Note how one can see at a glance that the applicant (KOHL) does not violate here any of the conditions.

Two years ago, Berry and Haakinson showed spread-spectrum land-mobile-radio systems are spectrum inefficient if the performance gain of the spread-spectrum system is equal to the "processing gain." This condition appears to be true for direct-sequence spread-spectrum systems, but there is evidence that it is not true for simultaneously-operating frequency-hopping systems, at least not for interesting numbers of systems. Thus, the question arises: would a land-mobile-radio service allocated to frequency-hopping spread-spectrum systems be spectrum efficient; that is, would it accommodate larger numbers of users than a channelized service without unacceptable interference? The FCC is considering such a service, and the 900 MHz Technology project is investigating the spectrum-efficiency question.

As a model, we postulate a voice system of arbitrary modulation in which the carrier frequency is pseudo-randomly hopped from frequency to frequency within a large set of frequencies according to a code assigned to a particular user network (a base station and its associated mobiles). The large set of frequencies (the spread-spectrum band) is shared by many networks assigned to the service, each with its own code. A user transmits whenever he has a message because he cannot tell if others are using the channel, so that user turn-ons are assumed to be random, and poisson distributed. We assume that all networks are synchronized so that all frequency changes are made at exactly the same time, but not so that code repetition patterns begin at the same time.

Now consider how interference occurs. If two or more transmissions occupy the same frequency-time slot, and if the power in the unwanted signals is sufficiently large, the information in the wanted signal is lost. If the time-slot is sufficiently short, an isolated event of this kind may not be a problem; a very short interruption of speech is not detected by the human ear. So the time slot of such a system should be made short enough that an isolated loss of information does not impair intelligibility.

However, if the time slot is very short, many hops are made during a message and there are many chances for a "hit" (two or more signals in the same time-frequency slot). If the time slots are too short, the number of hits may be in the audible range--that is, 100 to 3000 hits per second. In this case, while the hits may not be heard individually, their repetition is audible noise, which may degrade the service. Thus, the mutual interference of frequency hopping sytems depends on the interaction of the hopping rate (which controls the length of the time slot), the probability of a hit, and the probability that the unwanted energy is sufficiently strong. Parameters that affect these are the traffic intensity of each network, the transmission loss variability, and the number of networks. The probability has been derived in this project, and is

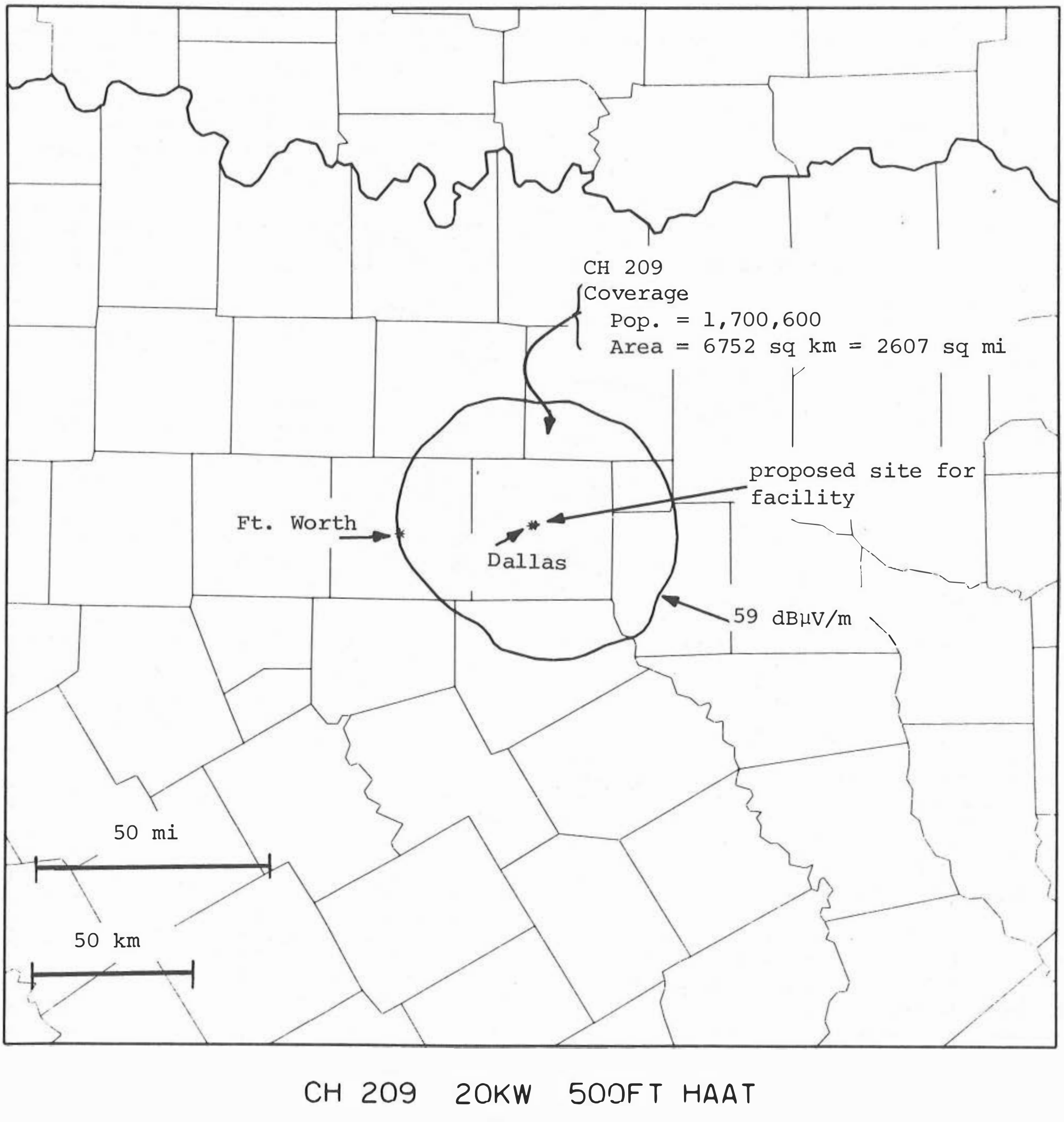


Figure 1-2. Proposed channel 209 coverage.

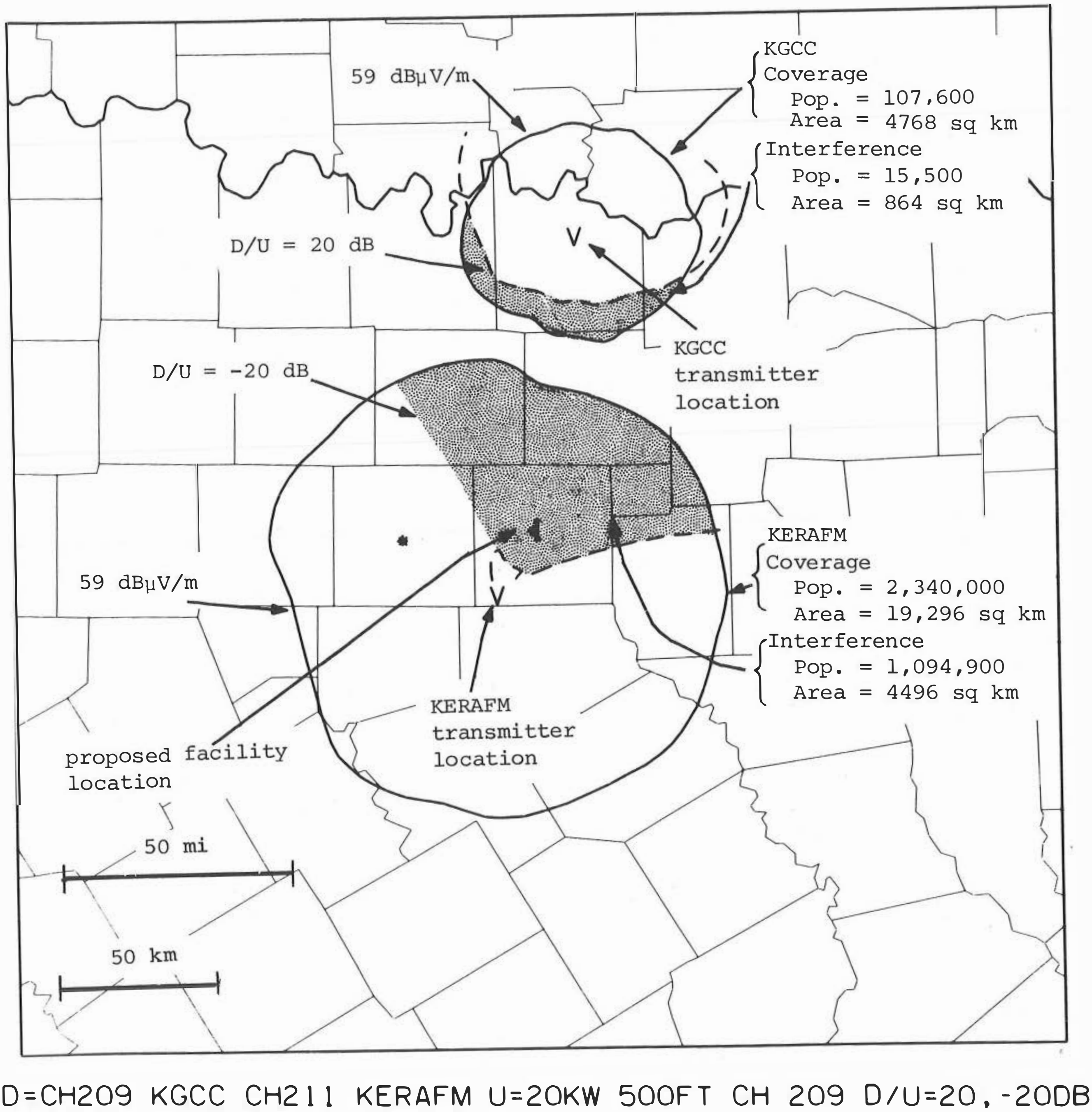
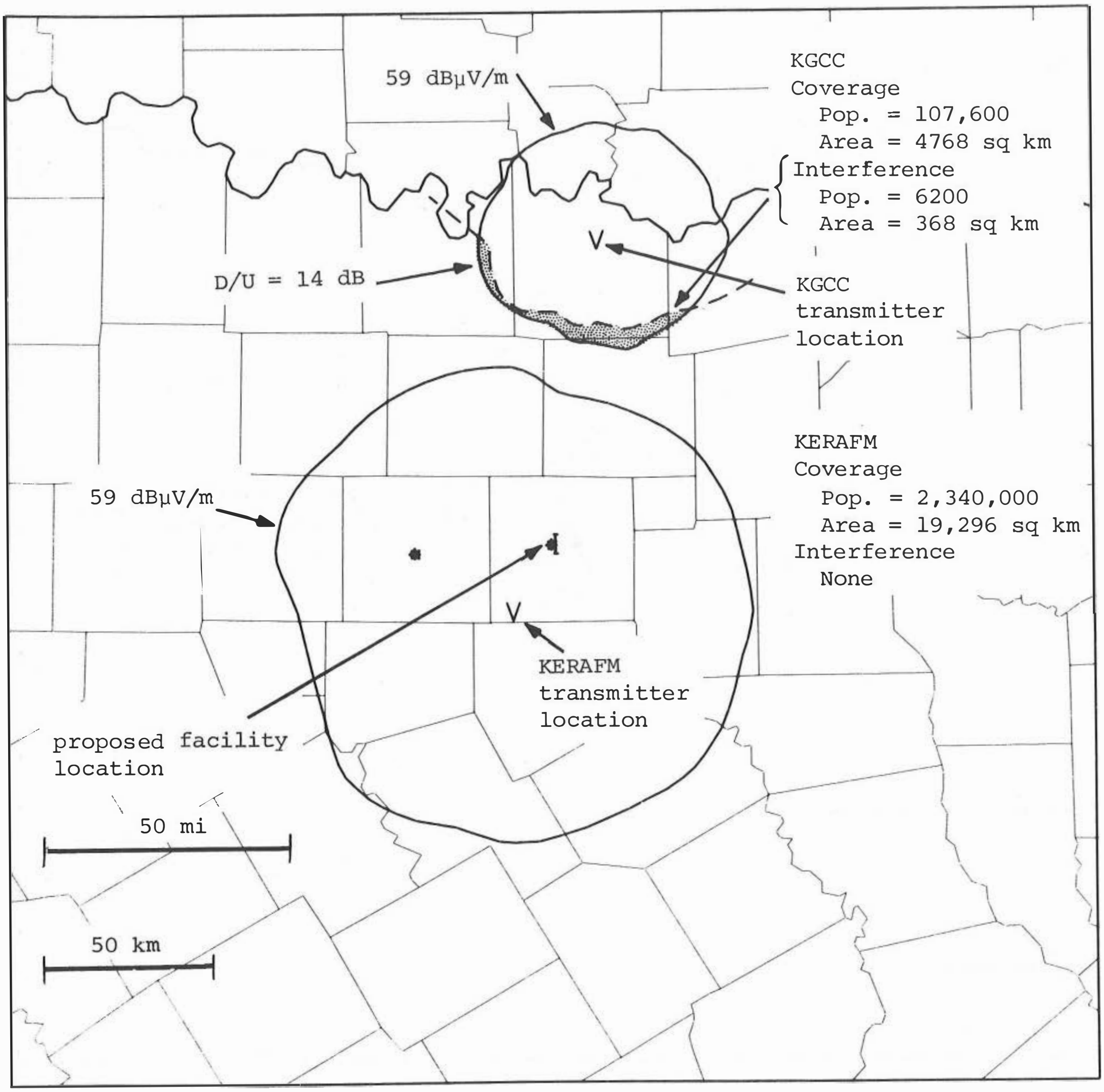


Figure 1-3. Existing stations' coverage and interference, existing protection standards.



D=CH209 KGCC CH211 KERAFM U=20KW 500FT CH 209 D/U=14,-50DB

Figure 1-4. Existing stations' coverage and interference, new protection standards.

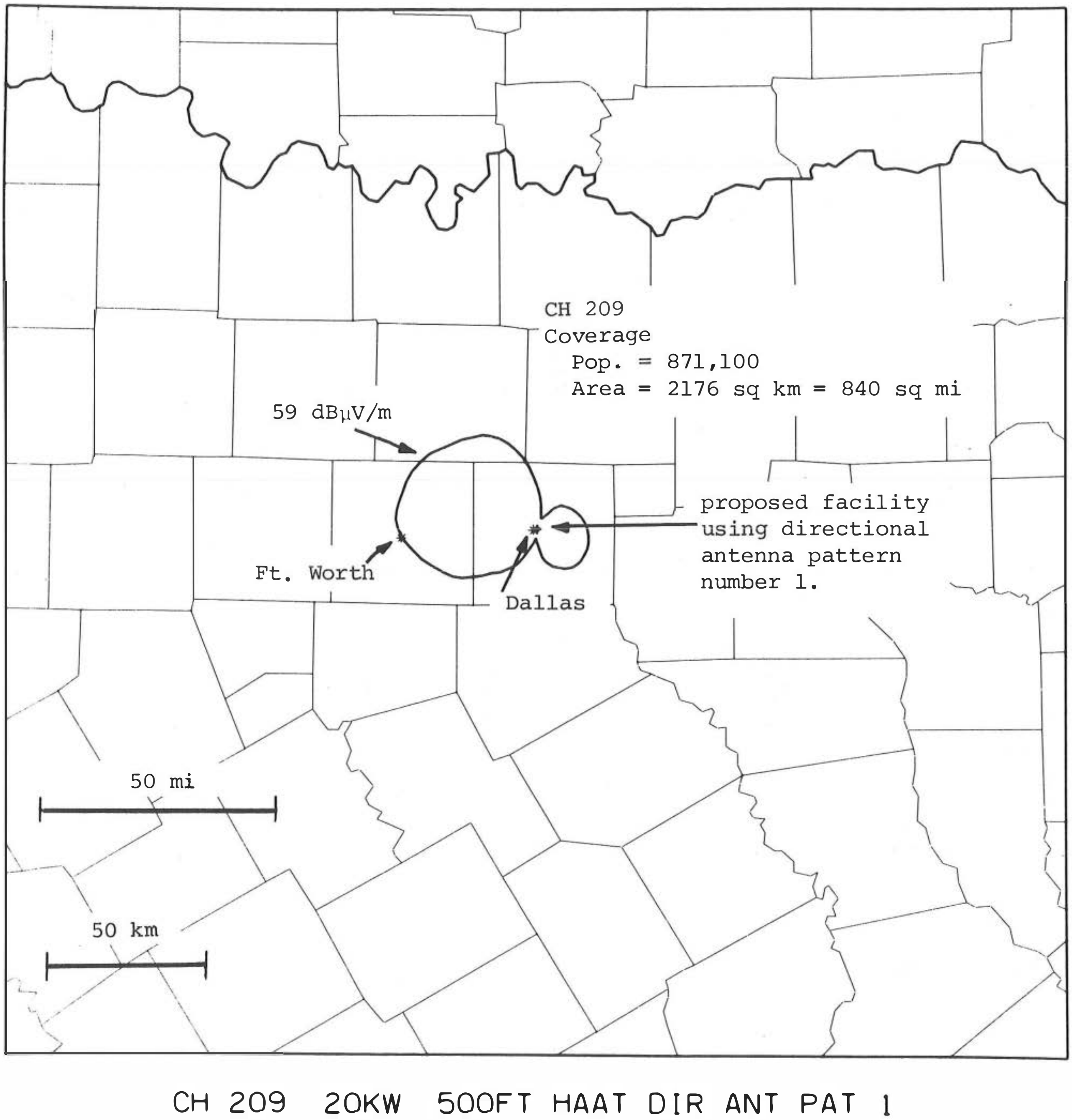
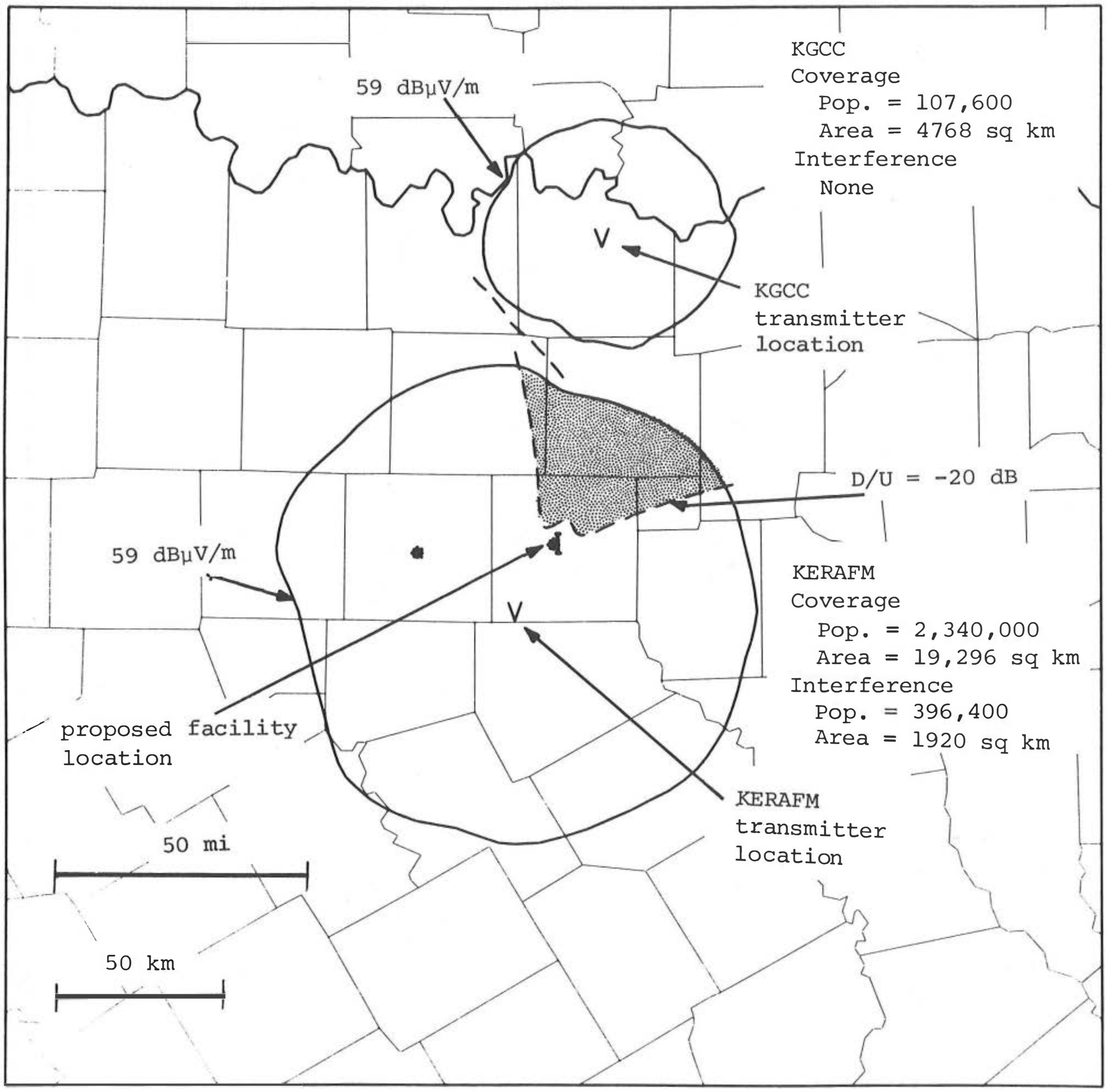


Figure 1-5. Proposed channel 209 coverage with directional antenna.



D=CH209 KGCC CH211 KERAFM U=20KW 500FT D-A CH 209 D/U=20, -20

Figure 1-6. Interference with existing protection standards and directional antenna.

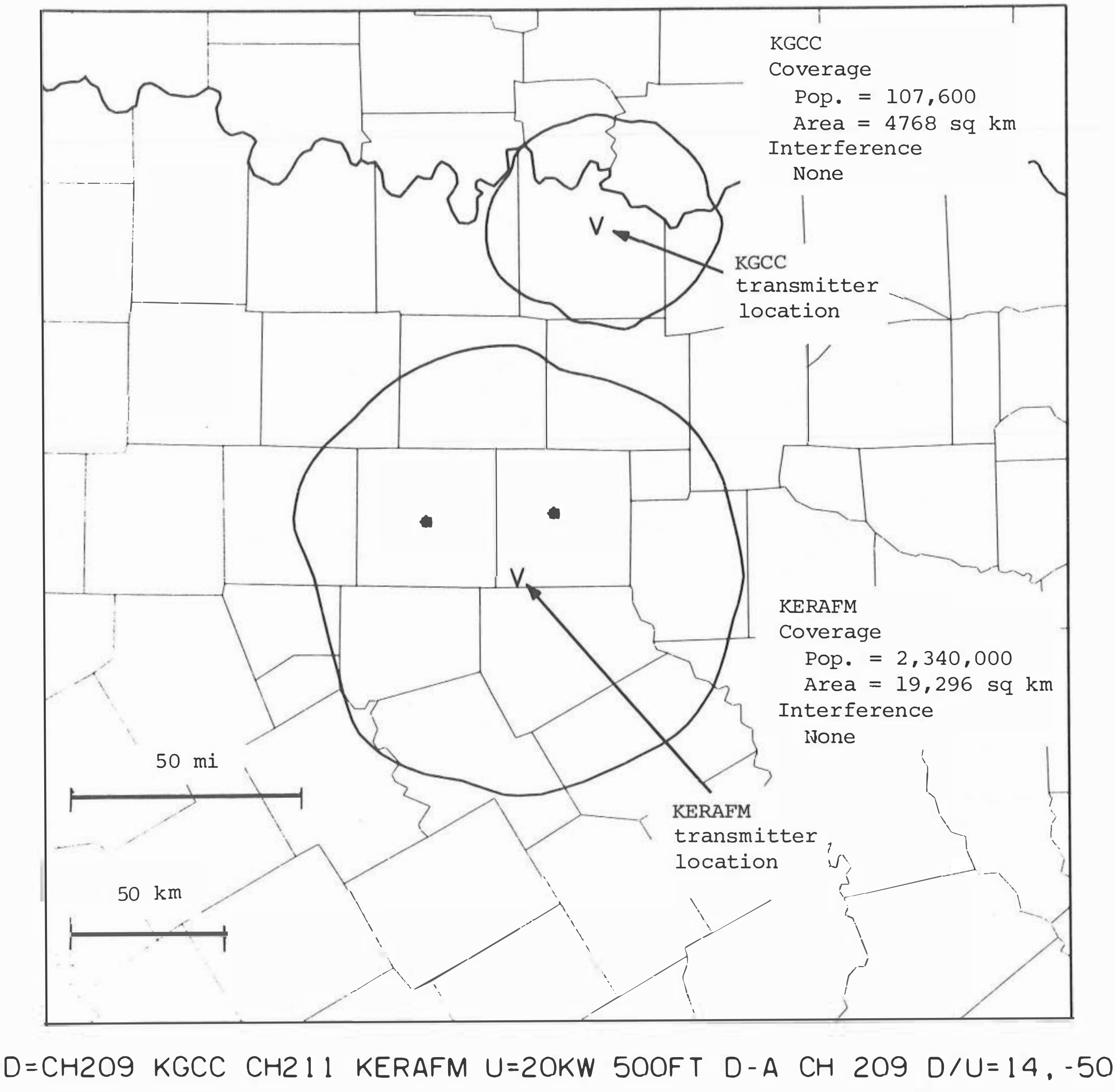


Figure 1-7. Interference with new protection standards and directional antenna.

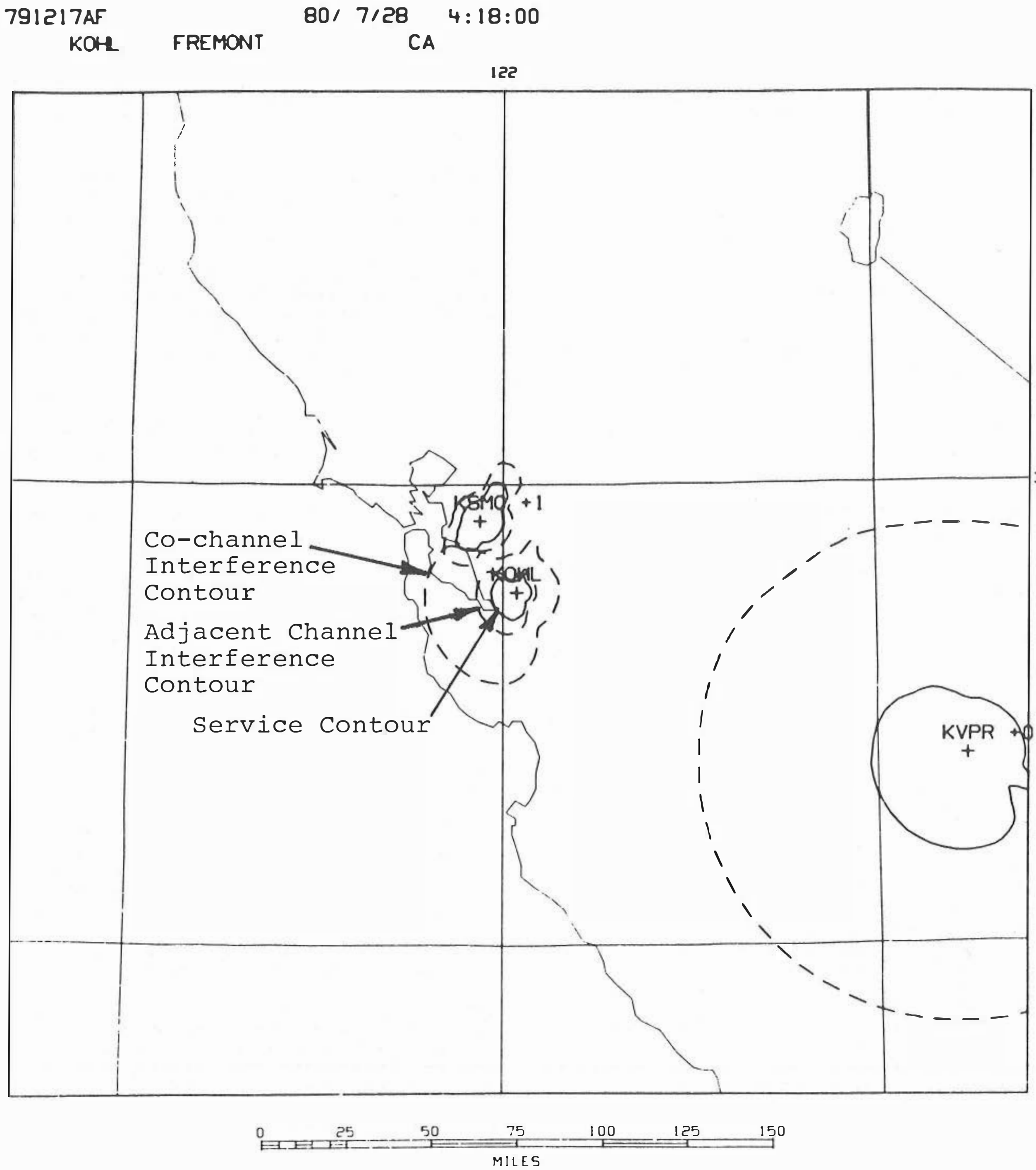


Figure 1-8. A sample of the output for FM license processing. KOHL is the "proposed station" on the same channel as KVPR and on the first adjacent channel to KSMO.

$$P(\text{degrading hit}) = \sum_{j=2}^{k} P[s/i \underline{<} r \mid j \text{ hits}] \times \left[\sum_{m=j}^{k} \frac{P_0 \, (kU)^m \, m! \, (N-1)^{m-j}}{j! \, (m-j)! \, N^m} \right] \quad (1)$$

where

s/i is the ratio of the power in the wanted signal to the power in all the unwanted signals,

r is the signal-to-noise ratio required to avoid degradation,

k is the number of networks operating in the service area,

P_0 is the probability that none of the networks are transmitting during a time slot, given that each network has traffic intensity (utilization factor) U,

U is the average traffic intensity of a network, and

N is the number of frequencies in the common set.

The probability, $P[s/i \underline{<} r \mid j \text{ hits}]$, can be computed with a program developed at ITS in previous years, given the system characteristics, propagation laws, and station distributions, so (1) is computable. This computation can then be used in conjunction with empirical data on the intelligibility of interrupted speech to determine the extent of interference as a function of traffic intensity, number of networks, and hopping frequency.

As an example of the spectrum efficiency and tradeoffs involved, consider a land mobile radio service in a band containing 100 channels. Assume that the average network in the band transmits 0.1 of the time and maintains perfect discipline within its network. Calculations with (1) show that if the band is assigned to frequency-hopping systems that change frequencies 100 times per second, 400 networks can use the band while maintaining over 95% intelligibility in spoken messages. The networks have instant access to the band. On the other hand, assume that the 400 networks use conventional radios and are assigned uniformly in the band so that there are four networks per channel. If we assume perfect circuit discipline, there is no interference while a network is using its channel. However, the probability that a network will have to wait before transmitting (because someone else is using the channel) is 0.394. The average waiting time is 0.22 times the average message length. We do not know whether users would rather give up some intelligibility in exchange for instant communications, or would rather wait a short while in exchange for a clear channel, but the spread-spectrum system is spectrum-efficient enough that perhaps they should be allowed to make the choice.

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.

As part of a continuing effort to better understand and improve the reliability of spectrum planning techniques, ITS has produced an atlas of curves of general air/ground and air/air interest with directions on how to apply them in a particular case. An example of these curves is shown in Figure 1-9.

The handbook recently published by the FAA exemplifies continuing cooperation between agencies. ITS did all the calculations to produce the many curves in the handbook.

Two tasks are currently underway on the project:

1. Production of computer-generated propagation-of-interference predictions as requested by the FAA. Part of this work is being used by the FAA to develop new standards and to publish new handbooks.

2. Ongoing comparison of predictions with experimental data and with other models.

JAMMER is an interactive computer program designed to calculate jammer-to-signal ratios for user-defined scenarios. It allows the user to investigate the effects that changing various parameters of a jamming system have on the jammer-to-signal ratios computed at selected locations. JAMMER was developed for the U.S. Army Signals Warfare Laboratory to aid in the design of electronic warfare systems.

JAMMER may be used to analyze systems for which several levels of detailed input information are available. The most general case allows the user to enter only the link distances, type of terrain at the site, and a qualitative siting measure for the antennas. If the elevation and average terrain height at the transmitting antenna sites are known, these values may be entered instead of the qualitative siting, and JAMMER will determine the effective antenna height more accurately. If the latitude and longitude of the antenna site are entered, JAMMER will calculate the link distances. If a topographic

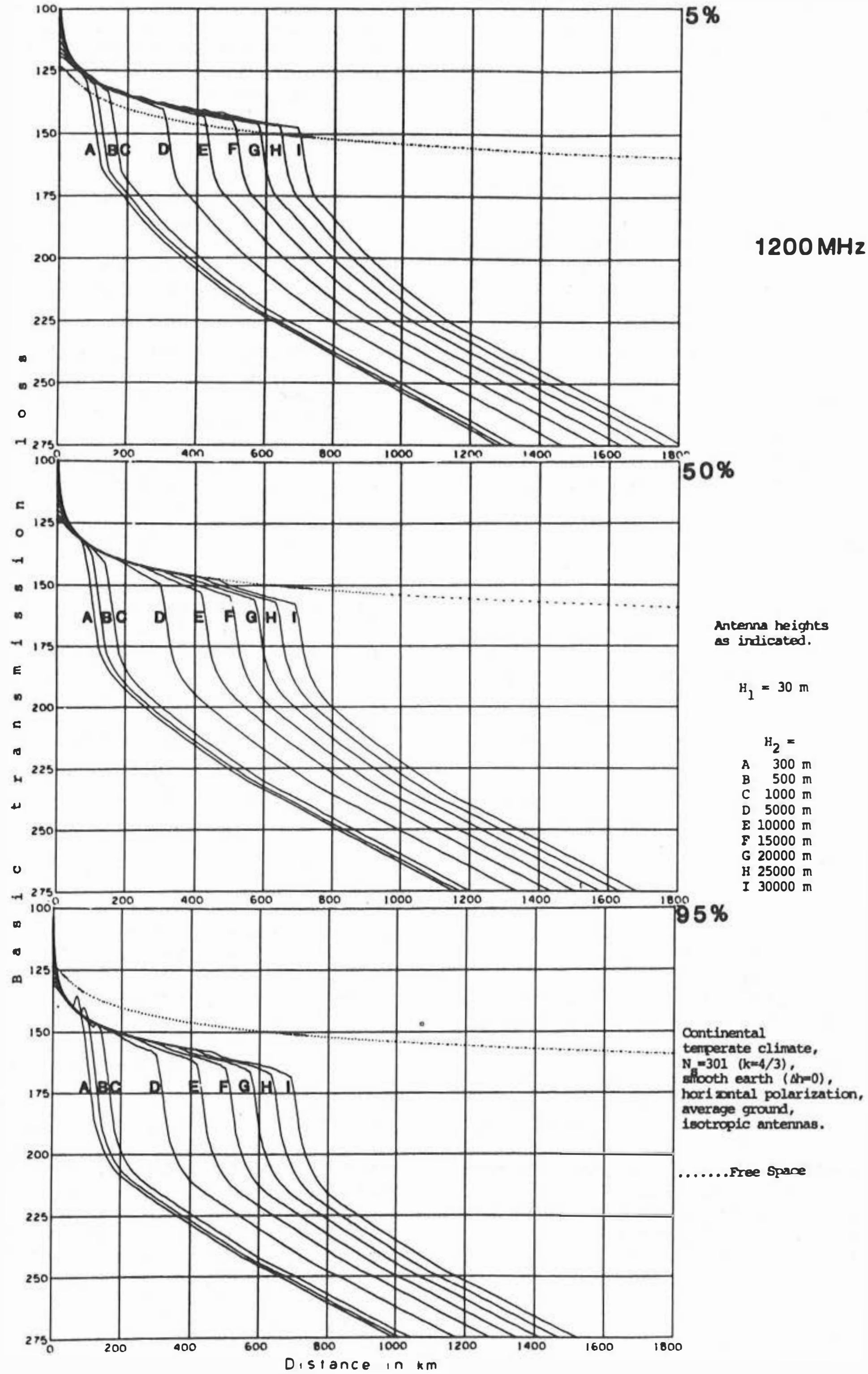


Figure 1-9. Basic transmission loss versus distance; F=1.2 GHz, H_1=30 m. The upper figure shows the loss not exceeded 50% of the time; the middle figure shows the median loss; and the bottom figure shows the loss not exceeded 95% of the time.

data base is available for the area in which the system is located, JAMMER will use the location data for each site to extract the average elevation and terrain irregularity needed for each path. This method produces the most accurate predictions.

JAMMER produces two different types of output. The first type of output illustrates the sensitivity of one parameter to changes in two other system parameters. For example, jammer antenna height and jammer-to-receiver distance might be allowed to vary over specified ranges. The matrix output would then display another parameter, such as jammer power, as a function of the two independent variables. JAMMER also produces tables of intermediate propagation prediction values, such as free-space loss, together with the calculated value for one parameter for a range of values of one independent variable. This output format illustrates the effects that changes to the jamming system have on propagation.

Travelers Information Systems (TIS) have been implemented at many airports in the United States. These systems operate at 530 kHz and provide important information about the airport terminal (locations of parking, airline terminal, rental car return areas, etc.) to the traveler. Also, Non-Directive-Beacons (NDB) may be installed at or near the airports as an aid to air navigation. These NDB may also operate on 530 kHz and could cause interference to the TIS.

The Federal Systems and Spectrum Management (FSSM) Office of NTIA pointed out the problem and determined that measurements were needed of the amount of interference that could be tolerated by the TIS when received in automobile radios.

ITS has made measurements on eight common automobile radios. The measurements made on each receiver included: 1) selectivity, 2) audio modulation response, 3) the ratio of signal to interference-plus-noise and distortion (SINAD), 4) distortion, and 5) articulation score. The measurement procedures and the measured data were described in a letter report to FSSM, who will make recommendations to the IRAC for minimum signal-to-interference requirements in siting TIS near NDB. An example of measured SINAD values for various levels of desired TIS and undesired NDB signals is shown in Figure 1-10. The threshold shown at the bottom of the figure is the just-perceptible threshold detectable by listeners of the receiver output.

Another task compared two methods of computing the probability of interference in congested land-mobile environments: an analytical formula developed by Dr. David Middleton under contract, and a numerical program developed by L.A. Berry. The research is detailed in "Comparisons of Analytical and Numerical Calculations of Communications Probability," NTIA Report 80-41.

Figure 1-11 shows a comparison of the probability of non-interference computed with the two methods for a particular set of identical inputs. The analytical model requires that the interference be represented by the canonical model for Class A noise (NTIA CR-79-4), the probability density function of the wanted path length must have a particular analytical form, and the propagation law must be deterministic with received power inversely proportional to $d^{2\gamma}$. The Class A noise parameters are

$\bar{I}_c$, the mean of the non-gaussian component of the interference,

Γ, the ratio of the mean of the non-gaussian noise to the mean of the gaussian noise, and

A, the "overlap index," which is the average duration of an interfering emission multiplied by the average number of emissions per second.

The abscissa, y, is proportional to the transmitter power and inversely proportional to the mean noise and the required signal-to-noise ratio. As Figure 1-11 shows, the two methods get identical results for identical input.

The numerical model allows greater flexibility and realism in the input parameters than the analytical formula (NTIA-CR-79-4). For example, the numerical model allows the propagation law to have a realistic variability. Figure 1-12 compares the probability of non-interference with (σ_s = 8 dB) and without (σ_s = 0) propagation loss variability. The main difference is that the probability of satisfactory reception is considerably less at reliabilities higher than 90% under the realistic conditions of variable propagation loss. The analytical model provides an adequate approximation at lower reliabilities.

To use the analytical formula, the Class A noise parameters that model the interference must be known. It is more likely that the locations, powers, and characteristics of the transmitters operating in a given area are known. So a way of getting Class A parameters from a scenario must be available. They can be approximated by running the numerical model for the scenario to produce the probability density function of interference, and fitting this function using techniques described in NTIA Report 80-41. Figure 1-13 shows a comparison of the actual probability of communications for a given scenario and the probability computed with the analytical formula using Class A noise parameters estimated as described. The analytical formula seriously overestimates the probability of communications for probabilities greater than 90%. Full details of the comparisons can be found in NTIA Report 80-41.

TOPOG is a computerized system for generating and retrieving worldwide terrain-elevation data. It consists of software to generate TOPOG tapes from Defense Mapping Agency terrain-elevation data tapes, to create auxiliary random-access disk files containing TOPOG data for a user-defined area, and to extract path profiles from the auxiliary disk files. The data base and software are designed for a CDC 6000 series computer with a NOS or NOS/BE operating system. The project was sponsored by USACEEIA to provide an impro-

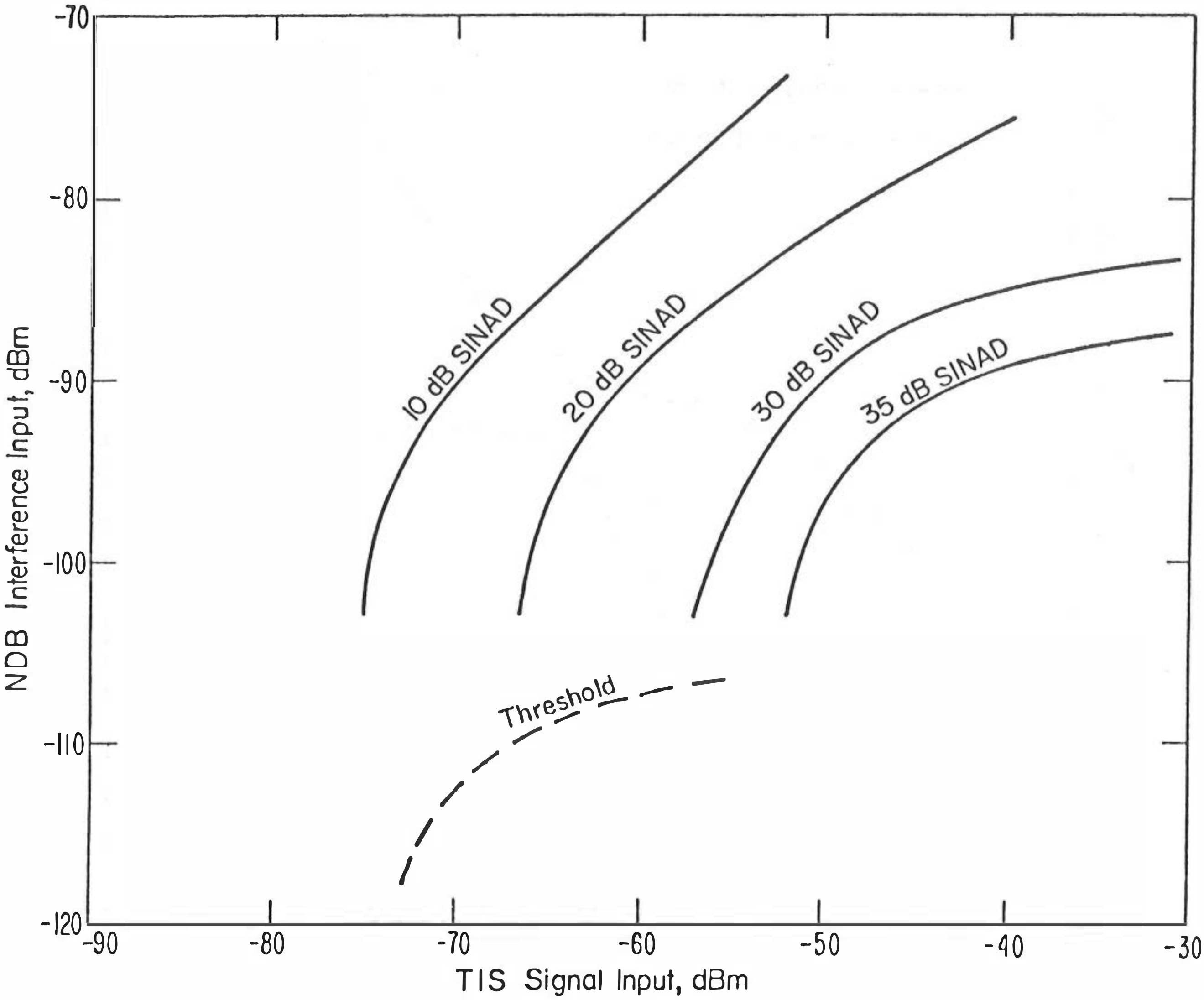


Figure 1-10. Level of NDB interference which will produce a specified SINAD as a function of wanted TIS signal. The threshold of perceptible interference is shown as a dashed line.

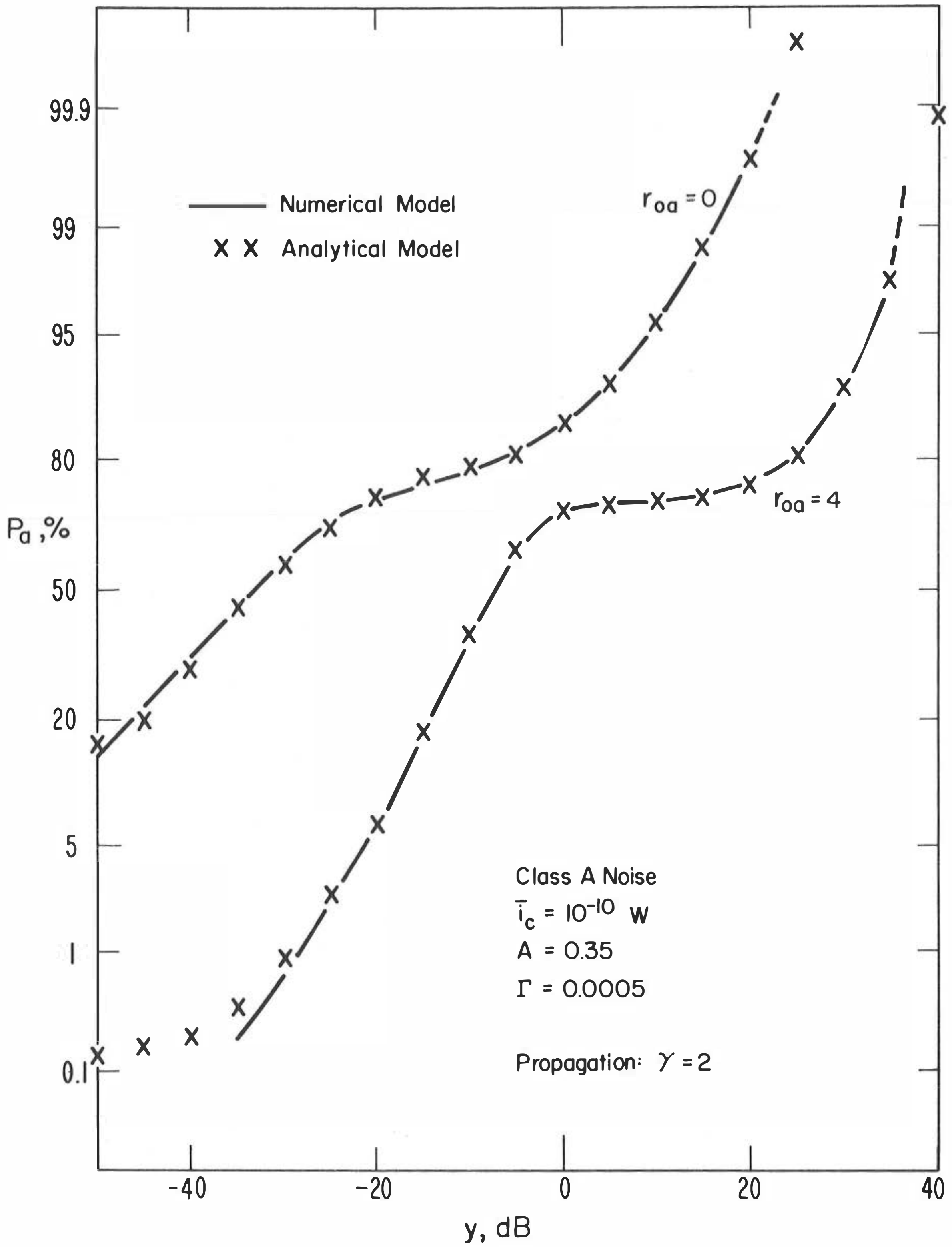


Figure 1-11. Probability, P_a, that the signal-to-noise ratio (S/N) exceeds the required threshold as a function of y - radiated power/mean noise/required S/N. The distance from the receiver to the center of operations of the desired transmitter is r_{0a}.

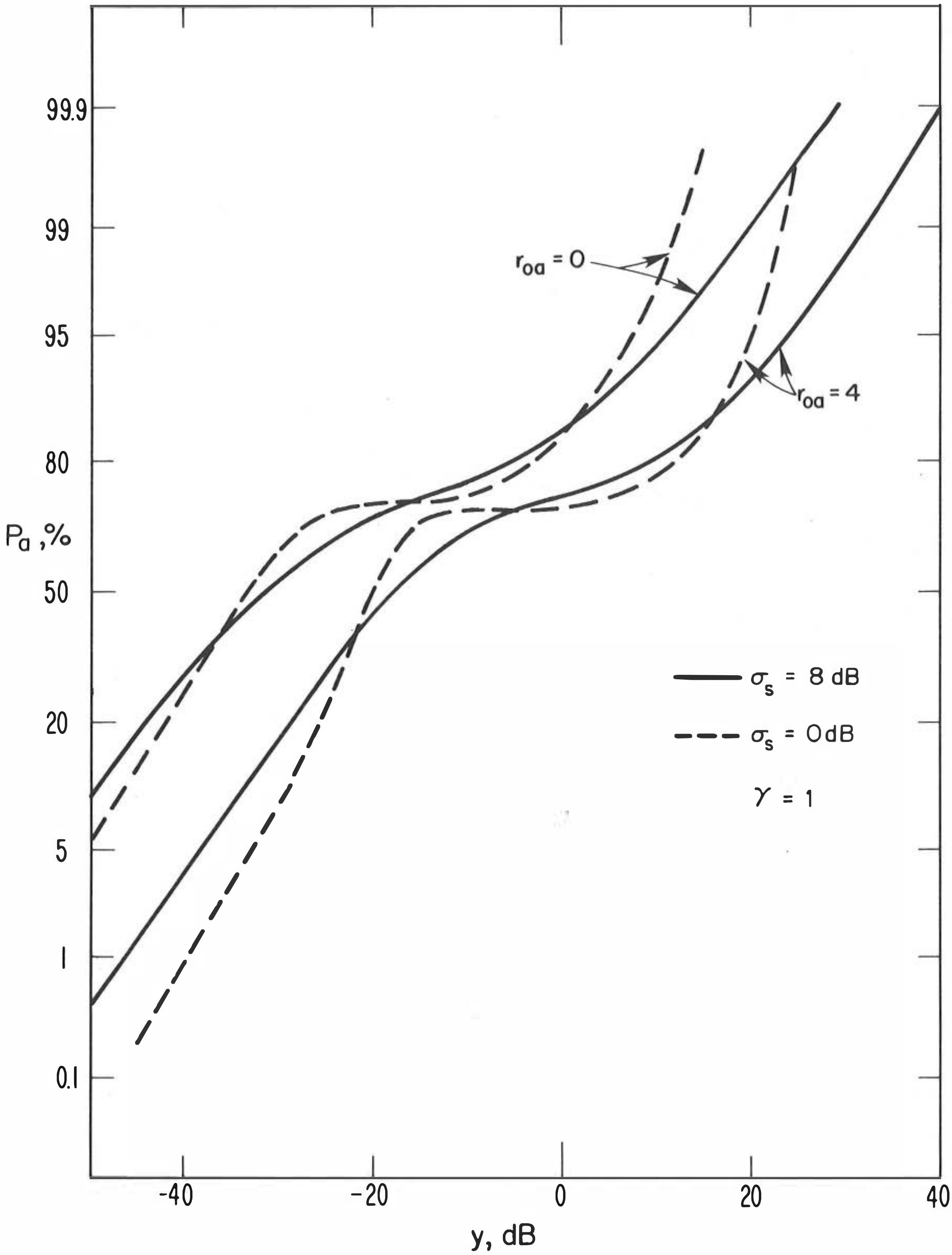


Figure 1-12. Probability, P_a, that the signal-to-noise ratio exceeds the required threshold when there is no variability of transmission loss (σ_s = 0 dB), and when there is realistic variability (σ_s = 8 dB). Other parameters are the same as in Figure 1-11.

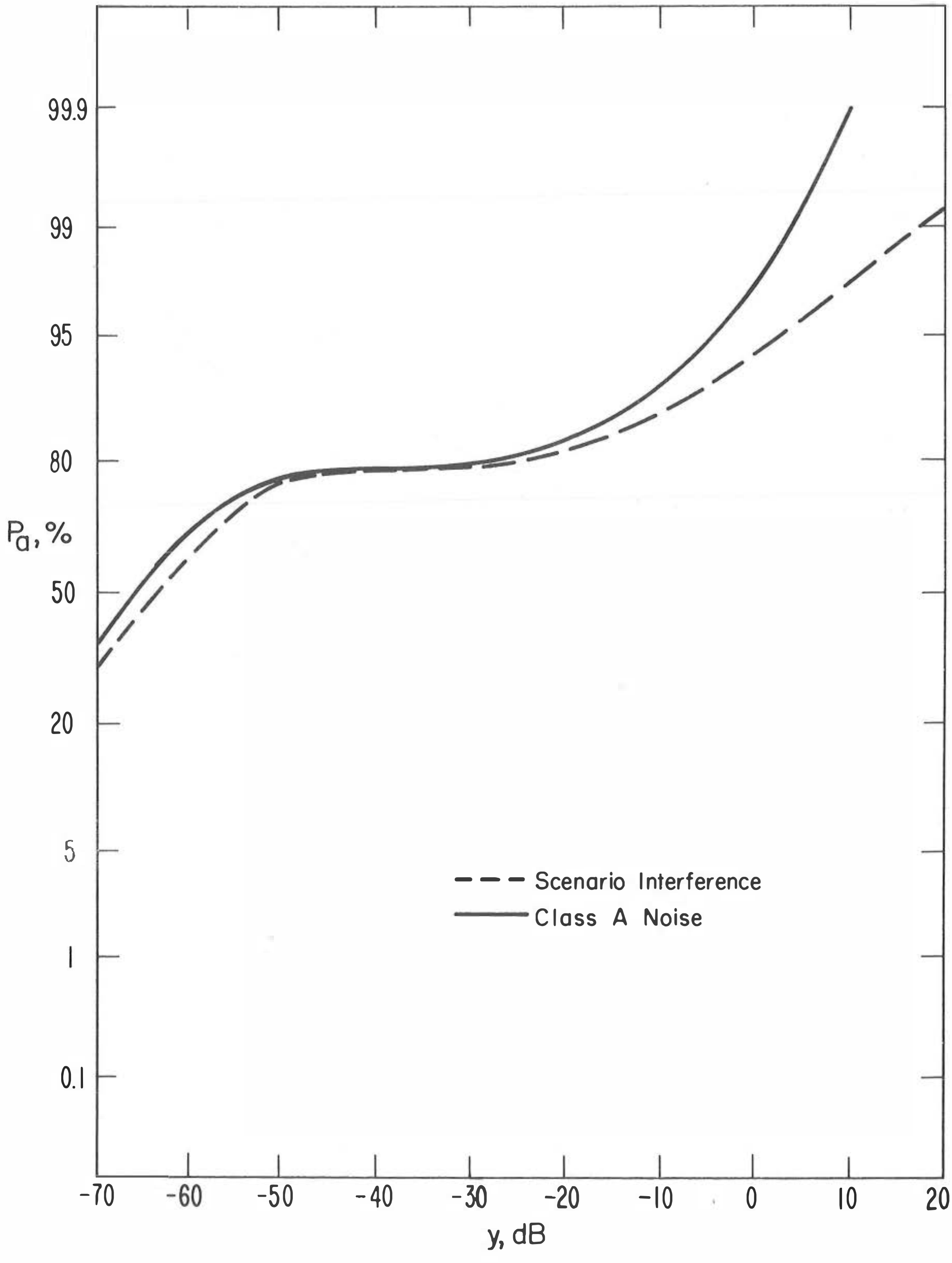


Figure 1-13. Comparison of probability of communications for a specific scenario (dashed line), and the same probability computed using the best-fit Class A noise formula (solid line). The greatest discrepancy is for P_a greater than 90%.

ved digital terrain elevation data base for use with the Communication System Performance Model and other related software that calculate propagation predictions based on path profiles.

The TOPOG data base is composed of a set of files stored on magnetic tape which contain terrain elevation values at the intersection points of a global grid on the World Geodetic System reference spheroid. The grid is comprised of parallels and meridians and segments of meridians. To achieve a consistent data density, the parallels included in the grid are uniformly spaced at 3-second intervals while the meridians spacing varies from 3 to 24 seconds depending on the latitude. This grid system allows a possibility of more than 66 billion distinct data points with a maximum linear separation of 129 meters to be contained in the TOPOG data base. Because of the large number of terrain elevation values involved, the TOPOG data base is designed as a hierarchical system of indices and data records that minimizes the total storage required and facilitates data retrieval. By denoting ocean areas in the indices as well as in the data records, substantially more than half of the terrain elevation values can be inferred to be zero without actually storing the zero elevation in the data base. To minimize the amount of storage occupied by the terrain elevation values that are included in the data records, TOPOG represents each value as an integer number of intervals above the minimum elevation in that data block. The interval size is a function of terrain roughness. The integers representing the scaled terrain elevation values for all the grid points within the block are packed into the data record using the smallest number of bits that will contain the largest value. The minimum elevation, interval size, and packing factor are recorded in each data record so that the actual elevation value can be reconstructed upon retrieval.

Figures 1-14 and 1-15 show comparisons of path profiles extracted from a 30-second TOPO data base, from the TOPOG data base, and from data read from 1:250000 scale maps. The path in Figure 1-14 is across Mt. Hood and shows the differences that finer-grained data make in representing profiles across isolated peaks. Figure 1-15 shows a path across Orcas Island in Puget Sound.

The continuing project on the study of the Theoretical Performance of FM Receivers in Interference has been extended to include the important practical situations where, in addition to the highly nonlinear effects of the limiter-discriminator combination, distortion is introduced by presence of the finite-bandwidth front-end (i.e., RF X IF) filters of typical receivers. As before (FY 79), a fully-general approach has been used, which is analytically and computationally much easier to use than the conventional treatments which employ direct harmonic analysis ab initio. This general approach permits immediate reduction to special cases of interest, without loss of the key model structure or the injection of simplistic assumptions, to the point where direct computations of the various analytic expressions are carried out.

The interference results obtained earlier are extended to include the effects of front-end filter distortion, which produces an unwanted amplitude modulation, as well as a distortion of the desired FM signal in the receiver in addition to similar effects in the accompanying interfering signals. Explicit, manageable general results for the instantaneous envelope (E) and frequency (Θ) of the receiver output are obtained when multiple (AM or FM) interfering signals are present in various combinations--co-channel and "off time."

In addition to the above general but deterministic approach, a parallel effort has been initiated to extend the "classical" analysis of FM reception in Gaussian noise to include random, non-Gaussian interference models recently developed at ITS. With the introduction of randomness, a broader spectrum of realistic operational conditions can be included to add to the necessary results of the deterministic model currently under study.

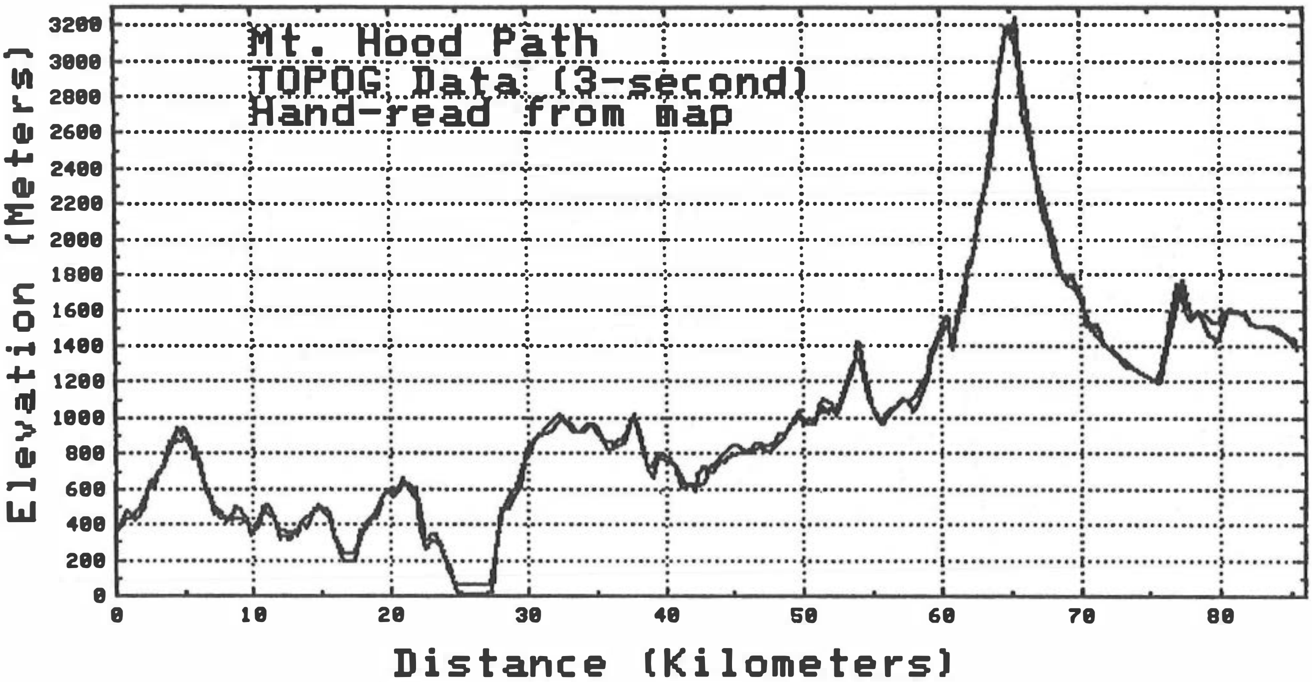
SECTION 1.2. SPECTRUM ENGINEERING FOR EFFICIENT SPECTRUM USE

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.

Radio Coverage of the Vessel Traffic Service in the Puget Sound. The Puget Sound, Strait of Juan de Fuca, and the environs of the seaport of Seattle, WA, are active shipping and boating areas. The Canadian seaport of Vancouver, British Columbia, is also served by some of these shipping lanes. The Thirteenth District of the U.S. Coast Guard is responsible for ensuring the safety of the ships and boats, both commercial and private, that use these waters.

The Vessel Traffic Service (VTS) makes use of a VHF communication network that the Coast Guard uses to maintain a real-time knowledge of each large vessel's position on the waters of the Puget Sound area. This system, it should be emphasized, is not used for vessel traffic control. Rather, it is used for vessel traffic information. The ships and boats entering the Strait of Juan de Fuca from the open sea or those beginning a voyage from, say, a dock at Seattle voluntarily provide the Coast Guard VTS operator with certain data--size and type of vessel, current location, speed, and planned course. These data are recorded at the VTS communication center by locating a model vessel on a "chart table" and updating its position at periodic intervals. The VTS operator will request or receive new data from the vessel as necessary.

As mentioned above, the vessel traffic is not controlled, but the potential problems and course conflicts that can be easily observed on the chart table are brought to the atten-



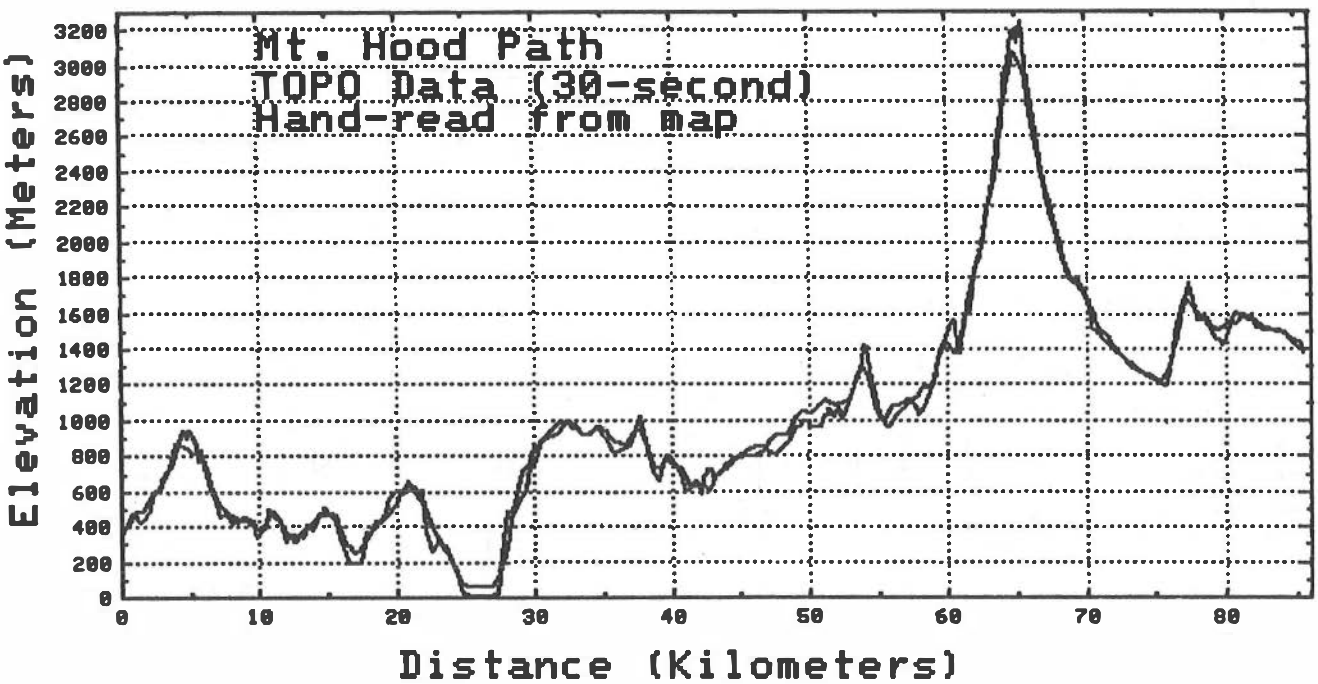
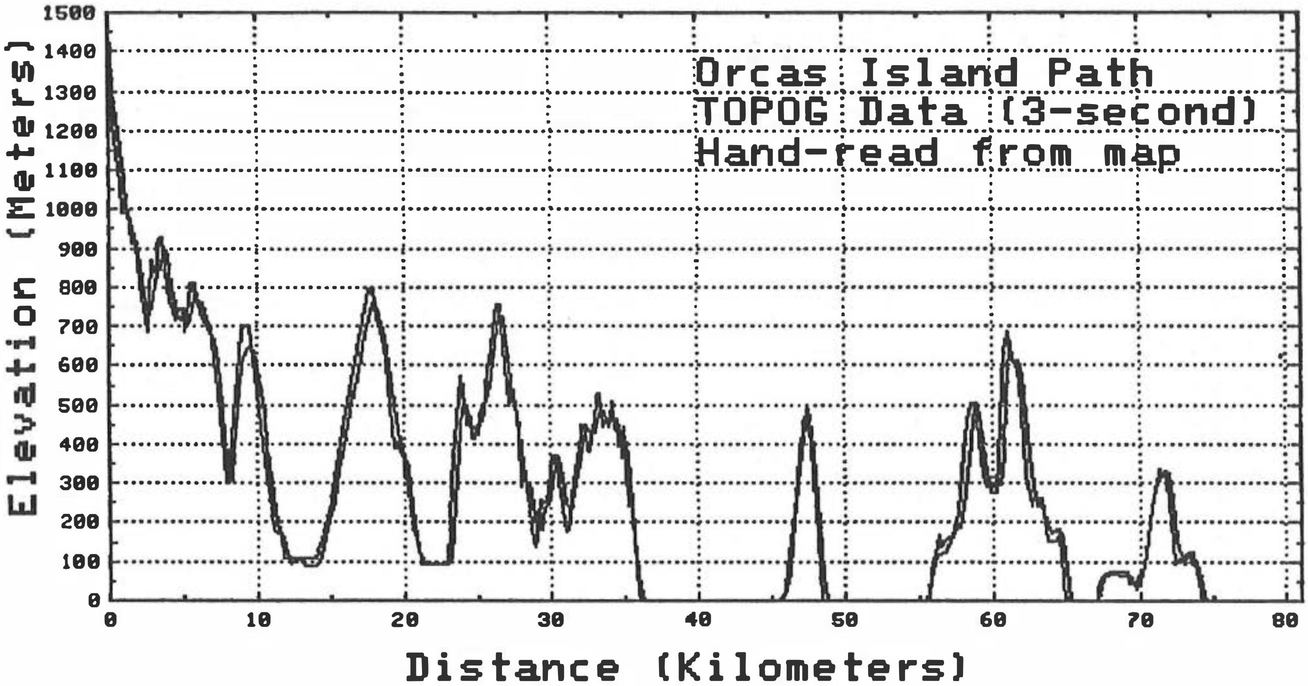


Figure 1-14. Comparison of path profiles across Mt. Hood.



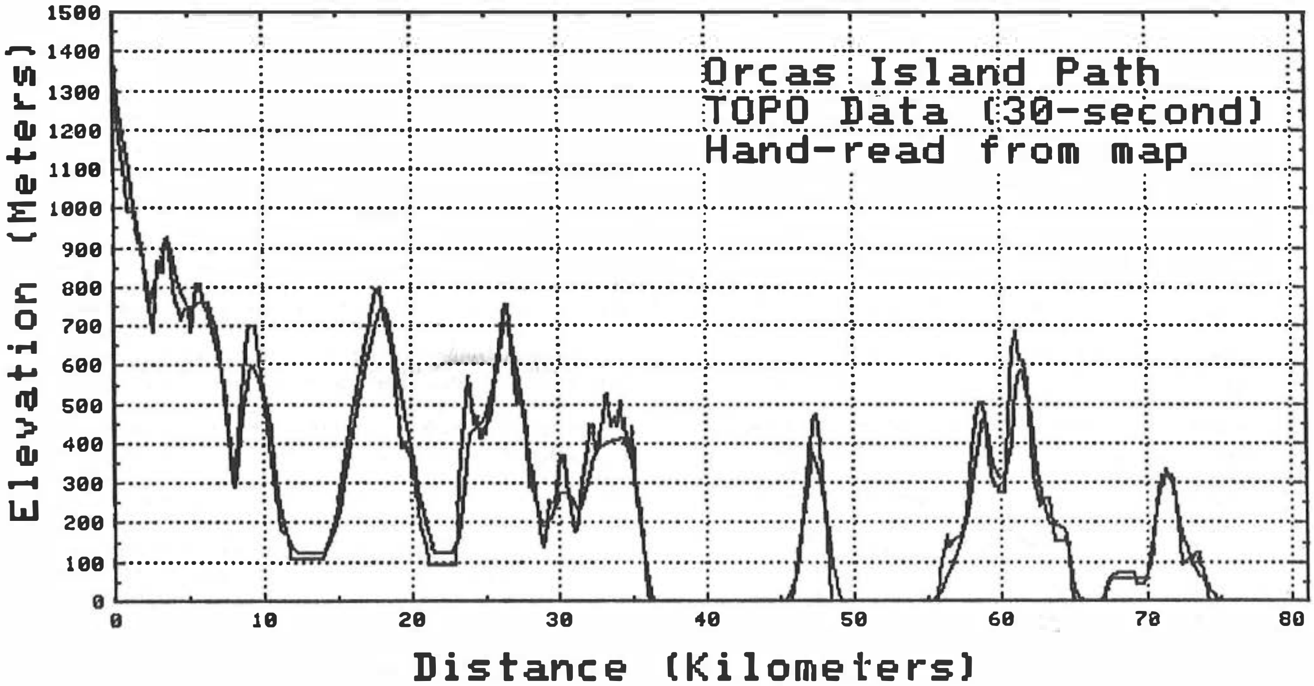


Figure 1-15. Comparison of path profiles across Orcas Island.

tion of the vessels involved. For example, a particular ship may be notified that it will be overtaken by another, and it and the overtaking ship may be requested to establish radio contact to arrange the maneuver. At other times, when visibility is poor, smaller boats may be warned of a large ship about to pass through a particular area.

Since the present VTS uses only one channel, one operator must handle all of the communications traffic. Of course, there are other personnel who support the VTS--some to maintain the chart table and some to watch the radar images of the area, for example. Although the system is operating well in its present configuration, a large increase in vessel traffic may increase the difficulties tremendously. In anticipation of this increased traffic, the Coast Guard is in the process of upgrading the VTS and communication traffic handling techniques. One major telecommunications change is being considered: defining sectors or subsectors of the waterways, with each sector served by a particular group of VTS sites. It is therefore desirable that the coverage within each sector be complete and that mutual interference between sectors be minimized.

In order to develop the sector scheme efficiently, the Coast Guard requested the ITS to provide VHF coverage predictions for (1) the present VTS sites, (2) the present sites with various modifications (e.g., directional antennas), and (3) proposed VTS sites. An NTIA Technical Memorandum (NTIA-TM-80-35) describes the prediction techniques used and some of the results (coverage maps for the present VTS sites).

The part of the system that we need to examine is the radio link from transmitter to receiver. We wish to make an estimate of the coverage of each station and must make several assumptions. First, we assume that the receiver sensitivity is 0.5 μV and that the antenna is a 5/8 wavelength whip at 1.83 m (6 ft) above the sea. Second, we assume that the fixed shore station is the transmitter with a radiated power of 1 W and an omnidirectional antenna with 6 dB of gain over an isotropic source. Last, we assume that there is an additional 2 dB of loss somewhere in the link which represents losses such as transmission line and mismatch losses.

Figure 1-16 is one of the coverage maps from the Technical Memorandum. Shown in the figure is the 1.36 μV/m contour for the VTS site at Pearson Creek.

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 predictions for Wellington, New Zealand; McMurdo Station, Antarctica; or Palmer Station, Antarctica, were supplied to the San Francisco communication station. These propagation predictions were used to choose the frequencies for "operation deep-freeze" communications.

In addition to the "quick reaction" propagation predictions, a radio coverage study was completed this year. The coverages for two maritime distress communication systems were calculated for those U.S. Coast Guard stations located in the contiguous United States. The two systems are the MF distress channel (on 2182 kHz) used for medium-range coverage along all coast lines and the VHF distress channel (on 156.8 MHz) used for short ranges ($\leq$37 km) along all coastlines and navigable inland water. This work supplies the Coast Guard with information needed to remove those stations whose coverage is insufficient or redundant.

The MF and VHF coverage maps will be published in an NTIA Technical Report entitled "The Coverages of the MF and VHF Maritime Distress Communications Systems." Figure 1-17 is an example of the MF receive coverage for those stations in the Eleventh Coast Guard District for the expected annual maximum of atmospheric noise. Figure 1-18 is an example of the VHF receive coverage for two stations in the Seventh Coast Guard District. The smaller contours on this map represent a lower transmitter antenna height and a lower radiated power than the larger contours.

The Broadcasting Spectrum Technology Policy Analysis project provided technical analysis and comment in support of a variety of NTIA policy issues. Some resulted in direct responses to Federal Communications Commission issues such as proceedings to revise frequency assignment practices for FM radio and for various aspects of UHF television operations. Other work provided technical bases for future regulatory or policy consideration.

The Power Line Carrier Interference project has determined 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 (PLC) 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 reradiation of the nondirectional beacon (NDB) signal by the nearby power lines. Due to the

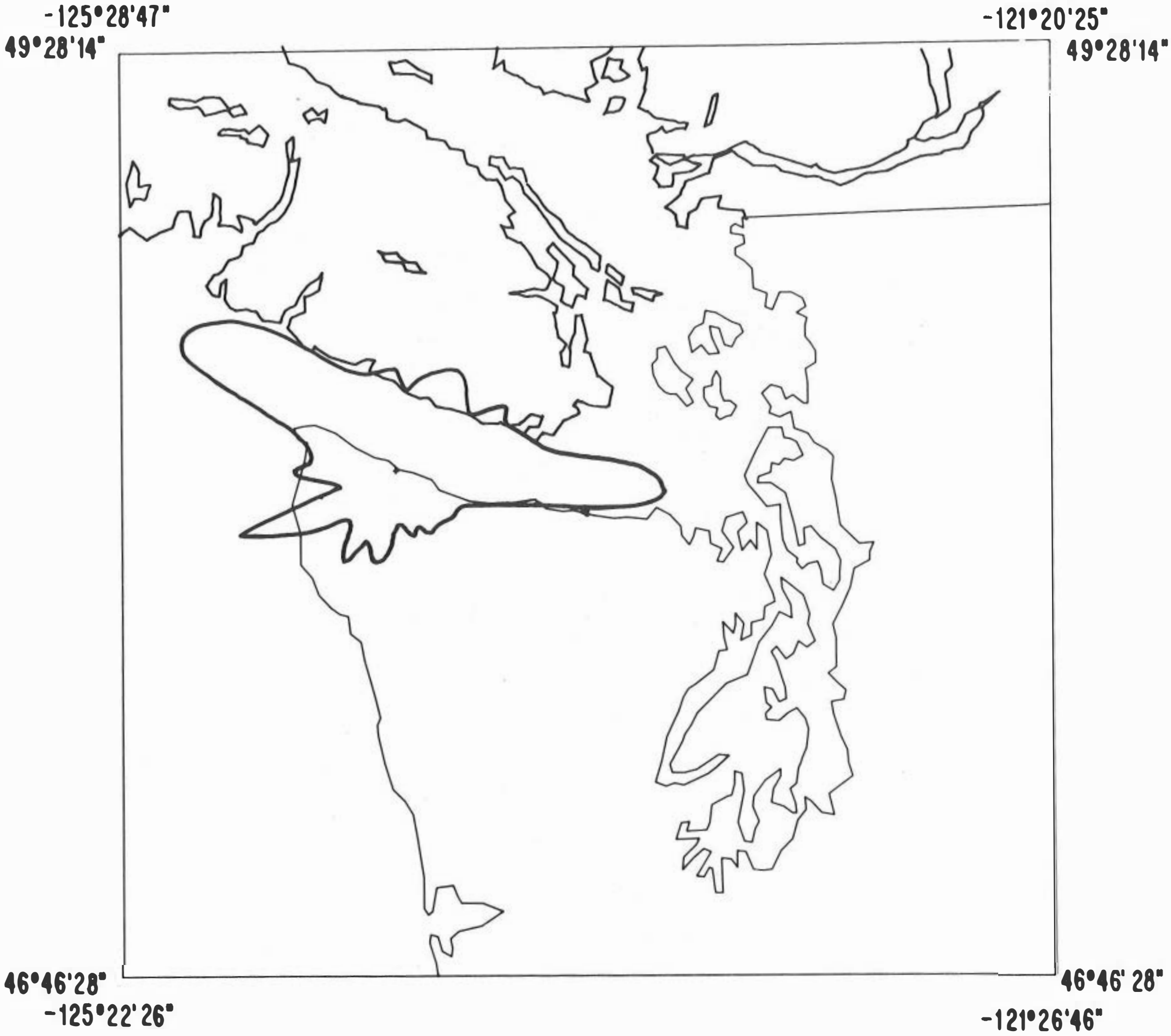


Figure 1-16. The 1.36 μV/m contour for the VTS site at Pearson Creek.

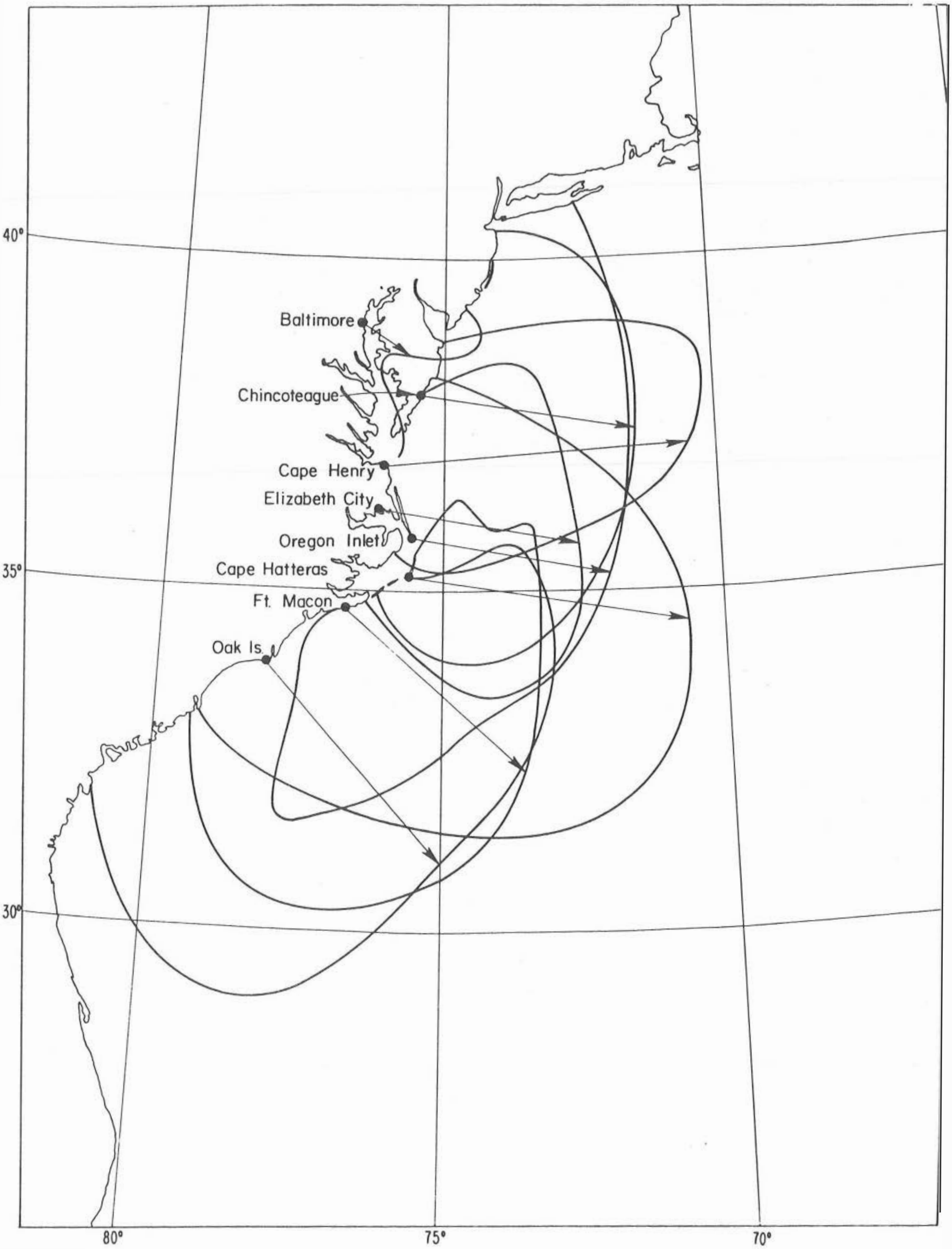


Figure 1-17. 2182 kHz receive coverage for Fifth District U.S. Coast Guard stations, assuming the expected annual maximum atmospheric noise.

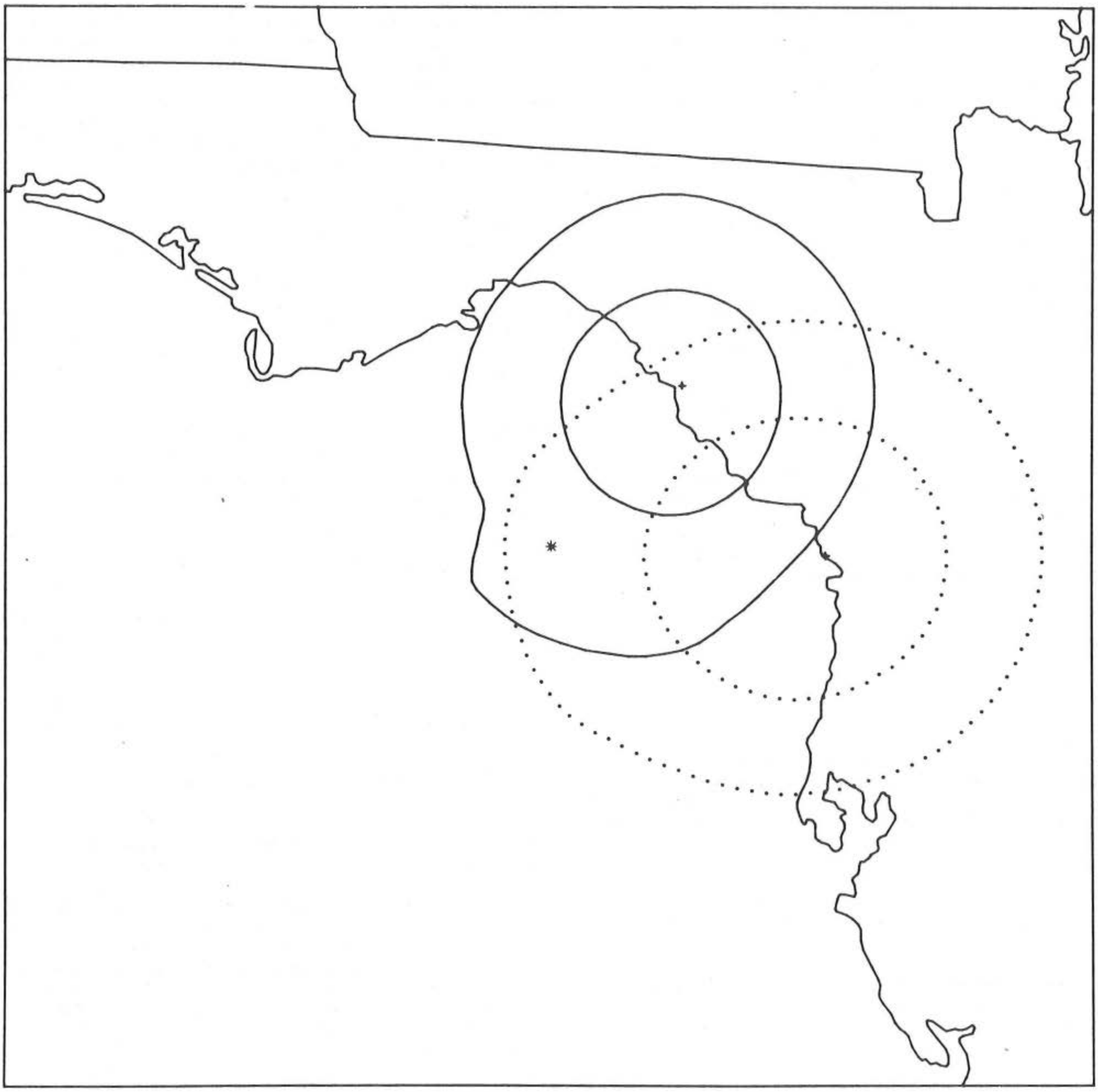


Figure 1-18. 156.8 MHz receive coverage for two stations in the Seventh U.S. Coast Guard District. The station locations are marked with a plus sign and the map center with the asterisk. The smaller contour represents a lower transmitter antenna height and a lower radiated power than the large contour.

above factors and unknowns, the Federal Aviation Administration initiated this study at the ITS to help answer the question: Do the power line carrier systems radiate sufficient energy to produce significant radio compass errors?

In order to answer the question, this work covered the following topics: the susceptibility of the ADF radio compass, review of the theories describing PLC propagation and radiation, actual measurement of PLC radiation, and an assessment of the potential for interference.

Radio compass receiver susceptibility was measured on two types of receivers: Receiver A, which utilized a gonimeter and is used mostly by commercial aviation, and Receiver B, which contains an electronic direction-finding circuit and is used mostly by general aviation. These laboratory measurements were made at the FAA aeronautical center in Oklahoma City. Simulated desired and undesired signals were presented to the test receiver as arriving from the same or orthogonal directions. The following conclusions can be summarized from the measured results:

- The bearing error is independent of frequency in the 200 to 400 kHz range for both receivers.

- The bearing error observed on the B receiver was more dependent upon the absolute undesired (U) signal level than on the undesired-to-desired (U/D) ratio. Significant bearing errors were observed at 44 to 54 dBu and above for the U signal level. The desired (D) signal level ranged from 30 to 60 dBu.

- The bearing error observed on the A receiver was more dependent on the U/D ratio than absolute signal levels. Significant bearing errors were observed at U/D ratio of 4 to 10 dB. The D signal level ranged from 30 to 60 dBu.

- Both the A and B receivers were less susceptible to the interference from the U signal at very high levels of the D signals.

- Little or no bearing error was observed for a U and D signal frequency separation of 3.5 kHz for the B receiver and 2.0 kHz for the A receiver.

The aspect of PLC systems that we are interested in for this work is not how poorly or how well PLC signals propagate along power lines, but how much of the PLC signal is present in the airspace above the power lines. The PLC signal, when propagating along the power line, can be viewed as a guided-wave and as such has some field distribution surrounding the power line. This kind of guided wave is predictable if the geometry of the power line and its environment (the earth's surface and the support towers) is simple; e.g., conductors at all times parallel to a planar earth. This kind of an analysis does not portray the real world very well, however. The point we wish to make is this: There is some field structure due to the guided wave nature of the propagation, and there is some radiation due to the departures from ideal geometry. This radiation is very difficult to predict and may be the dominant source of signal in the airspace above the power line. Note that there can be some confusion as to the meaning of "PLC radiation." This term is often used to mean all of the fields that surround the power line regardless of geometry and distance. Strictly speaking, PLC radiation ought to describe only those fields that will propagate independently after being launched by the power line. These radiated fields, then, are not a part of the guided wave mode of propagation.

None of the theories account for the many anomalies in geometry such as line sag and bends so they are insufficient for our purposes. Actual measurements of PLC radiation were used to determine the fields surrounding the power lines. A review of any previous measurements was made, and, as part of this project, measurements were made over power lines of the Tennessee Valley Authority (TVA).

To make the measurements over TVA power lines, an FAA flight inspection aircraft was used. That aircraft is equipped with a variety of avionics and a general-purpose spectrum analyzer/data recording system. One great advantage of this particular system is that it is interfaced with the aircraft inertial navigation system (INS). This means that data such as the location (latitude and longitude), heading, and ground speed could be recorded at essentially the same time as the signal level data were being recorded. The aircraft is equipped with dual ADF radio compass systems with an independent set of antennas. This provided the opportunity to use one of the ADF sense antennas to make the desired measurments. This equipment and a few additional items form the measurement system that we used.

For our purposes, it would be most informative to measure the actual field strength of the PLC signal. To do so, however, we must calibrate the aircraft and receiving system as a unit. This is because the only thing we can really measure is the signal level present at the antenna terminals (a voltage or power). So, the calibration we seek is a relationship between the field strength (in volts/meter) external to the aircraft and the received signal level as observed with the spectrum analyzer (in watts). This, in itself, is no trivial exercise. A brief description is given here.

In order to perform the aircraft calibration, a known electric field is needed through which the aircraft can be flown. This, in effect, is the crux of the calibration procedure. The known field was obtained by identifying several suitable NDB's, then measuring the ground level field strengths with a calibrated field strength meter, and lastly, predicting the field strength at some fixed altitude in the airspace above the beacons. An ideal beacon for this procedure is one that has a circularly symmetric (vertical) antenna; no nearby obstructions; and is located on flat, homogeneous earth. Of course, ideal beacons are impossible to find, but one with excellent conditions and two with reasonable conditions were found in the Texas panhandle and Oklahoma, respectively.

The two power lines that were chosen for the PLC radiation measurements have different characteristics and features. Both lines are horizontally disposed three-phase transmission lines with shield wires above the phase conductors. The relevant characteristics of these lines are listed in Table 1-2. For each line, several test configurations are specified, and for each configuration, flight paths over which measurements are taken are also specified. The test configurations involved different frequencies, modulation types, and powers of injected PLC signals. The flight paths included longitudinal paths directly over the power line from substation to substation, transverse paths, and grids above both transmitting and receiving substations.

The results are presented in two ways. The grid data are handled statistically and the transverse or longitudinal path data are plotted on a graph showing the field strength versus the percent of the path. This means that all of the data taken along a particular path are plotted sequentially. It was planned that the INS location data would be used to determine the distance along the line for the longitudinal paths or the lateral distance from the line for the transverse paths. However, due to software or interface problems, the INS location information was not recorded properly during the PLC radiation measurements. The flight paths are, however, fairly well defined. The longitudinal path data begin about 3 n mi (5.6 km) before one substation and continue to about the same distance beyond the other substation.

Figures 1-19 and 1-20 are examples of the results of the PLC measurements. Figure 1-19 is the signal strength for a longitudinal path and Figure 1-20 is the signal strength for a transverse path. The units for the signal strength are dBu/W; in other words, decibels above 1 μV/m normalized to 1 W of injected PLC power.

PLC systems, in practice, operate with injected powers that range from a fraction of a watt to tens of watts. We used powers of 20 and 100 W so that we would have a strong, reliable signal to measure. These high powers are not meant to represent typical usage. For the purpose of comparison to other measurements or predictions, the measurements we made were normalized to 1 W of injected PLC power-a convenient reference level.

The following are some observations regarding the PLC radiation measurements.

- There is about 5 to 10 dB more radiation from the lower frequency signal (coupled phase-to-ground on the 161-kV line) than from the higher frequency signal (coupled phase-to-phase on the 500-kV line).
- The transmitting substation shows a strong peak in field strength directly above the substation which drops 10 dB or more in the first few kilometers of horizontal distance in any direction.
- The transverse runs indicate that the field strength decreases with lateral distance at the rate of 18 to 22 dB per decade. This represents a 1/r dependence for the field strength.
- Some of the results indicate that the signal directly above the power line may be less than at some distance to the side. The transverse runs did not show this behavior. The reason may be that the field is not vertically polarized directly above the line.
- A simulated fault on the power line was used for some of the measurements; it caused little (about 2 or 3 dB) increase in the radiated fields in the vicinity. This is only a single, isolated test of radiation from a fault, and the conclusion should not be considered general; but we feel this is a strong indication that any fault would have little effect, except perhaps a fault in or very near the transmitting substation.
- The highest levels of field strength that we measured were about 40 dBu. These are in good agreement with the field strengths that others have measured.

Table 1-2. Characteristics of the TVA Power Lines Used for the PLC Measurements

LINE	GREAT FALLS - SPRING CITY	JOHNSONVILLE - CUMBERLAND
Voltage	161 kV	500 kV
Terrain	Relatively rugged	Relatively level
Tower type	Wood pole	Steel structure
Span length	Variable	Relatively constant
Line length	About 72 km	About 48 km
Location	80 km N of Chattanooga	100 km W of Nashville
PLC Coupling	Center phase-to-ground	Phase-to-phase

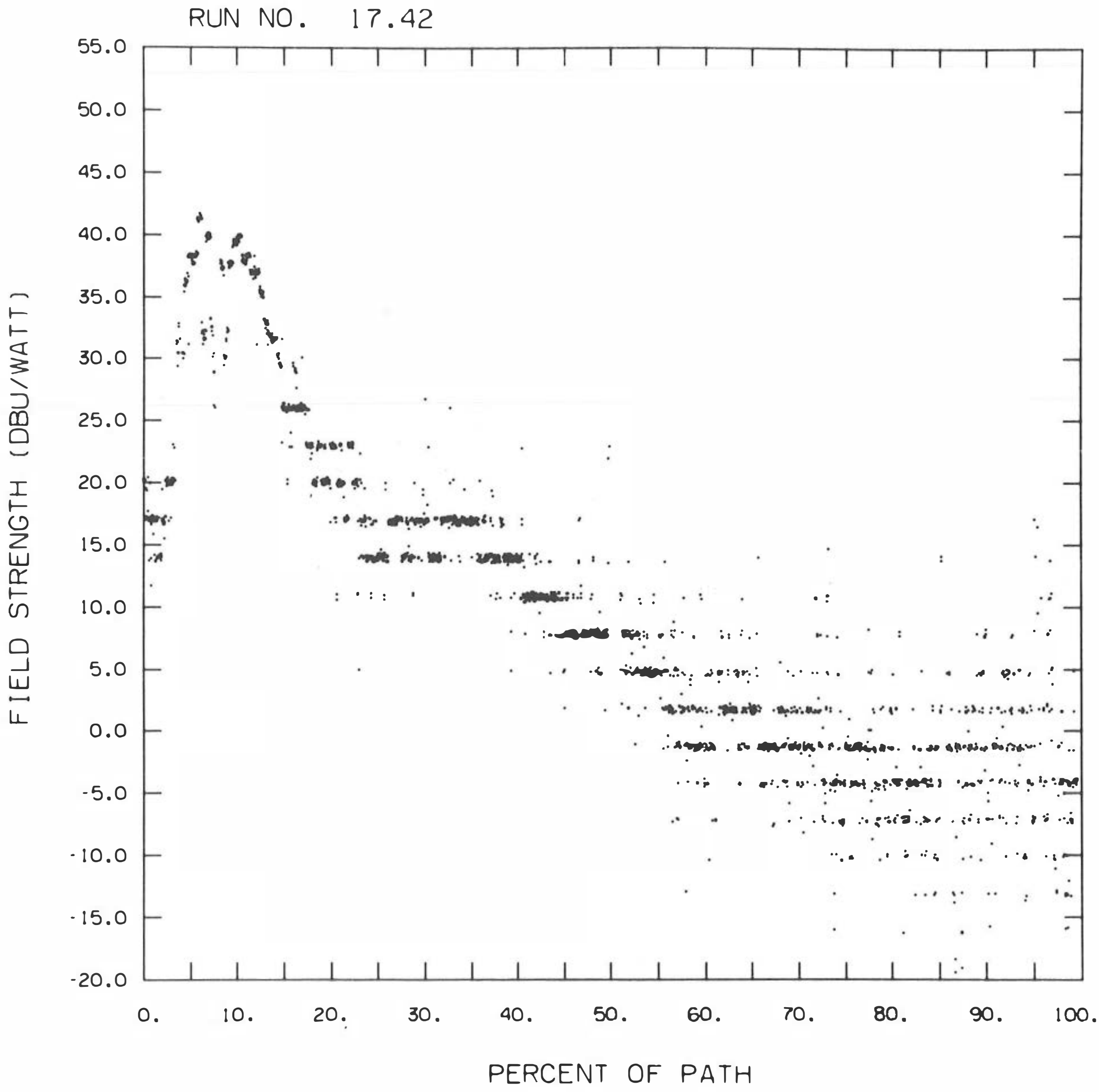


Figure 1-19. The field strength on a longitudinal path at about 400 m above the highest point along the Great Falls - Spring City line for a 200 kHz signal injected into the power line.

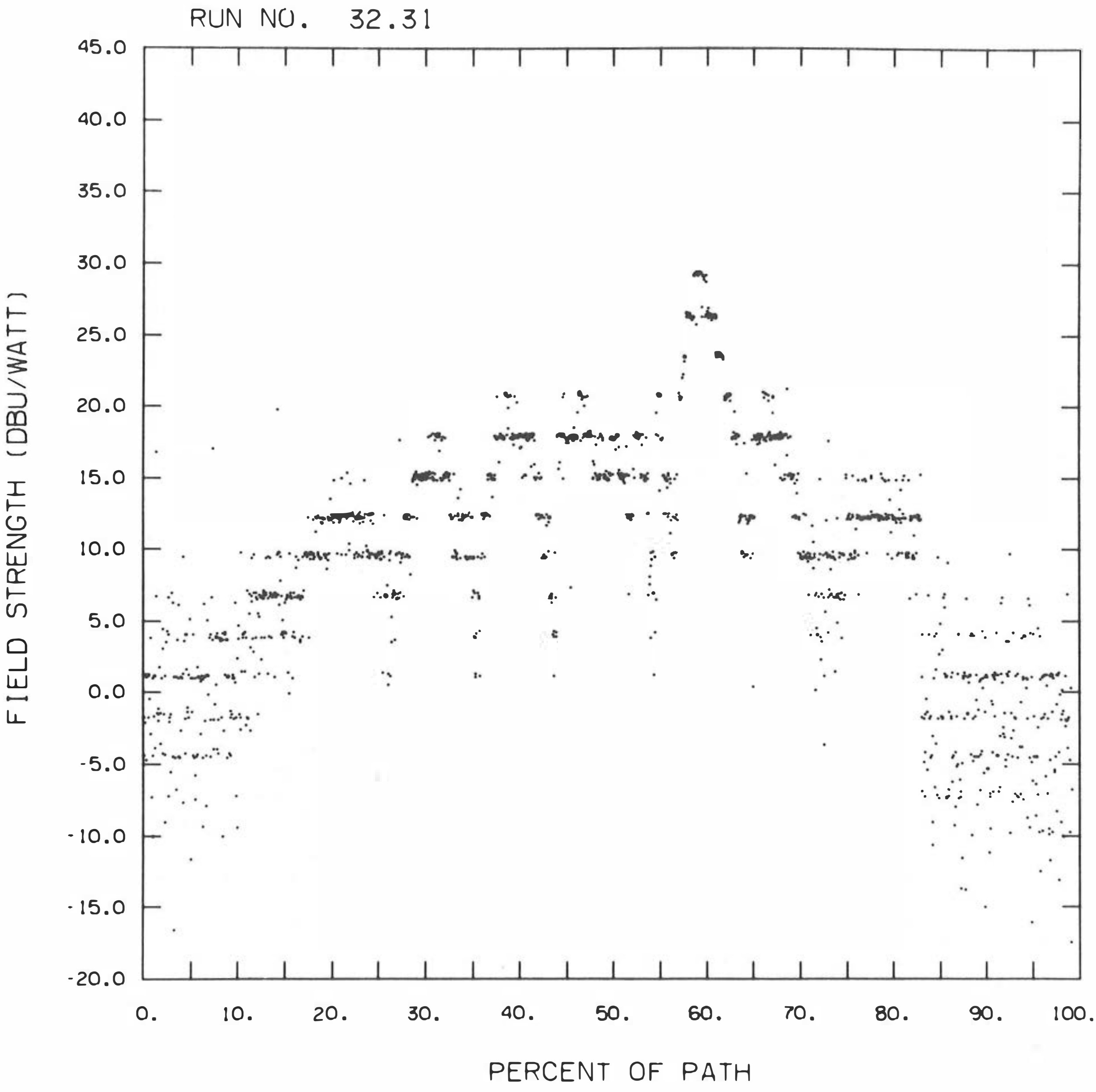


Figure 1-20. The field strength on a transverse path at about 15 km from Johnsonville at about 590 m (~1936 ft) above the Johnsonville-Cumberland line for a 400 kHz signal injected into the power line.

The following are conclusions regarding the interference that the radio compass could receive from PLC radiation. These conclusions are based on the assumptions that the injected PLC power is 1 W and that the aircraft is located about 400 m (∿1312 ft) above the transmitting substation (where the PLC radiation is the greatest).

- The PLC field strengths for 1 W of injected power are not sufficient to affect the B receiver unless the NDB signal (the desired signal) is very weak (30 μV/m) and at the upper end of the NDB band (400 kHz).

- Assuming that the minimum NDB signal (the desired signal) is 36.9 dBu (70 μV/m), the PLC field strengths for 1 W of injected power are not sufficient to affect the A receiver.

- If the injected PLC power were increased by 6 dB (to 4 W), perceptible interference to the radio compass would occur. This is true for the locations where the PLC radiation is greatest.

- The lateral distance dependence of the PLC field strengths, based on our measurements, was observed to be no more than -18 dB/decade. The height dependence of the PLC field strength may be the same as the lateral distance dependence if no surface wave propagation mode is present. However, for that portion of the PLC signal that propagates as a surface wave, there will be very little decrease in field strength with height for those heights below one or two wavelengths; then it will decrease rapidly.

The work described here was published as an FAA Technical Report, Number FAA-RD-80-30, entitled "Power Line Carrier Radiation and the Low-Frequency Radio Compass," dated May 1980.

SECTION 1.3. ADVANCED INSTRUMENTATION AND SPECTRUM MEASUREMENTS

Many forms of system design, spectrum engineering, and even tactical use of electronic systems depend on a realistic understanding of the electromagnetic environment in which the systems will be operating. Unfortunately, environmental measurements of spectrum usage cannot often be made simply, because of requirements for large amounts of data needed for a reliable statistical model, because of very detailed measurements needed to describe technical system interactions, etc. Some of these problems can be overcome with the aid of computer-controlled measurement systems. These computer-controlled measurement systems can provide several advantages over earlier manual systems including economical measurement of massive amounts of data, real-time measurement and analysis of high-speed phenomena, and sophisticated processing of data to provide a relatively untrained operator with answers that are not otherwise obvious.

Three major programs concerning the development and use of computer-controlled systems to measure the electromagnetic environment have been underway at ITS in the past several years. The Radio Spectrum Measurement System (RSMS) was designed to collect data for NTIA frequency management work, with the first use of the system starting in 1973. The two other major van-deployed measurement systems, TAEMS and AN/MSR-T1 to be discussed later in this section, substantially extended the RSMS capabilities in several different directions and will soon be providing additional measurement capability for the user agencies.

The Radio Spectrum Measurement System (RSMS) continues to provide data on the use of the Federal Government portions of the radio spectrum (Figure 1-21). In operation since 1973, this computer-controlled measurement system routinely makes measurements of spectrum occupancy in a dozen bands of interest between 30 MHz and 12 GHz. In the land mobile radio (LMR) bands, the RSMS takes up to 10 million samples of occupancy a day and compares measured occupancy against frequency assignment lists. In the radar bands, the RSMS has substantial capabilities in various pulse-sorting modes used to identify radars and to isolate them from the rest of the radar environment for detailed measurements. Detailed measurements typically include spectrum, pulse shape, and antenna pattern.

This year the RSMS has completed general occupancy measurements in the New York City metropolitan area and in Denver. A second set of measurements has begun in the Los Angeles area, repeating a set of measurements made in 1974-75. The flat geography of the New York area presented difficulties in obtaining a relatively high receiving site from which reliable coverage of most of the New York area was available. For this reason, the RSMS was lifted to the top of a 7-story building on the New Jersey waterfront, using a shipyard crane from the adjacent drydock facility (Figure 1-22). This site gave an excellent view of the New York waterfront and many of the activities in this area which were important to our measurements.

Over the years, the RSMS has been continually upgraded, and this year was no exception. Digital interfaces were added to a roof-top antenna pedestal to allow antenna orientation to be read by the computer. Programs were written to allow greater flexibility in graphing edited radar data from measurements recorded on magnetic tape. One of the major improvements in software this year was the addition of a direction-finding capability to the general search program used for radar measurements. This program now has 2 parts--one used for making a spectrum search across a frequency band (Figure 1-23) and one used to identify a direction-of-arrival for that radar signal (Figure 1-24). This program combines several RSMS capabilities which have been available before, but whose utility was somewhat limited by being disjointed pieces.

The general spectrum search part of the program (Figure 1-23) is used to see what radar signals can be received in a frequency band. In this example (not real data), the operator is looking at the 2700-2900 MHz band, using a 1000 kHz bandwidth, and dividing the frequency

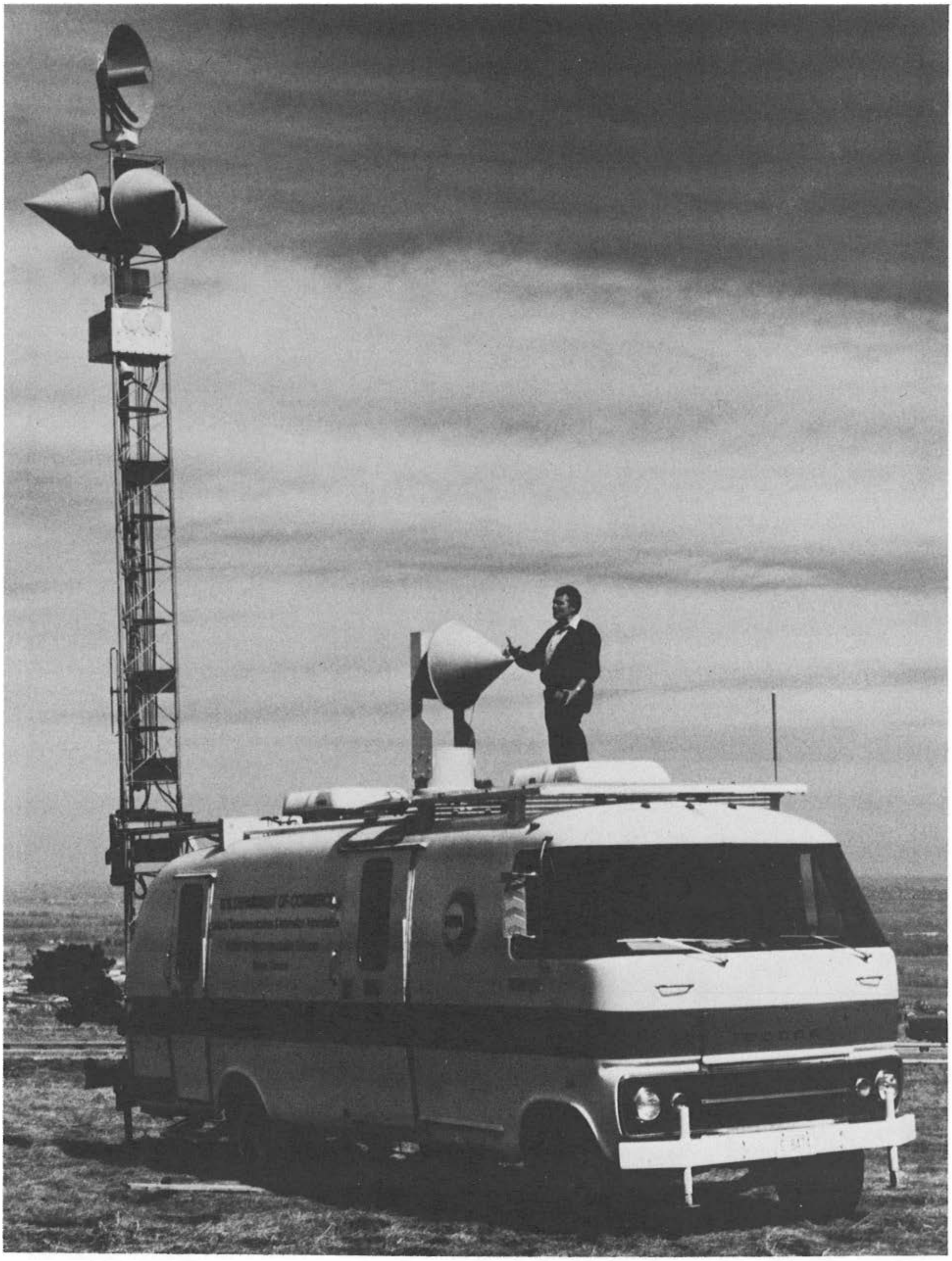


Figure 1-21. Radio Spectrum Measurement System (RSMS).

Figure 1-22. RSMS being raised to top of building for New York measurements.

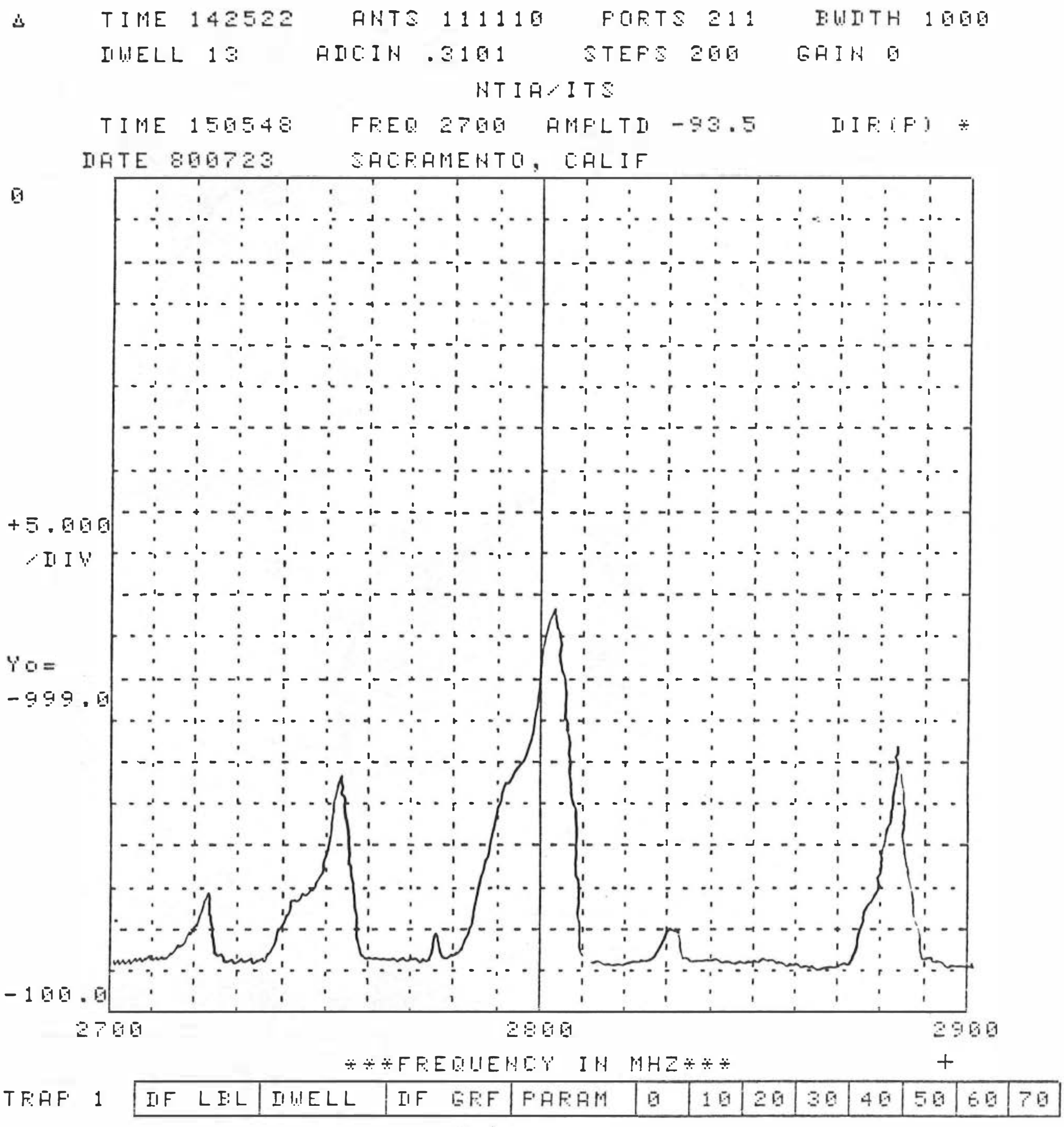


Figure 1-23. Frequency scan graph.

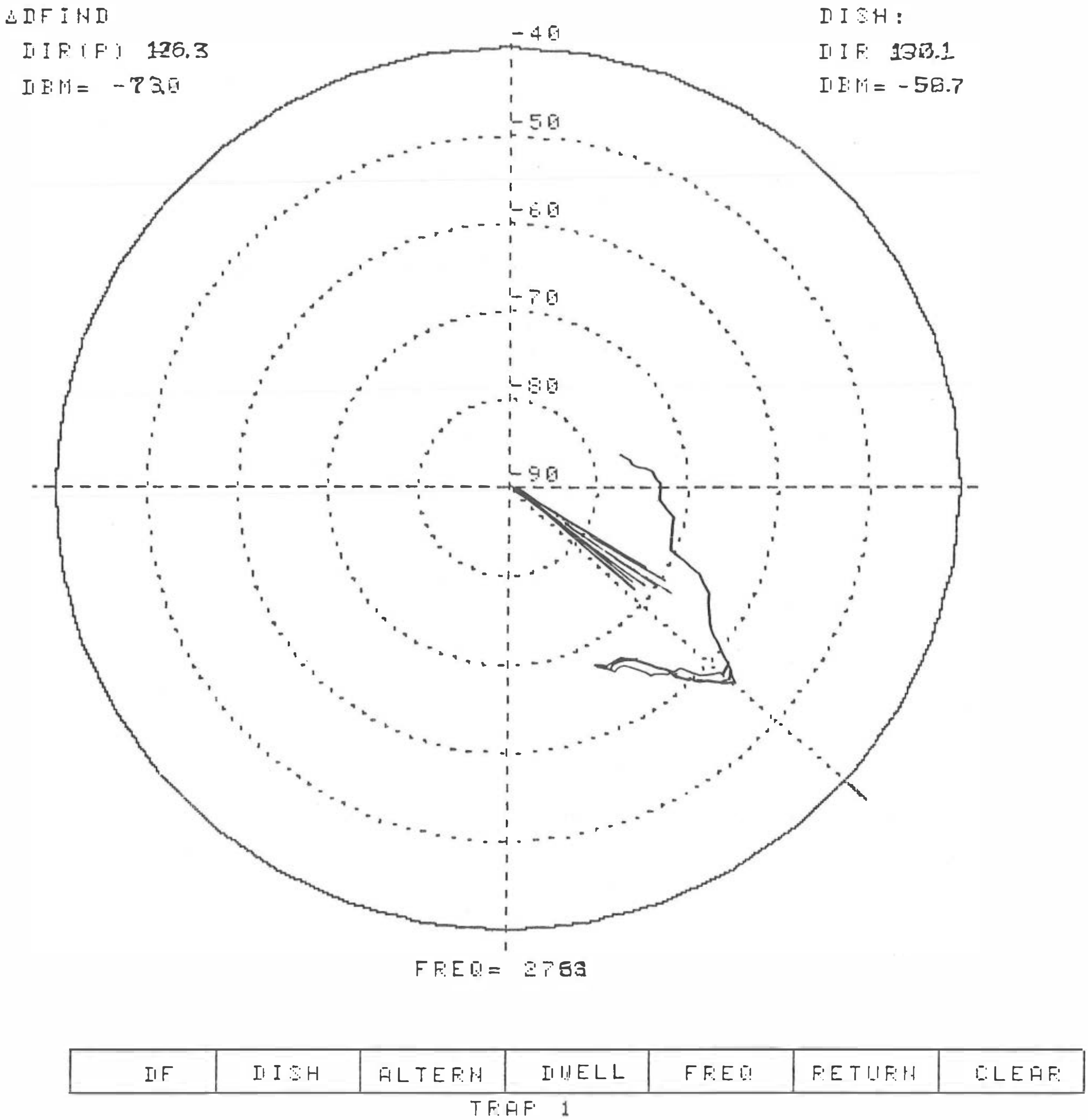


Figure 1-24. Direction-finding graph.

range into 200 steps (each step 1 MHz apart). At each frequency step, the system remains for 13 seconds gathering peak signal data from whatever radar may be encountered. This time is chosen to match or exceed the rotation time of radars known to be in that band, so that the radar will have pointed directly at the RSMS sometime during the "dwell" period. The data is plotted as it is measured, after various calibration factors have been added. A cursor, shown by a "+" near the lower right corner of the figure, is used with other controls to allow the operator to interact with the system while the measurements are in progress.

At any time during the measurements, the operator can place the cursor inside the graph, push "Trap 1," and tune to the frequency where the cursor was placed. Moving the cursor outside the graph and pushing "Trap 1" will cause the measurement to be resumed where it left off. A "menu" at the bottom of the graph allows additional control of the measurement process. RF attenuation can be inserted when strong signals are encountered by positioning the cursor over the desired attenuation (the numbers 0 to 70 on the right end of the menu) and pushing "Trap 1." Measurement parameters can be changed by positioning the cursor over "PARAM." The box labeled "DF LBL" causes the system to execute a direction-finding routine (described below) at a selected frequency, displaying a calculated direction of arrival above the graph in the space next to "DIR(P)."

If more accurate DF information or more detailed radar measurements are needed at a particular frequency, the operator can use the cursor to select the "DF GRF" mode. In this mode, the frequency scan graph is replaced by a polar plot (Figure 1-24), designed for easy interpretation of DF information.

Two direction-finding processes are used in the RSMS. One process uses a set of 4 cavity-backed spiral (CBS) antennas, aimed 90° apart from each other. These antennas are located in the white box partway up the antenna tower in Figure 1-21. A signal is measured on each of the four antennas; the relative levels allow a direction-of-arrival to be calculated. Since PIN-diode switches are used to select the measurement antenna, the switching and measurement process will typically take only a few milliseconds for each antenna. This is fast enough in most cases to allow the assumption that the measurements on all four antennas are taken simultaneously, which means that a single radar antenna rotation period is sufficient for a calculation of direction-of-arrival. Although this process is fast, its typical accuracy is only about 10°. The other DF process uses a narrow-beam, high-gain dish antenna on a rotor at the top of the antenna tower. This process is much slower than the CBS process, since only one measurement of relative amplitude can be taken every radar antenna rotation period, and many such relative measurements may be needed. However, it is much more accurate in direction, and it provides a relatively high-level radar signal for more detailed analysis.

The polar plot allows efficient interaction of both of these DF modes. If the operator uses the cursor to select the "DF" mode, the CBS antennas give rapid indication of approximate direction of arrival. Successive DF measurements are plotted as solid radial lines on the graph, with the length representing received signal amplitude and the angle equal to the computed heading of the signal source. If the operator selects the "DISH" mode with the cursor, the received signal amplitude is plotted vs. the dish pointing angle. The dish heading giving the maximum amplitude is the direction of arrival of the signal. A dotted line from the center of the graph continuously indicates the current pointing angle of the dish antenna. The actual graph shown here is made in the "ALTERN" mode, which alternates between the "DF" and the "DISH" mode. This mode gives advantages in tracking a moving radar. When the cursor is placed on "RETURN," the system returns to the original frequency scan mode (Figure 1-23), picking up the measurement at the frequency it last measured.

This program is a good example of the amount of help which a computer-controlled measurement system can provide in efficiently measuring the radio environment.

A number of projects are going on at ITS in support of the Transportable Automated Electromagnetic Measurements System (TAEMS), developed and built by ITS for the U.S. Army Communications Electronics Engineering Installation Agency (CEEIA). This compact, self-contained, computer-controlled measurement system has the capability to make measurements between 0.1 kHz and 40 GHz with state-of-the-art sensitivity from a directional antenna subsystem 50 ft in the air. Figure 1-25 shows the TAEMS Data Acquisition Vehicle in an operating configuration with the antenna tower partially erected. An auxiliary support vehicle (MCV) is in the background. Although much of the work has been completed and has been reported in detail in past years, the following projects are still underway.

<u>Mobile Automatic Receiver System</u>. This project is designing several new circuit boards to update the TAEMS down converters and fabricating one additional down-converter subsystem. This project is approximately 50% completed.

<u>EMC Van, Part II, and Part III</u>. Each TAEMS is comprised of two vehicles, a data acquisition van (DAV) and a maintenance and calibration van (MCV). TAEMS 1 DAV was delivered overweight and subsequently returned to the vendor to be refurbished to meet weight specifications. TAEMS 1 will be finished when DAV 1 is returned from the vehicle vendor. TAEMS 2 is now configured and is ready for operational testing.

During the past year, both TAEMS 3 and 4 were completed and are now ready for operational testing. TAEMS 3 will be field tested in November 1980.

<u>Application Software</u>. The major portion of this project involved writing applications software for the Transportable Automated EMC Measurement System (TAEMS). During the past year the software for the Satellite Scenario was completed. It is used while surveying an

Figure 1-25. TAEMS Data Acquisition Vehicle.

actual or a potential satellite receiver site for signals which may cause interference to the satellite receiver. There are three programs which measure the electromagnetic environment. One measurement program looks in the region of the satellite for signals. Another looks for signals originating on or near the earth's surface. The third measurement program uses some special techniques to measure potentially-interfering radars. Any signals detected by these programs are parameterized and recorded on magnetic tape. The frequencies of concern in these programs are the main satellite operations band of 7250 MHz to 7750 MHz and the corresponding receiver image band.

The measured electromagnetic environmental data is processed through a model of the satellite receiver. This model will calculate whether a particular signal causes interference in the receiver. The types of interference that are considered are co-channel, adjacent channel, intermodulation, and image frequency interference.

If a particular signal causes interference, a guard band is calculated for that signal. By choosing a satellite operating frequency outside of the guard band, the interference problem can be avoided.

A new project (TAEMS Application Software For Satellite Measurement and Analysis) is currently underway which is adding many new features to the satellite scenario. New measurement and analysis methods are being developed. In some environments a large amount of data is measured. Improved methods of data reduction and analysis are being formulated.

Voltage Tracking Filter. When using a spectrum analyzer to make measurements with a mobile system, rf signals can be encountered that are so strong and numerous that the signals of interest are hidden in the intermodulate distortion caused by the other signals within the area of concern.

A Voltage Tracking Filter (VTF) was developed to be placed between a receiving antenna and a spectrum analyzer to give a narrow band filtered input between 20 MHz and 500 MHz which would enable the system to make measurements in a congested rf environment. This particular hardware was developed to operate as part of TAEMS or as a part of a portable measurement system utilizing a conventional spectrum analyzer.

The spectrum analyzer (or TAEMS) generates a voltage proportional to its tuned frequency. The VTF contains a bank of 6 varactor-tuned filters, each covering slightly less than an octave in bandwidth. Logic in the VTF senses the tuning-voltage, determines which filter selection to use, and tunes the selected filter to track the spectrum analyzer frequency.

Verification Test Set. This project was started in 1978, and the objective was to develop one test set to be used in conjunction with the Army TAEMS project. As the project progressed, it was determined that two complete test sets were needed in the deployment of the four TAEMS systems.

The test sets are to be used to validate key performance parameters and to periodically calibrate the automatic receiver systems. The receiver system consists of an ARS-400 system and the down converters developed by ITS.

The pertinent key parameters to be verified for the ARS-400 system were established as follows:

1. reference oscillator frequency and amplitude,
2. tuning accuracy,
3. composite selectivity,
4. relative amplitude accuracy,
5. sensitivity,
6. input port isolation, and
7. intermodulation distortion.

The key performance parameters to be verified for the down converters are:

1. noise diode source level,
2. rf attenuator verification and wide-band amplifier gain compression test,
3. low noise amplifier gain compression test,
4. intermodulation distortion, and
5. down-converter gain verification using previously verified noise sources.

The tests are semi-automated; the test instrumentation is under computer control with active intervention by the operator.

The AN/MSR-T1 is a multiple receiver system that performs functions related to specific data required by the Air Force (TAC, SAC) in support of Operational Training, Testing and Evaluation (OTT&E) during electronic warfare (EW) tests and exercises at Air Force operational ranges. The Institute for Telecommunication Sciences was tasked by the Air Force Systems Command to develop, design, and test a first article preproduction model of the AN/MSR-T1 which would serve as a basis for production procurement of similar systems. The development/design goals were to provide a system that would evaluate aircrew operational skills, the operational status of airborne electronic countermeasures (ECM) equipment, and ground-based threat radars which are employed during complex EW mission activities.

In the dynamic world of EW, ECM techniques and tactics are attempting to keep pace with the rapid growth and diversification of the ground-based threat radar environment. Current tactics require successful penetration and withdrawal in these complex multi-threat environments with the aid of sophisticated ECM techniques. There is a need for evaluation of ECM skills and equipment capabilities in operational and training scenarios. The system's design must meet these current needs as an ECM evaluation tool, and have the capability and flexibility to be used in development tests and evaluation of new, more complex ECM systems. The ability to measure and assess the performance of airborne ECM equipment and how it is employed by aircrews in a far-field environment on a day-to-day basis is a primary requirement of the Air Force to insure the operational readiness of its defensive/strike forces.

The program was started in FY 76. Development, design, and fabrication were completed in FY 78, and Qualification Operational Test and Evaluation (QOT&E) was conducted and completed in the first half of FY 79. The QOT&E plan was prepared and conducted by the users, SAC and TAC, to determine the operational effectiveness and suitability of the preproduction AN/MSR-Tl. The knowledge, experience and lessons learned during the QOT&E will be used to reduce procurement and technical risks for the production systems scheduled in FY 80-81.

The AN/MSR-Tl contains five receiver/analysis channels, each capable of independent operation at any frequency in the range 0.5-18 GHz, with one channel extended to cover the frequency range 0.1-0.5 GHz. One receiver channel has a 500 MHz IF bandwidth and is used with an acousto-optic processor that provides 100 percent probability of intercept of any signal in its frequency range. This receiver channel is rapidly tuned (250 s) to any 500 MHz band in the range 0.5-18 GHz and establishes signal frequencies of interest for further analysis by the other four receiver channels.

The system is fully automated. A central computer interfaced to two satellite minicomputers and microprocessors provides command/control for all receiver channel functions, antenna selection, and directional antenna position via slave commands from an external identification, Friend or Foe (IFF) airborne target tracking system, and blanking of local threat emitters via pretrigger pulses. Extensive software programs were developed to combine command/control functions with special signal analysis routines. The programs are EW mission scenario dependent and provide user-oriented data necessary to assess the operational performance of a wide variety of ECM equipment and the aircrew's expertise in operating the equipment during tactical inflight deployment.

The QOT&E of the AN/MSR-Tl determined that, while the design concept was operationally effective and suitable to meet the user requirements, the five independent receiver channels could be reduced to three. One wide IF bandwidth (≥500 MHz) receiver channel and two narrow IF bandwidth (≤20 MHz) receiver channels, can perform all operational functions in a timely and efficient manner. This change plus other user requests for (1) a frequency extension of one narrow IF bandwidth receiver channel to 30 MHz and (2) an optional autonomous IFF airborne target tracking capability will be included in the follow-on AN/MSR-Tl production units.

The Institute was tasked to prepare the technical specifications for the AN/MSR-Tl production systems, assist in source selection of an appropriate contractor, and provide follow-on consultation and test and evaluation of all production units throughout the Air Force procurement cycle. The request for proposal was issued in July 1980 by AFSC/AD Eglin AFB, FL, and contract award was made in September 1980.

To meet an immediate operational requirement for a system with AN/MSR-Tl capabilities, the Air Force (TAC) Signal Analysis System was developed by ITS. Because of funding constraints, the TAC/SAS is of limited sophistication compared to the AN/MSR-Tl production units.

The TAC/SAS is not fully automated; certain functions must be performed manually. The frequency range is 500 kHz-18 GHz and includes antennas, 2-receiver channels, (one with 500 MHz IF bandwidth and an acousto-optic processor), a computer, a signal processor, data display/storage units, and support equipment. To provide an airborne target-tracking capability, the directional antenna system includes an electro-optical (narrow field-of-view) TV tracker subsystem for automatic tracking of a target aircraft at a range of 20-25 nautical miles. Tests have shown that the performance of this system is limited when TAC aircraft employ low level high-speed maneuvers. Initial acquisition and reacquisition are almost impossible even with the aid of a co-located, wide field-of-view TV system, which was added to the TAC/SAS.

The TAC/SAS was completed, tested, and delivered in June 1980 and is now being displayed on the Nellis AFB EW range.

The Institute has developed small, low-cost systems that produce digital records of valuable measurements so that they can be analyzed extensively. The field performance of these systems is a great improvement over present manual methods. 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 which will be used to make ordinance and personnel hazards measurements. The field intensity receivers used by the system are automatically calibrated. The operator then specifies frequency scan width, receiver bandwidth, detector, etc., to the system controller. The controller sets the specified parameters, collects the measured data, stores it on mag- netic tape, and computes statistics of the collected data. The system has been designed to operate unattended for long time periods (24 hours, one week, etc.), depending upon how often data are to be collected. The major contribution from this project is the development of application software which could be used by other agencies having similar ordinance hazards measurement requirements.

The previous pages have discussed some large automated spectrum measurement systems. The DM-4 described next was originally designed to operate as part of TAEMS. More recent work with the DM-4, however, has developed software to use the DM-4 as a separate calculator-controlled measurement system.

The DM-4 (Figure 1-26 and Figure 1-27) is an instrument designed and built by ITS specifically for the Army at Ft. Huachuca to make amplitude probability distribution (APD) and average crossing rate (ACR) measurements on impulsive noise and other phenomena which are best described in statistical terms. A year ago, ITS finished construction of a copy of the DM-4 for the Army, providing a TAEMS Noise Measurement Facility. This year ITS has continued its work on the DM-4 by designing and implementing software on a desktop calculator to operate with the DM-4. The DM-4 is designed to be connected to a logarithmic video output from TAEMS or from a spectrum analyzer or a field intensity meter in the range of 0 to 1 volt or 0 to -1 volt. Although the DM-4 measures the statistics of the signal at 31 evenly-spaced voltage levels within this range, these levels correspond to 31 levels spaced evenly in decibels at the receiver input. Since the end points associated with the 31 levels can be adjusted anywhere in the 0 to 1 volt range, various trade-offs can be made between resolution and dynamic range. Video bandwidths up to 10 MHz are accurately measured using a maximum sampling rate of 20 million samples per second. Up to 10^{12} samples can be stored at each of the 31 levels, making possible long sampling periods, even at the maximum sampling rate. An internal precision ramp generator makes it almost trivially easy to calibrate each of the 31 quantizing levels.

Although the DM-4 offers many advantages in bandwidth, calibration ease, and input range flexibility when compared to earlier instruments which measure APD's and ACR's, its major advantage comes from microprocessor control. The use of two microprocessor cards allows convenient programming of the DM-4 from its front panel keyboard or from its IEEE-488 bus port. This makes it easy to completely control the DM-4 measurement functions and data readout from a number of desktop calculators or minicomputer systems, or to use the DM-4 as a manual, stand-alone measurement system. More details on DM-4 operation can be found in the DM-4 instruction manual, to be published soon as an NTIA Technical Memorandum by R.J. Matheson.

The Institute has written a number of calibration, measurement, and analysis programs for the Army which incorporate the DM-4 and a spectrum analyzer (or a field intensity meter) into a measurement system controllled by an H-P 9825 desktop calculator. This DM-4/9825 software is described in a NTIA Technical Memorandum by G.D. Falcon, which will be published in the near future. This software includes complete calibration of the system with a signal generator and a noise diode, measurement and graphing of APD's and ACR's at a number of frequencies, recording of the data on magnetic tape cartridges, and combining of recorded data files at a later time. The programs are arranged so that the data can be graphed on a 4-color x-y plotter at the same time that the next set of data is being measured. Some additional work in the following year will adapt these programs to the HP85 calculator.

The H-P 9825 software was tested in a set of field measurements made for the Motor Vehicle Manufacturers Association (MVMA) in the spring of 1980 as part of the work on Objective Measurement of Land Mobile Voice Performance. The DM-4 measurements will soon be published as an NTIA Report by R.J. Matheson. The electromagnetic noise from the ignition systems of two configurations of cars was measured. One configuration included a set of 12 cars from the various U.S. car manufacturers' 1980 line. The other configuration was a so-called "super-noise vehicle" whose ignition suppression had been removed. Measurements were made at 5 frequencies between 30 MHz and 450 MHz, with vertically- and horizontally-polarized antennas located about 3 m from the center of the nearest car. At each frequency, APD's and ACR's were measured, except at higher frequencies, an equipment malfunction prevented the ACR measurement from being made. Figure 1-28 shows a plot of APD measurements made at 30 MHz with the DM-4. This figure is a reproduction of the figure drawn on the x-y plotter immediately after that measurement was completed. The APD has been numerically integrated to give various weighted averages such as the rms average, the average voltage, and the average logarithm. These numbers are plotted on the lower edge of the graph as rms, Vd, and Ld (rms is in dBm, Vd is the dB ratio between the rms and the average voltage, Ld is the dB ratio between the rms and the average logarithm).

Figure 1-29 shows a plot of average crossing rate (ACR) data for the same measurement conditions as Figure 1-28. This figure is plotted on a scale whose ordinate is labeled "N," denoting 10^N crossing/sec. One can see that the maximum crossing rate on the plot is about 8000 c/s, which occurs near the 50% level of the APD in Figure 1-28. Altogether, the DM-4 represents a major improvement in APD and ACR measurement capabilities--partly because of its greater measurement capability, and partly because of the ability to produce high quality plots of APD's and ACR's on an almost-real-time basis, which gives the operator an opportunity to interact with the measurements.

Over the past two years, measurements have been made at the ITS on home television receiving antennas and antenna components. Many of these measurements were reported last year. The purpose of the measurements was to develop a technical basis for estimating the performance of antenna systems being used. Our most recent work has been a Statistical Analysis of Television Broadcast Data from Chicago and Peoria, Illinois, Area. These data were obtained at 51 locations by measuring the received signal levels from selected television broadcasts (two VHF and three UHF stations from Chicago and two UHF stations from Peoria) using secondary standard antennas and the home antenna systems. These two types of data allowed calculations of electric field strengths and the home antenna system gain at each test frequency.

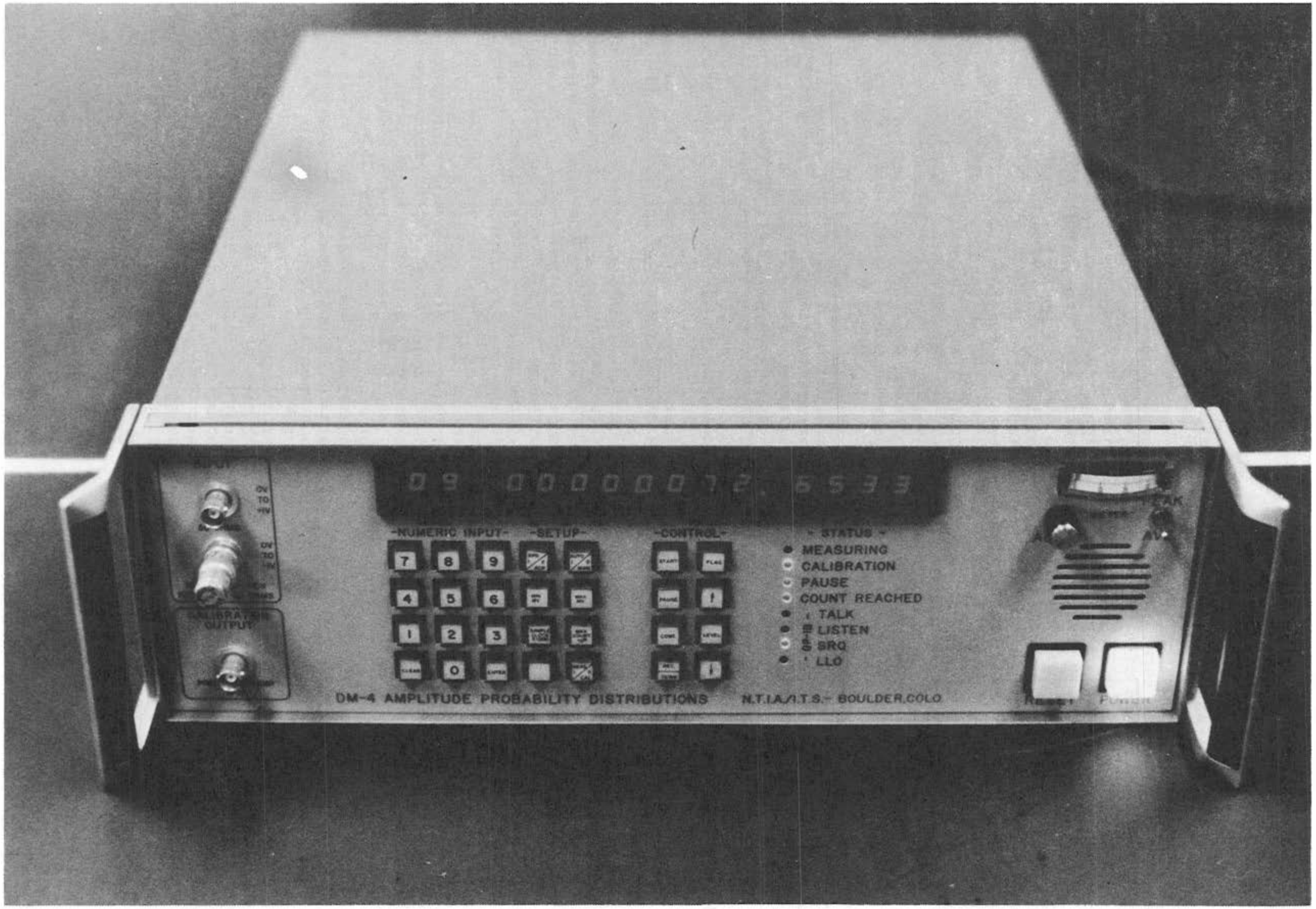


Figure 1-26. Front panel of the DM-4.

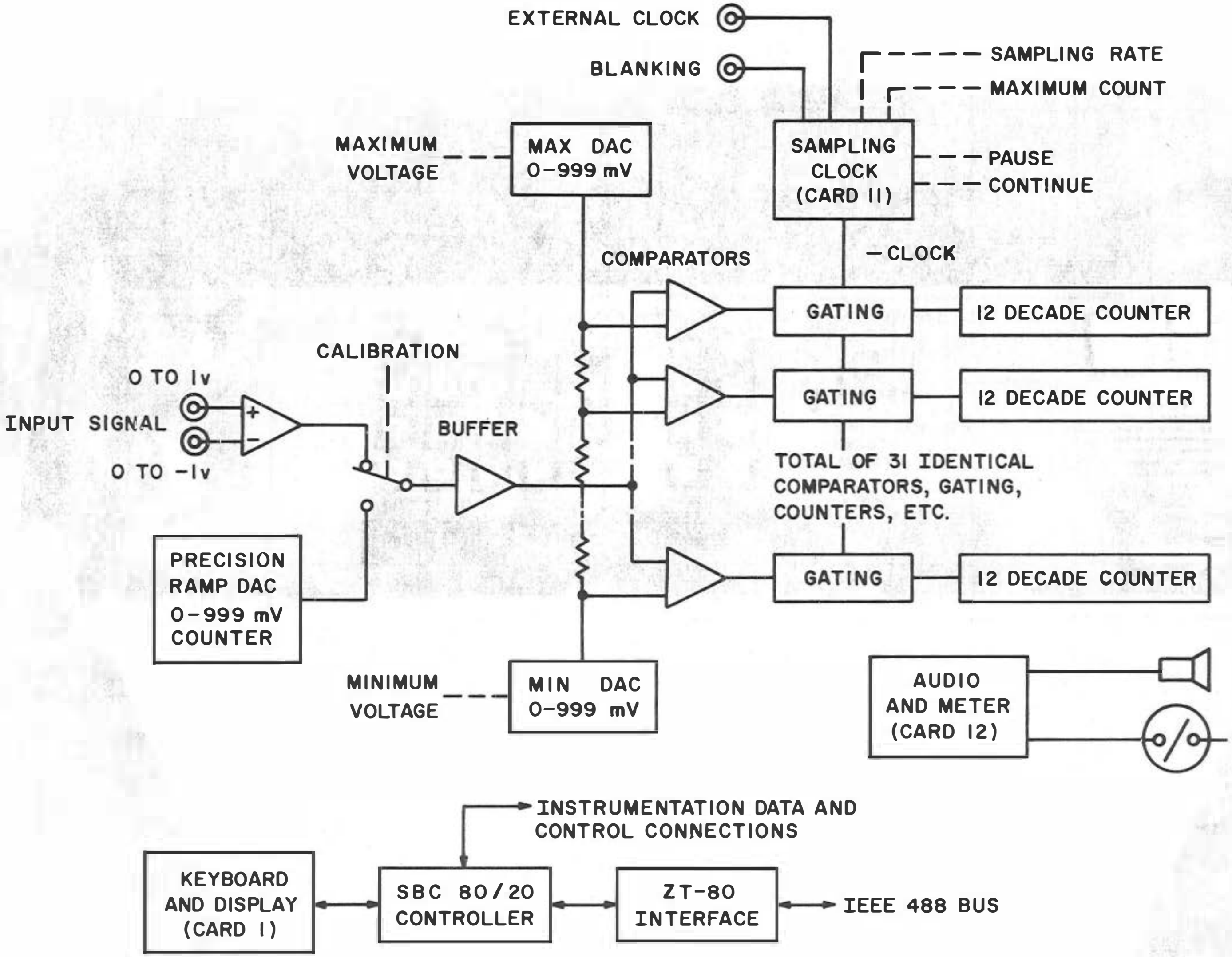


Figure 1-27. Block diagram of DM-4.

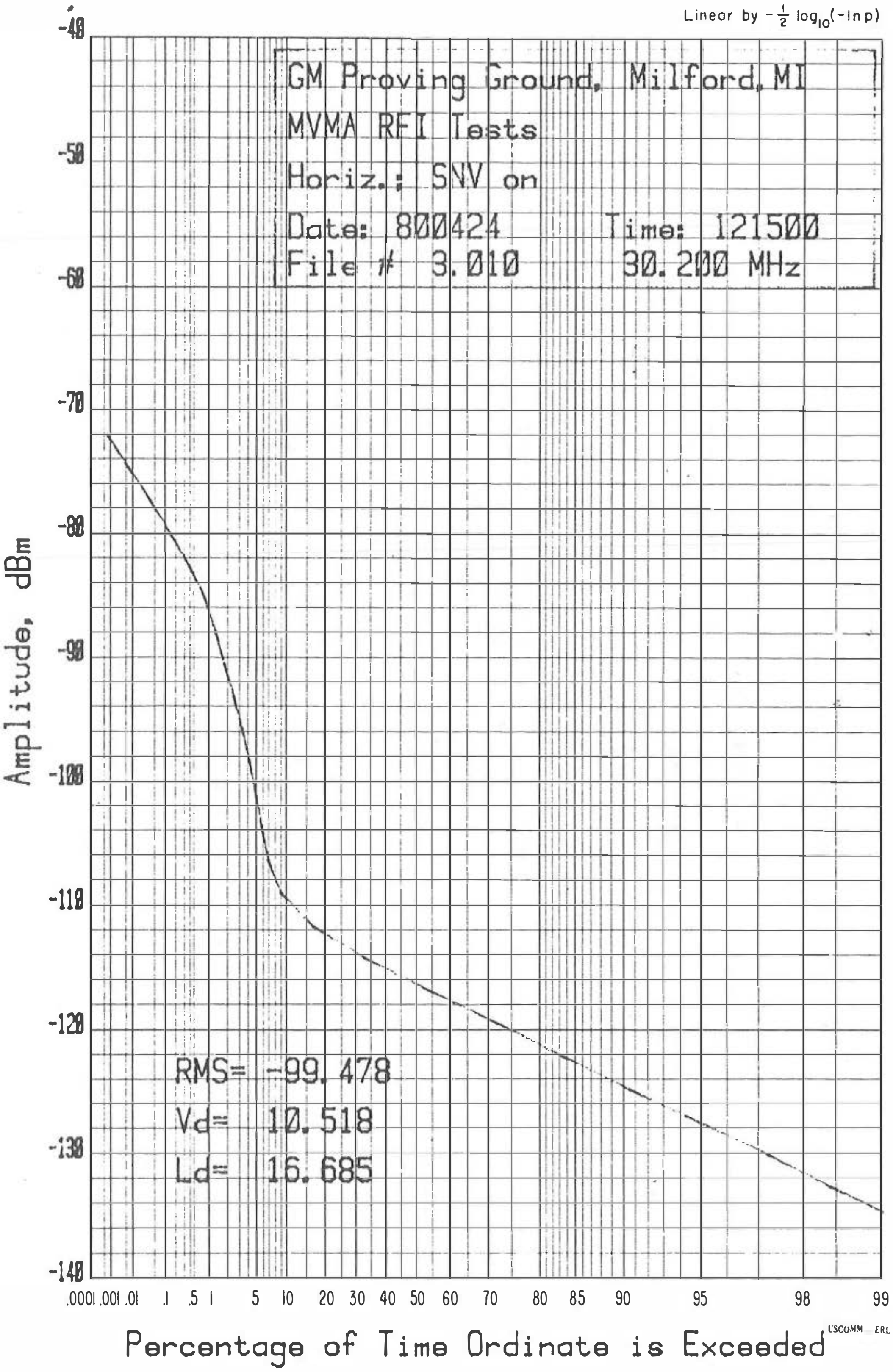


Figure 1-28. APD of automotive noise.

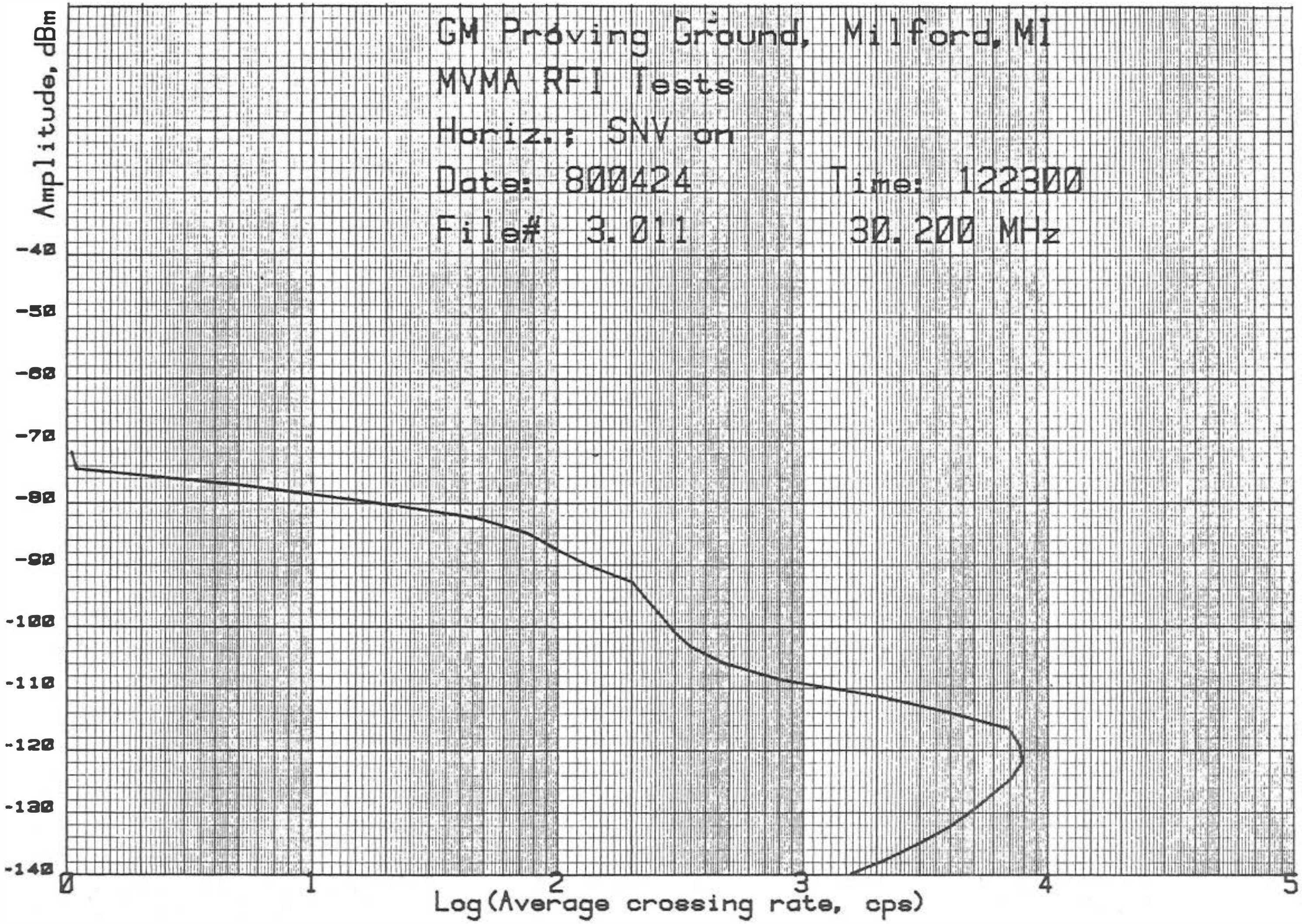


Figure 1-29. ACR of automotive noise.

The measurements at a given frequency and location produced a set of 500 values. Cumulative distributions, scaled for home antenna system gain, have been produced for each set of data. Median and decile values of gain have been tabulated from the cumulative distributions. A typical plot of received signal level vs. distance is shown in Figure 1-30 for measurements at location 10 for channel 26, 543.25 MHz. The cumulative distribution of these data is shown in Figure 1-31.

Table 1-3 is a summary of tabulated results. Frequency ranges and location classifications are shown which define the criteria for subgroups of median gains (these are median values for the tabulated median gain for the defined subgroup). The second and third columns show lower and upper decile ranges in the tabulated median gain data. The estimated error in the measurements is shown by the fourth column.

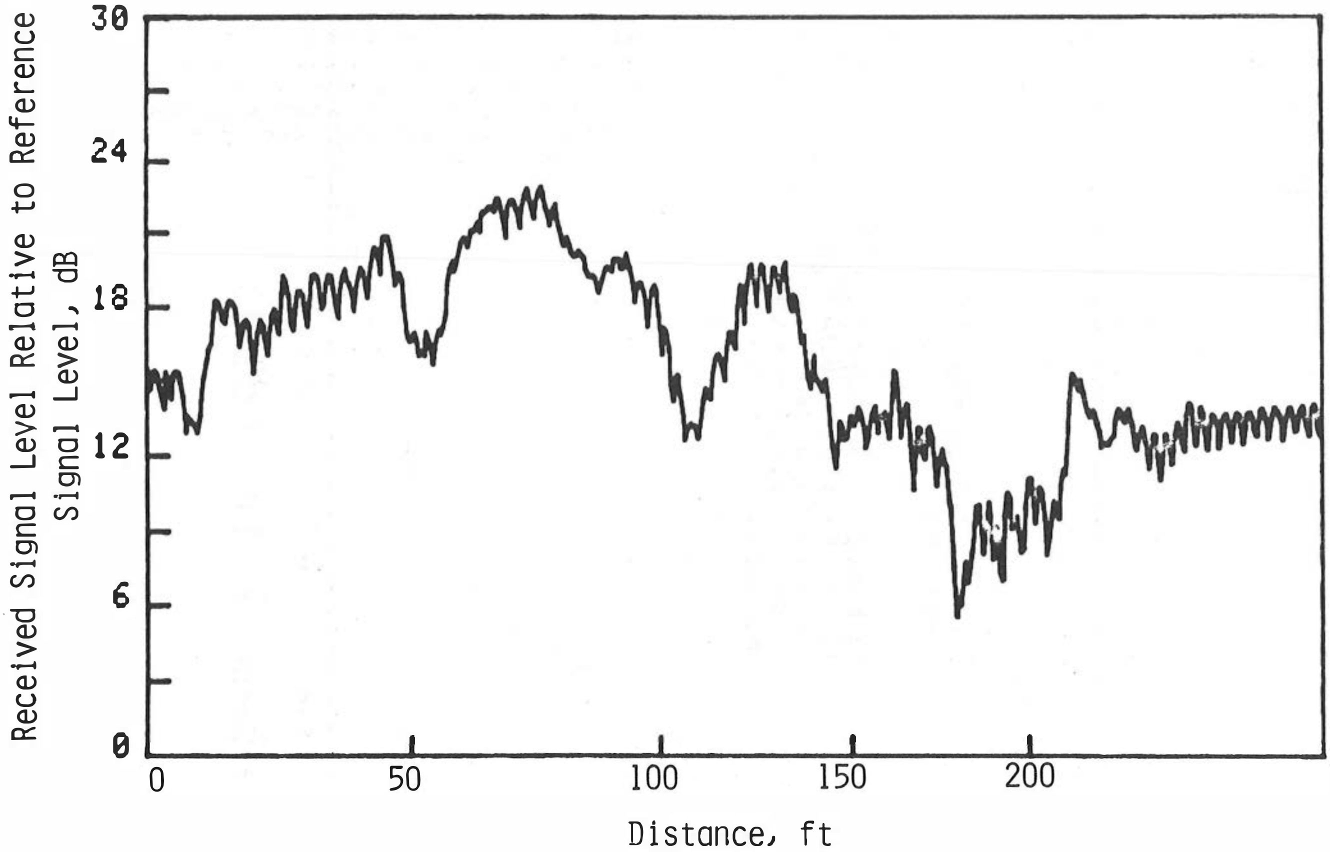
Commonly assumed values (O'Connor, Robert A., Understanding Television Grade A and Grade B Service Contours, IEEE Trans. on Broadcasting, Vol. BC-14, No. 4, Dec. 1968) for home antenna system gain vs. distance from the broadcast source (shown as urban and suburban or fringe areas) are shown in the fifth column of Table 1-3. The sixth column shows the fraction of our data for which median gain equaled or exceeded the assumed gain.

The data in Table 1-3 define a model of home antenna system gain for in-service antenna systems. The model will provide conservative estimates (upper decile values), typical estimates (median values), and liberal estimates (lower decile values) of system gain. These estimates are without regard to the type of transmission line or other devices (such as baluns, signal splitters, and/or multicouplers) that may be used in the system.

Our data have been examined to determine antenna system performance as a function of type of transmission line and type of antenna. The data were grouped according to antennas for the VHF-only reception, 75-ohm or 300-ohm transmission line; antennas for UHF-only reception, 75-ohm or 300-ohm transmission line; and combination VHF and UHF reception, 75-ohm or 300-ohm transmission line. Our data show that for a given type of antenna classification, the systems using 75-ohm transmission line had better performance than systems using 300-ohm transmission line. This was a surprising observation since "good" 300-ohm transmission line has less attenuation than "good" 75-ohm transmission line (FitzGerrell, R.G., R.D. Jennings, and J.R. Juroshek, Television Receiving Antenna System Component Measurements, NTIA Report 79-22, June 1979). We believe this observation can be explained by recognizing two conditions of the antenna systems we measured.

1. The systems using 300-ohm transmission line often were very old--older on the average than systems using 75-ohm transmission line.
2. The quality of 300-ohm transmission line used for antenna system installations often will degrade in performance quite rapidly due to weather and aging.

With regard to performance vs. type of antenna, we observed significantly poorer performance, on the average, for systems using combination VHF/UHF antennas compared with systems using antennas for VHF-only and UHF-only reception.



REFERENCE LEVEL IN DBM -50.
FREQUENCY IN MHZ 543.25
AVERAGE IN DB 17.2 VARIABILITY IN DB 2.6

HOME SIGNAL LEVEL 11.1 dB

Figure 1-30. Plot showing received signal level vs. distance for the electric field produced by station WCIU-TV, Channel 26, at Location 10.

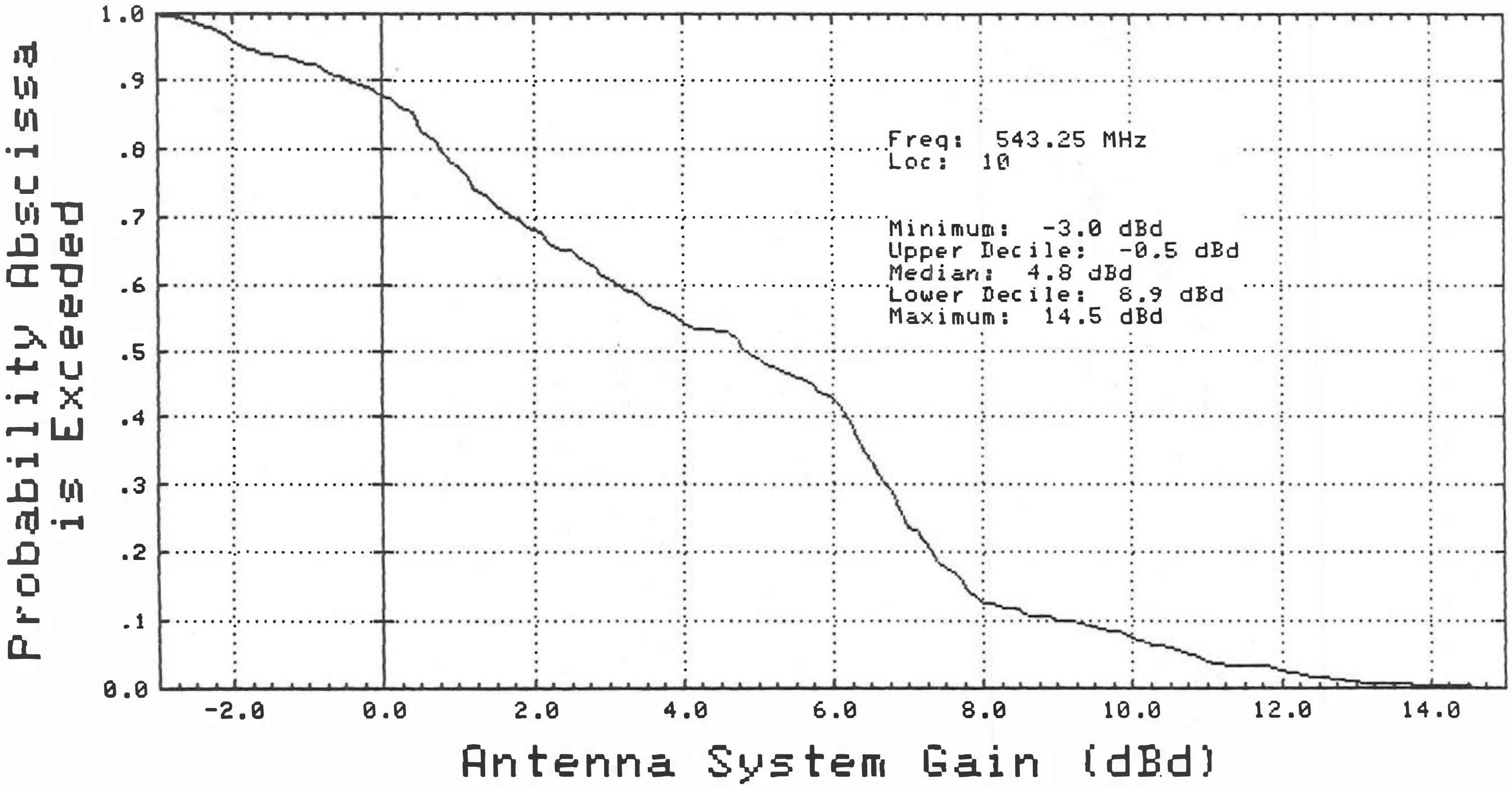


Figure 1-31. Cumulative distribution of home antenna system gain for location 10 at 543.25 MHz.

Table 1-3. Summarization of Measured Home Antenna System Performance

Frequency	Data Location Classification	Median Median Gain*, dB	Decile Values of Median Gain*, dB		Median Estimated Error, dB	Assumed Gain*, dB	Fraction of Median Values ≥ Assumed Value
			Lower	Upper			
VHF	Urban locations	-1.4	-23.6	3.8	1.9	0	0.37
	Suburban and fringe area locations	0.7	-18.3	8.3	2.5	6	0.16
	All VHF data	0.5	-19.9	5.9	2.0		
UHF	Urban locations (Chicago and Peoria)	-9.5	-34.4	1.3	2.8	8	0.01
	Suburban and fringe area locations (Chicago and Peoria)	0.9	- 6.1	10.7	2.1	13	0.05
	All UHF data	-3.6	-24.2	7.7	2.7		
	Peoria data (urban and suburban locations)	0.6	- 8.8	10.4	1.8	13	0.08

*Reported gains are relative to the gain for a tuned, half-wavelength dipole.

CHAPTER 2. SYSTEMS ENGINEERING AND EVALUATION

The objective of this program subelement is to provide telecommunication system oriented studies that include system requirement, definition, cost trade-off, 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.

Section 2.1 addresses those projects which consist of communication systems and services engineering, Section 2.2. presents those projects oriented toward terrestrial radio system performance and monitoring studies, Section 2.3 deals with standards activities, and Section 2.4 presents related work on guided wave 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 procuring, leasing, or establishing these services. The projects described are: Data Communications, Non-Speech Telecommunication Services, Sizing the Data Communication Requirements for the Region 1 National Forest System, Montana Telecommunications Architecture Study, The Shasta-Trinity National Forest Telecommunications Study, and Common Carrier Technical/Policy Planning.

Data Communications. On August 29, 1979, the General Services Administration (GSA) officially promulgated an important new Federal Telecommunication Standard: Interim Federal Standard 1033, "Digital Communication Performance Parameters." The purpose of the new standard is stated in its opening paragraph:

> "to improve Federal government procurement of digital telecommunication systems and services by providing user-oriented, system-independent means of specifying communication performance."

The essence of the FED STD 1033 approach is summed up in the phrase "user-oriented, system-independent." The FED STD 1033 parameters focus on user performance concerns rather than engineering design considerations; they describe end-to-end services rather than particular system facilities; and they apply to all systems, irrespective of transmission medium, network topology, or control protocol. These standard parameters will improve Federal data communication procurement by providing a common framework for functional specification and top-down design, and will promote competition and innovation in the data communications industry by enabling direct comparison of alternative service offerings.

GSA's promulgation of Federal Standard 1033 realized the first of three major goals of NTIA's Data Communications project. A second standard, Federal Standard 1043, was completed in draft form in FY 80. That standard defines uniform measurement methods to be used in conjunction with the FED STD 1033 parameters in assessing delivered performance. FED STD 1043 will be submitted to the Federal Telecommunications Standards Committee (FTSC) for formal coordination and GSA promulgation in FY 81. Both FED STD 1033 and FED STD 1043 are also being coordinated with the American National Standards Institute (ANSI) for eventual adoption as industry performance standards.

The third major goal of the Data Communications project is to define service performance classes and conduct protocol performance assessments needed to complete the Open Systems Interconnection (OSI) standards family. These standards are the focus of an ambitious international effort to facilitate direct interconnection of dissimilar, geographically distributed data processing systems via a uniform 7-layer protocol hierarchy. NTIA will propose standard OSI performance classes based on the FED STD 1033 parameters, and will use those parameters as a framework for evaluating the performance of alternative transport layer protocols. Selected OSI protocol standards will ultimately be adopted by FTSC in the "1000-series" Federal Standards.

FY 80 activities in the Data Communication project were focused on two specific objectives:

1. Supporting ANSI Task Group X3S35 in their review and adaptation of FED STD 1033.
2. Developing standard measurement procedures and data reduction software needed to complete FED STD 1043.

The ANSI X3S35 effort progressed well during FY 80. The Task Group has developed an ANSI version of FED STD 1033, designated X3S35/125, which retains the basic technical content of its progenitor while providing selective improvements in parameter definition and presentation. ITS contributed to that effort by developing inputs to the draft ANSI standard and by preparing an explanatory "Federal Standard 1033 User Guide." The latter report will be available early in FY 81. It is anticipated that the ANSI Task Group will submit a proposed American national standard based on FED STD 1033 to its parent committee, X3S3, during the same fiscal year.

A number of initial applications of FED STD 1033 were completed during FY 80. In one of these, described elsewhere in this report, the standard was used in defining end-to-end performance requirements for the future digital Defense Communications System (Nesenbergs, M., W.J. Hartman, and R.F. Linfield, "Performance parameters for digital and analog service modes," in press). In another, also described elsewhere in this report, the standard was used in defining requirements for an Army prototype (Linfield, R.F., M. Nesenbergs, and P.M. McManamon, "Command post/signal center bus distribution system concept design," NTIA Report 80-36). In a third application, the standard was used by the Environmental Protection Agency in a Request for Quotation covering the communications portion of a nation-wide time-sharing network. Responses complying with the standard were received from all qualified bidders. A complete list of the FED STD 1033 parameters is provided in Figure 2-1. A brief, relatively informal summary of the standard is provided in Seitz and Bodson (Seitz, N.B. and D. Bodson, "Data communication performance assessment," Telecommunications, Feb. 1980).

The major Data Communications project effort in FY 80 was devoted to completing the measurement standard (1043). Figure 2-2 illustrates NTIA's approach to that standard. The overall measurement process is portrayed as a discrete function which transforms a defined set of digital inputs (user/system interface signals and measurement precision objectives) into a desired set of numerical outputs (performance parameter values and associated confidence limits). The purpose of the measurement standard, quite simply, is to define a performance measurement system capable of performing that function given any reasonable set of inputs.

A major ITS objective in developing FED STD 1043 has been to specify not only what must be done to measure end-to-end performance, but also how those necessary operations can be accomplished. To that end, key elements of the FED STD 1043 performance measurement system have been implemented in a standard, machine-independent, FORTRAN computer program. Availability of that program will relieve measurement personnel of the difficult, time-consuming task of developing data structures and data reduction software, and will ensure the comparability of measured results obtained by different user organizations.

Four major elements of the FED STD 1043 measurement system are depicted in Figure 2-2. They are:

1. Data Extraction. This system element observes signals transferred across the user/system interfaces in real time, determines the performance significance of each interface signal, and outputs this performance information in the form of a chronological sequence of system-independent reference events. The reference event histories for each user interface provide the necessary basis for performance parameter calculations.
2. Data Recording. This system element consists of a set of standard FORTRAN files and associated Read/Write instructions. Its purpose is to record the real-time event histories produced by the data extraction function in a standard form for later (off-line) reduction and analysis. Separate files are maintained for user and overhead information, and for each direction of user information flow.
3. Performance Assessment. This system element consists of a standard FORTRAN program which merges, correlates, and analyzes the files stored by the data recording element to produce a set of measured FED STD 1033 parameter values. Primary elements of the performance assessment program are the access, transfer, and disengagement subroutines, which calculate values for the 19 "primary" parameters listed on Figure 2-1. These primary subroutines are supported by programs which calculate "secondary" and "ancillary" parameter values and perform various utility functions. The entire performance assessment program is written in ANSI (1966) standard FORTRAN to ensure its transportability.
4. Statistical Design and Analysis. This system element transforms user-defined measurement precision objectives into appropriate statistical test design and data analysis criteria. These statistical criteria are used to control the data extraction and performance assessment elements of the FED STD 1033 performance measurement system and to produce confidence limits or "error bars" for each measured parameter value.

These four measurement system elements differ substantially in the degree to which their implementation can be standardized, and their specification in the measurement standard reflects these differences. The extraction and statistical elements (1 and 4) are inherently application dependent, and they are therefore specified in the standard by means of relatively general design implementation procedures. In essence, these procedures guide standards users in designing data extraction and statistical design/analysis elements appropriate to their particular needs.

The user-oriented approach has made the data recording and performance assessment elements (2 and 3) application independent, and as noted earlier, the measurement standard exploits this property by completely standardizing their implementation in a machine-independent FORTRAN program. A prototype version of that program should be available for use outside ITS about the middle of FY 81.

A key element of the performance assessment function is an ITS-developed "standard data correlator" algorithm which matches transmitted and received bits and identifies undelivered and extra bits via pattern recognition. This algorithm was successfully tested during FY 80 under a variety of data error, loss, and duplication conditions. Further tests to select optimum data correlator parameters are planned for FY 81.

It is anticipated that NTIA's FY 81 data communications activities will include a comprehensive protocol assessment project. In that project,

SERVICE PERFORMANCE SPECIFICATION

Part A - Primary Parameters

1.	Access Time	________	Seconds
2.	Incorrect Access Probability	________	*
3.	Access Denial Probability	________	*
4.	Bit Transfer Time	________	Seconds
5.	Bit Error Probability	________	*
6.	Bit Misdelivery Probability	________	*
7.	Bit Loss Probability	________	*
8.	Extra Bit Probability	________	*
9.	Block Transfer Time	________	Seconds
10.	Block Error Probability	________	*
11.	Block Misdelivery Probability	________	*
12.	Block Loss Probability	________	*
13.	Extra Block Probability	________	*
14.	Bit Transfer Rate	________	Bits/Second
15.	Block Transfer Rate	________	Blocks/Second
16.	Bit Rate Efficiency	________	%
17.	Block Rate Efficiency	________	%
18.	Disengagement Time	________	Seconds
19.	Disengagement Denial Probability	________	*

Part B - Secondary Parameters

20.	Service Time Between Outages	________	Hours
21.	Outage Duration	________	Hours
22.	Outage Probability	________	*

Part C - Ancillary Parameters

23.	User Access Time Fraction	________	*
24.	User Block Transfer Time Fraction	________	*
25.	User Message Transfer Time Fraction	________	*
26.	User Disengagement Time Fraction	________	*

*Note: The probabilities and user performance time fractions are dimensionless numbers between zero and one.

Figure 2-1. Example Service Performance Specification form.

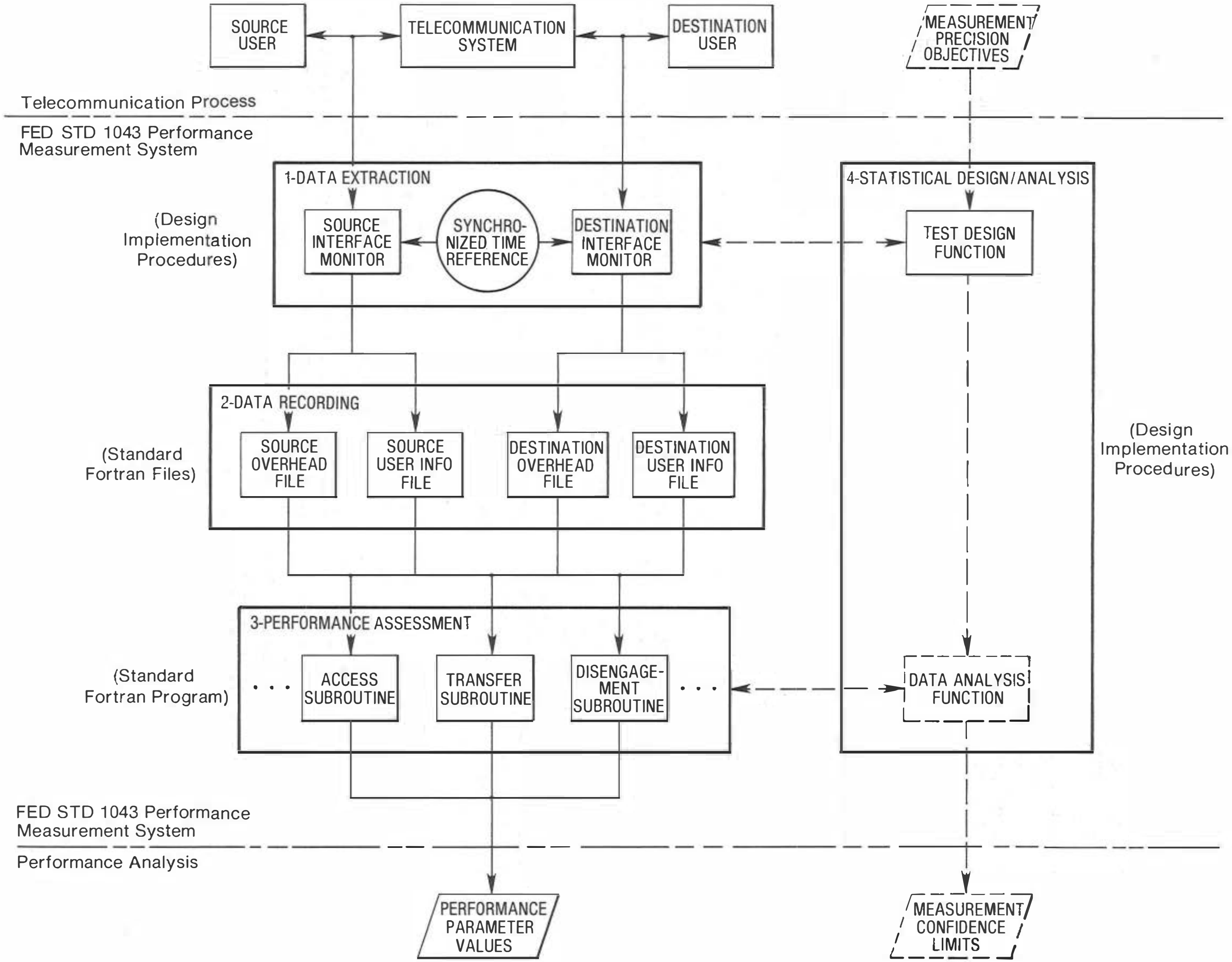


Figure 2-2. FED STD 1043 approach.

a number of candidate OSI transport layer protocols will be implemented via computer simulation, and their relative performance will be assessed using the FED STD 1033 parameters. These tests will specifically examine the robustness of candidate protocols under degraded transmission conditions and host "crashes." The tests will provide a much-needed factual basis for selecting transport protocol standards.

The user-oriented performance standards being developed under NTIA's Data Communications project will afford a substantial cost savings to the Federal Government in the specification, procurement, and operation of Federal data communication systems. Requirements specification will be simplified by the standardization of performance descriptors and by the existence of data base of similar previous applications. Procurement will be improved by the standard's "common denominator" property and by the development of facility and service performance data bases. Operations will be enhanced by more effective network control. An independent National Research Council study panel has estimated that the total Federal data communications bill could be reduced at least 20% through the use of a more efficient method of matching offered services with end-user needs--a yearly saving in excess of $400 million by the mid-1980's. NTIA's user-oriented data communication performance standards provide the essence of such a method.

A major determinant of the success of any standard is the breadth of participation in its development. In order to ensure the broadest possible consensus for Federal Standard 1033 and its companion standards, interested readers are encouraged to obtain and review these standards, suggest improvements, and if possible, contribute directly to the ANSI X3S35 effort. Copies of the standard and its supporting reports can be obtained from the authors (Seitz, N.B., P.M. McManamon, and E.L. Crow).

Non-Speech Telecommunication Services. NTIA/ITS has been involved in the identification and evaluation of a number of new telecommunication services known generically as Videotex information services. A home or office user can interrogate a computer data center, receive, and display information in alphanumeric or graphic form on a home or office terminal. The display unit may be a slightly modified commercial black and white or color TV receiver or any of a variety of desk-top business or computer display units. Access to information filed in data banks may be via telephone lines, coaxial cable, private wired networks, or via one or more commercial or public broadcast TV channels. In the broadcast mode, data in the form of "pages of alpha-numerics or graphics" is carried on a portion of the vertical retrace or blanking intervals of the video subcarrier. The receiver has a conversion unit called a decoder, which strips the information from the video signal for storage and display on the TV screen. The service can display any of hundreds or thousands of "pages" (or frames) which have been entered into the computer data banks. Available services may include any or all forms of public information: news, weather, stock market, sports, topical items, or information for private interest groups.

Several U.S. organizations have offered proposals during FY 79-80 for such services or have field trials in process to provide Videotex services both in the broadcast or interactive modes of operation.

1) AT&T and Knight-Ridder are developing a limited field trial operation in Florida.

2) GTE-Viewdata have an offering to business customers for private network filings and display of information for the specific use of such customers. Entry into such data banks is, of course, open only to authorized subscribers.

3) WETA (A PBS station in Washington, DC) has announced consumer trials of a Canadian (Telidon) version of broadcast Videotex starting in late 1980. The WETA trials are sponsored by NTIA, NSF, the Corporation for Public Broadcasting, and HEW.

4) KMOX-TV (St. Louis) has been experimenting with a number of differing approaches for broadcast TV Videotex. Trials have been with a limited number of customers in the viewing area and in closed-circuit experiments. CBS has now petitioned with the FCC for a ruling on Teletext standards based on these trials.

NTIA/ITS participated at the Interdisciplinary Colloquium on Teleinformatics, Montreal, Canada, June 9-12, 1980. The colloquium was held to discuss international standards for information services and to review the progress on a number of related non-speech telecommunications services in rapid development throughout the world. Included among the topics were national Teletext, Videotex, Telefax, and Datafax, and combinations of a number of such systems and technologies which would bring closer to reality the highly automated office, or the "office of the future."

A number of papers stressed the early needs for international standards and for internationally agreed upon services--terminal-to-terminal services, network services, terminal-network terminal services, and international services to users. Inherent in all of these are the needs for standards on protocols, character displays and codes, international trade agreements and tariffs, and, of course, system interoperability.

It was pointed out by an official U.S. representative to the CCITT symposium that it was both easy and difficult to develop a U.S. position. Viewpoints must be considered from industry, Government, and the public. U.S. carriers, user groups, and relevant U.S. Federal agencies find difficulty in arriving at concensus even among themselves. They may also take strong opposing positions from that of the relevant International CCITT Study Groups.

The meeting provided an update on the current and rapidly changing technologies in the field and the need by relevant agencies to participate in the Study Groups working towards standards for equipment, interoperability, protocols, and coding formats. NTIA has begun to work closely with domestic and international standards organizations, particularly the CCITT, in the interest of the U.S. public and private users.

A report entitled "Videotex Systems and Services," was prepared in draft form during FY79 to provide overall comparison among the many new Videotex systems under consideration or in operation in the U.S. and abroad. Emphasized in the report was the need for technical standards for systems, format for coding, and choice of transmission media. Discussed also were the problems that might be encountered in the local loops of the telephone networks and computer interconnects. The draft report is now in the process of being updated in preparation for submission as a publication by NTIA by the close of FY 80.

With U.S. manufacturers and potential suppliers of Videotex systems and services entering into competitive roles, pressures will develop over the next few years for comments and recommendations to the FCC concerning specific or more general standards for these new or emerging information services.

Sizing The Data Communication Requirements for the Region 1 National Forest System. The purpose of this study was to report on the assessment of computer and telecommunication needs by the Northern Region (Region 1) of the National Forest System. It was intended that this assessment would be blended with a similar activity at the national level of the Forest Service and would provide Region 1 management with sufficient information to size both hardware and telecommunication services to meet project demands through 1985. Region 1 will implement a Unit Facility Plan using these findings which will then definitize these new requirements, provide an equipment implementation plan, define a master implementation schedule, and develop a management organizational structure to support such needs.

This support program was prompted by the observed current heavy computational and communication system work load of Region 1 coupled with the potential system impact associated with the implementation of a Forest Service-wide land and resource management plan to be drafted for Forest Service executive management by 1983. The two most significant Federal legislative acts which prompted these planning activities are the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 and the National Forest Management Act (NFMA) which required that the land management planning process be explicitly defined thus placing an additional burden on the National Forest system computational capabilities.

The RPA required the Forest Service to assess its renewable resources beginning in 1975, with updates every 10 years starting in 1979. This would be accomplished through an analysis and concurrent surveys of present and anticipated users and demands for those renewable resources such as timber and rangeland. Every 5 years, the management would prepare documents which develop alternatives and select a particular program for protection, management, and development of these resources for the next 40 years.

The NFMA specifies that by 1985 each National Forest Supervisor develop his or her own unique load and resource management plan for his or her entire jurisdiction which addresses the goals and objectives established by a Regional Master Plan. Therefore, according to this act, each forest must:

- Identify parcels of land which are available, capable, and suitable for timber harvest.
- Build and maintain accurate data bases of resources for management retrieval.
- Provide retrieval and display architecture for easy review of load usage trade-offs and alternatives.
- Provide sufficient information for publishable documentation.
- Establish and maintain records of all decisions and actions taken.

Obviously, data automation is required to implement parts or all of these laws along with meeting the day-to-day requirements.

The Forest Service has also elected to automate its offices with word processing and electronic mail. The impacts on computers and the associated telecommunication systems over the next 10 years is profound indeed.

Region 1 National Forest System consists of 13 National Forests in the states of Montana, northern Idaho, and the northwest region of South Dakota. In addition, Region 1 manages National Rangelands in North Dakota and South Dakota. There are 74 Ranger District (RD) offices in Region 1 which represent the first line resource managers of the system. These Ranger Districts report to 13 Supervisor Offices (SO's) which manage the resources associated with the Beaverhead, Bitteroot, Idaho Panhandle, Clearwater, Custer, Deerlodge, Flathead, Gallatin, Helena, Kootenai, Lewis and Clark, LoLo, and Nezperce National Forests. These forests all report directly to the Regional Office (RO) at Missoula, MT. This is shown in Figure 2-3. The management structure is clearly decentralized, delegating responsibility and authority to the lowest feasible level of organization.

This management structure in 1979 employed 1,749 permanent full-time staff plus 3,515 other types of employees, harvested 1,209,100,100 board feet of lumber, and conducted 958 road and other engineering projects. Region 1 manages 24,011,900 acres of land of which 12,808,700 are commercial timber and 4,342,300 are designated wilderness. There are an additional 4,066,000 acres of rangeland.

In 1979, Region 1 managed its resources using a network of computers and terminals. Central to this system is a large, second-generation, general-purpose, computer located at the Ft. Collins Computer Center in Ft. Collins, CO. The Regional Office supports a smaller, second-generation, general-purpose system. There are smart terminal devices at each of twelve Supervisor Offices. The Clearwater National Forest supports a small minicomputer. And there are large numbers of low-speed data terminal devices scattered throughout the entire region. Virtually all Region 1 computational equipment accesses the system at Ft. Collins. This access is accomplished primarily through a

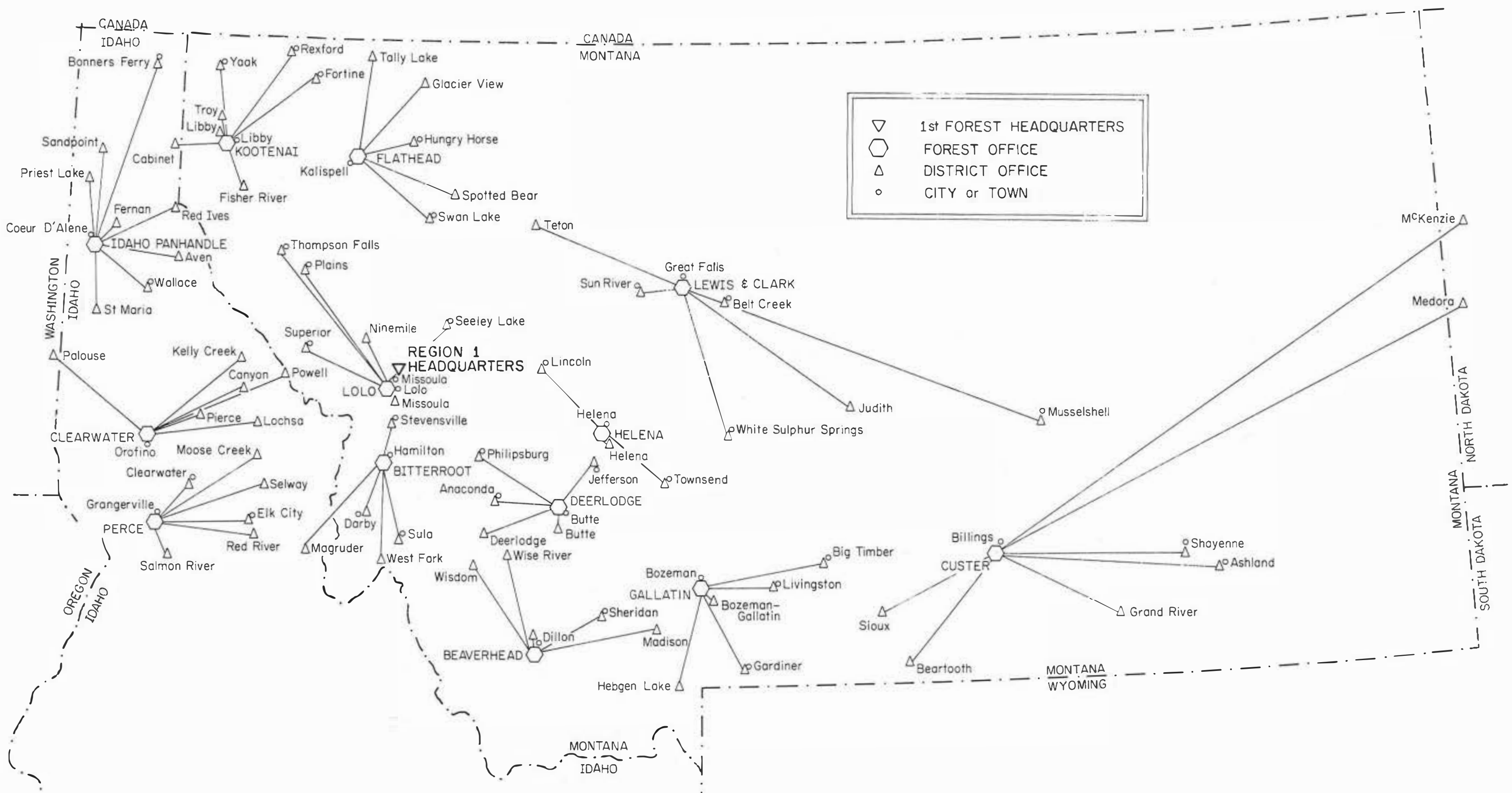


Figure 2-3. USDA Forest Service Region 1 represents the operating system under consideration.

dial-up network of Wide Area Telephone Service (WATS) and a Value Added Network (VAN), which are augmented with Foreign Exchanges (FX's), and interstate leased (private) lines.

The findings of this report are that Region 1 has a requirement to operate on 1386 megacharacters of application-type data. The average Forest Plan to facilitate RPA and NFMA will operate on 18% of the total Region 1 information data base. Each of the 13 National Forests in Region 1 will average 20.6 megacharacters of information to implement the forest plan and another 257,000 equivalent characters of computer memory to exercise the Forest Plan system.

About 70% of all ADP work volume in Region 1 is performed by the Regional Office under the current equipment configurations. This will change to 44% at the Regional Office and 56% distributed to the 13 forests.

The projected relative ADP work load distribution between forests is shown in Figure 2-4. There is a factor of 6.6 difference between the smallest and largest forest ADP requirement. Word processing and electronic mail will increase the ADP requirement by 32%.

There currently exists between 94 and 121 potential users requiring ADP services at any one time during the workday. As of January 1980, only 15% to 17% were actually receiving this service. This potential user force corresponds to 1 user per 55 to 60 employees. The work force requiring ADP service could potentially double with word processing.

ADP service requirements are projected to grow 27.2% compounded annually to a value of 3.3 times of current requirements reflected in this report by the year 1985.

Distributed type processing appears to meet the needs of Region 1 based upon the functional workload analysis, the Region 1 management reporting structure, the 80:20 Rule, and the word processing/electronic mail support requirement. Access times to data are shown in Figure 2-5. Implementation of a distributed system is a major management commitment. The magnitude of such a commitment could be implemented in phases to spread costs and personnel adjustments. Two computer zoning options are recommended. The cost of distributed system equipment will average $3,830 per month for an equipment lease and $1,201 per month for equipment maintenance. All cost data are in 1980 dollars. This average system will support application programming activities only.

Word processing and electronic mail require additional smart terminals which average $372 per month per terminal plus $92 per month for terminal maintenance. Therefore, a completed average forest system which supports all ADP functional requirements including word processing and electronic mail will cost an estimated $6,110 per month for equipment and $1,723 per month in maintenance. Initial installation and equipment start-up costs are estimated to be $22,826 per major operation for air conditioning, power systems, facility modifications to walls and ceilings, and so on. Cost savings are probable and likely.

There appears to be a continued substantial computational need at the Regional Office. Estimates for such a system are projected to cost up to $13,000 per month plus $3,874 per month for maintenance.

Fire computational support is one of two exceptions to normal type regional requirements. ADP fire support is projected to be high during summer months and low in winter. Quick response time is required, and high reliability is also essential. Geometronics is the second exception to normal ADP operations in Region 1. Substantial paper graphics requires off-the-shelf plotters and digitizers supported by a relatively large mini-type computer.

It is concluded that ADP service upgrade should include a well-established need to continue centralized ADP support from the Ft. Collins Computer Center for large programs and data base manipulation and storage. There are four minicomputer facilities in the National Forest Service system which have been successfully deployed and operated for over 12 months. They are located in the Clearwater NF (Region 1), the Tahoe NF (Region 5), the Plumas NF (Region 5), and the Mt. Hood NF (Region 6). It is concluded that they represent key information resources which support the need and application of distributed computers in Region 1.

It is concluded that the risks associated with distributing systems around the regions can be substantially reduced with a comprehensive measurement test and evaluation program which should begin with the four forests with minicomputers to establish a performance benchmark. As equipment is installed, there should be the associated performance tests and evaluation phase.

Based on the findings of this report, action must be prompt. The separation between near-term user needs and near-term capability is too large. If initiatives are delayed, users will develop capabilities illicitly without the knowledge or approval of management, which will result in disjointed ADP capabilities that will not interoperate. An alternative recommendation associated with delayed action is to force less automation and more manual processes by forest staff members.

The results accumulated in this study program were derived from well-established operations research procedures. These procedures and methods may be applied to other regions.

Montana Telecommunications Architecture. The primary goal of this project is to develop an integrated telecommunications model for rural, state, and local government. It will be a model which encourages shared technological resources and at the same time minimizes the operational constraints placed on the rural telecommunications user. The integration model is intended to minimize hardware and physical plant duplication in a rural environment, where resources are generally limited. The use of a telecommunications model in the formulation of rural economic development seems to be a reasonable approach to stimulating appropriate developments in response to the Presidential Initiative in this area.

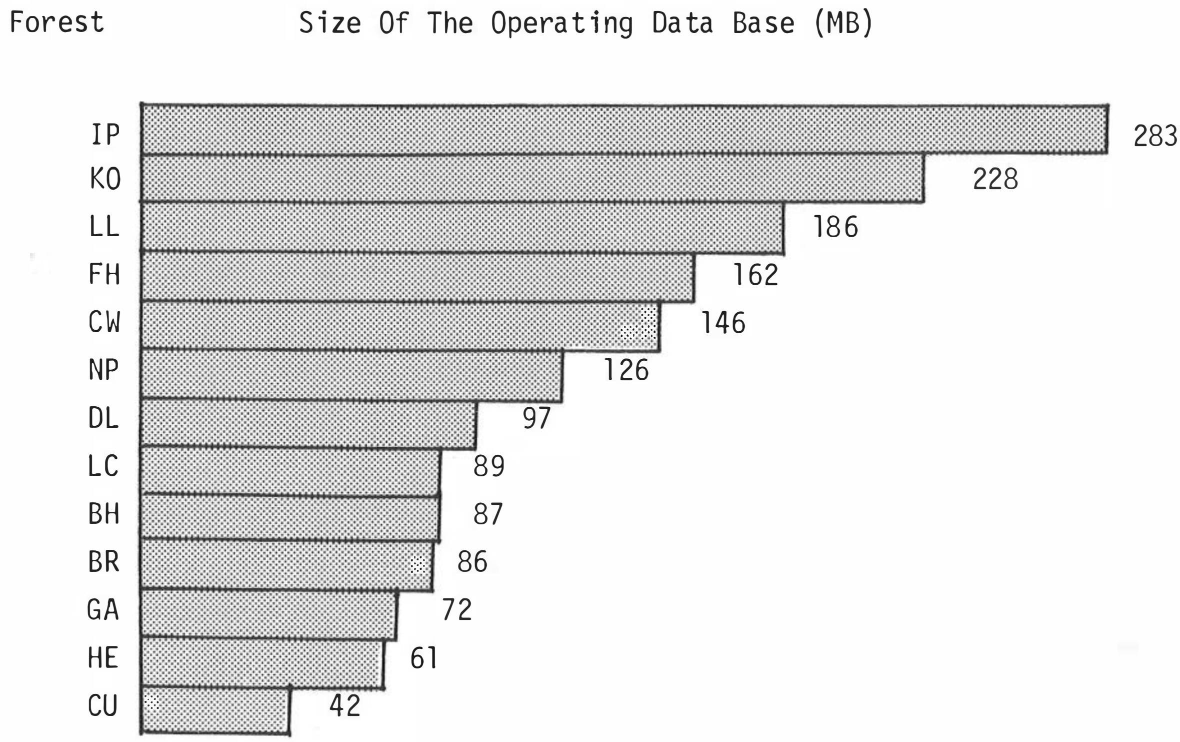


Figure 2-4. Region 1 distribution of data by forest.

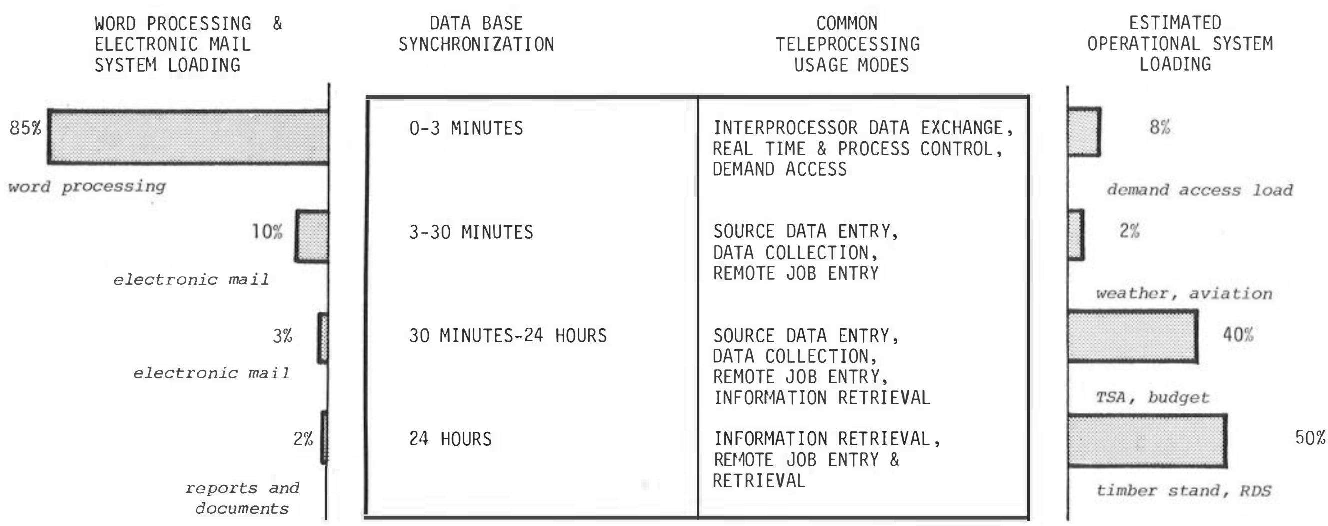


Figure 2-5. Turnaround time user requirement of word processing/electronic mail and operational (application) type activities.

The ITS project team interfaces with the State of Montana through the Department of Administration which is responsible for administering the State NTIA planning grant. Since project start-up in April, the primary ITS effort has been directed toward the following tasks:

- o Entry, orientation, and familiarization with the State of Montana telecommunication users.
- o Coordination and technical counselling with State project personnel and the Montana Telecommunications Advisory Council. This included the establishment of protocols and the definition of State priorities as set forth in a working agreement between ITS and the State of Montana.
- o Development of methodologies for data collection and needs assessment.
- o Preparation of a format for a selected rural telecommunications bibliography.

For the purpose of this model, the rural telecommunications infrastructure was divided into the following categories:

- o Telephony
- o Data Communications
- o Land/Mobile Radio
- o Noncommercial Video and Broadcast Radio.

Data collection methodologies are presently being developed for each of the four categories such that integration hardware alternatives will be more obvious to the State telecommunications policy makers, designers, and users. An underlying assumption of the model is that the cost of modifying or changing system requirements increases exponentially as the project proceeds; therefore, the methodology places a great deal of emphasis on user participation and ownership in developing the system requirements.

A bibliography of selected rural telecommunication publications is being formated into a data base for editing, coordination, and publication. The objective of the bibliography is to serve as a reference point for state and local government telecommunication policy makers, designers, and users.

In Fiscal Year 1981, the methodologies for the four categories will be completed and the quantitative/qualitative system analysis will be conducted to validate the model under operational conditions.

<u>Common Carrier Technical/Policy Planning.</u> During FY 80 a program was established at ITS to provide a technological component to the NTIA policy-formulation process in the areas of Domestic and International Common Carrier. This should not be characterized as technological "support" to policy, since telecommunication policy is an interdisciplinary field embracing legal, economic, political, organizational, and technological issues, with each constituent field providing a different but equally-important, view on the problems involved.

In the area of international telecommunication, the primary contribution this year was the initiation and completion of a technological and operational study of the Datel interconnection problem.

The International Record Carriers (IRCs) have, for a number of years, provided a switched, overseas voiceband data service called Datel. As currently implemented, IRC customers in the United States call through the Bell/Independent Domestic Message Toll Service (MTS) network in the usual fashion in order to reach a Datel switch. At this point, an IRC operator is usually required. The call is then placed over conditioned IRC and correspondent Post Telephone and Telegraph (PTT) transmission facilities in order to reach the country of call destination. Finally, the PTT domestic telephone network is used to complete the call to the desired party in the foreign country. Service in the opposite direction (from other countries into the United States) is also available.

The study conducted by ITS was concerned with the changes required in the Bell/Independent domestic MTS network to provide a more advanced form of interconnection to the IRCs. Examples of such changes include arrangements for a better quality of transmission between the IRC customer and the IRC switch and arrangements for a fully customer-dialed service.

Interconnection is not a simple issue. In this study the interconnection problem is factored into eight specific technical and operational areas. These areas are used to discuss the lengthy history of the claims and counterclaims made by AT&T and the IRCs, and to provide a framework for our own further analysis of the interconnection issue. Finally, the study discussed three classes of solutions as a function of the time-frame over which implementation is likely to occur. These solutions should be taken as examples or prototypes, indicative of what seems reasonable to us, and not as NTIA recommendations. This is consistent with the purpose of this study, which was to provide a framework of understanding so that more productive discussions could take place among the affected carriers.

In the Domestic Common Carrier area, technical guidance was provided for four filings made by NTIA before the FCC. In each case, this involved a review and analysis of the technical issues involved, as well as writing a part of the actual filing iself.

The first of these filings, in the Xerox XTEN (Docket No. 79-188) proceeding, was concerned with the establishment of ground rules for a proposed new "Electronic Message" or "Radio Distribution" service. Specific issues addressed in this filing related to interconnection and standards for this new service, the use of the service for voice-only applications, and the relationship of the cellular radio scheme proposed to existing loop plant facilities.

In the Resale (Docket 80-54) filing, the advantages and disadvantages which might be expected to flow from the proposed resale of MTS and Wide Area Telephone Service (WATS) services were studied. It was concluded that resale should not create any serious technical problems for the public switched voiceband network, and that innovative new service arrangements may indeed be provided by resale carriers.

In the MTS/WATS Market Structure Inquiry (Docket 78-72), the FCC sought to determine the proper role of competition in the provision of these services. NTIA argued for a reliance upon competition to the fullest extent possible. From a technical and operational standpoint, NTIA examined the incentives, means, and insitutional mechanisms available to insure the continued viability of the Bell/Independent MTS network, and of the combined Bell/Independent and Other Common Carrier (OCC) networks taken as a single entity. Although many details remain unresolved, the conclusions were positive with respect to competitive supply.

In the Petition for Reconsideration of the Final Decision in the Second Computer Inquiry (Docket 20828), NTIA focused on issues which relate to the definitional distinction between Basic and Enhanced services. This definitional structure lies at the very heart of the mechanism which the FCC is attempting to use to affect institutional reform, so a consideration and further refinement of these issues by NTIA was critical. In this connection, NTIA also commented upon some of the specific structural separation reforms which the Commission is seeking to improve.

As a part of the Domestic Common Carrier program, ITS also represented NTIA at the ENFIA II (Exchange Network Facilities for Interexchange Access) meetings. These meetings were held in an attempt to negotiate an enhanced form of interconnection for the domestic OCCs with the Bell/Independent MTS network. Although resolution of this problem was not achieved, ITS, as an impartial technical observer, was instrumental in keeping the meetings focused upon the technical issues involved.

The expertise created by the Common Carrier Technical/Policy Planning Program is relevant to the needs of other Federal agencies as well. This was demonstrated in FY80 when the Antitrust Division of the U.S. Department of Justice requested ITS to undertake an analysis of the technological and operational implications of various relief options as related to their suit against AT&T for alleged monopolization of telecommunication service and equipment markets.

The Shasta-Trinity National Forest Telecommunications Study. The telecommunication study of the Shasta-Trinity National Forest was undertaken to provide an overview of system design alternatives to satisfy the near-term operational requirements of all communication and information transfer needs of the forest. A published technical memorandum presents the approach, the development of system requirements, and the technical system design alternatives. Comparisons of cost and other attributes are made in providing the manager an insight into a cost effective system choice.

SECTION 2.2. TERRESTRIAL RADIO SYSTEM PERFORMANCE AND MONITORING STUDIES

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 system design and/or upgrading as requested by the sponsoring Federal agency. The projects described are: The Department of Energy - Transportation Safeguards Support, Voice Performance Measurements, Bell Technical Operations Textron Consulting, Marad Assistance, Microwave Propagation for Digital Radio, EFAS/PEP II Program, Multipath Induced Spectrum Distortion, and Automated Digital System Engineering Models.

The Department of Energy - Transportation Safeguards Support program was initiated by DoE in 1976 to provide systems engineering support to the development of an integrated command/control capability for the sensitive nuclear materiel transportation operations. Tasking during previous years has concerned propagation engineering, detailed measurements of communications functional characteristics (e.g., antenna parameters and control methods, receiver and signal processing single and multiple signal responses), and the design of a management support model to support facility enhancement and operational integration activities by equipment development agencies. The latter includes communications, intraconvoy control, and distributed software command/control components.

During FY 80, the principal tasking involved a review of receiver system design modifications to maximize sensitivity and signal discrimination characteristics, and an evaluation of the utility of the Global Positional System (GPS) for transport convoy movement tracking.

Receiver system modifications consideration emphasized S/N sensitivity improvements and increasing interference discrimination. The latter concerns unintentional interference from broadcast or teletype sources and deliberate interference by intruder groups. International interference would include CW, narrowband noise, and controlled FSK formats.

A typical SECOM receiver S/N characteristic is plotted in Figure 2-6. Modification of the receiver FSK detector to employ two narrowband time filters would extend the BER threshold by 3-5 dB over that displayed. Usage of tracking loops in the post detection processing would improve the S/N by an additional 3-6 dB, but require modification of the message preamble format. The spread in improvement ranges results from varying ionosphere propagation conditions.

Signal nulling techniques investigated include squinting of the relay site periodic array patterns and using closed loop nulling with a separate monopole antenna. Pattern squint would require phase shifters in the primary antenna elements, with single interference nulling depth of 6-12 dB when the source is displaced at least 20° from the main beam. Phase shifter, gain control, decision logic, and control loop stability represent significant

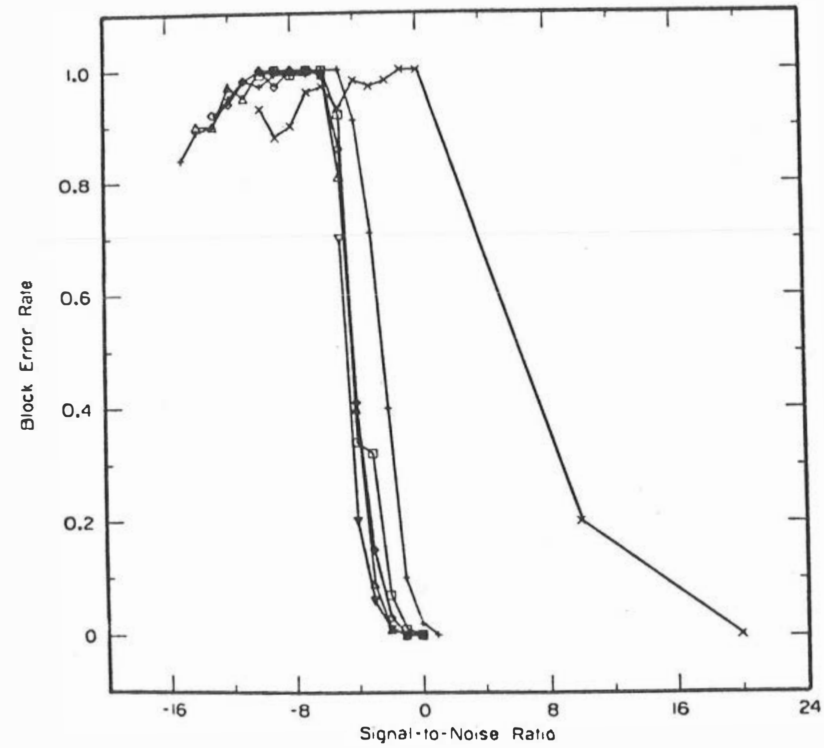


Figure 2-6. Representative SECOM receiver data test.

implementation problems. The stability factor is primarily influenced by the dynamic character of the ionosphere media.

A separate nulling reference antenna represents a more tractable method, with less control software complexity. The basic functions are diagrammed in Figure 2-7. This method indicated a nulling capability in the 6-12 dB range, with less development and operational cost than interference nulling with the primary site antennas.

Detailed design studies will be accomplished for the receiver modifications, and design studies and scale model tasks for the antenna nulling techniques will be completed during FY 81.

Location of active convoys with minimum uncertainty is of primary importance for incident control, particularly in directing law enforcement assistance to assist in the moving of disabled vehicles or rescue during a hostile situation, and minimizing public interaction. Previous location and tracking schemes investigated include visual identification by convoy personnel, measuring/beaconing operations between convoy vehicles, low frequency hyperbolic modes (CONSGA, LORAN-C), and active satellite navigation systems (TRANSIT, TDRSS). Severe limitations for these systems are identified from considerations of accuracy, cost, and availability. The utility of GPS addressed these factors in considering the utility for continuous tracking and integration into convoy command/control systems.

The GPS currently operates 5 satellites, with the primary purpose of operational evaluation by military services in operational tests in California, Arizona, Florida, and midcontinent test ranges. A full deployment of 18 satellites is planned for the 1983-84 period.

For military users a two frequency mode is employed to transmit time, ephemeris, and identification data; position determination is accomplished in the software processors in each user receiver. The dual frequencies allow compensation for propagation media perturbations in signal phase. For these applications, a positional accuracy in the 20-50 meter range can be attained with data from 3 to 5 satellites. This mode is not available to non-military users because of data security constraints.

A reduced accuracy mode using one frequency will be available to non-military users. The functional configuration of a receiver being developed for this mode is diagrammed in Figure 2-8. This receiver uses only the clear acquisition code with, therefore, reduced timing accuracy. Preliminary tests with surface vehicles in various simulated terrain conditions indicate position errors as plotted in Figure 2-9. These error magnitudes are within a factor of 3 of the maximum allowable for convoy location during emergency or threat situations.

Integration of the GPS receiver into the convoy communications systems required slaving of the GPS computer read commands to the convoy data controller, provision for serial read-out and format conversion, and clock syncronization. Since the GPS receiver will employ integrated circuits for all detection and computation functions, operator convenience was the primary physical integration consideration. A flush mounted helix antenna was designed for the GPS receivers.

Voice Performance Measurements. The purpose of this program was to improve the method of implementing the objective intelligibility scoring method developed by Gamauf and Hartman ("Objective Measurement of Voice Channel Intelligibility," FAA Report No. FAA-RD-77-153, October 1977) and to make additional comparisons of the objective scores with subjective (listener panel) scores.

A hardware correlation detector was designed and built. This detector was used for the automatic alignment of the spoken words between the master input tape and the output tape.

Different degradations of the noise signal included noise, interference, filtering, clipping, pre-emphasis-deemphasis.

The comparison between the objective and subjective scores supports the use of the objective measure as a predictor of the articulation score.

A Department of Transportation Report, FAA-RD-80-71, "Voice Performance Measurements," by W.J. Hartman and L.E. Pratt, June 1980, has been published.

The Bell Technical Operations Textron Consulting project aided Bell Technical Operations Corp. in developing a measurement system and making controlled measurements to determine the effect of vehicular ignition noise on typical tactical communication systems. The work was performed by Bell for the USACEEIA, Fort Huachuca, AZ, and the results are contained in Publication No. USAEPG-FR-1065-3.

At a quiet measurement site in the vicinity of Tucson, AZ, various combinations of from 1 to 12 vehicles of various ages, types, and manufacture were used to provide impulsive interference to four voice communication system types. These systems were SSB at 23 MHz with a 10 kHz bandwidth, FM at 75 MHz with a 30 kHz bandwidth, AM at 300 MHz with a 30 kHz bandwidth, and an FM/PCM system at 900 MHz with a 300 kHz bandwidth. The statistical characteristics (amplitude probability distribution of the received noise envelope and the average crossing rate characteristics) of the interference were measured simultaneously with the system performance.

Two methods were used to measure system performance. An objective measurement using instrumentation termed VIAS (voice intelligibility analysis system) was used which produces an intelligibility measure called articulation index (AI). In addition, a subjective method was used employing phonetically balanced work lists and a highly trained listener panel to obtain the articulation score (AS). One object of the measurements was to ascertain if a relationship exists between AI and AS for impulsive noise, and, indeed, quite good correlation was obtained for all four systems.

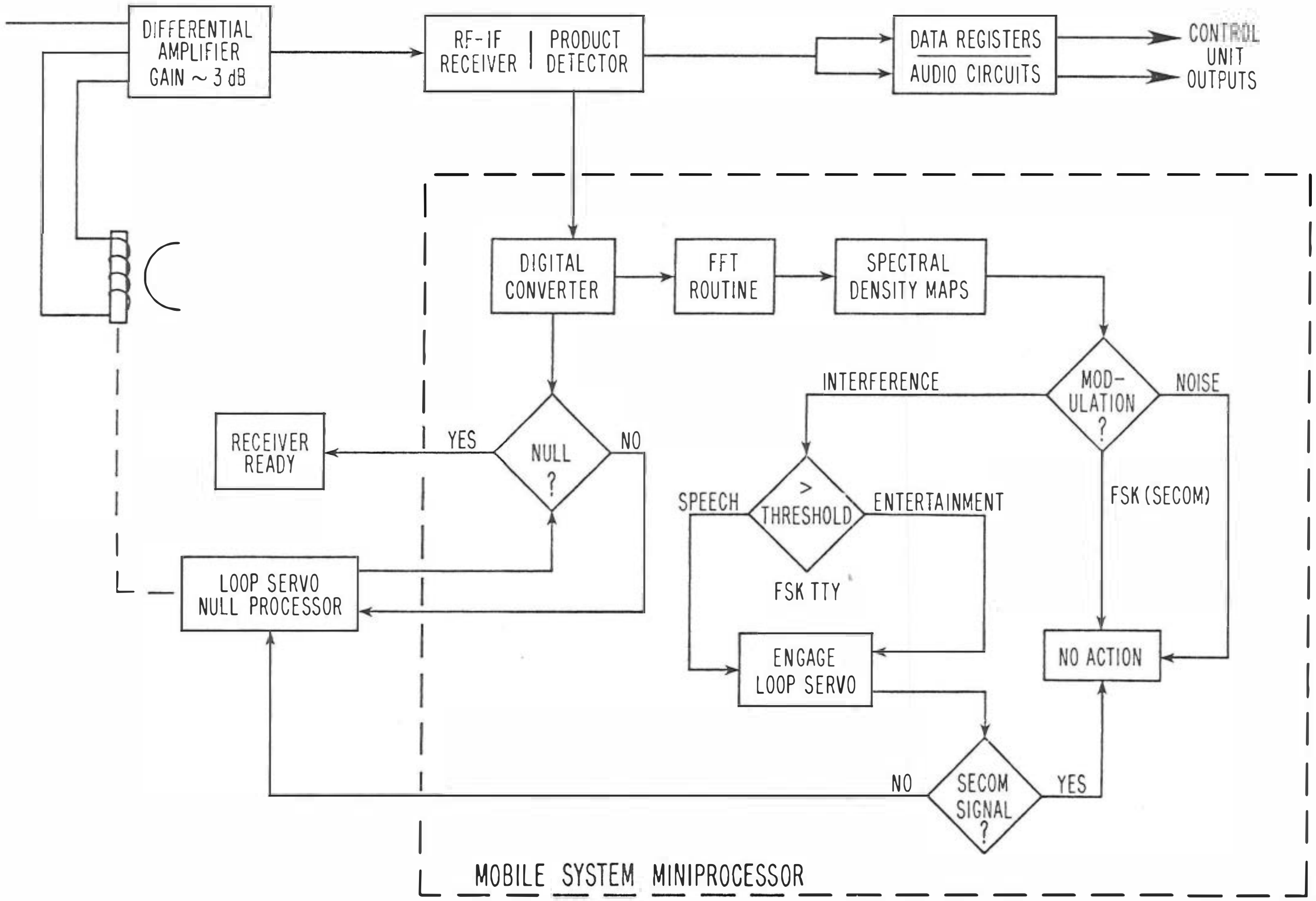


Figure 2-7. Mobile receiver control functions.

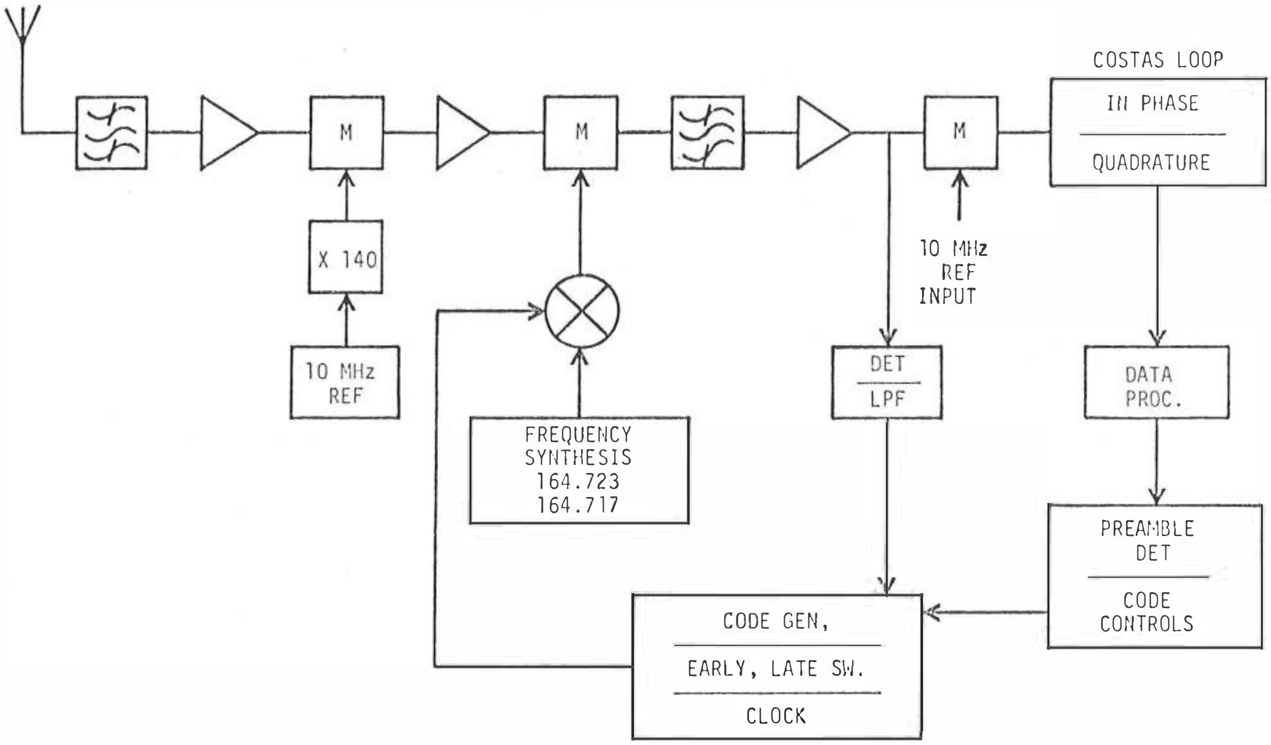


Figure 2-8. Functional configuration-GPS single channel receiver.

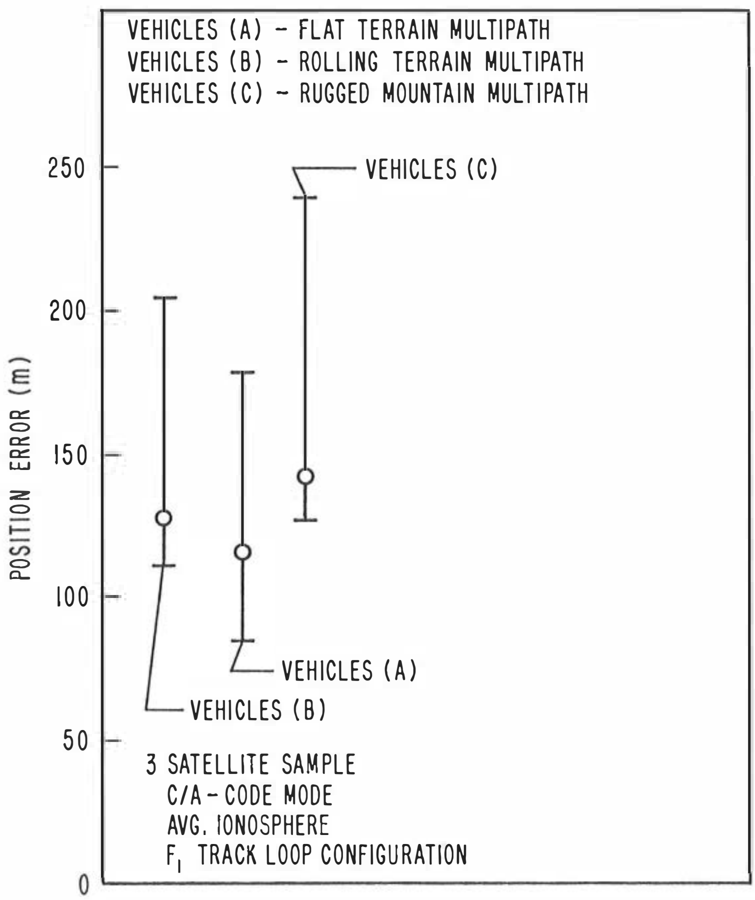


Figure 2-9. GPS location error distributions - prototype laboratory measurements.

The results of the system performance measurements can be summarized as follows:

1. For the AM system operating in impulsive ignition noise, good intelligibility can be maintained at significantly lower signal-to-noise ratios than those required for the ambient Gaussian noise.

2. The results for the FM system are similar to that for the AM system. The comparison (with ambient Gaussian noise), however, is not as dramatic and is more varied.

3. For the HF SSB system, the ambient interference was primarily CW which was much less degrading than the impulsive noise. The degradation in this case seemed to be relatively independent of the number of vehicles present.

4. The results for the FM/PCM system indicate that the system is impervious to ignition noise in that very high intelligibility was maintained in all cases until synchronization was lost.

MARAD Assistance. ITS continued to provide a range of technical services to the U.S. Maritime Administration (MARAD). For Fiscal Year 1980 the most significant efforts were in the areas of:

1. Development of Automated VHF/UHF Maritime Telephone System. ITS provides major technical input through RTCM SC-71 and CCIR Interim Working Party (IWP) 8/5. ITS prepared a Draft Recommendation on Automated Telephone Systems which resulted from the work of IWP 8/5. This Draft Recommendation was accepted at the April 1980 meeting of the IWP and final editing took place during a meeting of a subcommittee of the IWP in June 1980. ITS provided the U.S. technical representation in the IWP and the subcommittee meetings. The Draft Recommendation provides unified signalling procedures over the radio channel for both trunked and non-trunk systems, allowing truly world-wide compatibility. The Draft Recommendation will be presented to the full CCIR Study Group 8 meeting in November 1980. One item that has not been resolved is a world-wide allocation of frequency band for automated maritime telephone systems, the WARC-79 referred this to the Mobile WARC to be held in 1982.

2. ITS performed an analytical study of the feasibility and capability of an overlay spread-spectrum (SS) communications system in the VHF (156-162 MHz) band in the New Orleans area. The study confirmed results from earlier ITS studies, indicating that a simple overlay is not feasible, the predominant factor being interference with mobile reception at the base station from transmission of base stations in the other service, i.e., FM base station transmissions interfering with SS mobile reception at the SS base station(s) and SS base station(s) transmission interfering with FM mobile reception at the FM base stations. For a practical set of systems parameters, it was found, for example, that the maximum range of an FM base station would shrink from 35 km to 1 km, and for the SS base station from 73 km to 5 km. Then reductions were calculated for FM base station to SS base-station separation of 30 km, a distance substantially larger than would be encountered in the New Orleans area. The report of the study, "An analysis of the compatibility of spread-spectrum and narrow-band FM mobile radio systems," by de Haas and Watterson, (to be published) also suggests some alternative possibilities which may be worthy of further study. In support of the study, actual tests were performed in conjunction with Magnavox (supplier of an SS modem) in the New Orleans area. These tests substantially corroborated the findings of the study.

3. CCIR Interim Working Party (IWP) 8/8 was formed in 1979 to establish operational procedures and other matters necessary to facilitate the early introduction of Digital Selective Calling (SELCALL) in the maritime mobile terrestrial service. ITS has been a substantial contributor (with MARAD sponsorship) to the development of SELCALL both nationally and internationally. Continuation of the ITS effort has been in RTCM SC-74 and in the IWP 8/8. RTCM SC-74 developed a test plan for at-sea operational tests in conjunction with the U.S. Coast Guard and U.S. commerical coast stations in the San Francisco area and a vessel of American President Lines. The test covers 6 weeks, starting the end of August 1980, and is designed to provide information relative to modes of operation at coast stations, shared use of frequencies, and the feasibility and capacity (i.e., number of channels monitored) of scanning receivers on board ship. Data from the test will be analyzed at ITS and the results will also be submitted to the CCIR. ITS participated in the IWP 8/8 meeting of July 1980 where a Draft Recommendation on the operational procedures for both commercial use and safety applications of SELCALL was prepared. This Draft Recommendation will be submitted to the full Study Group 8 meeting in November 1980 and should provide a major impetus to the introduction of SELCALL in the maritime world.

Microwave Propagation for Digital Radio. The U.S. Navy Pacific Missile Test Center (PMTC) at Pt. Mugu, CA, operates a network of microwave and other communication systems in support of the test center missions. Future plans for the microwave system include conversion to all-digital transmission. However, it is known that severe propagation conditions exist in the Pt. Mugu region. These conditions are primarily caused by meteorological factors such as deep refractive layers with very high negative gradients. These layers develop due to a high marine layer of air at the coast line. The propagation is characterized by deep signal fading, caused by a mixture of power fading and multipath signals. In order to determine the digital data rate that these circuits will support under such conditions, ITS was tasked by PMTC to conduct some experiments over a link between Laguna Peak (LP) and San Nicholas Island (SNI), a distance of approximately 65 miles over water. The experiment consisted of three measurements as follows:

1. The impulse response of the transmission channel.

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

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

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

A typical example of the multipath observed on the test link is shown in the power impulse response functions presented in Figure 2-10. The PN probe signal was multiplexed onto the PMTC system at SNI, and the impulse response was simultaneously measured on both of the space diversity channels at LP. In addition, the error performance of the PN code used for the impulse response measurements was also monitored at LP. The PN probe was operated at 8.6 GHz. The PMTC microwave system was operating on 7.17 and 7.47 GHz. The results of this experiment were published in NTIA Report 79-24 (R.W. Hubbard, "Investigation of digital microwave communications in a strong meteorological ducting environment," August 1979).

Based on the results of the above experiment, it was concluded that a digital system operating with a mission bit-rate on the order of 50 Mb/s would perform adequately over this link, provided the proper space diversity and adaptive equalization were used to combat the multipath effects. Subsequently, the PMTC has purchased a commercial digital microwave system which operates in an 8-PSK mode at a T-3 transmission rate of 44.736 Mb/s (2.25 bits/Hz). This system has been installed on the LP-SNI link, and is being used in a new test program. It is expected that the system will be available for experimental purposes for a period of about one year. This will permit observation of the performance through the most severe anomalous propagation periods, which are the summer and early fall months. Similar conditions usually develop on this path during December and January, but do not persist for long periods of time. Therefore, both summer and winter periods will be emphasized in the experiment. The program was initiated on July 1, 1980.

The specific measurements for this experiment are outlined below. Currently, the experiment is oriented toward the PMTC 44.736 Mb/s system. However, it is anticipated that a second microwave system may be added to the experiment at a later date. This will be a prototype of the Digital Radio and Multiplex Acquisition (DRAMA) system under development in the TRI-TAC program. The experiment has been planned to accommodate this contingency.

This experiment will consist of the following measurements:

1. BER and burst-error statistics of the mission bit-stream of the microwave radio.

2. Control voltages developed by each adaptive equalizer unit in the two receiver channels of the PMTC digital radios. These signals are proportional to the "tilt" and "notch" gain function of the equalizers, and are thus a measure of the multipath effects in the signal pass-band of the receiver.

3. Received signal level (RSL) of each space diversity channel. In association with these measurements, the diversity switch status will also be recorded, so that a record is maintained as to which diversity channel has been selected for data reception. The RSL of the PN probe system will also be recorded for frequency comparison.

4. Impulse response data of the propagation channel, including statistics of the frequency selective fading in the broadband spectrum of the PN probe system. The impulse response will be measured on two diversity channels simultaneously.

5. Space diversity measurements, using variable vertical antenna spacing.

6. Angle diversity measurements. These will be conducted in a similar manner to that used in the earlier measurement on the PMTC link.

The BER and burst-error measurements will be emphasized in this experiment. A basic error detector will be used to monitor the reception of a PN sequence as a test signal, which is selectable in length from (2^7-1) to $(2^{20}-1)$ and will be transmitted at a T-3 rate of 44.736 Mb/s. The error analyzer will be set to match the code length and clock rate at the transmitter. The output signal will be a serial pulse for every bit in error in the detection process. The error-pulse stream will be fed to a companion instrument, a burst-error analyzer. This instrument provides the following information:

1. Number of error-free sync periods. (This statistic will be tabulated in fixed time intervals for long error-free periods.)

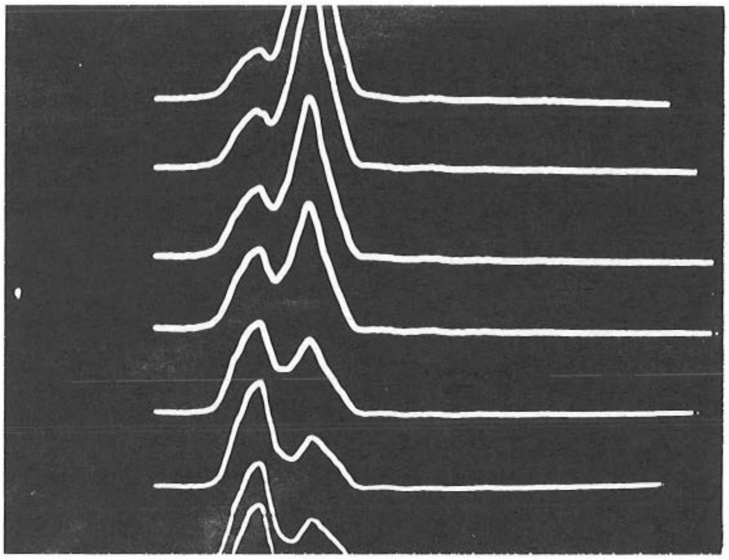


Figure 2-10. An example of multipath observed in the impulse response measured over a long over-water LOS microwave path. The sequence progresses from top to bottom in time, at 100 ms intervals. The delay time scale is 10 ns/cm. The response shows a two-path propagation mode with a delay of approximately 8 to 10 ns.

2. Number of error-free bits from the last sync signal to the first error burst.

3. Length of each burst of errors.

4. Number of bits in error in each burst.

Two parameters are selectable for the above burst-error analysis. The first is the length of a coarse sync period, and the second is the length of the error-free gap between bursts. The sync period will be selected on the basis of the PN sequence length, and the error-free gap may be selected within the binary range of 32 to 256 bits.

The data processing and analyses for this experiment will essentially be accomplished at PMTC, with ITS consultation. ITS will publish a final report during the first half of FY 82. Preliminary results will, however, be available in the form of informal reports to the sponsor and other paper presentations, where appropriate.

Multipath Induced Spectrum Distortion. Multipath fading in LOS links is known to cause short term outages when the signals from both the primary and diversity radios fade below the bit-error-rate threshold during flat fading. In addition, outages have been observed which occur at relatively high signal levels. These outages are often attributable to in-band (selective) fading.

To obtain statistics on selective fading and relate them to flat fading information, the Defense Communication Engineering Center provided ITS with funds to investigate this problem. The project consisted of a 2-month test by ITS to assist in determining the effect of selective multipath fading on digital line-of-sight microwave links. Data were collected within the Digital European Backbone Stage I (DEB I) on three LOS links on which ITS had instrumentation installed for another test program. Data collected on this selective fading project is being analyzed at the ITS laboratory. These results are needed for improving performance and design criteria for digital LOS links.

EFAS/PEP II Program. The EFAS program addresses the technical performance characteristics of the Digital European Backbone (DEB) communications system shown in Figure 2-11. 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 embedded in the new system.

Alarm and status reporting and remote switching are controlled by 1 of 3 minicomputers connected to the system that is 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.

Automated Digital System Engineering Models. The objective of this project is to expand the utility of a desk-top, computer-based set of programs previously developed by ITS for the U.S. Army Communications Electronic Engineering Installation Agency (USA CEEIA), Ft. Huachuca, AZ.

The program modifications are designed to reflect changes in LOS system standards based on work done at the Defense Communications Engineering Center at Reston, VA. The project is sponsored by USA CEEIA.

SECTION 2.3 STANDARDS

The standards activities described here represent areas where the work contributes to Federal, international, and industry standards. The projects are: FED-STD-1037, Glossary of Telecommunication Terms; DCS Radio Transmission Systems Standards Studies;and ITU participation.

FED-STD-1037, Glossary of Telecommunication Terms. Culminating a 3-year effort by ITS in conjunction with numerous DoD and non-military Federal agencies, this comprehensive glossary was published by GSA Federal Supply Service in July 1980. Containing over 2000 terms and definitions, the document is intended as the authoritative source of definitions for terms used in the preparation of standards, specifications, and other documents pertinent to the acquisition of telecommunication services, equipment, and systems by both DoD and other Federal departments and agencies.

This standard incorporates and supercedes MIL-STD-188-120, and therefore will support the MIL-STD-188-100 series of system performance standards. Approximately 700 entries came from the Federal sector, including many terms relating to digital data communications. The glossary will also form the nucleus of a common vocabulary for the evolving FED-STD-1000 series of system performance standards.

This work has been funded by the National Communications System and the Standards Branch of USACC/CEEIA, Ft. Huachuca, AZ, and coordinated through the Federal Telecommunications Standards Committee.

DCS Radio Transmission Systems Standards Study. DCS standards are structured hierarchically into system, subsystem, and equipment standards. The system standard defines end-to-end performance requirements and allocates these requirements to the various subsystems. In the area of transmission, this allocation is the basis for the subsystem standards for various transmission media which in turn are the basis for equipment standards. This project is divided into three subtasks, each of which deals with one of these hierarchical levels. Subtask 1 requires a study of the radio link portions of the long haul (DCS) and tactical system standards and the development of recommendations for a common long-haul/tactical system standard. Subtask 2 requires the development of the technical contents for common long-haul tactical subsystem standards for digital LOS microwave, tropo, and HF radio. Subtask 3 requires an assessment of the equipment design portion of the existing long-haul standard for digital LOS microwave radio.

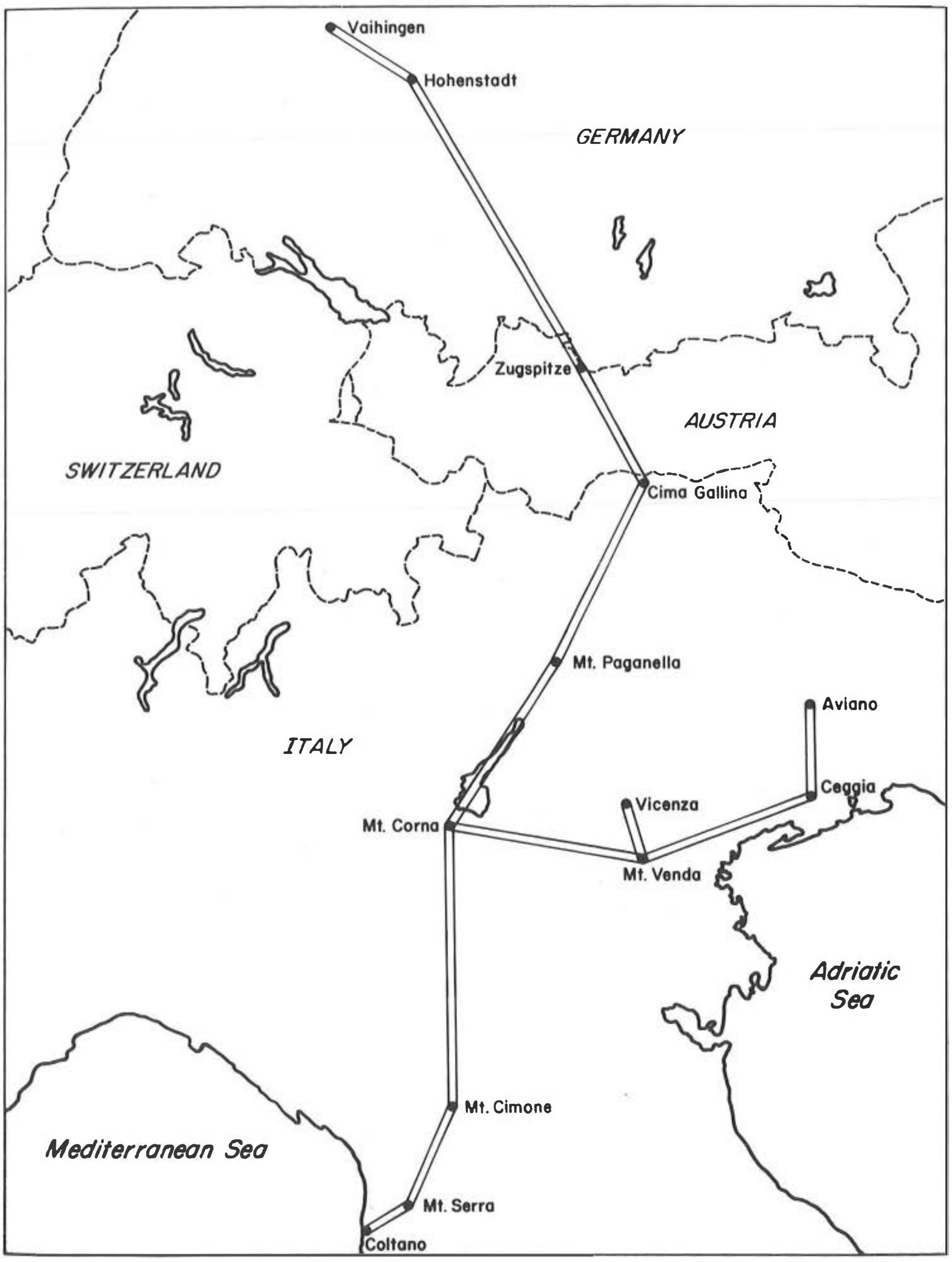


Figure 2-11. Digital European Backbone System, Phase I.

Subtask 1. ITS has reviewed the radio link sections of the draft DCS Digital Terrestrial Transmission System Standard and the draft System Design and Engineering Standards for Tactical Communications and developed recommendations for a common long-haul/tactical system standard. (See Figure 2-12 as an example of a system reference circuit.)

Subtask 2. ITS shall examine three standard development projects and develop recommendations for technical contents of subsystem design and engineering sections of three common long-haul and tactical subsystem standards for three types of digital radio systems, line-of-site, HF, and tropospheric scatter.

Subtask 3. Under this subtask, ITS shall perform a study to determine what improvements can be made to the equipment technical design portion of the standard for Design and Engineering and Equipment Technical Design for Long-Haul Communications Traversing Line-of-Sight Digital Microwave Radio Links.

This project is sponsored by DCA, Reston, VA.

International Standards Participation. ITS personnel are providing chairmanship of the U.S. CCITT Study Group D for Data Transmission and leadership for U.S. participation in CCITT Study Groups VII and XVII. These Study Groups have held their final meetings for the current plenary period and have submitted the result of their work for consideration by the Seventh Plenary Assembly of the CCITT which will be held November 10-21, 1980.

Study Group VII (Public Data Networks) prepared numerous new and amended recommendations pertaining to packet-switched network operation, circuit-switched network operation, link control including multi-link protocols, signaling, and interface standardization. Some of the significant topics that will be carried out in the next period pertain to access to and integration with Integrated Services Digital Networks and architectural reference models.

Some of the most significant outputs from Study Group XVII (Data Transmission over the Telephone Network) are Recommendations for 1200 b/s duplex modems for use in the public switched telephone network and for groupband modems operating at data rates of 72 to 144 kb/s.

In the CCIR, international chairmanship of Study Group 3, dealing with radio systems in the fixed services operating at frequencies below 30 MHz, was provided by ITS personnel. No meetings of this Study Group were held in this reporting period. Personnel participated in meetings of Interim Working Parties (IWP's) 8/5 (Automated Telephony at VHF/UHF for Maritime Mobile) and 8/8 (Operational Use of Digital Selective Calling). Both of these IWP's have prepared Draft Recommendations to be considered by the full Study Group 8. A more detailed discussion of these subjects can be found in Section 2.2 describing the MARAD Assistance program.

SECTION 2.4. GUIDED WAVE COMMUNICATIONS

ITS has continued to maintain an active role in the rapidly growing field of fiber optic communications. During this fiscal year, the work has included chairmanship of a CCITT/IEC Joint Working Group on Definition and Terms, Technical Advisor to IEC, SCY6E, preparation of a monograph on optical waveguide communications, and organizing and chairing semiannual meetings of an Optical Communications Task Force. The projects described here are: Guided Wave Communications and MX Long-Wavelength Consulting.

Guided Wave Communications. ITS has continued to maintain an active leadership role in the rapidly growing field of fiber optic communications. Participation in FY 80 has included chairmanship of a CCITT/IEC Joint Working Group on Definition and Terms, Technical Advisor to SCY6E (IEC), preparation of a monograph on optical waveguide communications (soon to be published), and the organization and chairing of the 10th and 11th semiannual meetings of the Optical Communications Task Force.

"Optical waveguide communications glossary," NTIA Special Publication 79-4, published in early FY 80, is a technical dictionary containing approximately 300 terms, concisely defined for the communication engineer, covering the field of optical fiber waveguide communications. It was written by a joint ITS/NBS staff of editors active in the field in recognition of the rapid emergence of this new technology and of the prior absence of a precise, common language among researchers, systems designers, manufacturers, and users. The goal of this glossary has been to nurture such a language.

The response within the year since publication, nationally and internationally, indicates that this goal is being fulfilled. The document is currently in various stages of formal approval as a standard by standards groups of the following organizations: CCITT, IEC, IEEE, EIA, and ANSI. Over 700 unsolicited requests for copies have been received by ITS, including 76 requests from 26 foreign countries. This effort represents an example of an ITS goal to utilize expertise of the Institute in furthering the development of standards as they become needed, particularly in the area of new technology.

Concurrent with the preparation and publication of the above Special Publication, ITS was asked to head a joint coordination effort (United States and Canada) on behalf of the CCITT Study Group "O" and IEC Working Group 46E. The output would be a recommendation for standards for terms and definitions to the CCITT/IEC International Standards Groups working for a vocabulary in English for optical waveguide communications. The coordinating committee, a select group of professionals with widely varying experience in the field, met a number of times in the summer and fall of 1979 and prepared a draft document of terms and definitions as the North American (U.S./Canadian) Position on Vocabulary to the International Joint Working Group Committee (CCITT/IEC). The committee met to obtain concensus for circulating a document through the national administrations of the various countries. The resultant document was based on the NTIA Special Publication, modified somewhat through inclusions of a number of CCITT adopted terms. The report is presently circulating to the

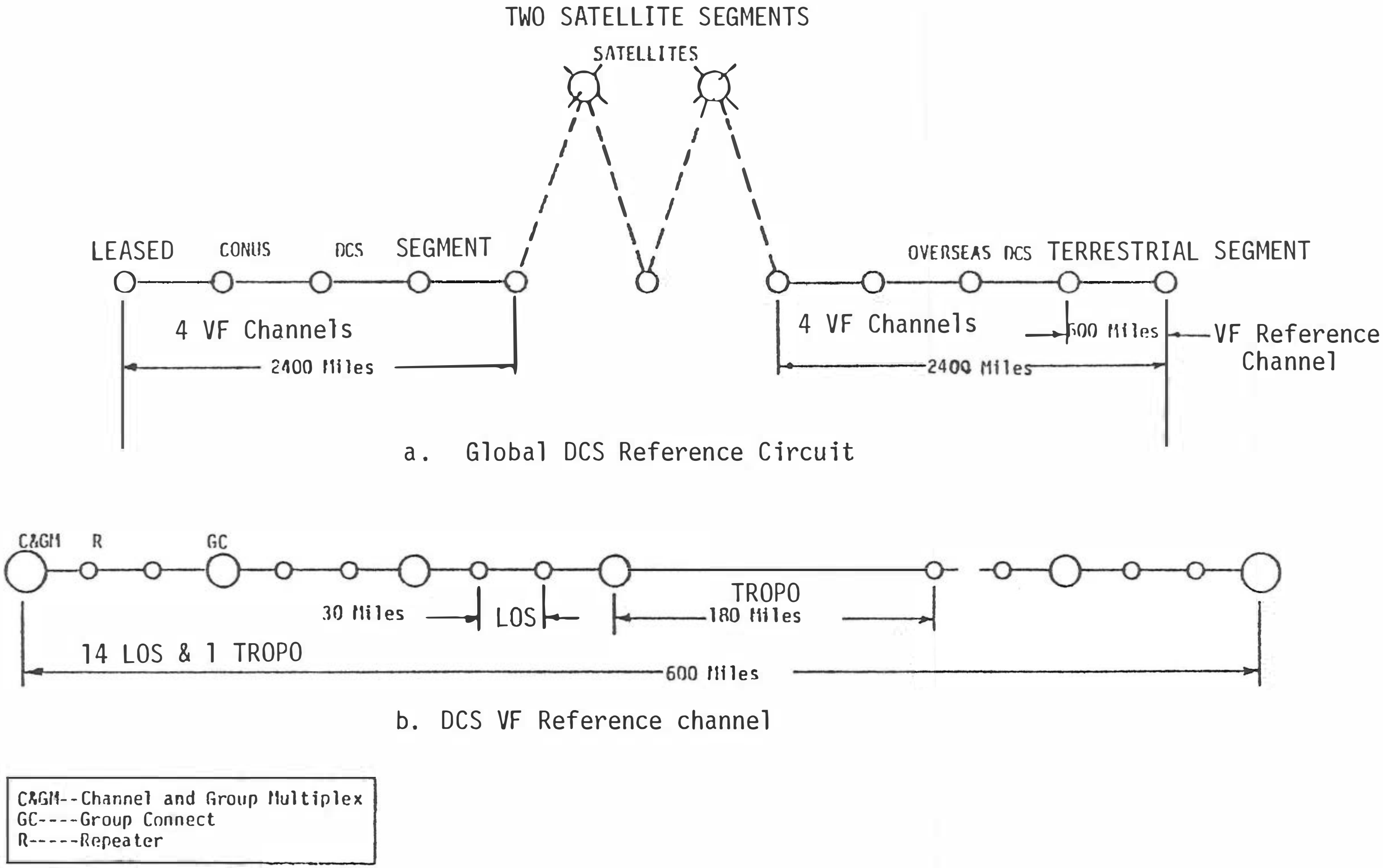


Figure 2-12. DCS reference configurations.

respective CCITT and IEC National Committees in preparation for presentation of the CCITT Plenary in Geneva, September 1980.

The Optical Communications Task Force (OCTF) met twice during FY 80, once in November 1979 and the second time (the 11th Semiannual Meeting) July 7-8, 1980. Both meetings were held at the Boulder Laboratories. The OCTF was developed to provide an informal, interactive forum among Government, university, and industry technologists as well as potential systems application groups, to explore jointly the technological and economic potentials of optical waveguide communications and specialized applications for this rapidly growing field. The Institute has, over the past few years, assumed a catalytic role with other Government agencies in the evaluation of this emerging group of technologies through interagency and industry participation in semiannual workshop sessions, augmented by the ITS preparation of Summary Reports of presentations given during the meetings of the OCTF.

Task Force participants have benefited from the early and opportune dissemination of technical information, product availability, reports on the economic and marketing climate, and the advent of new or unexpected applications for fiber optics. Of particular value have been the informal interactions among the participants - the meetings of manufacturers and the users.

Indicative of the subjects covered at the two FY 80 meetings of the OCTF, speakers discussed the quality of fiber optical measurements and the economics of the current testing and measurement practice in the fiber industry. It was pointed out that in the manufacturing procedures to date the high fiber measurement costs are instrumental in the higher costs for fibers than may be necessary. This is due to today's needs for 100% quality control. Better process control could reduce the costliness of attenuation and other parameter measurements and have a substantial effect on the economics of fiber optical systems. The alteration of the physical properties of the fibers themselves could provide a basis for highly sensitive gauges for measuring the size, velocity, and density of aerosols; the pressures of guide system at 274 Mb/s is under consideration for transmission at 1000, 2000, and 4000 miles. Items of special interest included the rapid strides being made in long wavelength fiber, sources, and detectors, allowing for as much as 30 to 40 kilometers between repeaters. Highly reliable components and the enhanced repeater spacing would have a marked effect upon the viability of optical waveguide underseas transmission.

At the most recent meeting of the OCTF (July 1980), forecast figures for optical fiber and system annual sales were revised considerably from the $1 billion estimate for 1990 given just 2 years ago. New estimates place the date for such sales volume at 1985-1986. Even such figures are now being considered as cautious and too low as the fiber optic applications for telephony, computers, interconnects, DoD operations, and specialized uses emerge as viable alternatives to existing techniques.

Leaky Feeder Communication Study. Leaky feeder communication systems offer many potential benefits in efficient use of the spectrum. Such systems provide linear coverage which is ideal for 2-way communication along mine tunnels, railroads, highways, buildings, etc. Although some leaky feeder systems are already in use, the basic theory of leaky coaxial cables is not well understood.

In this program, a rigorous theory was developed for solid metal cable shields with perforations. The propagation modes of such cables were computed over the frequency range from 10 to 1000 MHz. Also a simple sheet impedance description was derived for perforated cable shields.

An output of this project consisted of a paper, "Electromagnetic characteristics of a coaxial cable with periodic slots," to be published in the November 1980 issue of the IEEE Trans. on Electromagnetic Compatibility and a talk presented at the 1980 International URSI Symposium on Electromagnetic Waves in Munich.

This work extends a previous analysis of a coaxial cable with periodic circumferential slots to obtain the propagation modes in the source-free case. The two basic classes of modes are considered; one of these is the monofilar type where the return current path is external to the cable and the other is the bifilar or coaxial type where the return current is essentially in the shield. We also obtain results for the effective transfer impedance of the shield that, for sufficiently low frequencies, is essentially independent of the proapgation constant. Thus, for engineering purposes, the cable parameters can be simply described. An important finding is that the effective circuit parameters are particularly sensitive to the angular slot opening but relatively insensitive to the vertical slot width.

<u>MX Fiber Optics</u>. The MX/C^3 plan calls for the use of fiber optics in one of the most ambitious scenarios ever conceived. The magnitude of the communications problem is such that the choice of parameters can have significant influence on market and technology trends and on the total cost of the MX project. Wavelength is one of the most important parameters in this regard; 850 nm is used in most installed systems today, but 1300 nm wavelength in future systems is an intriguing possibility. Long wavelength devices are receiving considerable attention from researchers and there is now a contention that long wavelength LED-based systems will provide service comparable to a short wavelength ILD-based system. If so, the many advantages of the LED (vs. the ILD) would accrue to the user. There is a further fear among a few enthusiasts, that 850 nm systems will be obsolete in a few years and that 1300 nm represents the basis of next generation systems.

This project addresses the feasibility of using long wavelengths in the MX/C3 program. The study includes a technology assessment of the components, including fibers, sources, and detectors for use at the long wavelengths and identifies advantages and disadvantages in each of the two wavelength ranges.

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 Models and Multipath Observations. A major problem in micro and millimeter wave propagation over terrestrial paths for clear air conditions is the occurrence of fades and enhancements in signal intensity which are characterized by reduced channel quality such as high error rates in digital communication links. The cause of these signal changes is also responsible for changes in angle of arrival of a received signal and becomes of considerable concern in the upper millimeter wave band for military applications. The mechanism producing these effects is the dynamic refractivity structure of the atmosphere produced by the daily heating and cooling of the earth's surface, exaggerated by the movements of weather fronts. A change in the refractive index along a path will change the route the signal takes to arrive at the receiver, and most often two or more signal rays can reach the receiver by traveling different routes when a refractive layer forms. This multipath can occur by bending the ray so that it strikes the earth's surface and is reflected to reach the receiver or by taking different paths through the atmosphere without a surface reflection. These multipath signals can arrive with a delay which can produce either constructive or destructive interference; additionally, if the delay is long relative to the modulation rate carried by the signal, considerable distortion in the demodulated signal will occur.

The Boulder Atmospheric Observatory (BAO) includes a 300 meter tower with precision meteorological probes and an instrumentation carriage which travels the full height of the tower in about 8 minutes. This provides an unique facility for the study of atmospherically induced multipath effects. With this facility, height-gain data can be obtained when one terminal travels continuously from below, through, and above a refractive layer and back again while simultaneously recording the refractive index profile. The purpose of this experimental measurement is to understand the multipath mechanisms with a goal of producing an empirical model which describes the ray path and predicts the field intensity given the refractive index profile.

The Institute has developed the instrumentation to measure field intensity between a terminal mounted on the BAO tower carriage and the Department of Commerce Radio Building 23 km away. On the tower carriage, two sources with a common frequency reference generate a 9.6 and a 28.8 GHz signal. These signals feed antennas with a 5 and 10 degree beamwidth, respectively. The refractive index profile is measured with an accurate dry bulb and wet bulb thermometer and a precision pressure transducer, with all output telemetered from the carriage via a 405 MHz FM link to a portable, recording ground station.

At the receiver terminal, both receivers are tuned by a common reference through a phased-locked loop, assuring all signals in the link are coherent. A 1.7 degree receiving antenna beamwidth is used at 9.6 GHz. To compare signal statistics relative to beamwidth, a 1.2 and 10 degree beamwidth is used at 28.8 GHz. The BAO tower to the Radio Building path was chosen because an abrupt obstacle (Hoover Hill) shields the path until the carriage reaches a height of 80 meters, a feature which prevents surface reflections from reaching the receiver at any carriage height. It was felt that this would enable a determination of the magnitude of multipath components without a surface reflection. Measurements showed this reasoning was not entirely true, and this will be described in a forthcoming NTIA report.

Figure 3-1 shows a uniform gradient, refractive index profile without a layer and the corresponding signal intensities (Figure 3-3) at each receiver. Note that the classical theoretical knife-edge diffraction pattern is seen at heights up to 150 meters as a result of Hoover Hill. Superrefractive layers, defined as a vertical gradient in the refractivity height profile of greater than 80 N-units/km, exist in the profile shown in Figure 3-2 at heights of approximately 60, 150, 230, and 260 meters. In the corresponding signal intensity plots (Figure 3-4), severe fades resulted during an ascent of the carriage up the tower. Eight minutes later, on the carriage descent, no deep fades were seen but enhancements of 6 to 10 dB were observed. The profiles containing strong layering in the spring (May and June) all showed a very dynamic structure in the atmosphere where the profiles would change substantially in a 9- to 10-minute period (Figure 3-3). Some of the weaker layers producing fades in the neighborhood of 10 dB tended to show stability and uniform stratification over the path. It is believed more stable layers are likely to form in fall and winter.

A second path of almost identical length was established over terrain with good clearance and no obstacle. Receiver beamwidths for this path were 0.6 and 4 degrees. With this combination of beamwidth and ground clearance, atmospheric and surface multipath can be easily separated. A comparison of the two paths showed atmospheric fades in excess of 40 dB, 10 to 20 dB more than the path over Hoover Hill. The reason for this is believed to be the reradiation from the knife-edge obstacle filling in the fades.

A full-wave type model for calculating radio fields from refractivity profiles where it is assumed that the atmosphere is horizontally stratified has been numerically implemented. The model is closely related to the geometrical theory of diffraction and was derived by Hufford et al. (1975 OT Tech. Memo. 75-196, Radio propagation to the offshore extended area, limited distribution). The derivation differs from the geometrical theory of diffraction in that the hyperbolic, two-dimensional Helmholtz equation is converted to the parabolic equation of Fok before the eikonal and transport equations are found through asymptotic analysis. The eikonal equation is solved by the method of characteristics (ray tracing) in the classical way. The results of the ray tracing and the solution to the transport equation are used as parameters in the final solution. The solution is in the form of an integral expansion of the field in terms of plane waves incident on the vertical section passing through the receiver.

The model can be used to predict atmospheric induced fading potential for a specific millimeter wave link. Preliminary results in conjunction with experimental observations indicate agreement in predicting maximum fade and enhancement levels for a given profile. The unstable nature of the refraction layer, due partly to prevailing weather and path terrain, has provided only a limited number of cases for comparison.

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

1 to 1000 GHz Propagation in Clear Air. Atmospheric water in both vapor and liquid state is the major deterrent to an unrestricted exploitation of millimeter wavelengths. For most applications, the operation of ground-based systems is limited to five window regions, W1 to W5, these being the gaps between molecular absorption lines L1 to L6:

L1	=	22 GHz H_2O line
W1	=	24 to 48 GHz
L2	=	60 GHz O_2 line complex
W2	=	70 to 115 GHz
L3	=	119 GHz O_2 line
W3	=	120 to 165 GHz
L4	=	183 GHz H_2O line
W4	=	200 to 310 GHz
L5	=	325 GHz H_2O line
W5	=	340 to 365 GHz
L6	=	380 GHz H_2O Line and 1823 more (H_2O rotational band)

The main attraction of millimeter wave systems is their ability to penetrate the somewhat opaque atmosphere (haze, fog, clouds, dust, smoke, light rain) under circumstances in which electro-optical and infrared systems normally fail. Accurate and detailed knowledge of atmospheric transmission is essential to an evaluation of the advantages of millimeter waves over the shorter wavelengths. The radio engineer uses the optical term clear air for

BOA TOWER

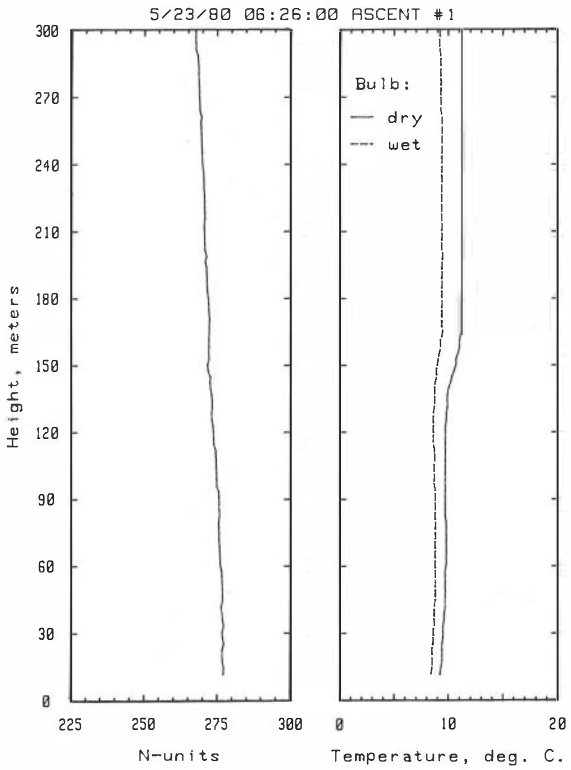


Figure 3-1. Refractivity and temp. profile with no layer on 5/23/80.

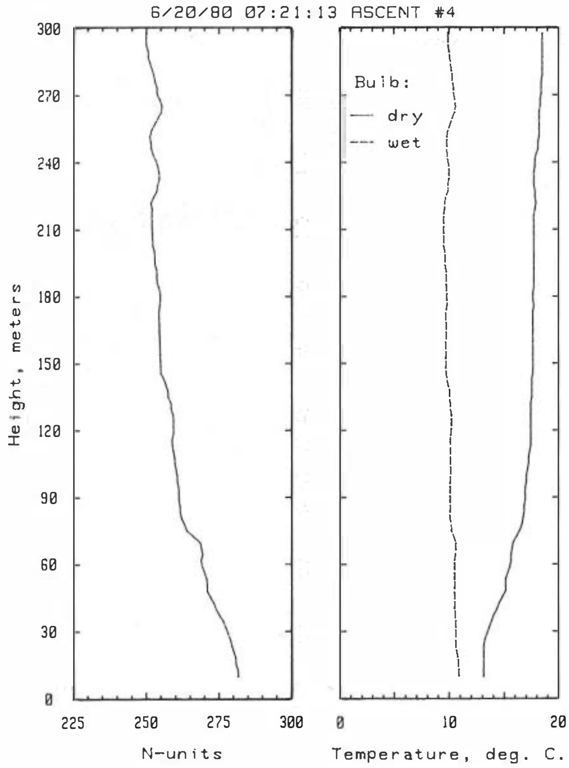


Figure 3-2. Refractivity and temp. profile with layers on 6/20/80.

RADIO BUILDING

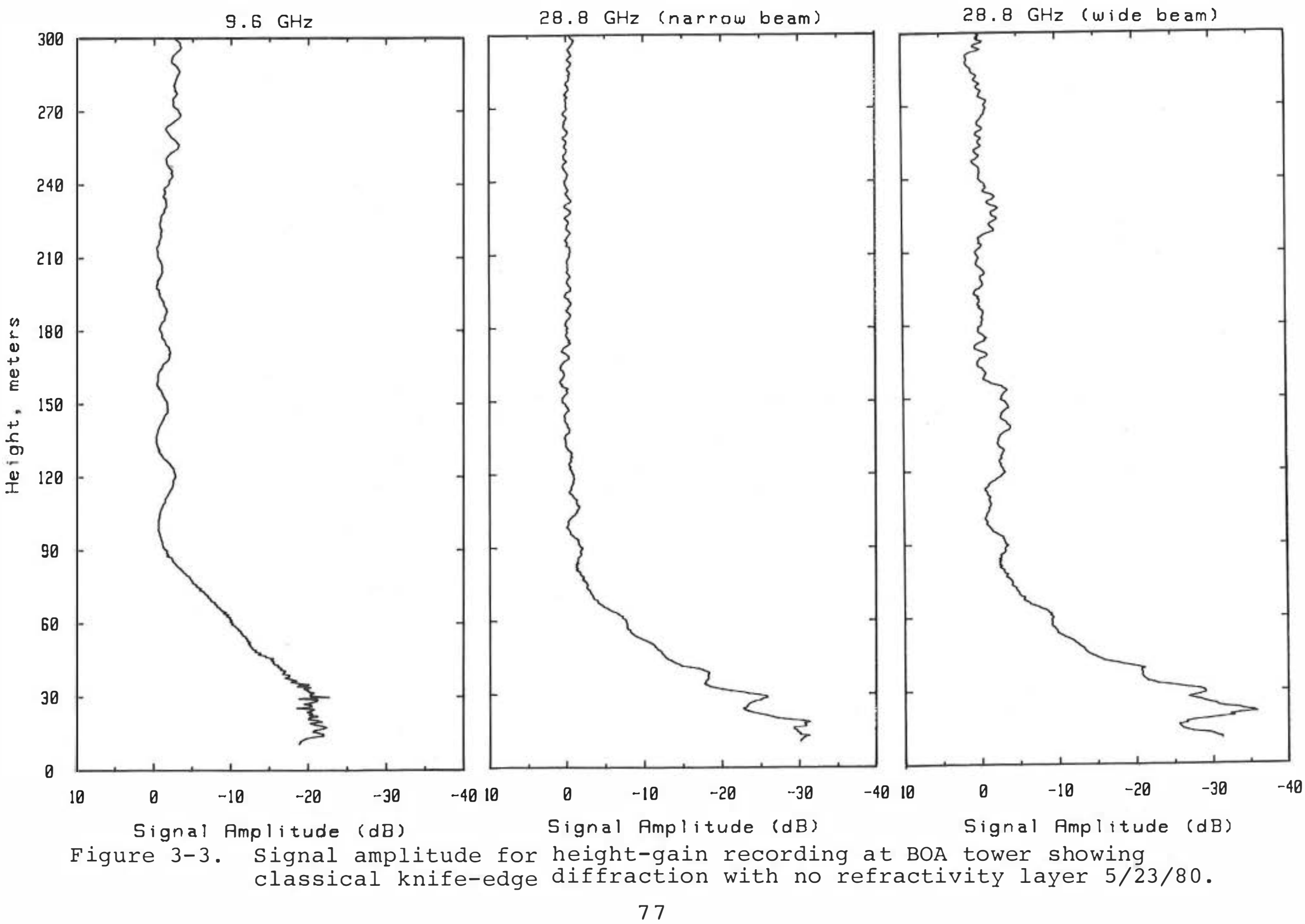


Figure 3-3. Signal amplitude for height-gain recording at BOA tower showing classical knife-edge diffraction with no refractivity layer 5/23/80.

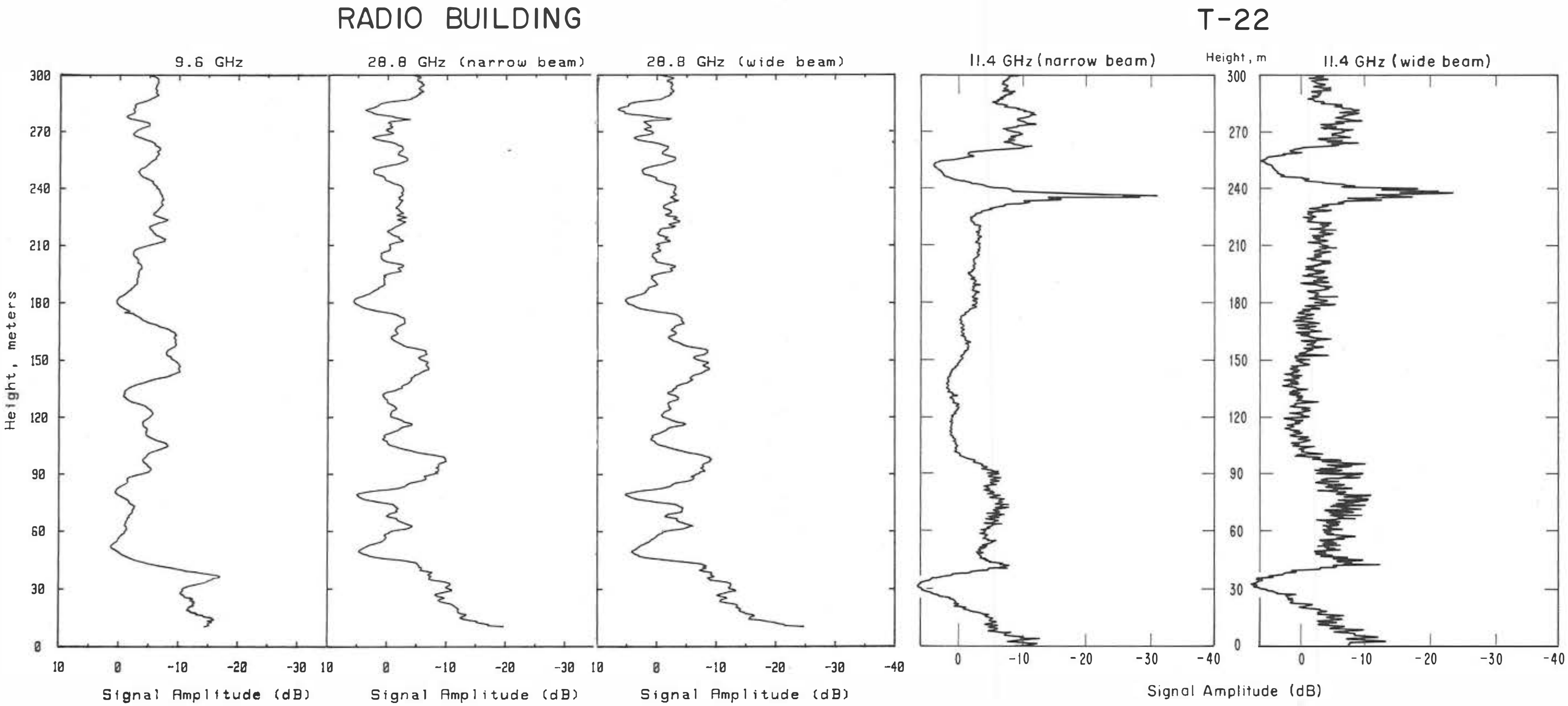


Figure 3-4. Signal amplitude for height-gain recording at BOA tower with refractive layer at 0721 MDT - June 20, 1980.

RH ≤ 100%, ignoring haze conditions. While many constituents contribute to the total atmospheric attenuation rate α (dB/km), absorption in the windows is dominated by water vapor and is of greatest concern for practical situations. It is a fact, even after allowing for difficulties in measuring the highly variable water content quantitatively, that the absorption by water vapor in the atmospheric transmission windows W1 to W5 is not completely understood. Something is happening in the atmosphere, under some conditions, which is not part of conventional wisdom.

A computer model was constructed for atmospheric millimeter wave transmission, subject to the following conditions: frequency ν = 30 to 1000 GHz, with special emphasis on the EHF range, 30 to 300 GHz; altitude h = 0 to 30 km for O_2 to h = 120 km); relative humidity RH = 0 to ≤ 100%.

The path model assumes a spherically stratified atmosphere in which each layer is homogeneous. The evaluation of total slant path behavior is done by the standard layer-by-layer and line-by-line methods. Figure 3-5 gives, in essence, a picture of atmospheric molecular absorption in the millimeter and submillimeter wavelength range. At higher altitudes (h = 16 km), spectral signatures of the trace gases O_3, CO, N_2O appear. At tropospheric heights (h = 0, 4 km), only lines of H_2O and O_2 (see markings at bottom of figure) are important. The attenuation rate spans seven orders of magnitude. The transparency in the window ranges W2 to W5, which are valleys between absorption line peaks, is dominated by a water vapor continuum absorption α_x.

The excess water absorption (EWA) α_x is mostly an empirical matter. Two schools of thought have evolved to explain EWA:

- a molecular approach searching for water polymers $(H_2O)_n$ and their spectra in the atmosphere [sizes of n = 2 (dimer) and n = 3 to 30 (cluster) are possibilities];
- liquid water uptake by submicron aerosol particles under conditions of high relative humidity (RH > 85%).

Each conjecture is supported by some as well as contradicted by other bits and pieces of experimental evidence. Currently, ITS is preparing a laboratory experiment to shed some light on the EWA problem.

An experiment is being prepared to study under controlled laboratory conditions the absolute attenuation rate α (dB/km) of cloudless, moist air as a function of the quantities listed in Table 3-1.

Perhaps the most difficult problem in laboratory studies of water vapor is the attachment of H_2O molecules to the walls of the spectrometer cell. A substantial fraction (1 to >30%) becomes bound on exposed surfaces and, as a consequence, the humid air tested may not be at all representative of the boundless atmospheric state. A paramount consideration is the design of a cell which neither adds nor removes H_2O from the sample air. A sub-pump station was set up for studying humidity instrumentation and for testing passivity measures using stainless steel vessels with various surface coatings. A new spectrometer cell (Fabry-Perot resonator) is being designed based upon the findings.

USAF-ESD/AN/TRC-170 Digital Tropo Tests. During FY 79, ITS conducted special measurements over a number of troposcatter propagation paths in southern Arizona, near Fort Huachuca. 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 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.

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 replica 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 6 ns. 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 results of the measurements were briefly outlined in the ITS Annual Technical Progress Report for FY 79.

A continuation of these measurements was conducted during FY 80 as a part of the test and acceptance phase of the AN/TRC-170 development. This phase of the program is sponsored by the USAF Test and Evaluation Center (AFTEC), Kirtland AFB, NM. The later measurements were performed in the same manner as described above, and the only difference in the sets was

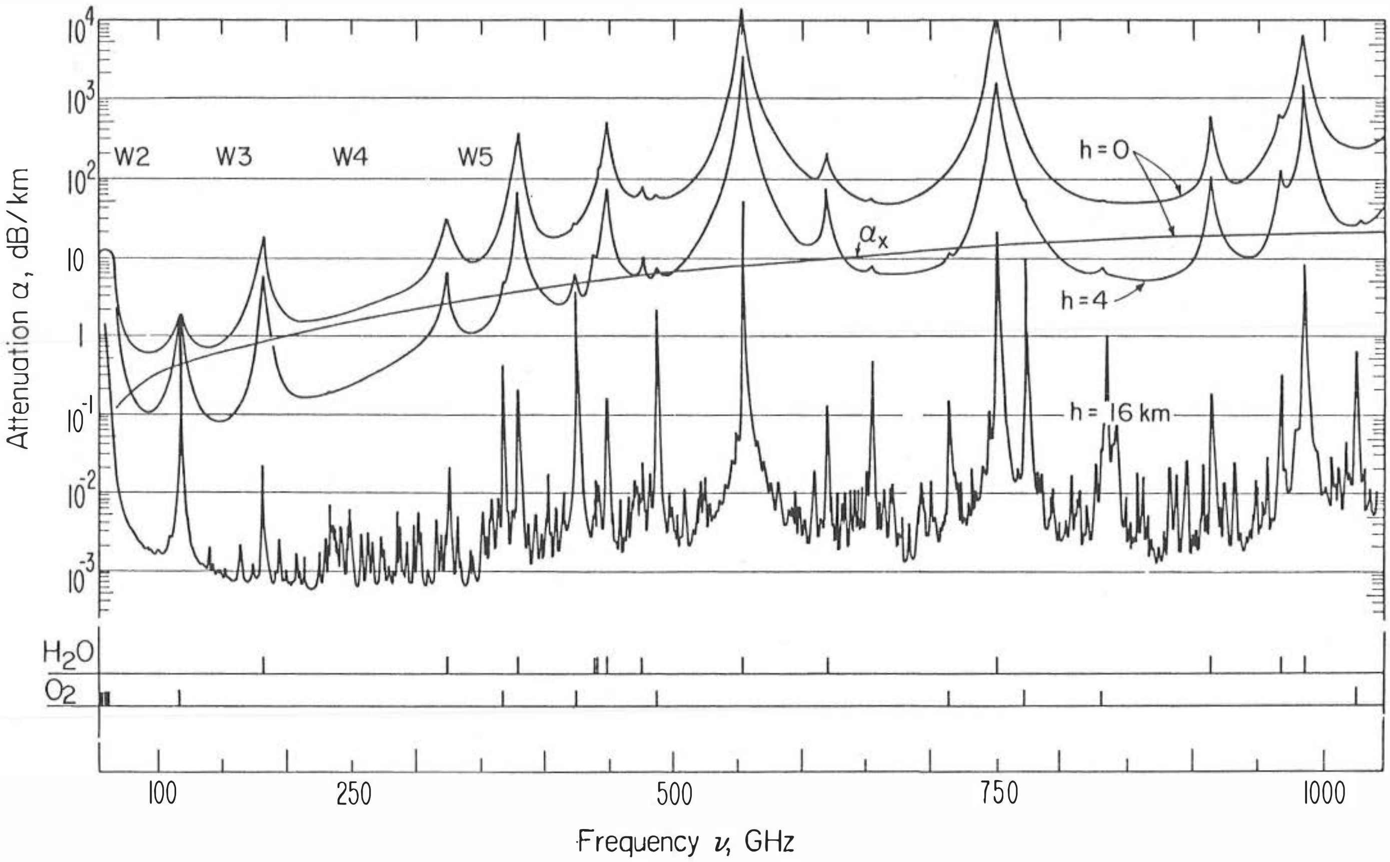


Figure 3-5. Attenuation rate α at the altitudes, h = 0, 4, 16 km over the frequency range, ν = 100 to 1,000 GHz. The following atmospheric conditions (p = dry air pressure, ρ = water vapor concentration and trace molecule number densities M (molecules/m^3) were used in the calculation:

h, km	p, kPa	T, °K	ρ, g/m^3	M (O_3)	M (CO)	M N_2O)
0	101	288	5.91	6.78E17	1.91E18	7.12E18
4	61.6	262	1.10	5.77E17	1.28E18	4.76E18
16	10.4	217	6.1×10^{-4}	3.01E18	2.59E17	9.67E17

Table 3-1. The Variables for an Experimental Study of EHF Attenuation in Simulated Moist Air

			RANGE
Single Frequency	ν	(GHz)	30-60-90-140-220
Dry Air Pressure	P	(mbar)	100 to 1000
Temperature	T	(°K)	250-275-300-325-350
Water Vapor Pressure	P_W	(mbar)	0 to 50
Relative Humidity	R	(%)	50 to 99.9
Aerosol Dry Mass	m_O	(μg/m^3)	0 to 200
Liquid Water Content	ρ_L	(mg/m^3)	0 to 100

the fact that the most recent measurements were made in parallel with performance testing of the AN/TRC-170 equipments over the same test paths. The measurements were completed during August and September 1980. Test results will be published in a final report during the first quarter of FY 81.

Absorption Test at 35 GHz. Millimeter wave devices are anticipated for a low altitude ballistic missile defense. Such devices must operate in severe, nuclear-burst disturbed environments. Of particular concern is the disturbed chemistry exterior to the fireball. The molecules HNO_3, HNO_2, and H_2O_2 have been identified as having increased concentrations which could cause absorption near 35 GHz. The Institute is preparing an experiment to determine the absorption rates for various simulated concentrations. The difficulties with this experiment lie in the corrosive nature of the three test gases. Presently, a static and a flowing gas system are being studied to meet the requirements.

MM-Wave: Vegetation Effects. A measurement of millimeter wave (mmλ) propagation in vegetation is under preparation for the Army Communication Research and Development Command. The objective is to obtain information on signal attenuation, depolarization, and scattering characteristics for propagation through both deciduous and evergreen groves for a variety of foliage density and moisture content at three frequencies near or in the mmλ band. One of the important needs for this information is in the use of vegetation for camouflage of one or both terminals. Later measurements will be aimed at determining channel quality by recording bit error rates on a 500 to 1000 mb/s, QPSK digital link, as well as, time delay spread.

A measurement system has been developed to provide data relative to signal characteristics between two terminals which can be positioned within a path obstructed by vegetation. Both terminals are mounted in 4-wheel drive van trucks with the rf hardware and antennas mounted on an elevator which permits height scans from 1 to 10 meters, with an extension to 16 meters possible if needed. The link will operate at three fully coherent frequencies, 9.6, 28.8, and 57.6 GHz. Beamwidths of the transmitting antennas are 10 degrees on all three frequencies. Receiver beamwidths used are 4.8 degrees on the 9.6 GHz and 1.2 degrees on the upper two frequencies. Narrower receiver beamwidths are also available if higher resolution appears necessary on the scattering components. The receiving antennas mount on a remote control positioner to scan in azimuth and elevation. All antennas are linearly polarized and can be quickly changed from vertical to horizontal to cross polarization. A 70 dB dynamic range and a minimum sensitivity of -100 dBm is available on all frequencies. The photograph in Figure 3-6 shows the transmitting terminal and Figure 3-7 the receiving terminal.

To describe vegetation density, an attempt will be made to photograph a light beam at night on each measured path with a standard exposure. Because considerable data and theory are available on propagation through vegetation in the frequency range of 100 to 200 MHz, the voice communication link at 163 MHz will also be attached to the elevator to determine if meaningful measurements are possible with this link.

Measurements of single trees and groves of trees have been successfully completed in the Boulder, CO vicinity and results will be reported after the recorded data have been processed and assembled.

30-300 GHz Communication Links. A study was conducted for the State Department to determine the interference level in the millimeter wave band that can result from a variety of scattering, diffracting, and reflecting surfaces common to an urban area. A frequency in the atmospheric attenuation window of 38 GHz and a frequency at the peak of the oxygen absorption band (13 dB/km) of 60 GHz were compared using a state-of-the-art hand held communicator. Each used lens antennas with approximately a 3° beamwidth. An interference condition was assumed when one communicator would lockup on the carrier of the unit used to transmit. Observations were made within buildings and outside but near walls of buildings. Many non-line-of-sight paths produce lockup at both frequencies.

Separations of 3 and 10 km were also investigated, and with the 38 GHz, some non-line-of-sight lockups were still possible. However, only line-of-sight lockups were possible at 60 GHz. At 10 km, only line-of-sight paths produced a lockup at 38 GHz and no lockup was possible at 60 GHz.

Some field intensity mapping was performed, assuming high-gain parabolic antennas and best known state-of-the-art receiver sensitivities for frequencies of 40 and 60 GHz.

3.2.2. Ionospheric Characteristics and Effects

HF Ducted Propagation. In April and June of 1979, high frequency (HF) radio signals were launched into a trapped ionospheric (ducted) mode by a transmitter in Australia and returned to ground by an artificial scatterer created by the high powered (HF) transmitter at Platteville, CO. The experimental work was performed for the Rome Air Development Center in 1979 to determine if low-loss trapped propagation modes exist and if field-aligned irregularities produced by the large rf field generated by the Platteville transmitter at ionospheric height could provide a reflector to recover the trapped signal from the ionosphere. Observations were made during all hours of the day and night, but only when the transmitter was at the day-night terminator were trapped-elevated modes detected. The reason for this is well known from the around-the-world signal observation and depends on appropriate tilt of the ionized layers to permit the signal to become launched into a trapped mode.

The effort on this project is directed toward reviewing the available propagation data and determining the probable ray paths of signals transmitted from Australia and scattered to the

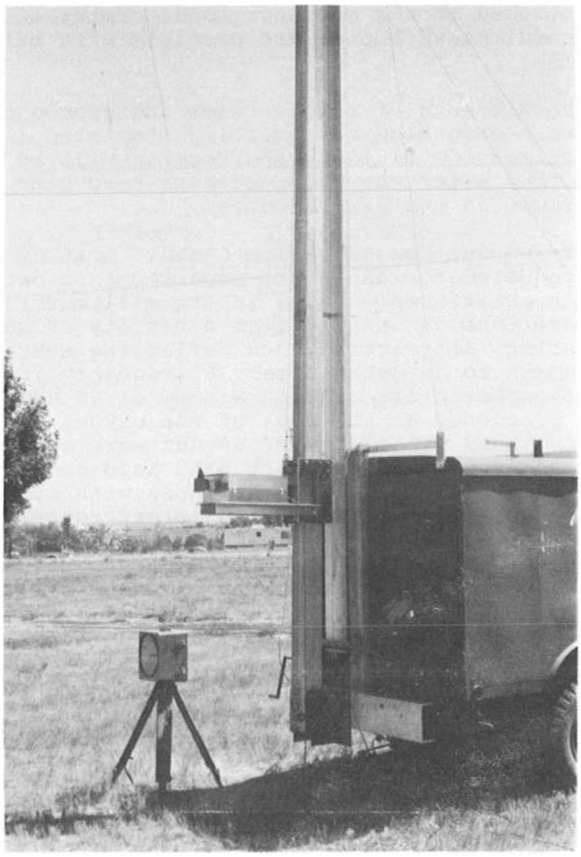


Figure 3-6. Photograph of transmitter terminal for vegetation measurements.

Figure 3-7. Photograph of receiver terminal for vegetation measurements.

receiving sites in the United States by the modified ionospheric region above Platteville. The electron density distribution along the path from Australia to the U.S. has been obtained from the IONCAP program for the appropriate solar and geophysical conditions. A ray tracing technique is used to determine the most likely modes of propagation. Emphasis is placed on simulation of long distance ducted modes and on inferring the ionospheric condition that could lead to supporting a ducted mode. The simulated results are compared to the measured data for both normal multi-hop and scattered modes. Time delays were computed for each mode, which limited the possible paths taken by the trapped mode and aid the analysis. Figure 3-8 shows a ray plot taken from the IONCAP program of the path for conditions indicated.

Signals received from Australia via the artificial field-aligned scatter are tabulated in terms of reflector heights, signal strength, and propagation delay. Data recorded at the receiving site from a transmitter located in the U.S. provide an estimate of the artificial field-aligned scatter cross section distribution. The data observed at the receiving sites have been reduced to absolute signal levels and these are compared to calculated values using appropriate heater heights and receiving site geometry.

Since the magnetic field vector is inclined southward at 67° to the earth's surface over Platteville and the maximum received signal strength will result from specular reflections at normal incidence to the field, the optimum receiving locations for recovering trapped modes are in southern Colorado and northern New Mexico.

Topside HF Noise. In order to assess the HF environment in the topside ionosphere, ITS has continued to investigate 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. By producing and analyzing maps, 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 agrees with the manner in which the HF spectrum is utilized for terrestrial 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.

Current studies in this area are being directed toward assessing the detailed interaction between a radio wave of terrestrial origin and the ionospheric plasma as the wave passes through the ionosphere to a satellite-borne platform. In addition, maps of HF noise intensity during sunrise-sunset and dawn/midnight periods are being analyzed.

HF Antenna Simulation. The Institute undertakes studies of the ionosphere in order to predict ionospheric propagation effects. The basic prediction program used for assessing ionospheric propagation conditions (IONCAP) was intended to provide the necessary data for the design of HF communication systems and for selection of frequency complements for such systems. A substantial effort has been devoted to the development of antenna models and a program code to be used with the IONCAP program. The intention of this effort is to create an antenna package to be used with the HF sky-wave predictions.

Radio waves under consideration here have been reflected from the ionosphere and thus have traveled a considerable distance. This allows the problem to be viewed as two parts: (1) the local effect of the ground at the transmitting site on the antenna, and (2) the local effect of the ground at the receiving site on the antenna. Further, the assumption of plane-wave reflection is justified for this sky wave case.

The analysis of the antenna models was broken into two logical subdivisions:

(a) the exterior (radiation) problem which deals with the interaction of the antenna with the propagation medium; and

(b) the interior (circuit) problem which deals with the interaction of currents, voltage, etc. within the antenna system itself.

The solution to the interior problem is implemented as precalculated curves or as measured curves where available. The exterior problem is implemented using the equations as developed by ITS. For arrays of dipoles, the practice introducted by Uda of expressing the array equations as that of the resonant dipole element and a reduced array factor is used. This procedure results in a computer code which is quite stable and fast in running time. There are no matrix inversion routines nor any use of the complex arithmetic routines.

The revised code includes all the antenna types previously included with the IONCAP program. The old antenna submodules were designated as ITSA-1 as part of the ITSA-1 prediction program (Lucas, Haydon, "Predicting Statistical Performance Indexes for High Frequency," 1966) and as ITS-78 as part of the ITS-78 prediction program (Barghausen, Finney, Proctor, Schultz, "Predicting Long-Term Operational Parameters of High-Frequency Sky-Wave Telecommunication System," 1969; and Haydon, Leftin, Rosich, "Predicting the Performance of High-Frequency Sky-Wave Telecommunication Systems [The Use of the HFMUFES 4 Program], 1976). The version of the ITSA-1 code which was on the CDC-3800 computer was used as the basis of the revised code as this contained more antenna types and more stable code. The code was subdivided into separate modules and then additional antenna types added. The initial version of the revised code is designated as IONCAP VERSION

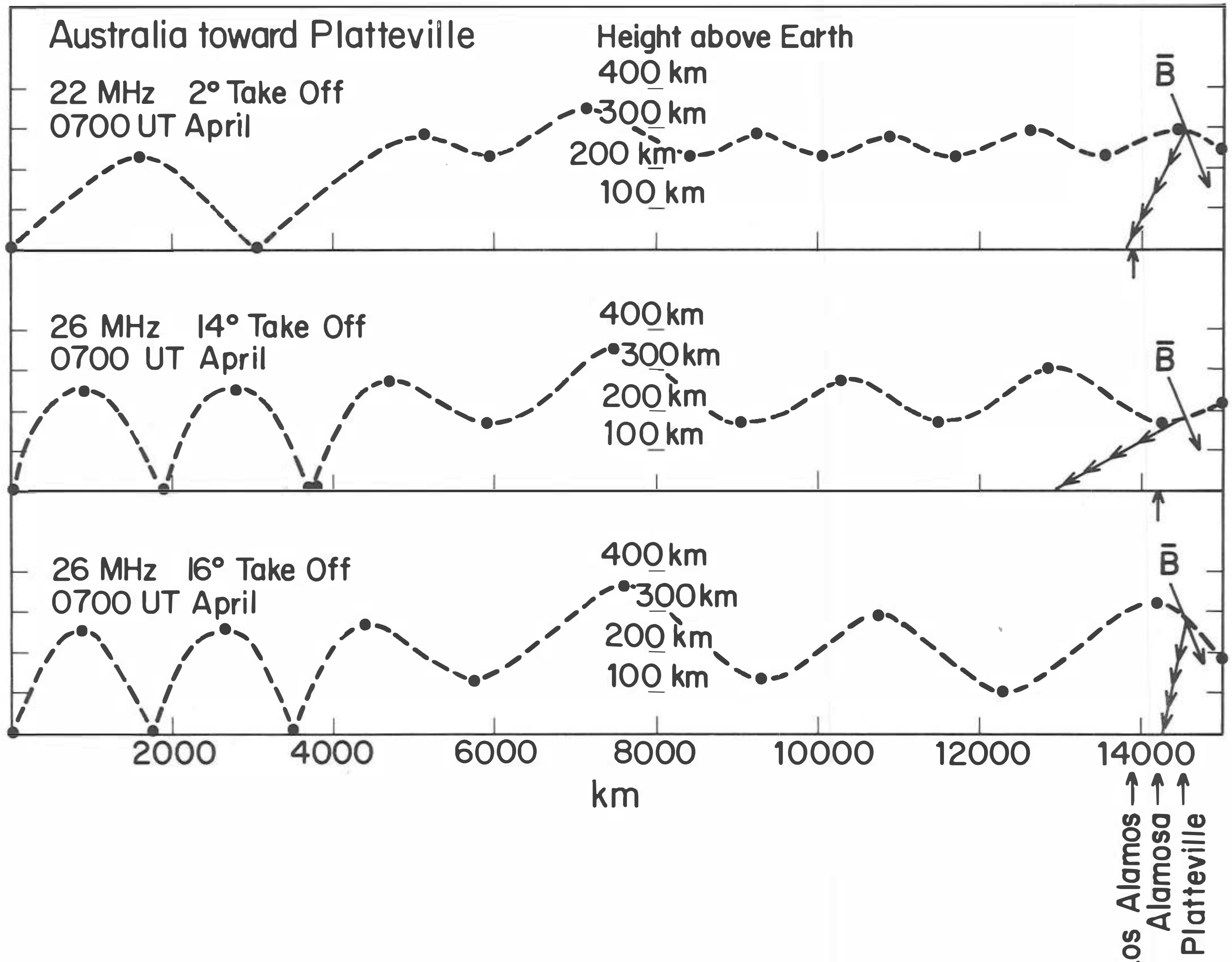


Figure 3-8. Ray plot from IONCAP showing one and two surface hops before elevated mode is achieved.

80.01 (first version completed in 1980). The primary simplification used was to solve the interior problem in free space. The resulting antenna patterns are reasonably accurate when the antenna systems are well designed, and the frequency complement specified is within the design limits. All of the antennas modeled in both the ITSA-1 and the ITS-78 package are included in the new package. The new antennas added are the log periodic array of vertical dipoles, stacked arrays of such LPD arrays, and the Hermes 8E13 endfire array of vertical loops.

In addition to the antenna work, a survey of ground-wave propagation was undertaken in order to include this effect into the sky-wave prediction program. The problems associated with this addition are of three kinds: first, the actual antenna gains to be used with the ground wave; second, the ground wave model itself; and third, the combination of the ground wave with the sky wave, including the statistical variation of each. The intended procedure was to initially take an existing ground wave program and make only the necessary interfaces with the existing IONCAP program. This does not appear feasible at this time. The available programs do not address the problem of the antenna-to-ground wave, nor the statistics of the signal strength. Also, they are in some places oversimplified due to physical assumptions and in others overly complicated.

The propagation problem can be divided into four parts depending upon the configuration of the system: the near field close to the antenna (which will not be included in the model); the line of sight region, from the near field to near the radio horizon; the diffraction region well beyond the horizon; and the intermediate region between the diffraction region and line-of-sight region. The problem is further complicated by the nature of the atmosphere and by the nature of the ground. There are many practical engineering solutions to this problem. All of them are useful when the nature and limitations of the approximation are understood.

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 nonionized 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. Reports that have been published thus far include: "A Preliminary Catalog of Programs and Data for 10-100 GHz Radio System Predictions," OT Report 78-141; and "An Additional Catalog of Programs and Data for 100 MHz to 100 GHz Radio System Predictions," 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.

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

Data acquired on this project 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. The 93 km path is primarily over water. The data acquisition period was 1 year beginning April 1979. Recording of data was done using digital magnetic tape after the data were first preprocessed by computer in 1-hour blocks. The data were recorded on strip charts 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 are being analyzed to predict Rayleigh fading incidence occurring during the worst 30-day periods.

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.

Tropospheric Ducting. The purpose of this study was to generate a model for use in determining the feasibility of detecting radar signals beyond the normal radar horizon. The mechanisms considered were tropospheric ducting and earth diffraction. Until recently, models of tropospheric ducts assumed that the ducts were horizontally homogeneous, which led to significant errors when compared with experimental results. Under this study, ducts are treated as laterally nonuniform stratifications in the lower atmosphere.

A Green's function approach was used to derive an expression for the field inside a laterally inhomogeneous duct. The laterally inhomogeneous duct was assumed to have a single step discontinuity.

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. The three links terminating at Mt. Corna were monitored on both 8 and 15 GHz for one year. The two links terminating at Ceggia, Italy, were monitored at 8 GHz for one year. Recording and processing of data are done using the same techniques used for the 15 GHz project.

The types 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.

Preliminary results obtained from this data show good agreement with the Rice-Holmberg (ITS) point rain rate model using the interpretations and data base provided by Dutton (ITS). The long LOS multipath model developed by Morita (Japan) shows good agreement on two of the paths, but is pessimistic for the long path over Lake Garda (probably because of high angles of penetration of the ray path through the atmospheric layers along the path).

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 mechanisms 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, IL.

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

3.3.2. Ionospheric Transmission Models

Polar Ionospheric Propagation. The Institute is continuing support to the Air Force Geophysics Laboratory that is directed toward the assessment of the performance of the CONUS Over-the-Horizon (OTH) radar system. The Institute is tasked with developing models of the structure of the polar ionosphere at times when the OTH radar is operating. These models provide representations of various ionospheric parameters that are then used by the sponsor to simulate actual radar performance.

The polar model that is being developed is a composite representation of a number of different ionospheric parameters. Taken together, these parameters provide the necessary information needed to obtain a complete latitude, longitude, and height variation of the electron density in the polar ionosphere.

The approach adopted in the polar ionospheric modeling is to use actual observations of ionospheric and geophysical parameters to modify and update a first-guess estimate of the electron density in the polar ionosphere. Data obtained from ground-based vertical-incident ionosondes, riometers, and magnetometers located in the polar region are used to effect this updating and modification. In addition to the ground-based data, satellite observations are being used to isolate and position large-scale features of the high-latitude ionosphere such as the auroral oval and the high-latitude trough of ionization that is observed to occur immediately south of the auroral oval. Figure 3-9 illustrates the position of the auroral oval (shown as the dotted area) with respect to the radar coverage area (shown between the striped lines). Also shown on the figure are locations at which ground-based ionospheric or other geophysical data are observed and used in the development of the updated polar model.

As mentioned above, the polar model being developed is a composite representation of a number of ionospheric parameters applicable to the polar ionosphere. The model is adjusted to account for local time and universal time effects. For each time period selected, the following parameters are provided as a function of latitude and longitude:

1. the critical frequencies of E_1, F1, and F2 regions;
2. the heights of maximum electron density in the E_1, F1, and F2 regions;
3. the semi-thickness of the E_1, F1, and F2 regions;
4. E and F region electron density irregularity indicator;
5. absorption parameter;
6. north and south boundary of the auroral oval;

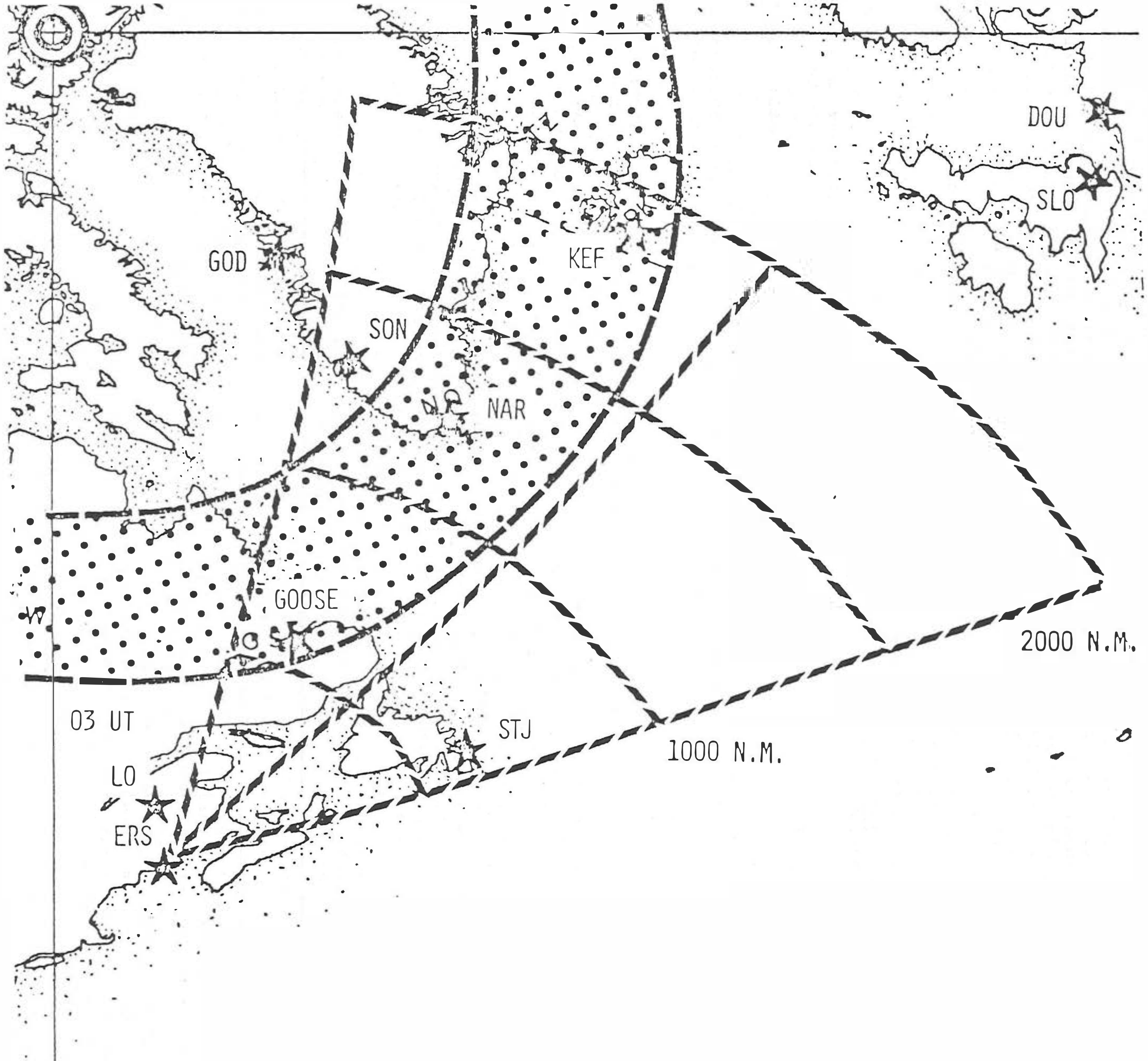


Figure 3-9. Coverage area over-the-horizon backscatter radar.

7. north and south boundary of the high-latitude trough.

VHF/UHF Measurements. Measurement techniques developed during FY 79 to make measurements in the VHF band were used in FY 80 to collect additional data in the UHF band. The Spanish International Network (SIN) started transmitting UHF television on Channel 31 (572-578 MHz) in the Denver metropolitan area during the month of March 1980. SIN receives the signal from the Westar II satellite and rebroadcasts it from an antenna located on the KWGN-TV (Channel 2) tower on Lookout Mountain in Golden, CO. A comparison of the Channel 9 (187.24 MHz) and Channel 31 (573.25 MHz) video picture carrier signals as measured simultaneously along 44th Avenue in Golden is shown in Figure 3-10. There are typical received signal variations measured at a mobile speed of 30 mph over a test course (same route used for FY 79 measurements) of approximately 0.7 miles, which simulated the urban environment of large steel and concrete buildings. Figure 3-11 shows the probability distribution for the data displayed in Figure 3-10, and Figure 3-12 gives the corresponding power spectrum distribution for the two signals.

Statistical analysis of the FY 79 data has shown that in the majority of cases the probability density distribution (Figure 3-11) is not "Rayleigh," and that the actual cumulative distribution function for mobile reception of VHF can be better characterized by an exponential probability distribution (Weibull model) that gives the degree of deviation of the received signal envelope from a random (Rayleigh) multipath effect.

As would be expected, the probability density distribution is only "Rayleigh" when there are no strong specularly reflected waves (which would set up standing wave patterns) and the main line-of-sight beam from the transmitting antenna is totally obscured from the receiving antenna on the moving measurement vehicle by large buildings, terrain, etc. However, in the most general case, there are always specular reflections and the main beam of the transmitting antenna is present along some portions of the measurement route. Consequently, the cumulative distribution function will deviate from a straight line. To investigate the cause of this deviation it is necessary to examine the power spectrum (Figure 3-12). Spectrum analysis of the FY 79 data demonstrated that calculating the spectral density as a function of inverse distance (wave number) normalizes the data to a spatial variation. The magnitude of the bumps or lines in the power spectrum (Figure 3-12) may indicate the degree to which standing waves, produced by strong specular reflection, have perturbed the fading pattern. However, additional data will have to be obtained and further analysis undertaken to verify this 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 has been conducted for the Department of Defense to determine if there are any systematic differences with either solar cycle activity or season. The observed and predicted foF2 values were compared for the years 1968, 1970, and 1972, and the observed and predicted MUF(3000)F2 values were compared for 1968 and 1972. The average absolute percentage errors for both parameters are given in Table 3-2. In general, the numerical maps adequately represent the observations in those areas where there were a significant number of vertical incidence stations. The predictions for high latitudes in both hemispheres often have larger rms errors, and the predictions are usually too high in local winter. The rms prediction errors are also large for equatorial stations, particularly for the night hours.

The overall results indicate that the 1954-1958 numerical maps do not adequately represent the solar cycle variation, particularly the descending phase of solar activity. The numerical maps of foF2 would be improved by a better definition of the relationship between solar activity and the F2 parameters and by incorporating new or more recent ionospheric observations.

Preliminary results of the application of a theoretical model indicate that this technique could be used to improve the representations in the ocean areas. Comparisons of the observed maximum electron density (NmF2) at vertical incidence stations with NmF2 predicted from the statistical model and theoretical model show that, on the average, the two predictions are comparable. Figure 3-13 shows the diurnal variations of NmF2 predicted using the time dependent continuity equations for three southern latitudes for the South Pacific Ocean for August 1974. Shown also are the AEROS observations and the corresponding predictions from CCIR Report 340. The agreement between the theoretical model could improve the representation of foF2, particularly in the ocean areas.

HF Antenna Simulation. The interactive radar analysis program was delivered to the field site at Fort Monmouth, NJ. This program was jointly developed by ITS and the Naval Research Laboratory (NRL), Washington, DC. The program takes ionospheric parameters as input and the backscatter clutter level as output. Since the computer system at Fort Monmouth does not have a graphics display system, all program codes associated with the graphics were eliminated. Also, the one-way communication area coverage optimum was added. The program input consists of transmitting system information, environment parameters, and ionospheric data. The program then generates an ionogram, a rayset table, and a signal level as a function of distance. If median ionospheric data are entered, the output is then the median signal level. The intent of the program was to analyze the measured radar ground and thus determine the state of the ionosphere in real time.

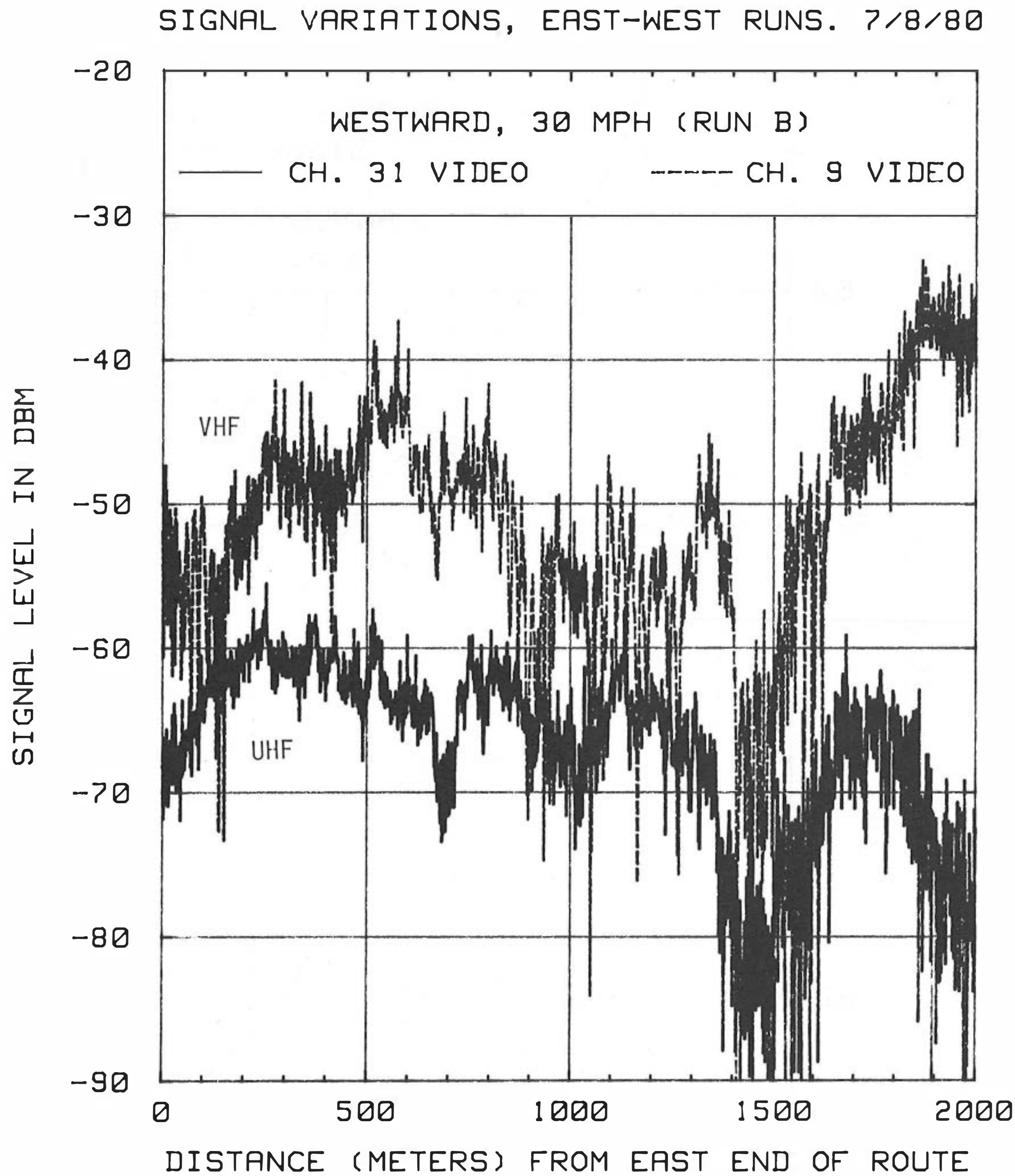


Figure 3-10. Typical received video signal variations of Channel 9 (KBTV, upper trace) and Channel 31 (K31AA, lower trace) measured simultaneously at a mobile speed of 30 mph between 2.5 and 3.5 miles from the transmitter tower site on Lookout Mtn. near Golden, CO.

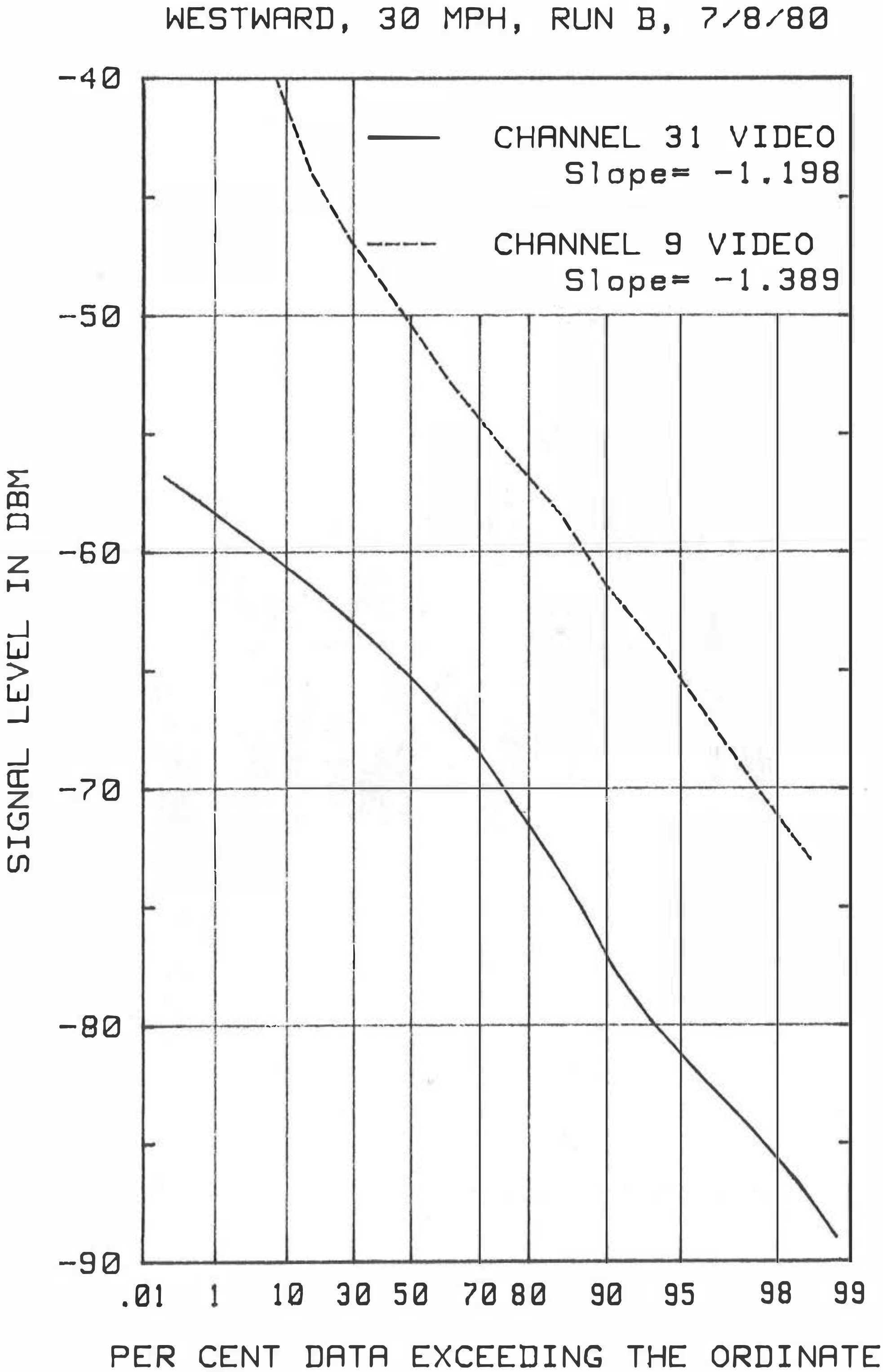


Figure 3-11. Cumulative probability distributions for the Channel 9 (KBTV) and Channel 31 (K31AA) video signals displayed in Figure 3-10.

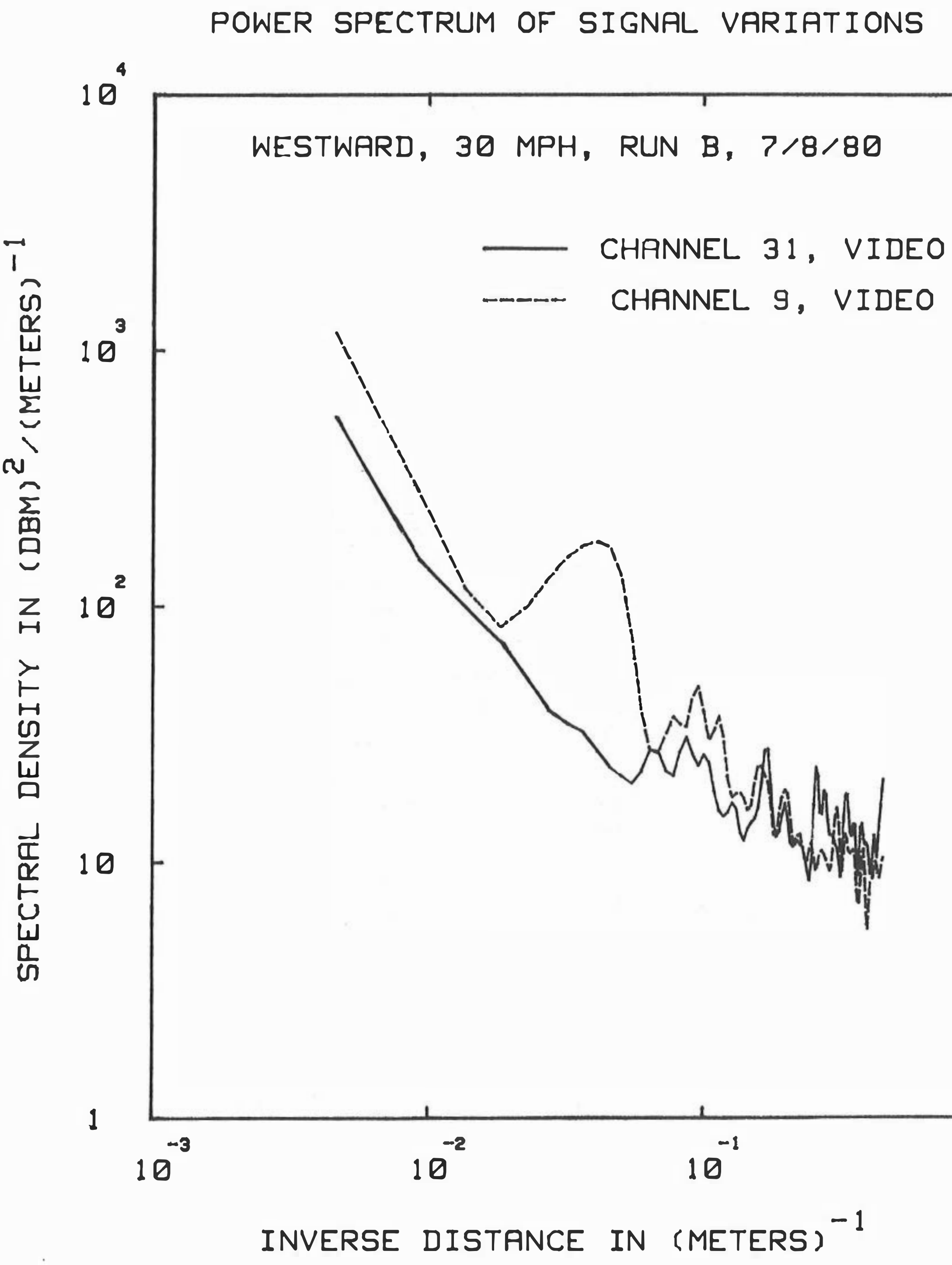


Figure 3-12. Power spectrum of the Channel 9 (KBTV) and Channel 31 (K31AA) video signals shown in Figure 3-10.

Table 3-2. Average Absolute Percentage Errors for the Predicted MUF(3000)F2 and foF2

		MUF(3000)F2								MUF	foF2
		LOCAL ZONE TIME									
Month	Year	0	3	6	9	12	15	18	21	AVG.	AVG.
March	1968	12.2	12.5	10.5	7.6	6.4	4.8	6.7	10.6	9	8
	1972	12.6	13.2	8.7	7.6	7.6	7.7	9.6	9.7	10	8
June	1968	14.7	14.6	13.5	9.2	7.6	8.8	10.7	14.4	12	8
	1972	16.0	17.1	13.6	11.6	9.0	11.5	12.0	14.2	13	10
September	1968	19.9	17.0	10.7	8.3	5.8	4.4	6.1	11.2	10	10
	1972	12.3	13.3	10.0	8.5	9.2	9.6	13.4	12.8	11	10
December	1968	17.5	21.2	19.7	9.5	8.1	5.8	13.2	14.6	14	14
	1972	18.8	14.9	14.2	7.5	9.0	7.3	10.9	12.9	12	12

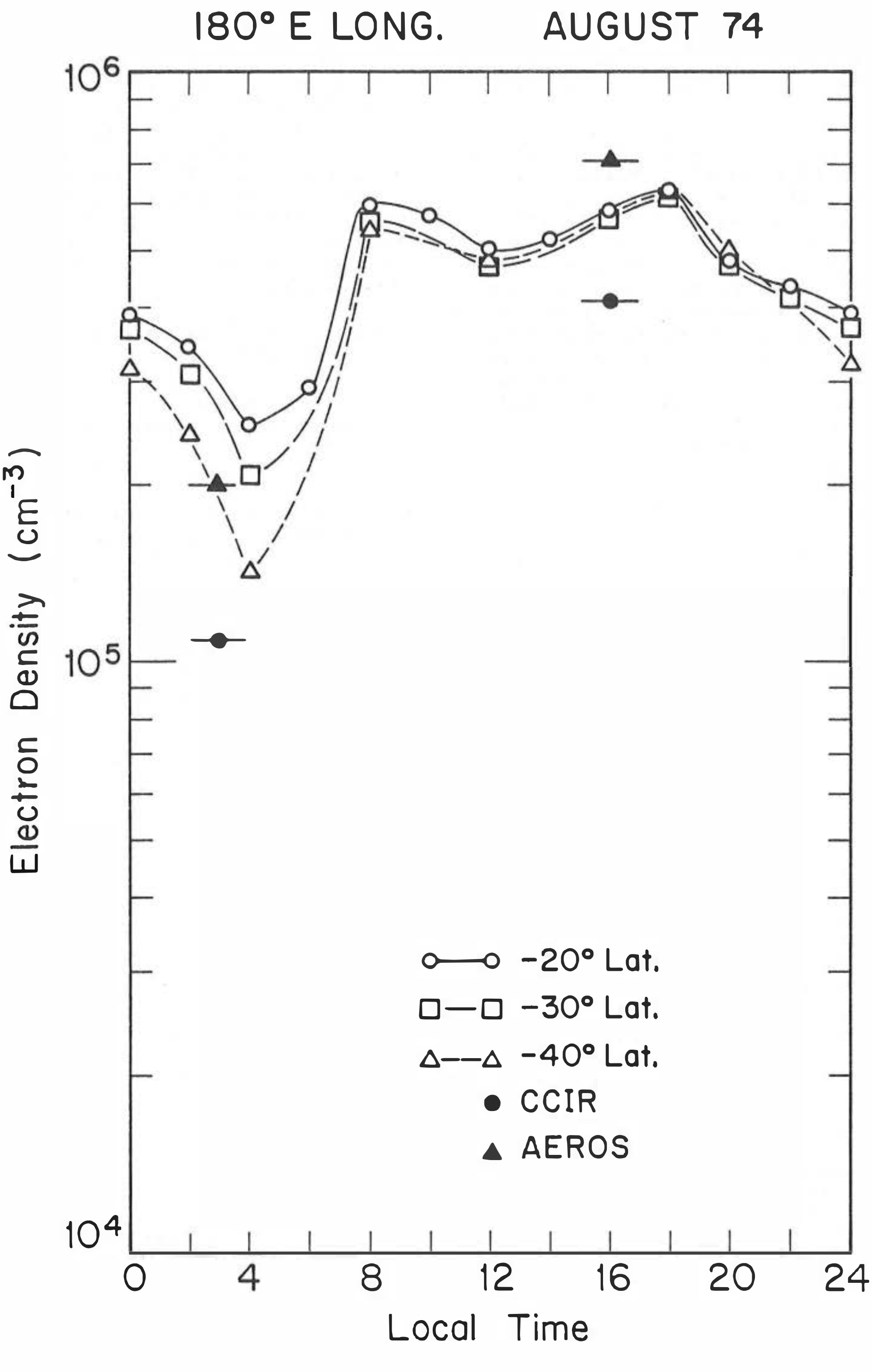


Figure 3-13. Comparison of observed and predicted NmF2 for South Pacific Ocean, August 1974.

HF Ground Wave. The general goal of this project is to provide a quantitative understanding of ground-wave propagation over complex propagation paths beyond the optical horizon. The primary application is low-angle radar coverage over land, sea, and sea ice.

Ground-wave propagation over land and sea has been well understood for some time, but there have been numerous reports of anomalous propagation over ice covered seas at high latitudes. A theoretical model of a lossy ice layer over highly conducting sea water has been analyzed. Earth curvature effects are included, and the ice layer can be either isotropic or anisotropic. Extensive propagation results have been computed for frequencies from 2 MHz to 20 MHz, and the effects of the various ice parameters (dielectric constant, loss tangent, and thickness) have been thoroughly studied. The primary effects of the ice layer are to increase both the magnitude and phase angle of the effective surface impedance and to support a trapped surface wave. At short ranges (i.e., < 10 km), the trapped surface wave can dominate the conventional ground wave modes, but at large ranges the field strength is generally degraded due to the ice layer.

The height variation of the ground wave field has also been studied. The trapped surface wave supported by an ice layer is found to decay rapidly with height in the same manner as conventional surface waves on planar structures. The conventional ground wave modes increase with height, and the height variation is found to contain diagnostic information which could be useful in remote sensing of the sea ice parameters.

Ground-wave propagation over mixed paths has also been studied for various land, sea, and sea ice transitions. The "recovery effect", that is well known for propagation from land to sea, is also predicted for propagation from sea to sea ice. The transition is found to act as a secondary source in exciting the surface wave in the sea ice portion of the path. The mixed paths effects are found to be reduced for receivers at elevated heights.

Microwave Multipath Analyses. Over the past several years, ITS has collected propagation data relative to atmospheric multipath in LOS microwave communication systems. These data were measured using a psuedo-random noise (PN) probe that measures the effective impulse response of the transmission path (R. F. Linfield, R. W. Hubbard, and L. E. Pratt, "Transmission Channel Characterization by Impluse Response Measurements," OT Report 76-96, 1976). The data were derived from a number of projects, sponsored by the DoD, in which the probe was used to investigate other propagation phenomena. The probe measures independent delay components in the received signal with a resolution of 6 ns. However, components with delays less than this period (on the order of 1 ns) can readily be observed in the analysis of the data.

The USACEEIA at Fort Huachuca, AZ, has been tasked to perform various performance tests and studies in support of the development of the Digital Radio and Multiplex Acquistion (DRAMA) radio system. The DRAMA system will be the military version of a digital microwave communication system to be used on LOS links in various parts of the world. There is a lack of documented data relative to atmospheric multipath parameters that are likely to be encountered over certain links where these systems will be deployed. Thus, in order to provide some preliminary summaries, USACEEIA has sponsored a project in ITS to analyze the existing data. The data base includes measurements made in both United States and European locations. The latter includes some data recorded during tests performed on the Digital European Backbone (DEB) Stage I links during 1975 and 1976.

The data were analyzed by ITS to provide the following summaries:

1. Distribution of the delay-spread of the multipath components. This includes a distribution of the delays that are less than 6 ns.

2. Distribution of the power under the power impulse function at various delay-spread values. This provides a measure of the relative magnitude between the more direct and multipath components in the composite signal.

3. Estimates of the rate-of-change of multipath delay for the major multipath components.

4. Received Signal Level (RSL) fading statistics associated with the periods analyzed for the above data.

The summaries of the above analyses will be compared and/or correlated with the following path characteristics as appropriate:

(a) path length

(b) climate and meteorological conditions

(c) terrain type and variation

(d) other specific link features, including diversity where data are available.

A final report will be published during the first quarter of FY 81.

In Computer Model Extension, we have devised a new version of the Longley-Rice model which extends the region of applicability to very high (50 km) antennas. Usable only for area predictions, this new version has several features that improve the underlying logic and, we believe, the overall accuracy. At present, we are treating it as an experimental version and are planning to subject it to extensive tests.

The U.S. Army Communications Research and Development Command (CORADCOM) is currently planning a multiphase effort spanning several years to obtain empirical data and statistical analyses on which channel characterization estimates may be based for ground-to-ground mobile spread-spectrum communications in the range from 400 MHz to 2 GHz. Potential deployments include varied terrain and foliage.

In Wideband Measurements, ITS is supporting the very early phases of this program. The primary aim this year has been to assemble representative measurement equipment, to deploy it in the field in CONUS, to find what special problems there are when measurements are attempted, and to define solutions to those problems. Because great interest lies in channel characterization in and near forested areas, the field site chosen was in south-central Tennessee where logistic support was available from the Arnold Engineering Development Center and where a forest management program provided us with an excellent test environment.

The principal instrumentation used was a pseudo-noise channel probe which had been previously developed at the ITS laboratories. Its output gives a direct representation of the impulse response for the channel under study. It has a bandwidth of 300 MHz and a pulse resolution of 6.7 ns. The center frequencies used were 600, 1200, and 1800 MHz. Coupled to the probe was a digital data acquisition system which acquired the raw impulse response curves and other pertinent data and recorded these on standard 9-track magnetic tapes. The combination of these two pieces of equipment should provide a powerful research tool.

Figure 3-14 is a photograph of the van used to house the receiver as it appeared in Tennessee. The transportable tower behind it was used in several of the recording sessions. It is shown here positioned so that the receiving antenna is well above the surrounding trees. In other experiments the tower was lowered or the antenna was placed on a short mast so that actual forest penetration studies could be made.

In Figure 3-15, we have taken the digital data and reproduced a single recorded impulse response. In the situation involved here the receiving antenna was on the tower about 8 m above the forest top while the transmitter was buried in the forest about 160 m away. The figure shows the impulse response plotted three times in three different ways. At the top are plotted the co-phase and the quadrature-phase components on the same axis. In the middle is the amplitude--the root-sum-square of the two components. Finally, at the bottom is a kind of Lissajous figure in which the co-phase component is plotted along the x-axis, the quadrature phase component along the y-axis, and time serves as the independent parameter. This latter plot is intended to display the phase relations between the larger multipath components. But we think, instead, that the large open loops and circles here imply that there are really no isolated multipath components, but rather a very dense, unresolvable set of them. The multipath spread of about 300 ns observed in the figure was typical of all measurements involving a radio path passing through the forest.

The Federal Communications Commission (FCC) has been receiving a large number of complaints concerning interference between co-channel stations in the private radio service located in the Los Angeles/San Diego area. Complaints have also been received from customers in the Domestic Public Land Mobile Radio Service (DPLMRS). The problem of long-range co-channel interference in this region also has important implications for a number of other proceedings, including the following:

(1) negotiations with Mexico concerning the use of land mobile frequencies;

(2) UHF-TV studies (low power stations, comparability, reallocation);

(3) studies regarding effects of LM/TV frequency sharing, including the 470-512 MHz band;

(4) interference to LM stations from TV stations on channels 14, 68, and 69;

(5) interference to TV service from LM stations on image frequencies; and

(6) allocation and assignment of frequencies in the 806-960 MHz band including dispatch, trunked, DPLMRS, cellular, and CB systems.

The problem arises from anomalous propagation caused by a persistent inversion layer of air over a moist marine layer along the coast of southern California. Attention has been called to the existence of this anomalous propagation in a number of proceedings before the Commission during the past 20 years. Although some theoretical work has been done and some propagation measurements have been made, the information available is not adequate to permit realistic propagation predictions for the area.

A propagation model for the areas is needed that would predict the degree of signal enhancement for a given path in terms of a percentage of the year and percentage of the worst month with a reasonable degree of confidence. This would permit realistic planning studies and allocation and assignment schemes that took into consideration frequency, geography, distance, and antenna heights in order to maximize spectrum efficiency and limit interference.

In order to obtain the data needed to develop a propagation model for the area, a project, Radio Propagation Measurements at VHF/UHF in Southern California, will be carried out to record signal levels (and then calculate transmission loss) for a period of 1 year over a number of paths involving combinations of terrain types, antenna heights, frequencies, and path lengths. In order to better understand the phenomena involved and permit interpolation of the findings within the area and extrapolation to similar situations in other regions of the country, meteorological data including radiosonde data and/or other data will be obtained and correlated to the measurement data.

Ideally, data would be taken over a large number of paths involving four to five ranges of each of the various parameters involved--terrain type, antenna height, frequency, and path length.

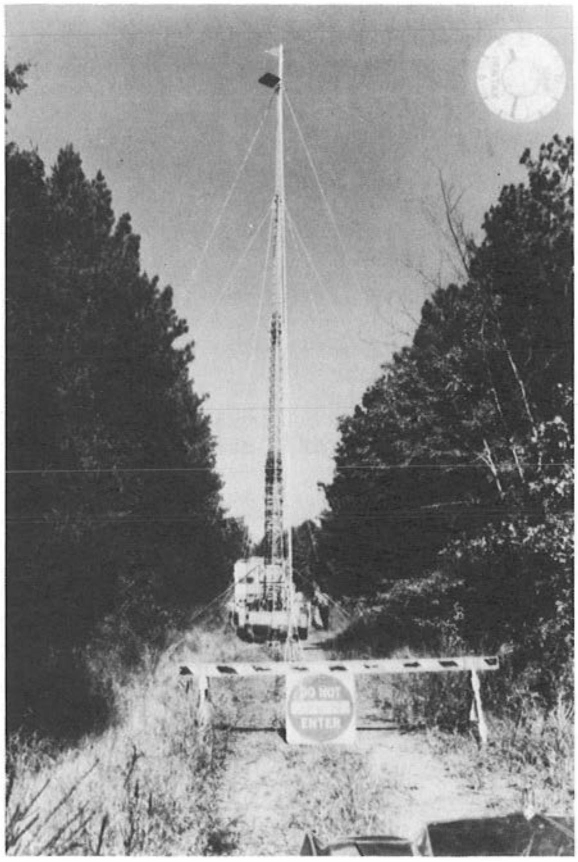


Figure 3-14. The receiving van and antenna tower in Tennessee.

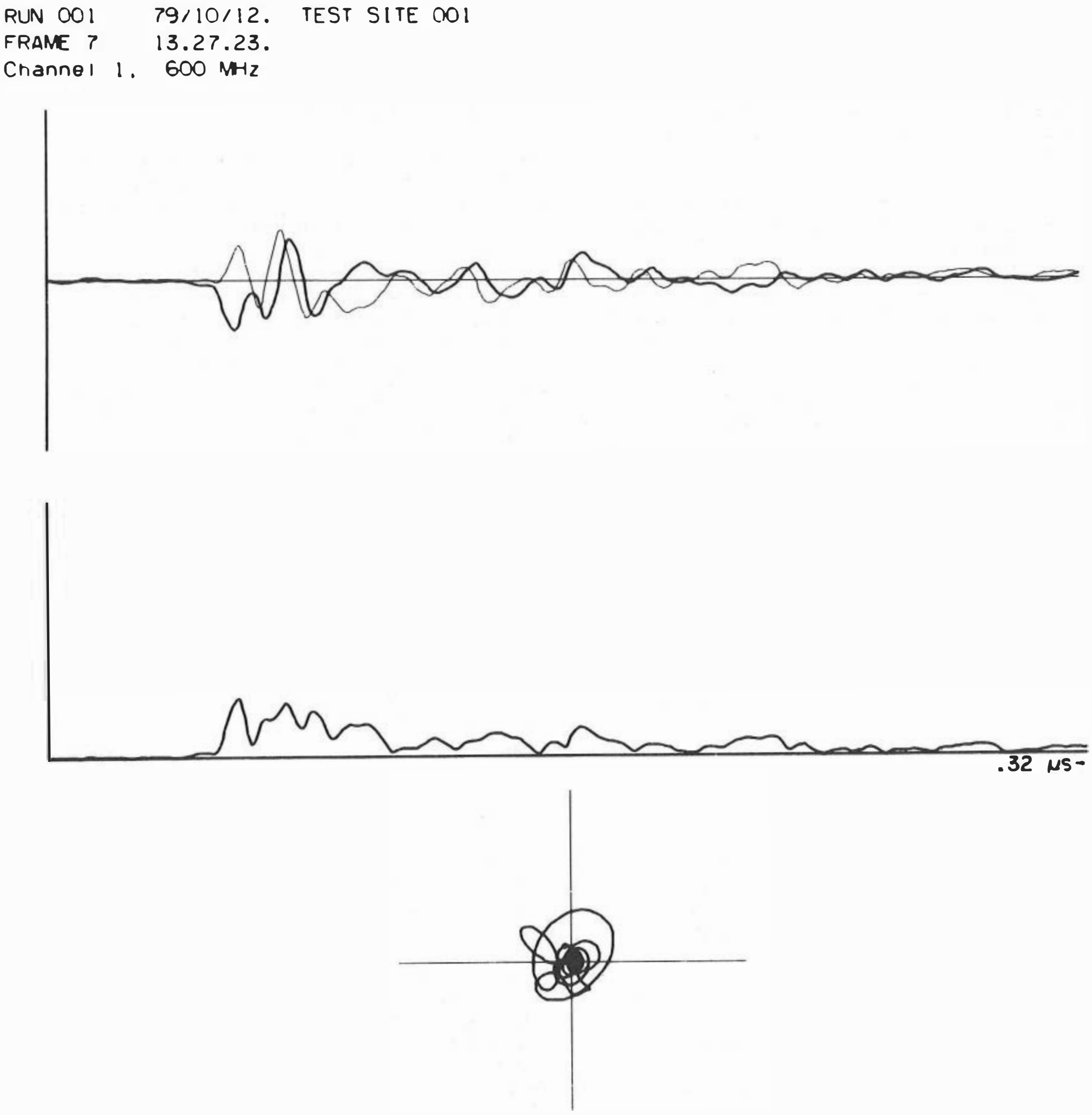


Figure 3-15. Three representations of a recorded impulse response after the wave has travelled through the forest.

It is anticipated that a minimum of 25 to 35 paths will be recorded, including:

(1) a variety of paths for each of three frequency ranges--150, 450, and 900 MHz;

(2) transmitters and/or recorders on certain specific commonly used mountain tops--Santiago Peak, Sierra Peak, Mt. Wilson, and Mt. Lukens; and

(3) a variety of path types including all or mostly over water and mostly over land.

There are several possibilities regarding the signal sources--dedicated transmitters purchased for the project, manufacturer-supplied and radio user operated transmitters, and transmitters supplied and operated by other Government agencies (e.g., U.S. Navy) and signals of convenience, including land mobile and TV.

This project will be carried out in three phases. The first phase, which has been completed, addressed the planning for the long-term measurements. The second phase, also completed this fiscal year, allows for detailed propagation measurement system design and procurement of some of the needed hardware and equipment. The third phase, anticipated for the next fiscal year, will provide for the final development and assembly of three propagation measurement systems, final testing, and deployment of those systems.

The results of phase one were documented in an informal letter report to the FCC. The contents of that report are:

(1) a review of the propagation phenomena involved based on available theoretical and empirical studies and interference reports;

(2) recommendations as to paths, recording sites, and transmitting sites required to obtain needed data;

(3) recommendations as to signal sources;

(4) recommendations as to meteorological data needed and sources; and

(5) recommendations as to desirable data sampling rate, amount of on-site data reduction, statistical parameters to be recorded for reduced data, and the desirability of variable sampling rates.

Based on the FCC's response to the recommendations, phase two of the project was undertaken. The propagation measurement system design has been better defined and about one-half of the needed hardware and equipment has been procured.

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 worldwide HF broadcasts.

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

CDC 6600 files have been maintained for local batch processing and, under the VOA Time Share Service, they are available for use by means of 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). The Institute made predictions for TRT Telecommunications Corporation; Polar Research Laboratory, Inc.; Naval Underwater Systems Center; National Telecommunications and Information Administration; Canadian Marconi Company; Cohen & Dippell; Gulf Oil Communications; HCJB World Radio Missionary Fellowship; BR Communications; Adventist World Radio; International Aeradio (North America), LTD; Mr. William A. Kissick, ITS; and Phillips Petroleum Systems.

The following organizations received tapes of IONCAP including auxiliary material (test data numerical maps, and documentation) for use on computers accessible to them: Naval Research Laboratory; Computer Science Corp.; Interstate Electronics Corp.; Naval Underwater Systems Center; Polestar Communications, LTD., Canada; U.S. Department of Energy; Remote Measurements Laboratory; Philips Telecommunications, Netherlands; General Electric Company; E-System, Inc.; USAF Rome Air Development Center; Page Iberica, SA, Spain; and Minister of Information, Saudi Arabia.

Region 2 MF Broadcasting Conference. The ITS has played a significant role in the preparation of U. S. positions that were presented at the Region 2 MF Broadcasting Conference. In addition, ITS personnel have participated in numerous meetings leading up to the conference as well as the conference itself.

The Institute participated in the CCIR IWP 6/4 meeting in early October 1979. A CCIR report providing the output of this meeting was published in December. The NTIA positions with regard to MF allocation and usage were coordinated with appropriate CCIR and FCC individuals.

Preparation for the 6th CITEL Working Group meeting was undertaken. As part of this preparation, an analysis of potential inter-regional interference using the Cairo North-South curves was conducted. This analysis was submitted to the U. S. delegates to support the U. S. position. Also undertaken was a study to investigate the distribution of received signals in order to determine if interfering signal levels exceeded various percentages of time.

In January 1980, the Director of ITS participated in the 6th CITEL/ITU meeting for the first session of the Regional Administrative MF Broadcasting Conference (Region 2). He was part of the U. S. delegation and participated actively in discussions concerning 9 kHz channel spacing and increasing protected signal levels in high noise areas. During the month of March 1980, he also attended the Region 2 MF Administrative Broadcasting Conference as a member of the U. S. delegation.

As a fall-out of this program, ITS has developed computerized methods of calculating MF sky-wave field strength to assess interference potential from emitters in Regions 1 and 2.

3.4.2. Medium Frequency Transmission Studies

Planning for FCC. Medium frequency sky-wave emissions from locations south of the United States border in ITU Region 2 (the Americas) have interfered with the performance of some U. S. AM broadcast stations. To verify the extent of this interference, the Federal Communications Commission (FCC) has proposed a measurement program whose data will be used to derive a more accurate field strength prediction model. Current accepted models tend to underestimate field strengths in Region 2. Such a program requires gathering data over a long period of time so that effects of frequency, geomagnetic latitude, ionospheric loss, and solar activity can be properly evaluated.

The Propagation Predictions and Model Development Group has developed a plan for such a medium frequency field strength measurement program. The plan includes sources to be monitored, other stations on co- or adjacent channels which might affect the desired field strength measurements, the receiving sites, and the propagation paths between the sources and receivers. Also, the plan includes the possible design of the monitoring system, including the antenna system, cost estimates, and expected delivery times. Further discussion is included about the measurements themselves and the data parameters to be obtained, as well as on-site data reduction requirements.

MF Sky-wave Propagation. As part of the support ITS has given NTIA in its initiative to the Federal Communications Commission to reduce the channel spacing for AM broadcasting from 10 kHz to 9 kHz, the Propagation Predictions and Model Development Group has undertaken three field trips to ascertain the extent of inter-regional interference. Three locations were chosen as the most probable for reception of interfering signals. The sites were San Clemente Island, CA; Belfast, ME; and Key West, FL. At the San Clemente site, 18 Asian stations were tentatively identified by their mid-channel carriers. There were no audible AM signals from these stations, however, and no audible heterodynes with the adjacent channel broadcasts of United States stations received at the site.

The Belfast site was located at the FCC monitoring station there. In addition to the antenna on the monitoring equipment, high gain, directional antennas at the monitoring site were available for use. Signals were received from 15 foreign sites with audio modulation detectable from some Caribbean stations, two West African stations, and one European station. The other stations had detectable carriers at inter-channel frequencies. Again, no heterodyne effects were audible on received U. S. stations. Table 3-3 summarizes these observations.

At the Key West site, several Central and South American as well as Caribbean stations were received. In many cases, three or more stations were audible on the same channel. This made possible identification difficult, but 17 out of 35 stations of interest were audible with carriers identified on 9 of the remaining 18 channels. The ambient noise at the Key West site was noticeably higher than the other sites because the monitoring occurred in May, whereas the other monitoring occurred in January and February. There were no heterodynes audible on received U. S. stations.

Microwave Interference by Elevated Layers. As one aspect of radio spectrum management, the efficient allocation of frequency assignments is very much dependent upon the determination of coordination distance (the minimum permissible geographic separation between co-channel stations without formal coordination). Determination of this distance requires the capability of predicting both service fields and interference fields.

As a result of this year's and the previous fiscal years' activities, a consolidated model for UHF/SHF telecommunication links between earth and synchronous satellites has been described in a technical report (NTIA Report 80-45). This model is presented in the form of engineering-type formulas which consolidate all of the known external elements significant for system performance. This UHF/SHF model, adoptable for subsequent updating, includes state-of-the-art estimates of noise, attenuation, depolarization, and turbulence. The role of system geometry in signal depolarization is presented, and the basis for the evaluation of linear versus circular polarization is developed. The conventional figures of merit are included; the determination of earth/satellite service fields (desired signals) and potential earth/satellite interference fields (undesired signals) are described. See Figure 3-16 which illustrates the earth/satellite service and interference path geometries. The application

Table 3-3. Monitoring Summary for the Belfast, ME, Site

MONITORING OF MF SKY WAVES AT BELFAST, ME

F(KHZ)	TIME (LOCAL)	ANTENNA*	AUDIBLE AM SIGNALS	RECORDED AGC, AM AUDIO	MOST LIKELY STATION	POWER (KW)
567	1425	1	YES	YES	TULLAMORE, IRELAND	500
575	1922	1	NO	NO	TIRN SAN JOSE, COSTA RICA	50
585	1940	1	NO	NO	VIENNA, AUSTRIA	1200
595	1945	1	NO	NO	ROSEAU, DOMINICA	10
725	1934	1	NO	NO	TILX SAN JOSE, COSTA RICA	2
756	1950	1	NO	NO	BRAUNSCHWEIG, GERMANY	800
765	1650	1,2,5	YES	YES	DAKAR, SENEGAL	400
800	2020	3,5	YES	YES	PJB BONAIRE, NETH-ERLAND ANT.	500
834	2030	1,5	YES	YES	BELIZE, HONDURAS	20
1035	1920	1,5	YES	YES	4VCL HAITI	10
1134	1805	1	NO	NO	BIOGRAD, YUGOSLAVIA	1200
1386	1740	1	NO	NO	KAUNAS, USSR	1000
1395	1735	1,5	NO	NO	LUSHNJE, ALBANIA	1000
1403	1720	1,2,5	YES	YES	KIPE, GUINEA	400
1555	1710	1,5	YES	YES	GEORGETOWN, GRAND CAYMAN ISLAND	10

*1 = LOOP, 2 - E-W RHOMBIC, 3 - N-S RHOMBIC, 4 = MONOPOLE, 5 = WULLENWEBER DF

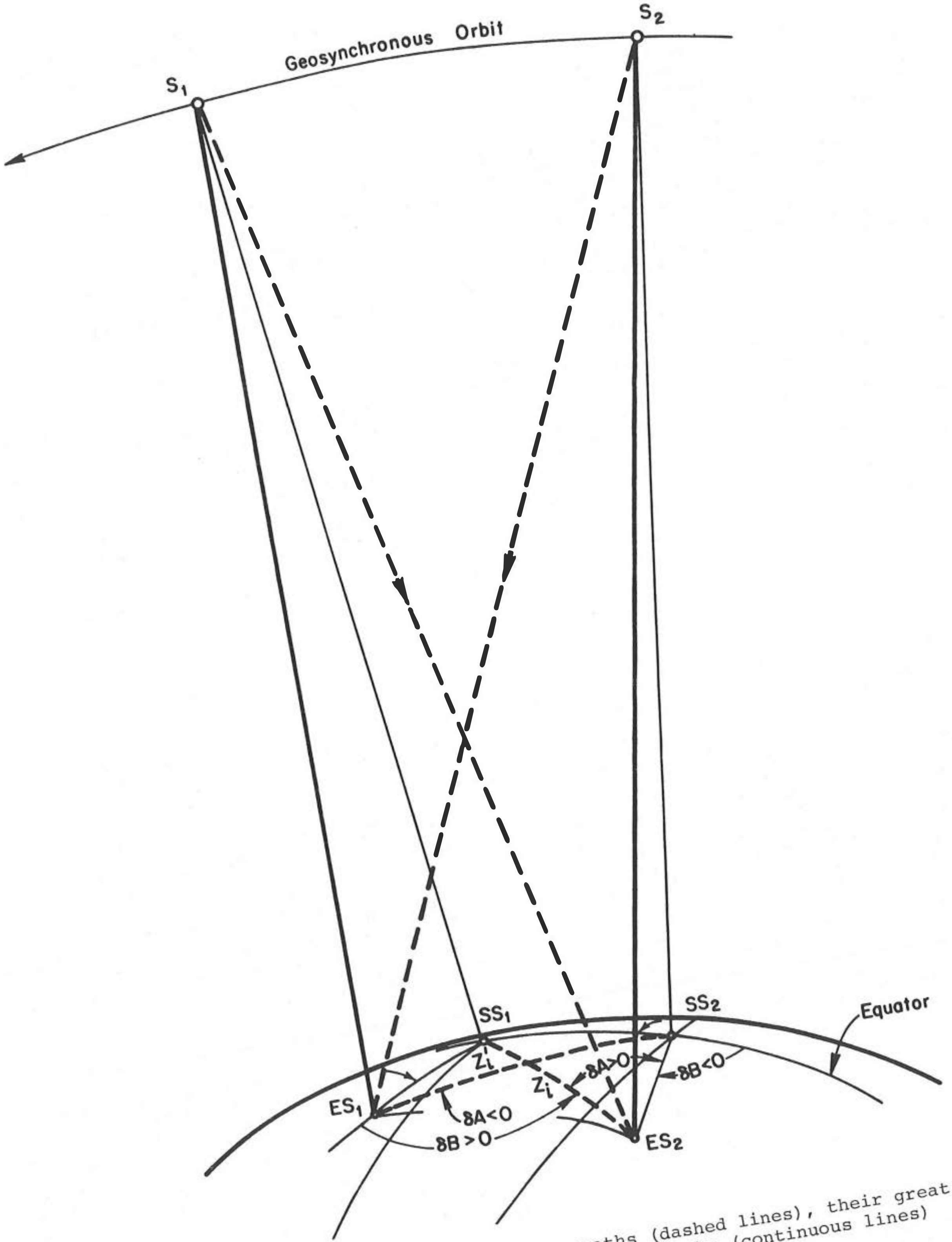


Figure 3-16. Earth/space interference paths (dashed lines), their great circle projections, and service paths (continuous lines) for two systems (ES_1/S_1 and ES_2/S_2).

of the formulas and graphs given in the above report are also illustrated by numerical examples; their associated derivations are either referenced or described in appendices.

NTIA has also initiated a study to develop engineering methods for the prediction of potential interference between terrestrial stations. This reduces essentially to the problem of predicting the occurrence of those meteorological conditions (such as atmospheric refractivity layering) which support interference fields. By using the results of previous studies, one can predict the occurrence of those elevated layers conducive to the long-distance, low-loss propagation typical of the more serious, otherwise unexpected, interference. Figure 3-17, for example, illustrates the occurrence of elevated ducting layers for the U.S.A. There, the contours describe the percent of all hours of the most favorable month that elevated ducting layers would be expected to occur for arbitrary locations in the continental U.S.A. A report will summarize the associated layer characteristics pertinent to the interference (via elevated layers) problem, based upon historic radiosonde data. This report provides a preliminary estimate, detailing the limitations of the presently available data and likely means of improving that data base. The report also describes the presently available methods for applying this derived meteorological data to the prediction of interference fields.

In recent years, there has been a renewed interest in the foundations of the radio propagation models that are in use today for many practical applications at VHF and higher frequencies. Two such models of especial interest are the ITS, or Longley-Rice, model and the FCC model for FM and television broadcasting. In particular, several organizations have now had the opportunity to compare model predictions with one or another set of measured data; and they often find, to their dismay, that the discrepancies are much larger than they would like. They are therefore concerned whether (1) the model is inaccurate, (2) they are misapplying the model, or (3) they are misinterpreting the results.

The project Engineering Models (VHF/UHF for Broadcast and Mobile) has the goal of helping out in such studies and of making independent studies of its own. For applying models and for interpreting results, we want particularly to set forth rules and procedures which can be used in common agreement by all organizations involved. In this way we would hope to eliminate the last two concerns listed above, leaving only the question about model accuracy.

Clearly, these studies depend a great deal upon measured data. In past years and also at present, there have been many measurement programs devised to collect precisely the data needed. These programs have been carried out by many organizations, ITS and its predecessors being one of the more active. The first step in our present project, we feel, should be to collect as many of these data as we can and to assemble them into a consistent series of machine readable files. This we have been doing. We have, for example, reduced to machine readable form a very interesting set of data which simulate land mobile operations in fairly rugged mountains. Taken for the U.S. Army long ago in 1964, these data were thought to be lost to the community. But we have been fortunate this year to have been given a copy of the original report, thus providing us all the necessary information.

WARC Study Program. Programs to develop the technical material required for planning the use of HF bands allocated to the broadcasting service were prepared for the Voice of America. Emphasis is on the preparation of material for submission through the CCIR in preparation for a World Administrative Radio Conference for HF broadcasting.

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 secion deals with a variety of programs which show the broad spectrum of applied electromagnetic sciences.

3.5.1. Antennas and Radiation

Over the Horizon Radar. In 1975 ITS built a new phased-array, over-the-horizon radar on San Clemente Island off the coast of California. During the mid-to-latter part of FY 79, considerable effort was expended to refurbish and update the San Clemente facility (i.e., environmental protection for the 25 antennas, design update of all 25 transmitters, and a new digital data acquisition recorder).

The primary function of this facility is threefold: observations of airborne and surface-borne targets, and observation of the wind-generated waves on the ocean's surface. The most recent efforts have been directed toward identifying and classifying surface targets such as freighters, tankers, destroyers, cruisers, etc. Each test requires several minutes of data at ten or more frequencies between 2 and 30 MHz. The tests also require that the target present several aspect views to the radar when a cooperative target vessel is being observed by the radar.

During this period, field operations were manned for the measurement of two U.S. Navy fighting ships. These operations were part of a program intended to determine the feasibility of extracting sufficient information from multi-frequency radar cross-section data to (a) broadly categorize the target, e.g., between naval or commercial shipping, and, (b) in the case of naval ships, to identify the type or class of ship. Information from one of the tests is under examination by the Naval Research Laboratory. System difficulties prevented the acquisition of useful data from the second test.

Figure 3-18 gives an example of the measurements. The figure plots radar cross-section (in dB) against Doppler frequency. The measurement data shown were taken with the target ship

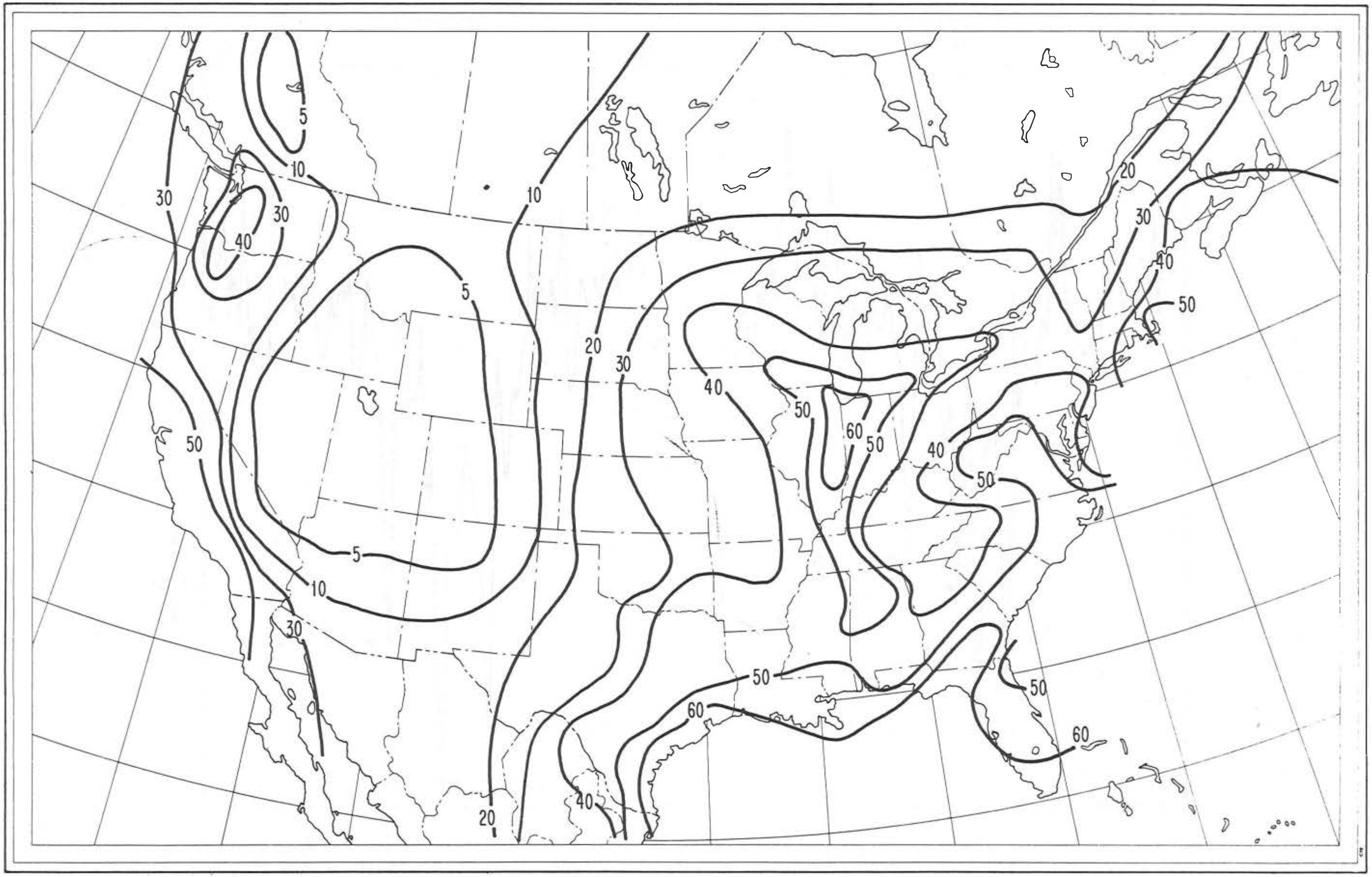


Figure 3-17. Contours of the percent of occurrence for elevated ducting layers during the most favorable month over the continental U.S.A. and in the vicinity of its borders.

Legend

A - Sea waves advancing towards the radar
O - Zero Doppler (target not moving and/or Santa Barbara Is.)
R - Sea waves receding from radar
S - Ship moving towards radar

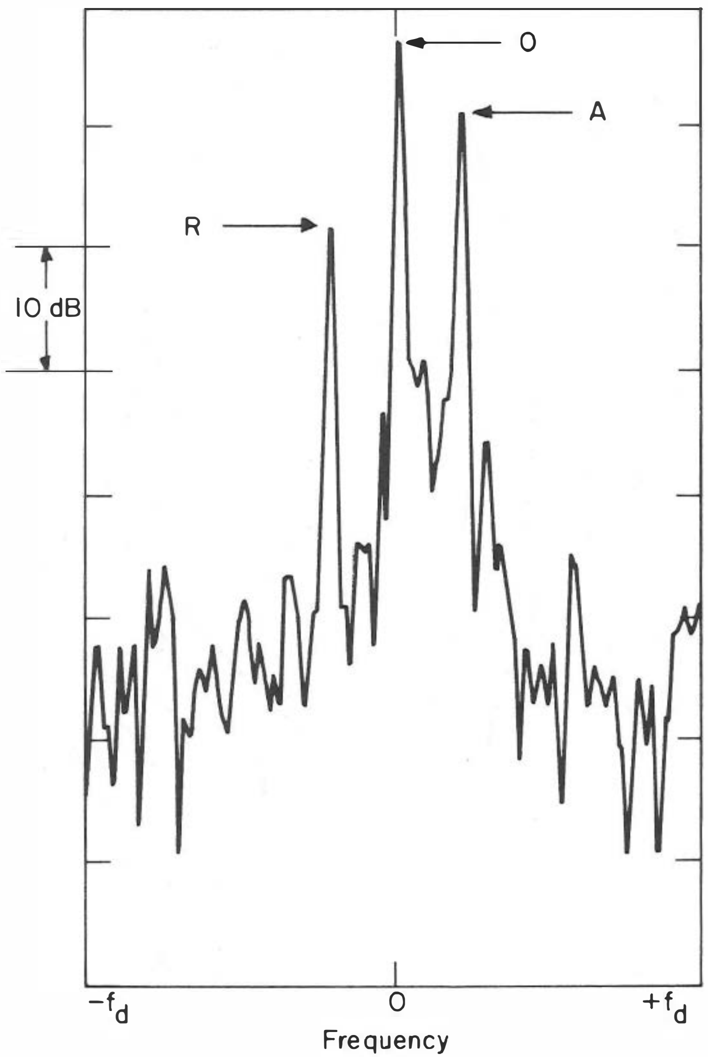


Figure 3-18. Radar Doppler with stationary ship.

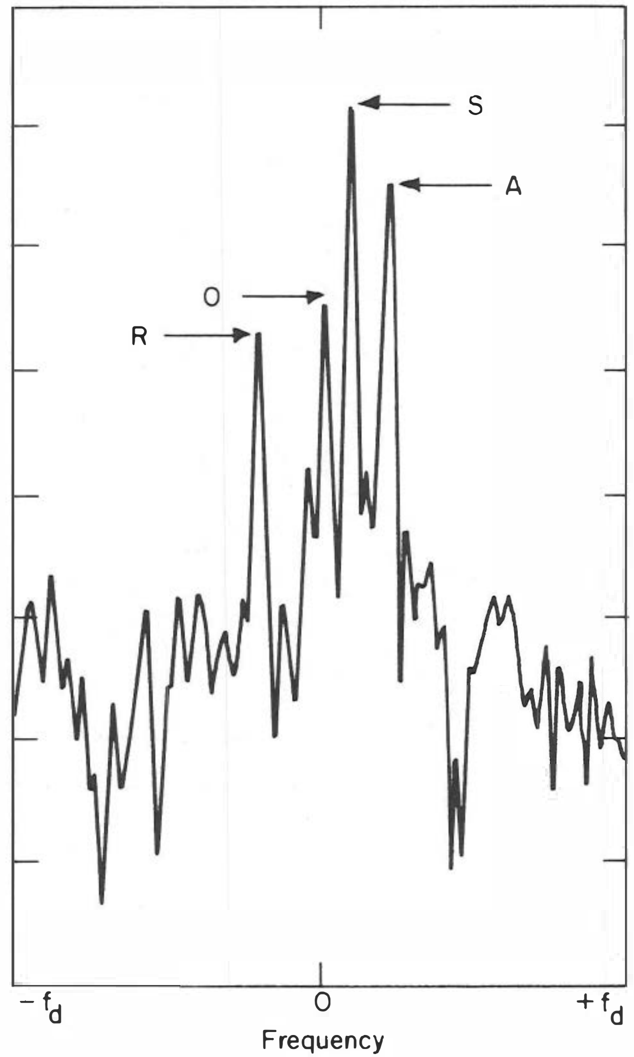


Figure 3-19. Radar Doppler with moving ship.

lying broadside to the radar and substantially dead in the water. Figure 3-19 shows the resonant lines produced by the sea (far left and far right), a radar return at zero Doppler produced by Santa Barbara Island, and finally, the ship showing a slow translation toward the radar. The zero Doppler of Figure 3-19 agrees with the results of a measurement made 6 minutes earlier than Figure 3-18. The ship signature is clearly merged with the land return signal, but by comparison, is significantly higher.

EM Waves in Mines. Various subsurface electromagnetic wave problems have been analyzed for the U.S. Bureau of Mines. The applications are to both operational and emergency communications in mines.

The surface fields produced by a buried loop antenna of arbitrary shape have been analyzed. Extensive calculations have been performed for the special case of rectangular loops. The application of this geometry is to uplink emergency communication at ELF. The rectangular loop geometry arises from the constraints of the standard room-and-pillar mining where wire loops can be strung around the remaining rectangular coal pillars.

The problem of VHF transmission in a network of intersecting tunnels is important for operational mine communications. A tunnel junction can be characterized by a scattering matrix which relates the transmitted and reflected modes to the incident mode. The approach is similar to that employed by microwave engineers on waveguide junctions. An important finding of the analysis is that the corner loss is quite high for the low order modes. This high corner loss will limit communication into crosscut tunnels unless some type of scatterer can be installed at junctions.

A related hazard problem involves coupling of radio signals to blasting cap circuits. Calculations of the pickup current in blasting cap circuits have been made for various geometrics and frequencies. An important finding is that the induced current is essentially proportional to frequency and to the dimensions of the blasting cap circuit.

Some basic transmission loss estimates were supplied to the Pacific Missile Test Center (PMTC) in response to the consulting task of the Ground/Air Propagation Prediction project. These were intended to help PMTC resolve a potential radio frequency interference (RFI) problem associated with an electronic warfare (EW) transmitting site.

3.5.2. Transmission Through the Atmosphere: Applications

SPS Ionospheric Heating. The United States Department of Energy (DoE) is investigating a number of different alternatives in order to meet the energy needs of the Nation in the twenty-first century. One of the alternatives currently under study centers around a Satellite Power System (SPS). The current systems concept with regard to the SPS is the placing into geostationary orbit of one or more satellites equipped with photovoltaic cells to produce direct current from solar radiant energy. Each satellite, which will be 10 km long, 5 km wide, and 0.5 km thick, will be equipped with instrumentation to transform the dc produced by the solar photovoltaic cells to microwave energy at the satellite. The microwave energy will be transmitted to the surface of the earth at a frequency of 2.45 GHz, which currently falls within an industrial, scientific, and medical band (ISM) allocation of the electromagnetic spectrum. At the surface of the earth, the microwave energy will be rectified and conditioned to interface with utility grids. The input into the utility grid is designed to be somewhat larger than 5,000 MW of continuous power for each SPS.

There is concern that the operation of the SPS may result in substantial changes to the earth's environment. The ITS is undertaking, for the DoE, an effort to assess the impact of the operation of the SPS upon the ionosphere. The power density associated with the passage of the SPS microwave power beam as it is transmitted from geostationary orbit to the surface of the earth is 23 mW/cm^2 at the beam center. Such power densities are of sufficient intensity to give rise to changes in the electron temperature and electron density in the earth's ionosphere. These changes, in turn, can affect the performance of telecommunications systems that rely upon the ionosphere as a medium for electromagnetic propagation.

Numerous telecommunications systems rely on ionospheric reflections or trans-ionospheric propagation as part of their communication signal path. Any system that can significantly modify the ionosphere has the potential to produce wide-ranging telecommunications interference. In addition, the role of the ionosphere in solar-terrestrial coupling and climate change is not well understood. As a result, modification of the ionosphere by the SPS microwave beam is of general concern.

The environmental and system impacts on the ionosphere that ensue from passage of the SPS power beam will depend on the degree of beam self-focusing, the size of the resulting large-scale density striations, and the change in ionospheric temperature. Figure 3-20 provides an artist's concept of how telecommunication systems could be impacted by the operation of the Satellite Power System. The figure shows an SPS beaming energy to the surface of the earth and giving rise to an enhanced electron temperature in the D region and the formation of irregularities in the F region. Telecommunication systems, whether they be situated on the surface of the earth or in space, can be affected by the modified ionosphere. The modifications in the ionosphere result from the heating of the ionosphere as the SPS microwave power beam is transmitted from satellite orbit to the surface of the earth.

Because of the frequency involved (2.45 GHz), the heating that the SPS power beam will provide to the ionosphere is believed to be that arising from ohmic interactions between the power beam and the electrons, ions, and neutral particles comprising the ambient ionosphere. The rate of energy that is input into the ionosphere by ohmic heating due to radio waves is given:

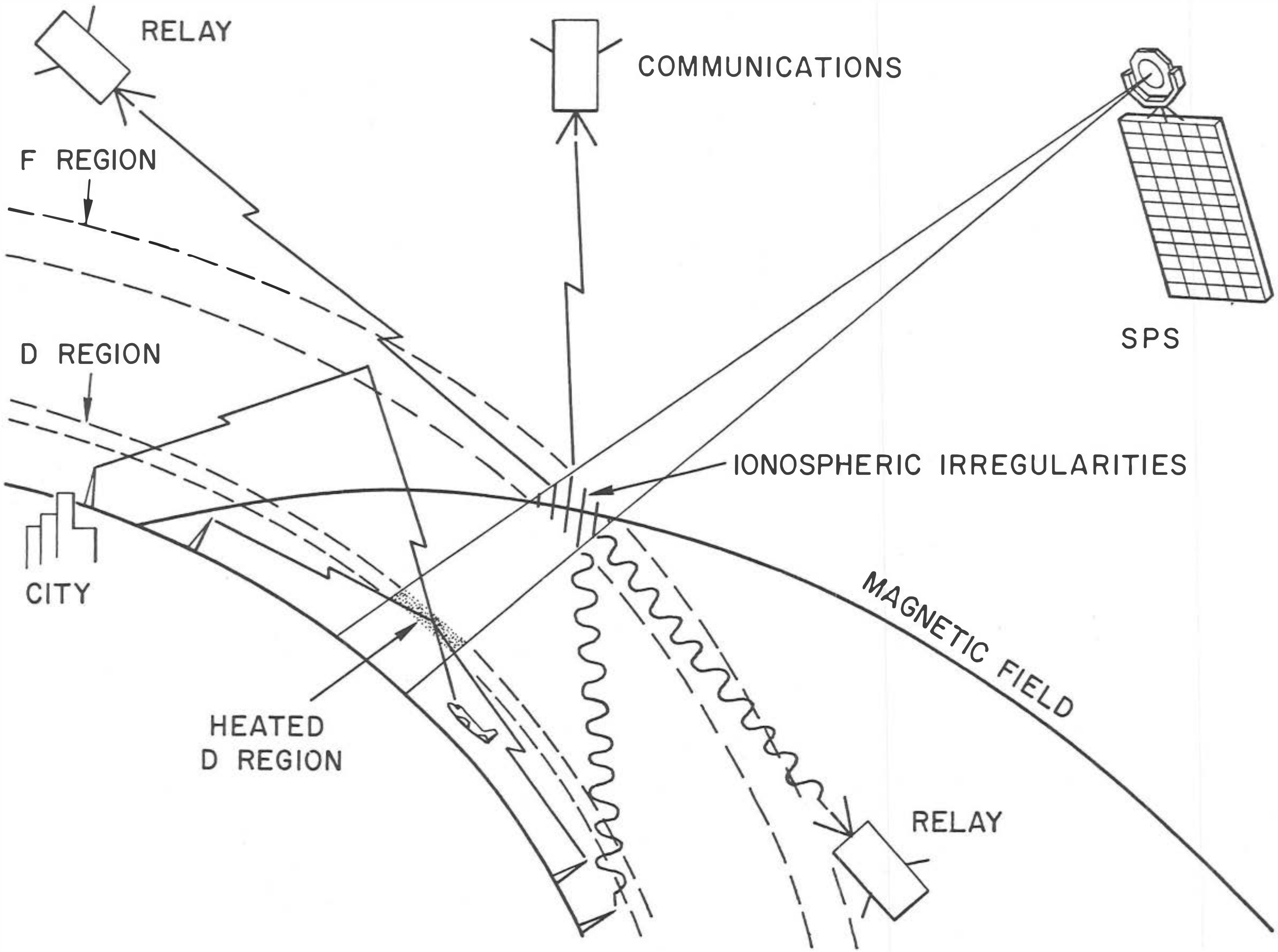


Figure 3-20. Artist's concept of SPS effects on the ionosphere and telecommunication systems.

$$Q = \frac{E^2}{8\pi} \; {\frac{f_p \pm f_H}{f^2}}^{2} \times \nu_{ei} + \nu_{en} \qquad (1)$$

where,
- Q = the energy input,
- E = the electric field amplitude of the perturbing heating wave,
- f_p = the local plasma frequency,
- f_H = electron gyrofrequency,
- f = the wave frequency,
- ν_{ei} = the electron-ion collision frequency, and
- ν_{en} = the electron-neutral collision frequency.

Under conditions of ohmic heating, the resulting power flux at microwave frequencies can be related to the resulting power flux at another frequency through the relationship

$$\frac{P_{SPS}}{f^2_{SPS}} = \frac{P_{HF}}{f^2_{HF}} \qquad (2)$$

where P_{SPS} and f_{SPS} are the SPS microwave power density and frequency and P_{HF} and f_{HF} are the power density and frequency at another frequency in the spectrum. It follows from Equation (2) that heating the ionosphere using radio waves at a lower frequency than that of the SPS requires a smaller amount of power density to achieve an SPS-comparable effect. Provided that the heating is accomplished by radio waves that pass through the ionosphere, high-powered HF waves can be used to simulate SPS heating.

In addition to heating the ionosphere through ohmic processes, the SPS microwave beam can generate instabilities that are driven by the heating of the power beam with a scattered electromagnetic wave, creating a ripple of Joule heating. This heating can give rise to successive perturbations in the temperature and electron density. The electron density perturbation leads to changes in the index of refraction which in turn divert the microwave beam into the troughs of the density perturbations. The process is self-consistent and unstable; hence the name thermal self-focusing instability.

The threshold for the onset of thermal self-focusing is proportional to the cube of the wave frequency. Thus, we can write an expression for the rate at which energy is imparted into the self-focusing instability that is analogous to Equation (2), viz.

$$\frac{P_{SPS}}{f^3_{SPS}} = \frac{P_{HF}}{f^3_{HF}} \qquad (3)$$

Equations (2) and (3) indicate that the amount of energy associated with the operation of the SPS that goes into heating the ionospheric plasma and that goes into generating the thermal self-focusing instability can be realistically simulated using much lower frequencies and power densities provided that the lower frequencies pass through the ionosphere.

The validity of Equations (2) and (3) are crucial to the ground-based simulations of the SPS operation. The results obtained by heating the ionosphere with HF waves must be extrapolated over a frequency range of nearly a factor of 1000 in order to arrive at the SPS operational frequency. It is possible that instabilities in the ionosphere will result from the passage of the SPS power beam that can not be simulated using ground-based HF facilities. However, the current understanding of the processes that are anticipated to occur in the SPS environment indicates that the ohmic heating ($1/f^2$) and thermal self-focusing instability ($1/f^3$) scaling laws are valid.

The ground-based heating facility located at Platteville, CO, and the soon to be completed heater facility located at Arecibo, Puerto Rico, funded by the United States National Science Foundation, are capable of producing continuous SPS equivalent ohmic heating in the lower ionosphere. At higher heights the delivered power flux density is significantly less than the frequency-scaled SPS microwave beam, following a ($1/f^2$) scaling law. The energy density that scales to the SPS scenario for the onset of self-focusing ($1/f^3$) is greater than the SPS power density at all ionospheric heights up to 700 km, however.

The high-power, high-frequency ionospheric heating facility located at Platteville, CO, was the focus for studying telecommunications impacts.

A number of studies of the performance of telecommunication systems in an experimentally simulated SPS environment were undertaken. Two series of experiments were conducted. The objective of one series was to determine the degree to which ionospheric changes induced by ohmic heating due to SPS operation would impact upon telecommunication system performance. Since the Platteville Facility provides SPS-comparable power density due to ohmic heating ($1/f^2$) only to the lower ionosphere, telecommunication systems whose radio energy is reflected and controlled by the lower ionosphere were investigated. The lower ionospheric studies were conducted during the time period August, September, and October 1979. The objective of the second series of experiments was to determine if thermal self-focusing effects could be produced using underdense radio waves. The primary diagnostics of telecommunication system performance used were satellite transmissions in the very high frequency (VHF, 30 MHz-300 MHz) band. The self-focusing studies were conducted in March and April 1980.

The following sources were used to assess the potential impact of SPS operation on telecommunication systems operating in the lower ionosphere:

1. VLF Signal Sources - OMEGA

2. LF Signal Sources - LORAN-C Stations

3. MF Signal Sources - AM Broadcast Stations

Figure 3-21 shows an example of the received VLF amplitude and phase recorded at Brush, CO. The data were obtained for the time scale indicated on August 16, 1979. The hatched blocks immediately above the time scale indicate that the Platteville Facility was operating in a continuous mode, and the shaded blocks indicate square-wave (50% ON - 50% OFF) modulation, with the modulation rate given in events per second. The amplitude and phase scales are indicated. The phase output from the receiver was designed such that, when either the zero or full scale (10 μs) outputs were reached, a reset occurs which placed the record pen at the opposite limit and another 10 μs of trace was then possible.

The results obtained in the VLF, LF, and MF experiments provide strong evidence that ohmic heating of the lower ionosphere with radio waves having power densities comparable to the SPS microwave power beam will not lead to adverse impacts upon the performance of VLF, LF, and MF telecommunication systems. On numerous occasions in August, September, and October 1979, the D and lower E regions of the ionosphere above Platteville, CO, were illuminated with radio waves in the high frequency portion of the spectrum whose ohmic heating power density scales to 23 mW/cm^2 - the current design power density of the SPS microwave beam. Signals from VLF, LF, and MF transmitters that propagated through and near D and E regions illuminated by the Platteville Facility displayed no obvious change that could lead one to suspect adverse system performance attributed to SPS operation.

In addition to changes in the ionosphere due to ohmic heating, the SPS microwave power beam may create striations or irregularities in the ionospheric electron density resulting from thermal self-focusing instabilities.

An experiment was undertaken at Carpenter, WY, that was directed toward monitoring the transmissions from the LES-8 satellite at 249.2 MHz. Figure 3-22 shows the LES-8 signal recorded between the times 0256 and 0335 UT on March 12, 1980. The Platteville Facility was turned on at a frequency of 9.9 MHz with an input power of 1.5 MW at 0300 UT. Between the times 0045 and 0300 UT, the Facility was "OFF." At 0258 UT, foF2 at Platteville was observed to be 8.1 MHz and at 0312 UT, foF2 was observed to be 7.9 MHz. The entire period of heating was therefore underdense. It is readily apparent that, about 5 minutes after the onset of underdense heating, the LES-8 signal started to fluctuate considerably. Peak-to-peak fluctuations of 10 dB were observed, and at 0315 UT, when the Facility was turned "OFF", the LES-8 immediately started to settle back to its pre-heating level.

The program of research and exploratory development undertaken in order to assess the impact of the operation of the Satellite Power System on the ionosphere and telecommunication systems has relied upon SPS simulation, theoretical studies, and experimental observations. The program has been directed toward obtaining corroborative evidence of ionospheric heating phenomena that pertain to the SPS operational scenario. Using the fact that processes emanating from ohmic and self-focusing interaction in the ionosphere can be scaled according to frequency-dependent laws, ground-based simulations of SPS heating in the ionosphere has been performed. This heating has been performed using the high-powered, high-frequency transmission facilities operating at Platteville, CO, and at Arecibo, Puerto Rico. Because of facility limitations, ohmic heating experiments can only be performed in the lower ionosphere.

Studies that investigated the performance of VLF, LF, and MF telecommunication systems operating in an experimentally simulated SPS environment have yielded results indicating that VLF, LF, and MF systems will not be adversely impacted by SPS operation. These studies were conducted using transmissions of actual system signals. The effects of SPS heating on HF, VHF, and UHF systems need to be studied also.

Results have recently become available indicating that underdense self-focusing can produce changes in the signal level of satellite transmissions received on the ground and in aircraft. The preliminary results show that changes in signal level are much slower and much smaller than those associated with overdense heating processes.

Los Alamos Scientific Lab. This project was primarily to provide the service of the high-powered (2 megawatts) Platteville HF transmitter and technical assistance to the Los Alamos Scientific Lab. The purpose of the project was to determine if the correct conditions could be established to propagate an HF signal along the earth's field lines, out a distance of several earth's radii, and receive a return via a reflection at the southern conjugate point. Also, observations were made for signal returns from the earth's magnetotail which would require 30 seconds or more to complete a round trip.

A considerable amount of signal processing was performed, producing strong backscatter returns from terrain irregularities of other continents, as well as around the world signals, but during about 2 weeks of observations, none were identified as propagation along either of the desired paths.

SPS EMC Assessment. 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 MW of electrical power on the earth.

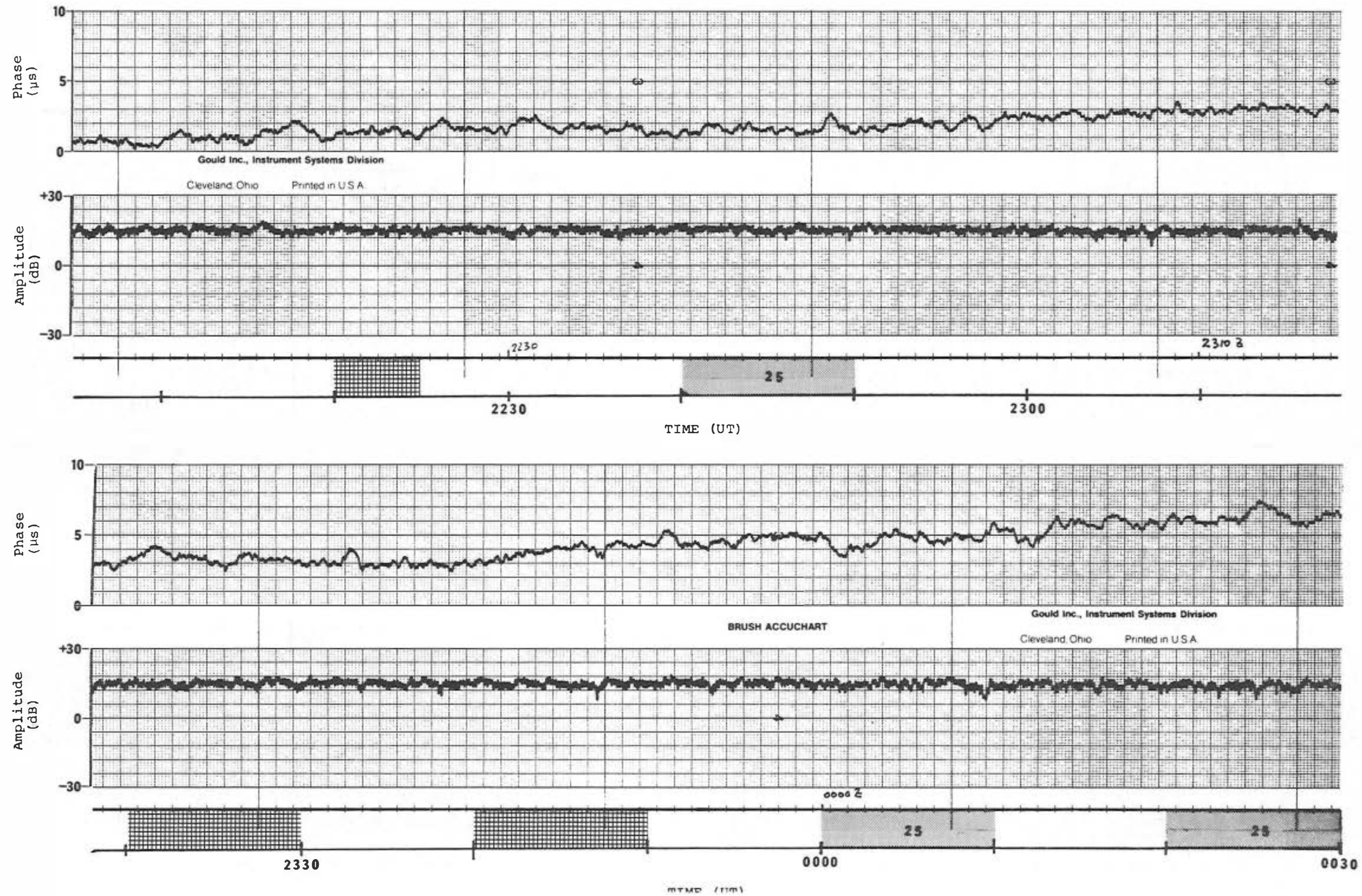


Figure 3-21. OMEGA phase and amplitude data recorded at Brush, CO, from Hawaii to Platteville Facility.

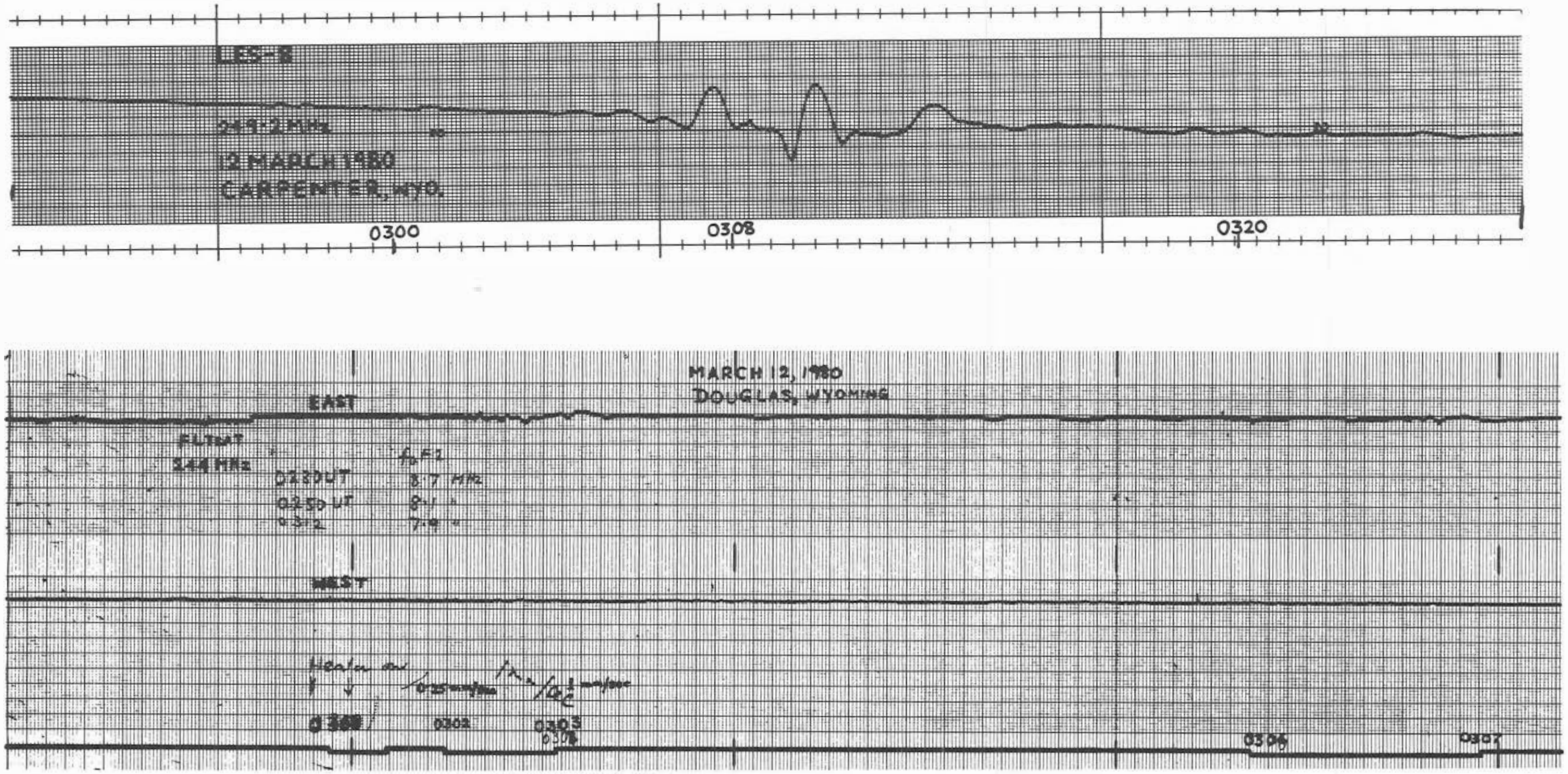


Figure 3-22. LES-8 amplitude data observed at Carpenter, WY, on March 12, 1980, during underdense heating.

The EMC study covers a broad spectrum of EM and electronic systems studies to determine effects of an SPS. This includes GEO and LEO satellites as well as terrestrial systems. The program is too wide in scope to speak to much of the work accomplished this fiscal year. Only three representative areas will be discussed here.

Media effects on power and pilot beam: Transient meteorological events and dynamic anomalies cause signal amplitude and phase modulation for the power and pilot beams. These perturbations are important in specification of the power beam aiming and beam forming control system. Modulation transient amplitudes and rates of onset and short term spectral density distributions must be played into the control loop models to allow tradeoff in modular gain, software control delay, adaptive mechanisms for accommodating larger perturbations, and beam sensing feature definition and discriminant weighting.

Dynamic anomaly spatial densities and refractive index gradients vary seasonally; both characteristics are largest during summer and are reduced during winter. Temperature variations also indicate larger occurrence rates and boundary gradients in southern warmer regions than the colder northern areas.

A representative summer afternoon "snap-shot" plot for anomaly linear dimension and apparent velocity is indicated in Figures 3-23 and 3-24. This is a sample of data collected over a 2-year period in the Tucson-Ft. Huachuca area of Arizona using an X-band pulse Doppler radar. Boundary gradients of 50 N/m to 450 N/m were measured over the altitude range of 1,000 ft to 12,000 ft.

A communications experiment employing a 5 MHz bandwidth link in the 3 GHz band exemplifies the variation of the error in a carrier tracking loop with small anomaly density (summer midnight to sunrise) and large gradient fluctuation-moderate density (summer-late morning) situations. A typical loop error spectra is indicated in Figure 3-25. For transmission through the full troposphere, a similar error for an uplink with a S/N margin of 15 dB would have a data error of 10^{-4} to 10^{-5}, with a loss of lock probability of 10^{-1} to 5.10^{-1}.

Control of the SPS during major transient events such as a storm front passing over the rectenna represents a significant impact in control system design. Short term transients that could escalate the data error rate or cause a momentary carrier track loss, or induce aim point wander could represent an unacceptable environment and safety risk.

A typical refractivity variation over a 6-hour afternoon period for an undisturbed weather condition is indicated in Figure 3-26. A storm front refractivity situation is plotted in Figure 3-27. This represents the character of transient that will be integrated into the control system model to quantify loop gain, phase limiting, and adaptive functions to minimize carrier lock loss and escalating data error in the uplink which could possibly cause power beam wander. The control system model would define beam phase and amplitude sensor geometry, signal feature discriminants, and the decision matrix organization for array control in the presence of such transients. The storm front refractivity plot is smoothed; short term transients in the 0.5-5 minute period range are not displayed.

Power loss for various rain rates during storms assumed to be centered over a rectenna is plotted in Figure 3-28. Only direct beam scatter is considered in the EMC evaluation. Reflected and radiated components from the rectenna would not increase the interference environment since these components are emitted upward with a relatively low power density. Refractive index gradients integrated over the full altitude range are insufficient to return any significant power densities to terrestrial, aircraft, or space vehicle receivers. Reflected and reradiated components are 10^{-4} and 10^{-7} of the direct power beam where these secondary components are above any receiver out-of-band response threshold.

Space telescope: One of the LEO satellites studied to determine possible performance degradation during SPS power beam intersection was the proposed space telescope. In 1977, the space telescope project was approved by the United States Congress. The space telescope has major advantages over ground-based telescopes in three important areas: 1) the first and most significant is an order of magnitude improvement in angular resolution, 2) twenty-four hour per day observing time, and 3) the telescope being beyond the earth atmosphere allows photometric data collection over a much wider wavelength range--ultraviolet, infrared, and submillimeter wavebands as well as the visual spectrum.

The planned schedule shows the initial launch in the last quarter of 1983. The design lifetime is 15 years in orbit. The orbit is circular at a 500 km altitude and 28.8° inclination. A cross-sectional view of the satellite observatory is shown in Figure 3-29. The telescope consists of the primary and secondary mirrors, the metering structure for maintaining the relative positions of the mirrors, the internal light baffling system, and the fine guidance sensors. Communications with the satellite will be via the TDRSS. The scientific instruments on-board are as follows:

Wide Field/Planetary Camera - the camera contains eight charge-coupled device (CCD) detectors, each consisting of 800 x 800 elements.

Faint Object Spectograph - uses digicon detectors, each of which consists of a linear array of 512 independent diode elements.

Faint Object Camera - the design uses a three-stage image intensifier with an intensified silicon target television camera tube.

High Resolution Spectrograph - the detector is a digicon device consisting of a linear array of 512 diode elements.

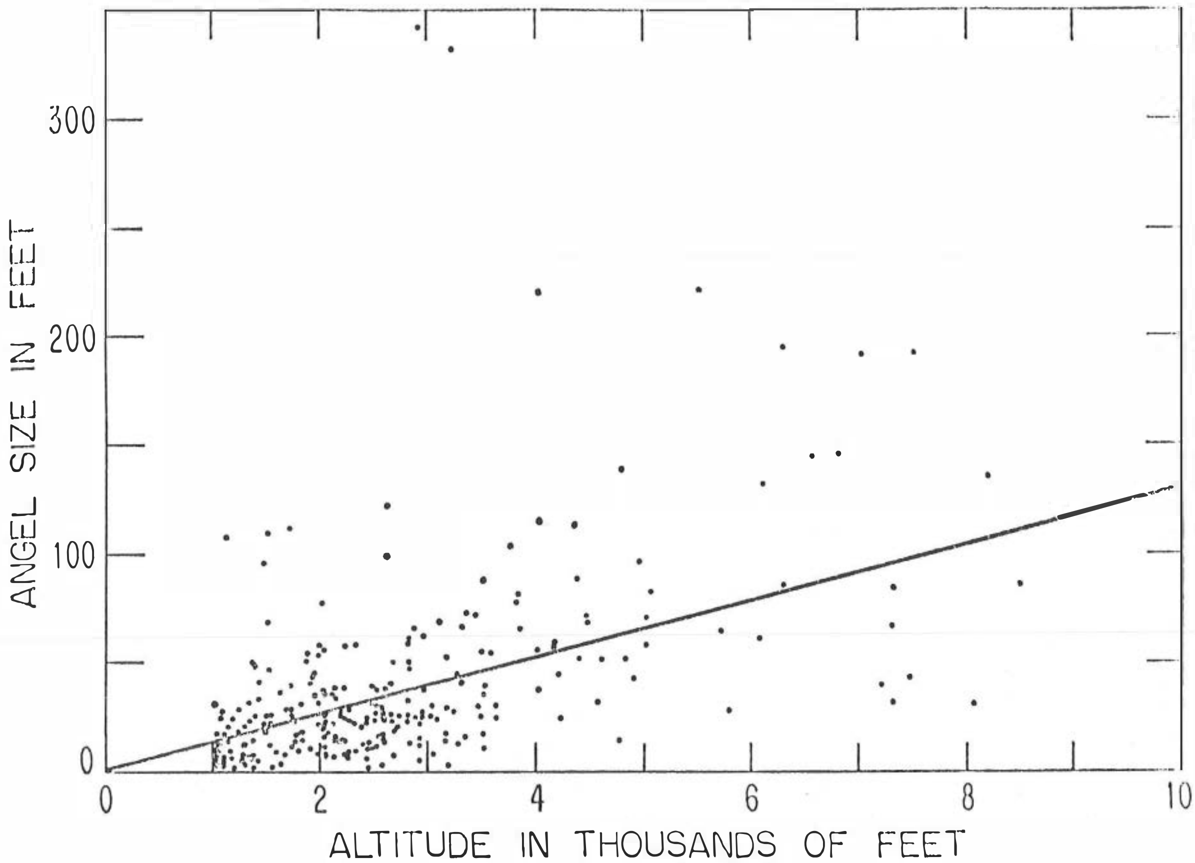


Figure 3-23. Atmospheric anomaly size distribution versus altitude.

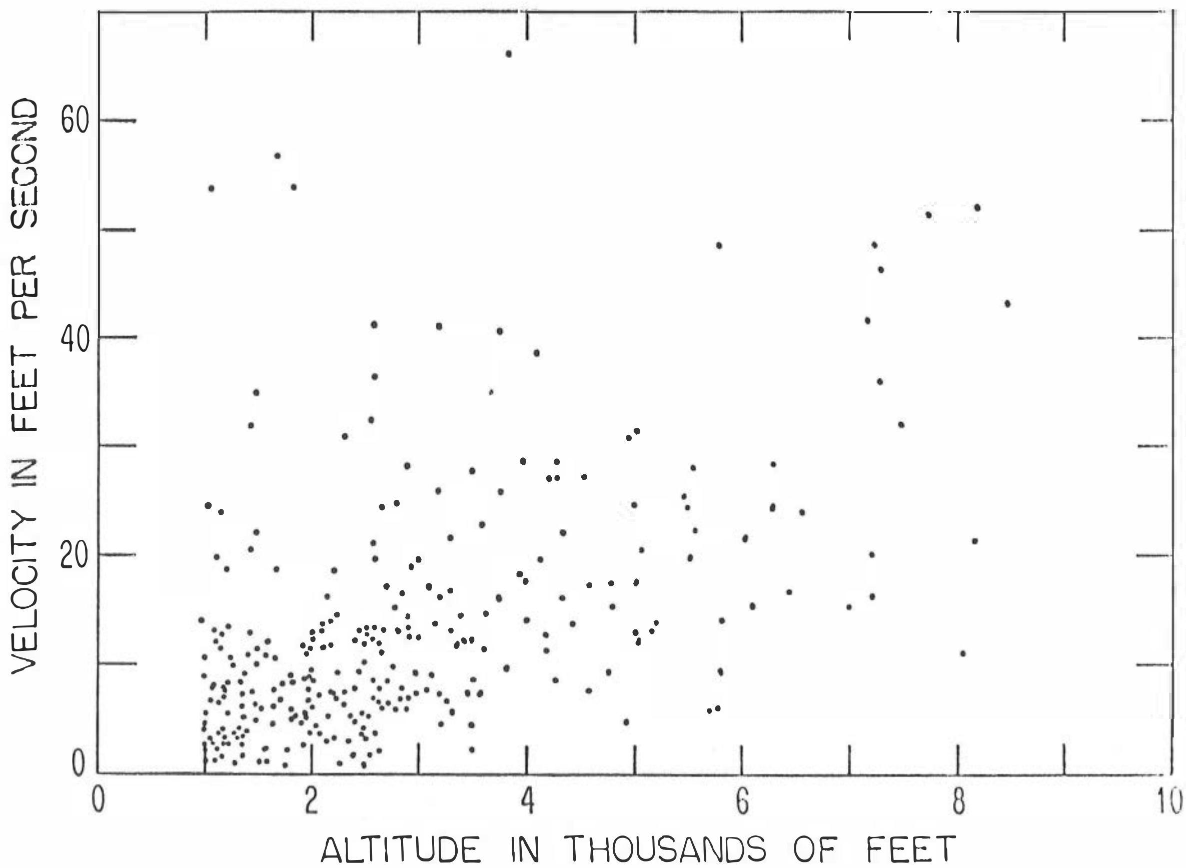


Figure 3-24. Atmospheric anomaly apparent velocity versus altitude.

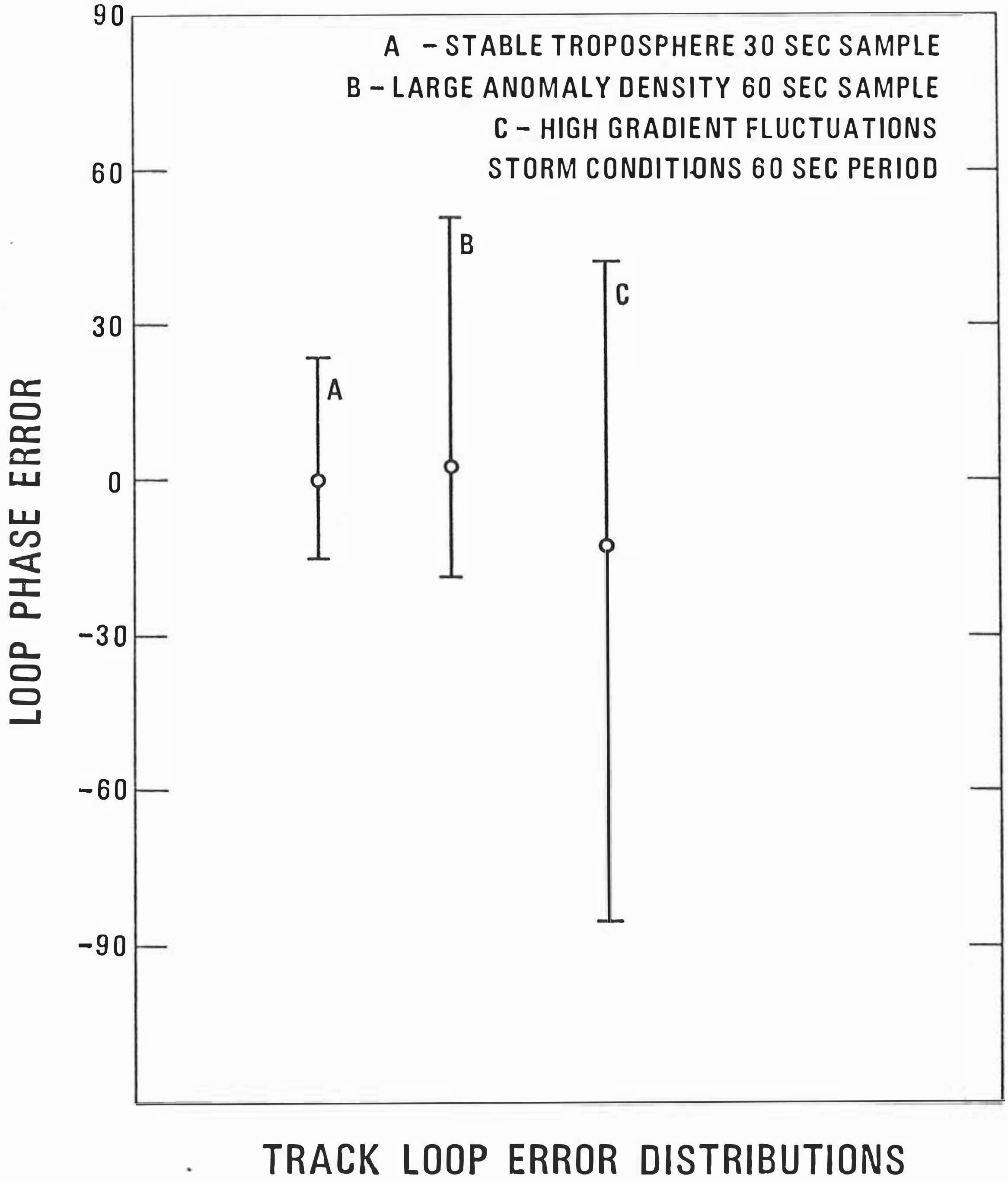


Figure 3-25. Media effects on a 36 Hz microwave communication link.

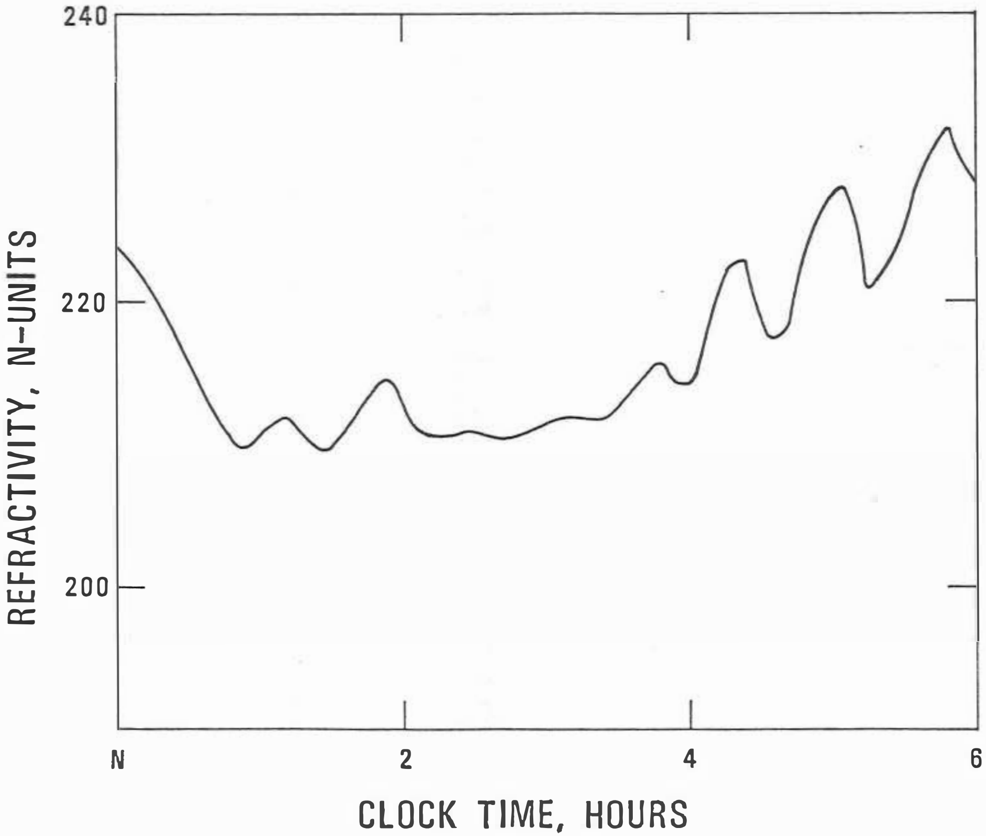


Figure 3-26. A typical atmospheric refractivity variation-- undisturbed afternoon condition.

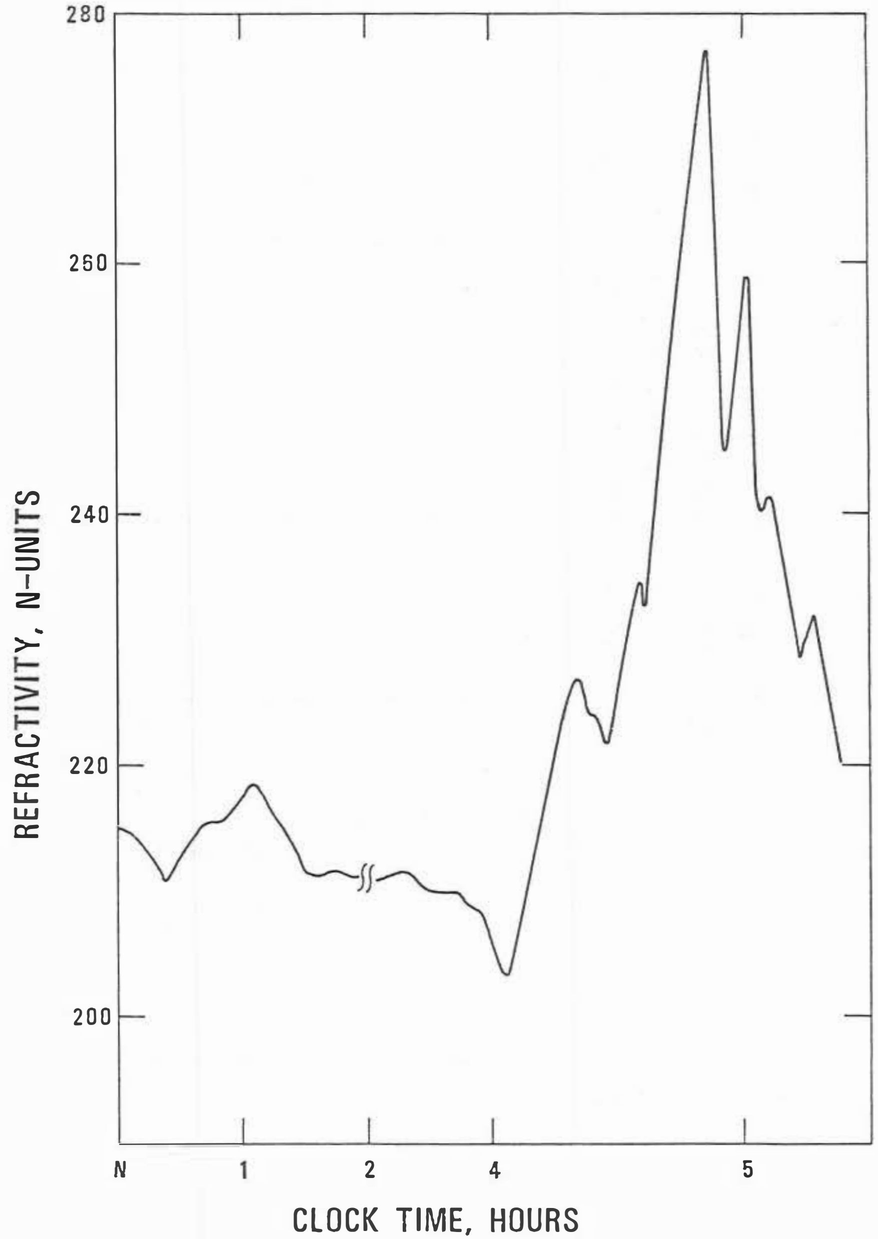


Figure 3-27. Radio refractive index variation in conjunction with a storm front.

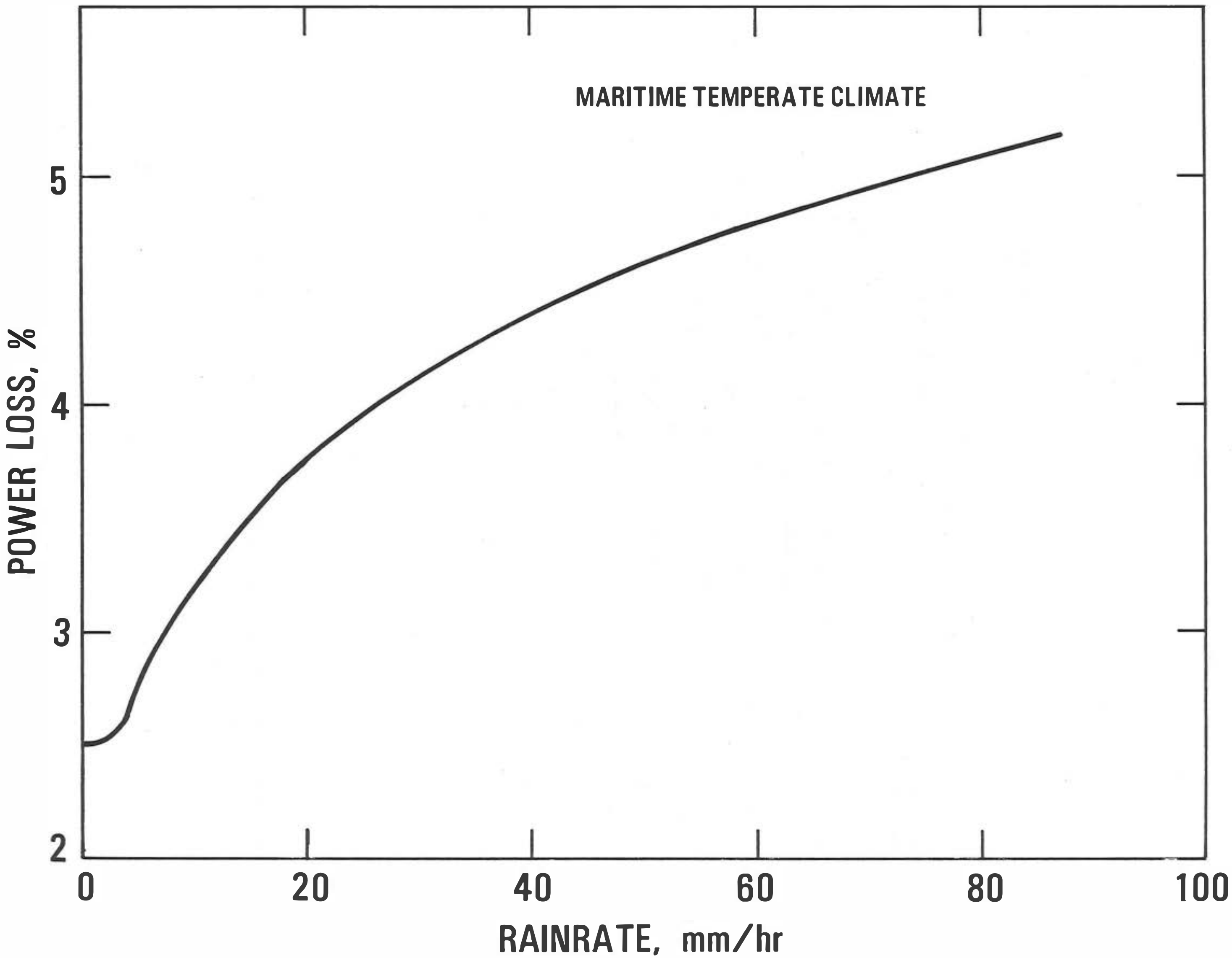


Figure 3-28. Power loss due to storms centered over rectenna.

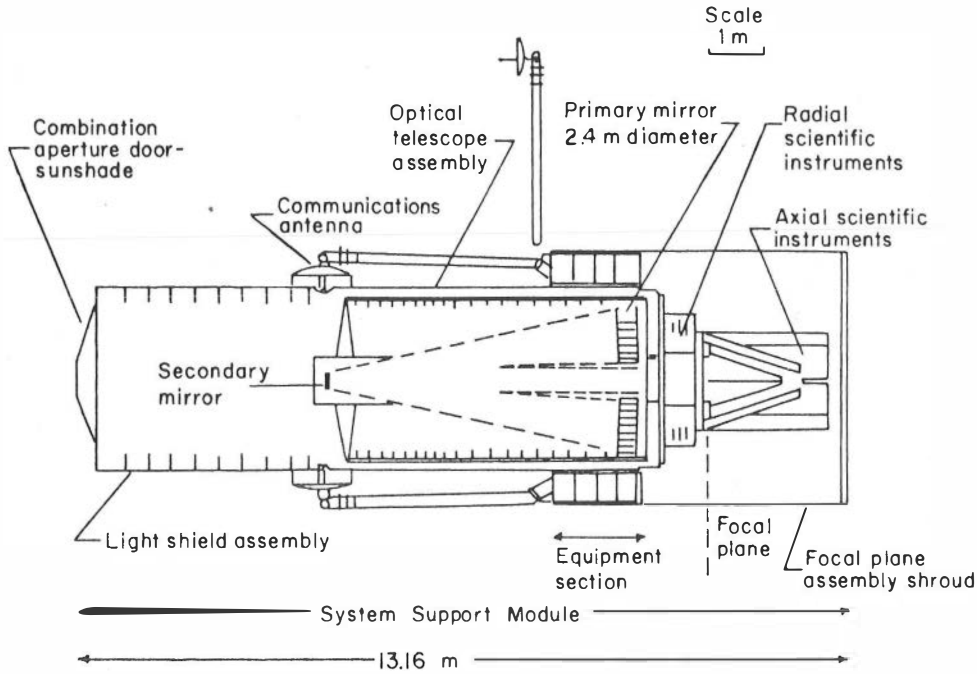


Figure 3-29. Cross section view of proposed space telescope.

High Speed Photometer/Polarimeter - the device consists of a number of image dissectors, their associated electronics and a focal plane aperture mask, and filter plate.

Astronomy - accomplished with use of the fine guidance system which uses three independent sensors and detectors located in annular segments around the field of view in the focal plane.

Fine Guidance and Astronomy - three high-resolution sensors to provide data for star field maps to support future stellar experiments planning. These sensors must acquire stars at M = 13 with an accuracy of 7×10^{-3} arcsec.

The SPS microwave power beam geometry at space telescope orbit altitude is shown in Figure 3-30. Coupling of electromagnetic energy into the satellite instrumentation will occur mainly through the telescope's 2.4 meter optical aperture. The SPS peak field intensity would be approximately 28 mw/cm^2. This would be equivalent to 12.67 kw of microwave energy on top of the telescope. About 40% of the energy would be coupled through the baffled area to the primary mirror. Some 20% of this energy would then be reflected through the mirror system into the detector areas. There would be about a 60% penetration into the detector areas, which would be equivalent to 55 watts of 2.45 GHz energy directly into the instrumentation area.

The impact of SPS radiations on the scientific instruments would be to increase detector channel noise, reduce spatial resolution, and reduce dynamic range. For the satellite guidance system and astrometry missions there would be increased detector channel noise and reduced spatial resolution which would increase attitude instabilities for the few seconds the space telescope is in the SPS beam.

Figure 3-31 shows voltage output versus illuminating frequency for a 512 element CCD array at two widely separated temperatures given in degrees Kelvin. These video noise spectra show the normal response curves for CCD arrays. Figure 3-32 shows the CCD array spectra in the presence of a 2.5 GHz 2 mw/cm^2 field. Comparing Figures 3-31 and 3-32, it is seen that the frequency resolution has degraded considerably in the illuminated case particularly above 100 Hz. This would adversely effect the imaging capability of such an array.

Figure 3-33 shows the same CCD array being illuminated with a normal source signal and the associated resolution given in lines per minute. The solid line is the normal response of such an array. The dashed line shows the degradation in resolution in the presence of a 2.5 GHz, 2 mw/cm^2 RF field. Here it can be seen that it takes a higher source illumination for a given resolution in the presence of the microwave field, particularly below 10^{-5} mw/cm^2.

CCD matrices, digicon devices, image intensifiers, and image dissectors will experience degraded capabilities in the presence of SPS energy as the satellite observatory intersects the main power beam and major side lobes. The apertures in front of the detectors afford very limited protection since the axial length will be much less than $\lambda/2$ for the SPS fundamental or primary harmonics.

Mitigation techniques would include wire mesh shielding for image dissectors, digicon devices, and CCD arrays where focusing optics are employed. For submillimeter, infrared, or ultraviolet detectors, the wire mesh would cause unacceptable distortion and large data errors. Increasing the axial length of the apertures for the instrument detectors up to 6 cm will provide 40-60 dB microwave attenuation. Uplink communications through TDRSS should not be accomplished during beam intersection. Crystal lenses in the optical link would attenuate microwave energy to keep unacceptable interference from the fine guidance system or other on-board systems used in stabilization and tracking for the telescope. Upset in attitude stabilization would be corrected over a considerable portion of an orbit to stabilize the total system after passage through an SPS beam. A provision for "coasting" through the power beam should also be acceptable because of the short transit time. To maintain specification accuracy, a rate memory mode will be required.

Intermodulation products: The SPS space system intermodulation product is principally an electomagnetic environmental factor for GEO satellites in adjacent orbit slots and wideband communications channels used by high altitude LEO satellites (altitudes ranging from 10,000 to 15,000 miles). There are three principal sources of intermodulation emissions:

a. spacetenna and space vehicle structures illuminated by the SPS fundamental and harmonic frequencies along with other terrestrial and space sources (e.g., communication terminals, communication satellites, space radar systems, etc.);

b. signal mixing in nonlinear circuit elements in the power generation chain; signal generators, power amplifiers, and phase and frequency control circuitry;

c. signal mixing in the solar cells and power conditioning circuitry on the SPS space system.

The SPS reference design indicates use of graphite epoxy composite materials for the space vehicle structure, the solar blanket and supporting members, and the spacetenna. These materials have significant advantages in strength and weight characteristics over any metal structure for a system having the area of an SPS satellite. Bonded joints of trusses and struts represent intermodulation sources where large variations in electrical characteristics over the bond area occur. Priority parameters include resistivity, permittivity, and reluctances (bond-composite-bond interfaces). Compared to metals, composites are apparently more sensitive to electrical parameter variations induced by torsional stress across bonded areas.

Intermodulation outputs from any junction are produced by multiple signal illumination of an area having nonlinear resistance and reluctance characteristics with the general relationships defined as follows:

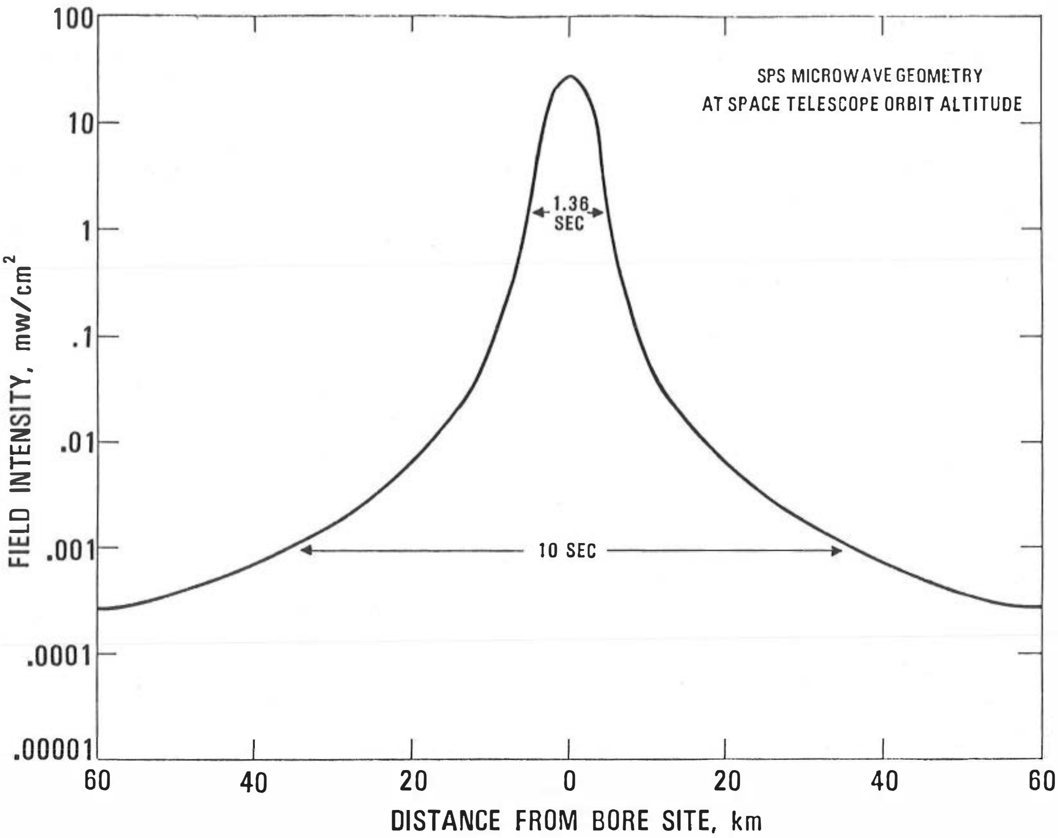


Figure 3-30. SPS power beam geometry for space telescope EMC analysis.

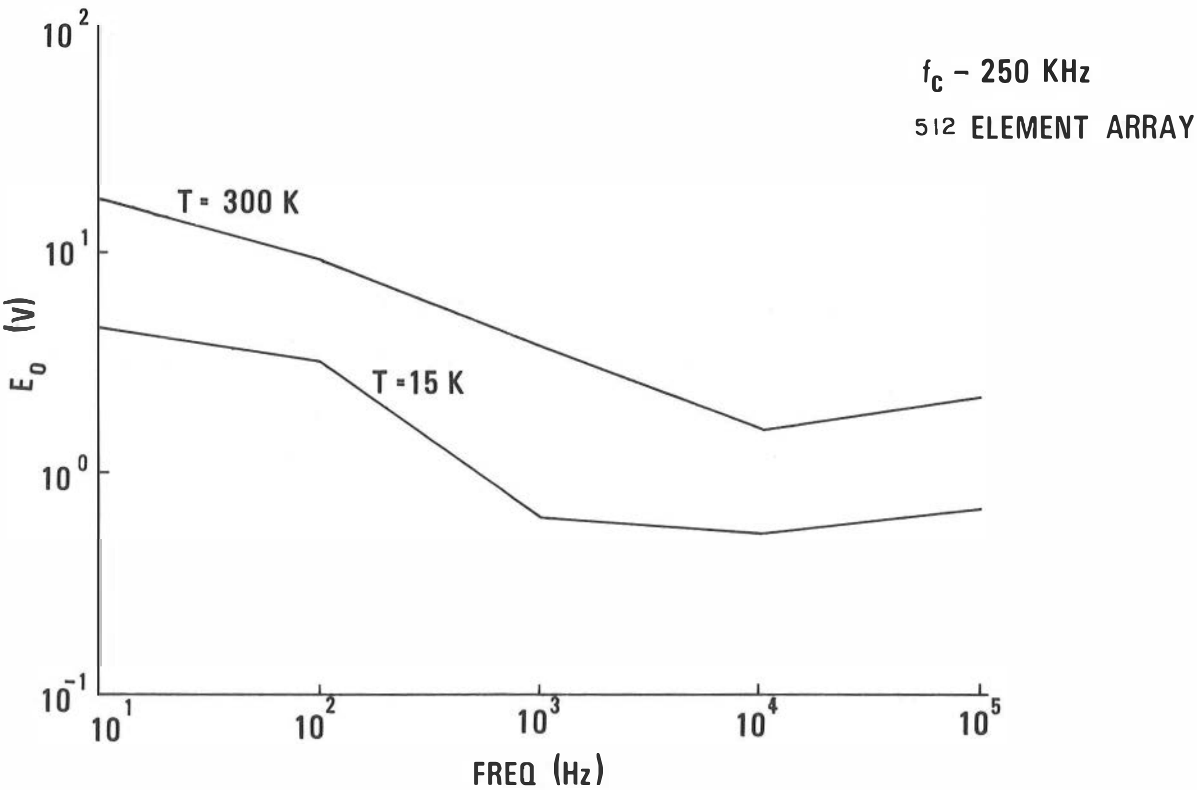


Figure 3-31. CCD video noise spectra.

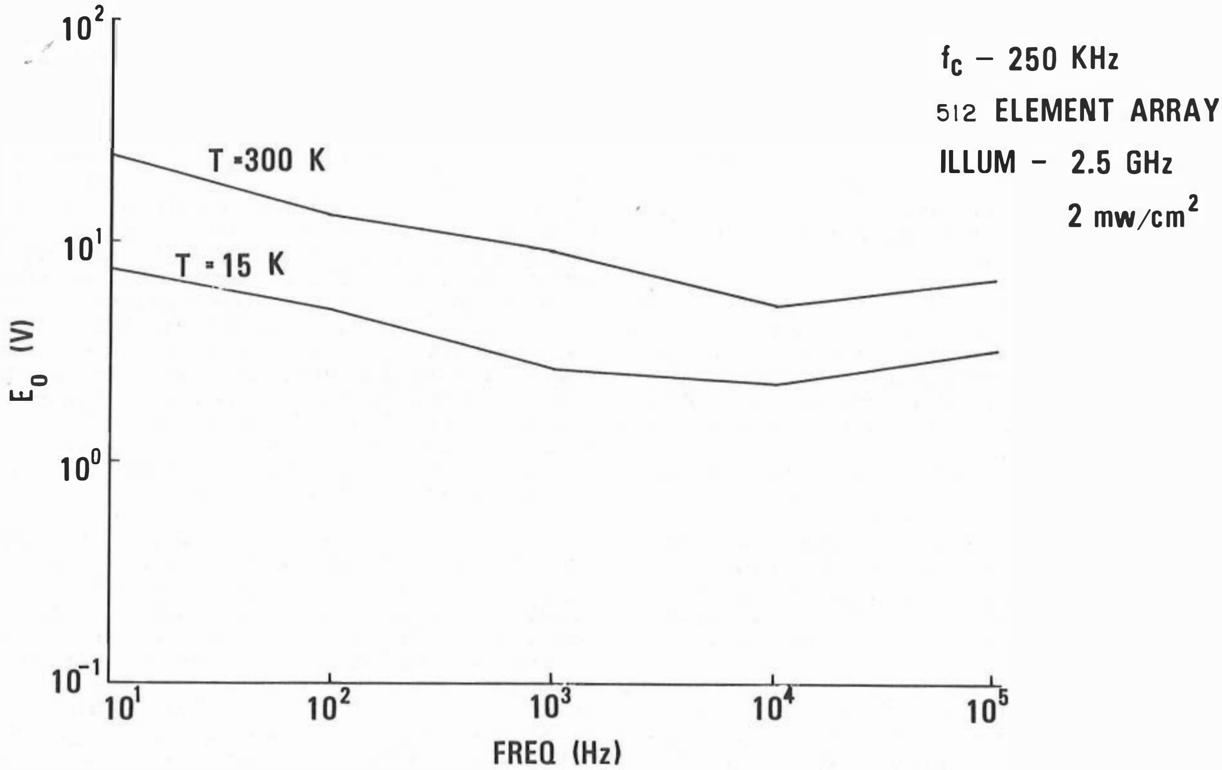


Figure 3-32. CCD video noise spectra - SPS F_0 illumination.

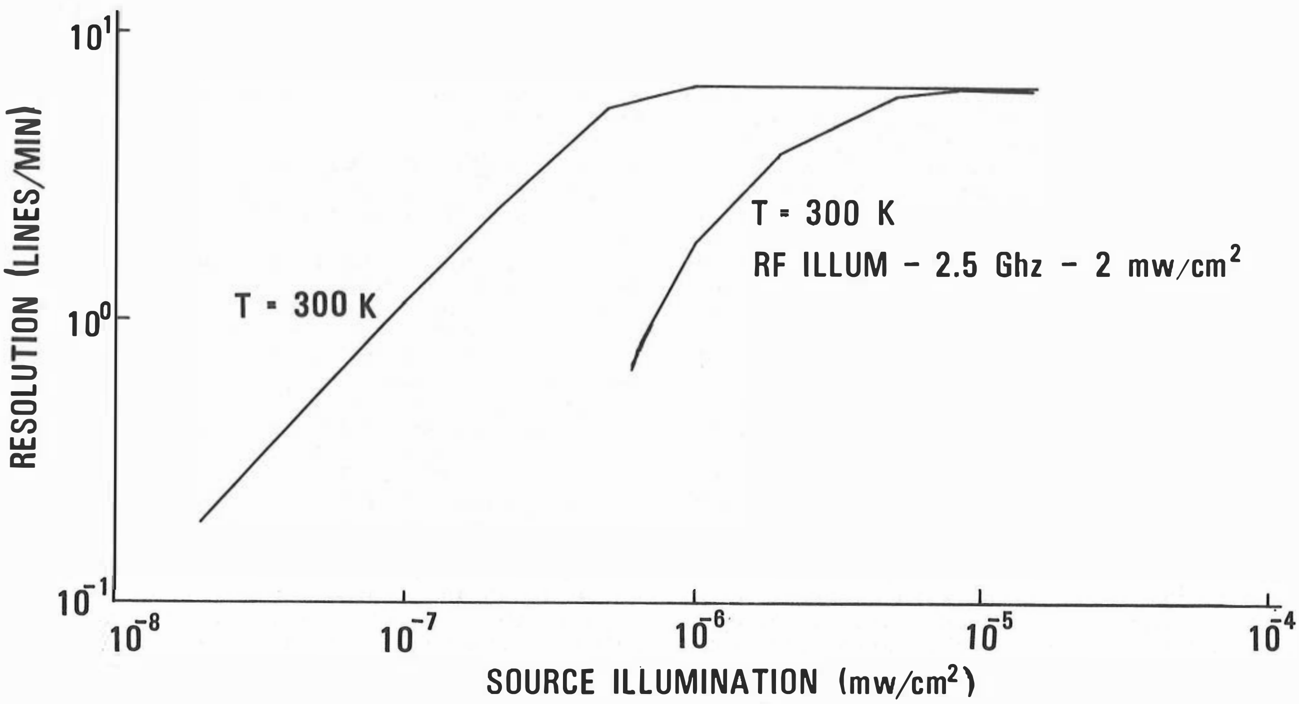


Figure 3-33. CCD array imaging characteristic.

$$f_{1m} = af_1 \pm bf_2 \qquad (1)$$

where a and b are even or odd integers. Frequencies and amplitudes depend on the parameters of the nonlinear junction, and the effective aperture and current return path impedances. Wide variations, particularly in the junction characteristics, occur because of material impurities, time variant surface conditions, and the torsion stress factors.

The military services have initiated parameter measurements for various composites to quantify shielding characteristics and junction properties relative to intermodulation generation. Existing data are limited in scope, but indicate a trend toward amplitudes in the range 0.3 to 0.5 (a and b of Equation 1) relative to aluminum or copper in identical configurations.

For composites, the emission frequencies tend toward higher order frequency components. This is correlatable with the higher distributed reluctances and conductivity indicated in the preliminary measurements. No generalizations are justified on the basis of these data.

The interests of the SPS program will be served by continuing military R & D in this area. Measurements during development of bond surface and studies in depth variations of electrical parameters will continue to provide data translatable to SPS needs. This information will support a task being initiated by ITS to relate material and bond characteristics, illumination frequencies and amplitudes, and dominant emissions. The military measurements will also include torsional stress variations to indicate bond parameter dependencies, which are uniquely important for the SPS because of the large moments caused by a station-keeping orbit adjustments over a system operational lifetime.

Because of the high radiation power of the SPS, careful circuit coupling and configuration design are particularly important to minimize inadvertent intercoupling of signals. Shielding and filtering for power amplifiers and modulator elements associated with phase or frequency control must provide 40 to 60 dB isolation to assure suppression of intramodulation components into the final power module by at least 80 to 100 dB. This requires increased emphasis in the shielding area because of reduced isolation due to composite structure shielding characteristics. A representative comparison of shielding effectiveness for aluminum "thick wall" and foil versus various composites is shown in Figure 3-34. These data imply the possibility of dual shields for the high power modules and control of ground bus currents through large area-low resistance contact areas and single point topology. Another area of intermodulation generation, along with use of composites, would be the solar panel and conditioning circuitry directly coupled to groups of solar cells as these are exposed to SPS power along with exposure by other satellite illumination sources. Space radars employed for military, earth resource, and atmospheric monitor applications and transmissions from GEO satellites in orbital positions adjacent to SPS represent the primary EM environment as it would exist today. Future space communication operations that would be impacted by SPS concern satellite-to-satellite modes, where SPS will be stationed between communication satellites (see Figure 3-35). As the figure indicates, the large cross-section of the SPS satellite (~40 km^2) represents a generally unacceptable signal multipath situation as depicted by the single satellite geometry. The SPS will require an on-board frequency translator/repeater to support this satellite-to-satellite communication mode as shown in Figure 3-36. These additional signals will illuminate portions of the SPS satellite solar panels, thus mixing with ambient SPS power beam fundamental and harmonic components. The large active solar panel area represents a major source of sum and difference frequency products for combinations of SPS, radar, and communication signals and increase spurious emissions and on-board EMI problems.

A functional diagram of the solar cell and conditioning system is diagrammed in Figure 3-37. The cell is electrically a diode, usually biased to maximize current flow for a range of solar illumination. Cells are connected in combinations of series and parallel through voltage and current controllers. The voltage and current controllers would consist of summing amplifiers and silicon controlled rectifiers (SCR). The SCR units represent a nonlinear impedance at the input terminals, coupling switching frequency components into the cell circuits. The intermodulation modes are described in Figure 3-38.

Mitigation methods include band-stop filters in the cell lines or a wire mesh around the cell blanket. The latter should be a square grid mesh with a mesh dimension of less than one-half the wavelength of the highest illuminating frequency, with a wire size in the AWG 26 to 32 range. This wire size presents insignificant blockage of solar cell illumination from the sun. To minimize circulating current effects in the small diameter mesh, corrections to a vehicle ground bus should be provided at 10-30 ft intervals.

OMEGA Propagation Studies. The purpose of this project is to provide propagation expertise to the OMEGA Navigation System in three specific tasks. The first task is to identify and record the prompt effects of solar X-ray events on the phase of OMEGA signals. Navigation accuracy may be reduced during sudden phase anomalies (SPA's) produced by these X-rays. The magnitudes of the SPA's will serve as a data base for examining the effects of the sun on navigation accuracy. For example, the results show that SPA's last from about 15 minutes to 4 hours, the cumulative probability distribution of the durations is non-Gaussian, and the median is about 80 minutes when observed on 4 long propagation paths. On short paths, the durations are shorter, non-Gaussian in distribution, and the duration may be typically about 40 minutes. These observations suggest that the effects of solar X-rays on OMEGA is related, in part, to the distances from the navigator to the transmitters.

The second task is to make theoretical estimates of the extent of the multimode region

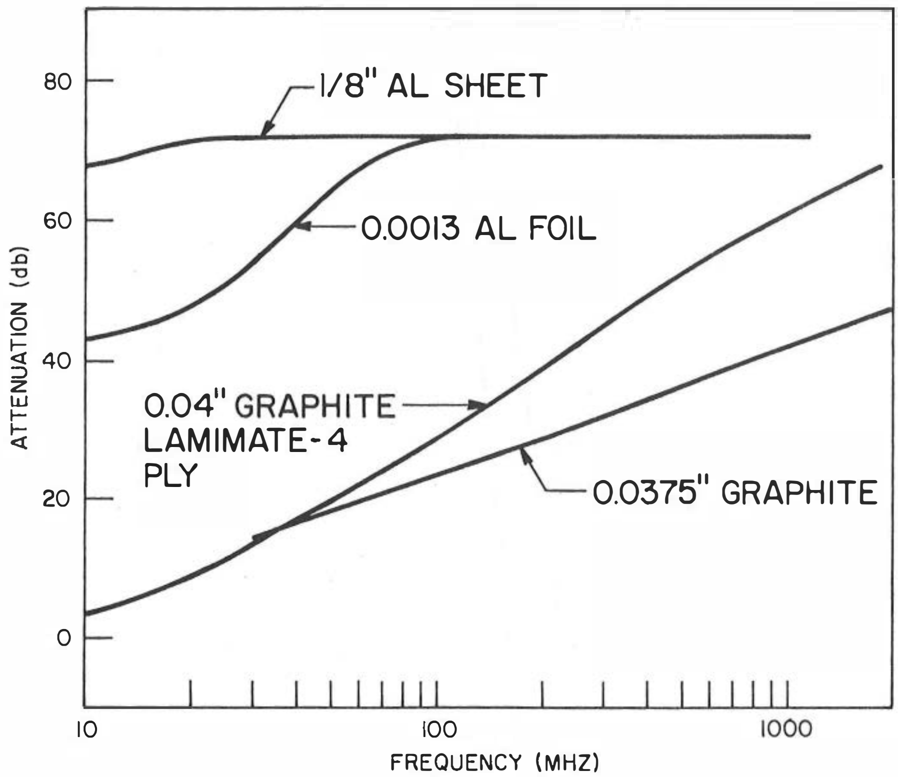


Figure 3-34. H field shielding effectiveness.

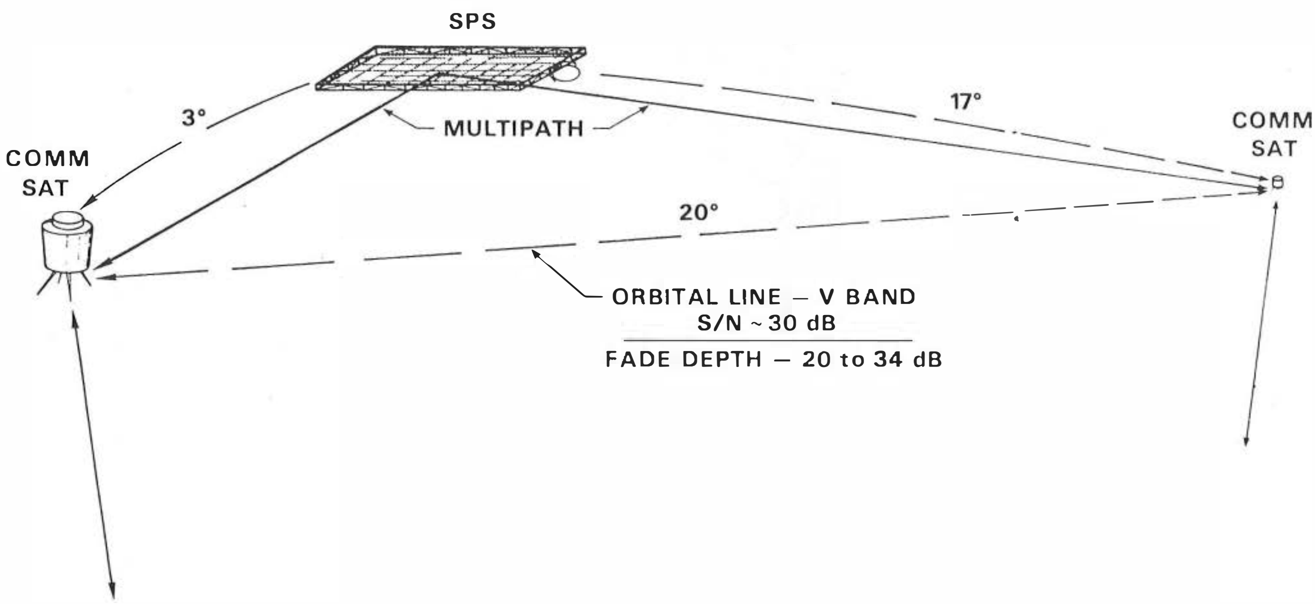


Figure 3-35. Possible signal multipath problem with SPS stationed between two communicating satellites.

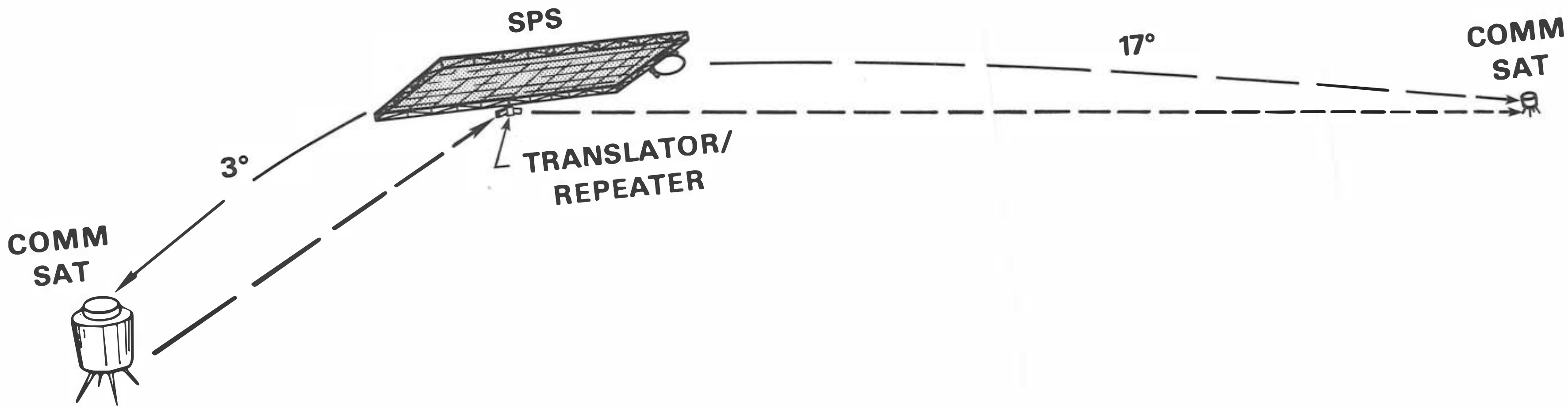


Figure 3-36. SPS acts as translator/repeater for two communicating satellites.

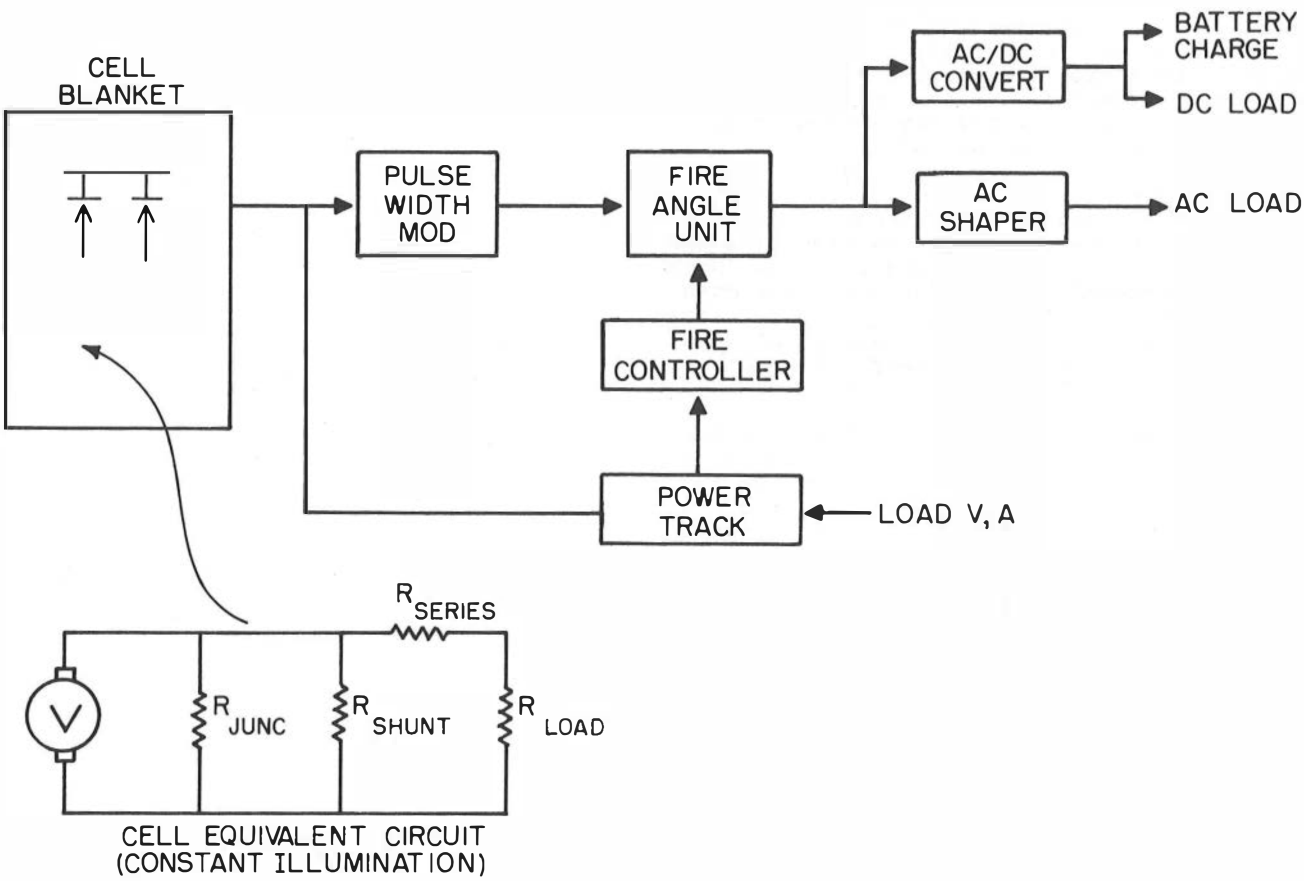


Figure 3-37. Functional diagram of a solar cell conditioning system.

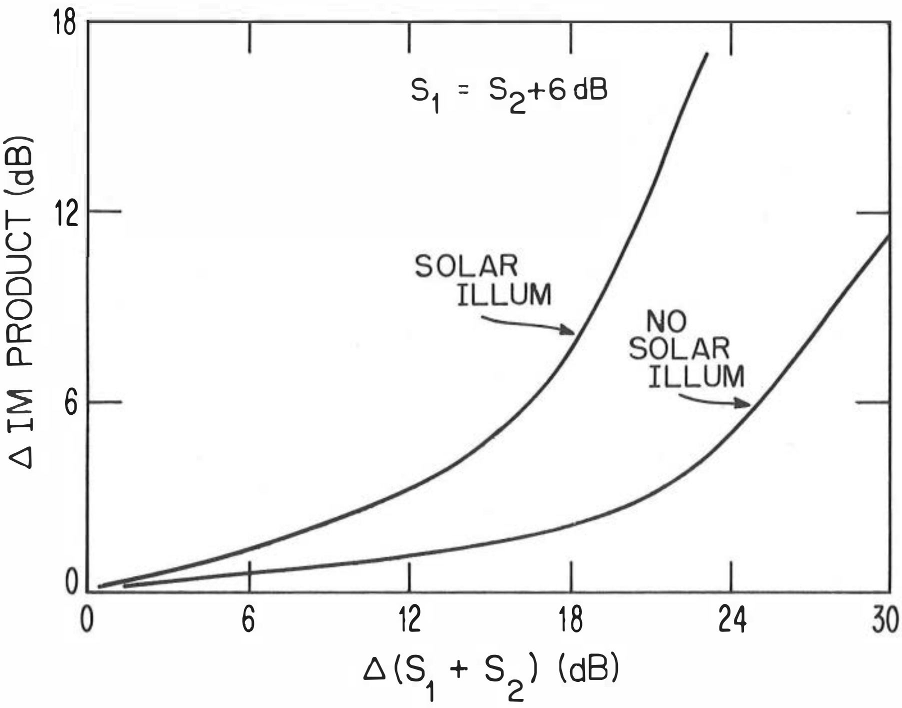


Figure 3-38. Typical solar cell power processor IM response characteristic.

surrounding an OMEGA transmitter and to formulate a plan for empirically determining its bounds. The estimates indicate that the multimode region, where navigation accuracy is re duced, is not circular and may extend to 4000 km during times of low sunspot number.

The third task is to establish diurnal and seasonal variations in the propagation characteristics of the unique frequencies 11.8 kHz (Hawaii), 12.8 kHz (Japan), and 13.1 kHz (North Dakota) as received in Boulder, CO. The data show that the signals propagate normally within the regions involved and could likely be used to disseminate time and frequency to OMEGA users.

DOT Navigation. This project is for consultation with the Department of Transportation in the development of a test plan to improve the reliability of North Atlantic Air Traffic circuits. Emphasis is on the use of sky-wave communication systems with a special interest in the theoretical justification for the use of path diversity during ionospheric disturbances.

The nature of ionospheric storms including their geographic extent was investigated and a conclusion was drawn that the likelihood of improved communication through the use of diversity transmitters was such that a test operation was warranted.

CHAPTER 4. ADVANCED COMMUNICATION NETWORKS

This Division conducts a broad program of applied research and analysis of advanced communication networks. Division programs investigate technology options for developing competitive, lower cost communications networks to provide improved services and better resource utilization. This research incorporates technical, economic, market, regulatory, and policy factors in an integrated fashion. These studies, designed to assist NTIA policy, applications and spectrum programs and the telecommunications research and applications needs of other Federal agencies, are focused on three categories:

Communication Protection,

Switched Networks, and

Specialized Networks.

Each of the sections below discusses those projects that relate to one of the above categories, and a summary of progress and results is given for each project.

SECTION 4.1. COMMUNICATIONS PROTECTION

The Communications Protection program was initiated by NTIA in fiscal year 1979 after Presidential Directive (PD)-24 designated the Secretary of Commerce as one of two Executive Agents. The Secretary delegated responsibility to the Administrator, NTIA. The program is directed by the NTIA Special Projects Office (SPO), a unit within the Office of Federal Systems and Spectrum Management in Washington. The SPO develops policy recommendations and conducts telecommunication surveys of the federal agencies. Technical support functions of the program, including system analyses, policy support, and survey support, are performed by ITS in Boulder.

Presidential Directive PD-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 Secretary of Defense, the other PD-24 executive agent, has assigned the National Security Agency (NSA) the responsibility for protection of classified information, as well as national security related unclassified information. The Department of Commerce (NTIA and ITS) is addressing the protection of non-national security related, unclassified information. Fxamples of this type of information are as follows:

- 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.

The principal threat to telecommunications information is the vulnerability of both terrestrial and satellite microwave radio to eavesdropping by foreign adversaries.

Although many aspects of the Communications Protection program are classified, the following unclassified specifics are provided to offer an insight into FY-80 efforts. The topics described below fall into general work categories established within the program:

1. "Interim Microwave Propagation Loss Model,"

2. "DES and Federal Standards Efforts" - Communication Protection Standards Project,

3. "Public Key Cryptography and its Implementation" - Public Key Project,

4. "Digital Radio Studies" - Common Carrier Networks Project.

4.1.1. Interim Microwave Propagation Loss Model

In order to predict the propagation loss over LOS and non-LOS, point-to-point paths in the 2 to 11 GHz frequency range (in the U.S.), an interim microwave propagation loss model has been developed. This model is based upon standard knife-edge diffraction theory and is used to compute the biased median estimate for the propagation loss. At microwave frequencies, significant terrain features may be treated as sharp knife-edge obstacles. In order to apply the model, a determination is first made as to whether the path is:

1. radio line-of-sight (LOS),

2. single knife-edge (SKE), or

3. double knife-edge (DKE).

This determination is made by knowing the knife-edge (obstacle) location and the horizon heights and angles from the transmitter and receiver to the knife-edge. When the type of path and its physical characteristics are known, the knife-edge attenuation can be found. The propagation loss over the transmitter-receiver path is found as the sum of the free-space loss and the LOS, SKE, or DKE loss relative to the free-space value.

For paths where the transmitter and receiver are within radio line-of-sight, the propagation loss may exceed the freespace value by up to 6 dB. This occurs when the top of the knife-edge (obstacle) is at the same height as the direct ray, T-R, between the transmitter T and receiver R as illustrated in Figure 4-1. As the distance between the direct ray and the knife-edge increases, the loss approaches that of freespace. In the interim model, the knife-edge chosen for the LOS case is that terrain feature which comes closest to the direct ray between the transmitter and receiver.

If the transmitter-receiver path contains a terrain feature high enough to form a common horizon, then single knife-edge (SKE) diffraction theory is used to find the path attenuation. As with the LOS case, the knife-edge loss is approximately 6 dB when the direct ray, T-R, grazes the top of the knife-edge (obstacle) (See Figure 4-2). As the obstacle height increases, the loss relative to free-space increases.

When the transmitter-receiver path, T-R, as shown in Figure 4-3, has separate horizon obstacles for the transmitter (O_t) and receiver (O_r), the path attenuation calculation is based upon double knife-edge diffraction theory. In order to compute the double knife-edge (DKE) attenuation, an approximation is applied which allows the single knife-edge function to be used. The attenuation for the DKE is then found by assuming the DKE attenuation is the product of the attenuation at each knife-edge due to the other knife-edge. The accuracy of this DKE approximation for most paths is within ± 2 dB of the exact DKE model. However, the deviation may range up to 10 dB or more in some cases.

Comparisons of the interim loss model results with actual observations have been very encouraging. Other models' results have been compared against the same observed paths (under the same conditions), but for both the LOS and SKE paths, the interim loss model's predicted values, in general, deviate the least of any of the models from the observed data. (Data associated with DKE path is limited, and it is not yet possible to draw firm conclusions relative to model validity. However, because of the DKE approximation used in the interim model, it is unlikely that the predicted values obtained will be as close to the observed data as those obtained for LOS and SKE paths.)

The final propagation loss model, which will be completed in early fiscal year 1981, will refine the LOS and SKE calculation techniques and utilize an exact DKE calculation which will be much more accurate than the approximation in the interim model.

4.1.2. DES and Federal Standards Efforts

The Data Encryption Standard (DES) was adopted by the National Bureau of Standards (NBS) as a Federal Information Processing Standard (FIPS) in 1977. The DES is to be used to cryptographically protect sensitive, but unclassified, data.

Data to be cryptographically protected is called plain text. Encryption is the process of transforming plain text into cipher text (or unintelligible text). Decryption is the inverse of the encryption process;i.e., transforming cipher text into plain text. The DES is a block cipher, or one which operates on fixed size blocks of symbols. The DES operates on 64-bit blocks. During encryption it maps (transforms) 64-bit plain text input blocks into 64-bit cipher text output blocks. There are 2^{56} possible mappings. Each is unique and invertible. The specific mapping utilized is selected by a 56-bit keying variable, which is entered by the user. Decryption is the inverse of the encryption mapping. In order to successfully decrypt, one must know which of the 2^{56} possible keying variables (or keys) was used to encrypt the information. This information is normally known only to the originator and intended receiver of the encrypted message. In addition, with a properly designed algorithm such as DES, there are no known shortcut methods of determining the correct keying variable, save for exhaustive search of all possible keys.

The basic DES can be utilized in a number of ways to provide encryption.

4.1.3. ITS' Efforts in Encryption Related Standards

The Institute has been actively involved in the development of federal standards related to use of the DES for telecommunications protection. Standards currently under development include proposed FED-STD-1026, which defines interoperability requirements for use of the DES in data communications, and proposed FED-STD-1027, which defines security requirements for use of the DES.

More recently, ITS has been involved with the National Bureau of Standards (NBS) in the development of a proposed Federal Information Processing Standard which defines authorized modes of operation of the DES. The DES can be used in four primary modes. These are:

a. Electronic Codebook (ECB) Mode: This is the most basic mode of use of the DES and is illustrated in Figure 4-4. In this mode, a 64-bit plain text data block is input to the DES. This block is then encrypted by the DES device using a specific keying variable. The result of this encryption is a 64-bit ciphertext output block which is a non-linear function of each of the bits of the input block and keying variable. The decryption operation, Figure 4-4, is the inverse of the encryption operation. The 64-bit cipher text blocks are input to the DES device which is operated in the decrypt mode using the same keying variable as was used for encryption. The result is a 64-bit plain-text output block.

    Using the ECB mode, the same input plain-text block will result in the same cipher-text block each time it is encrypted under the same keying variable. (This is analogous to the classic codebook method of encryption; hence the name Electronic Codebook.) This property means that the compromise of any plain-text/cipher-text pair will allow an eavesdropper to identify this particular block of

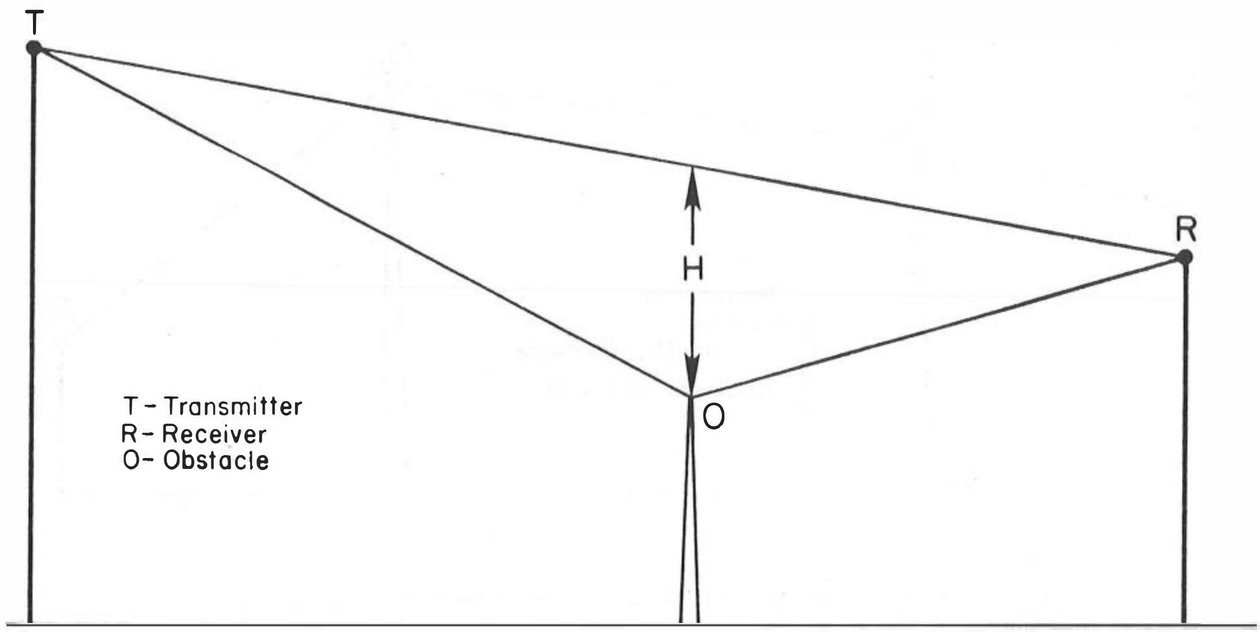


Figure 4-1. Geometry for a line-of-sight (LOS) path.

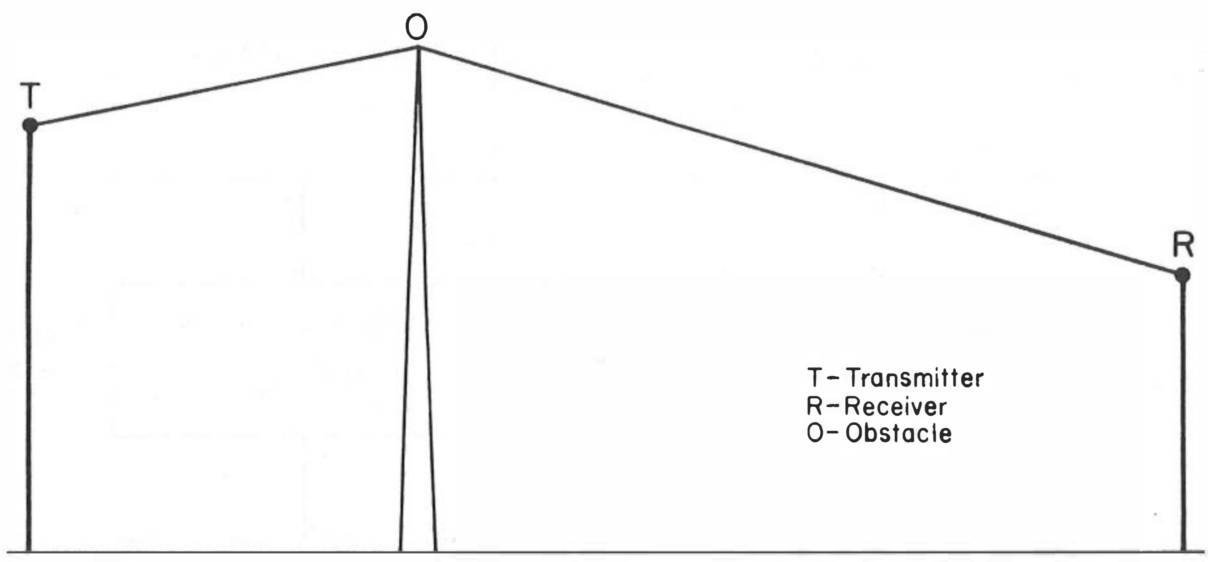


Figure 4-2. Geometry for a single knife-edge (SKE) path.

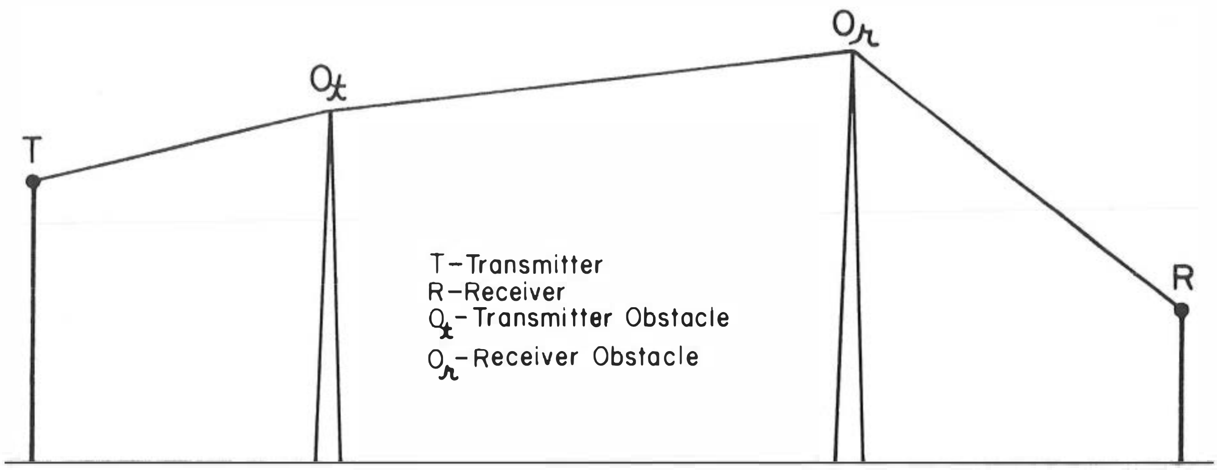


Figure 4-3. Geometry for a double knife-edge (DKE) path.

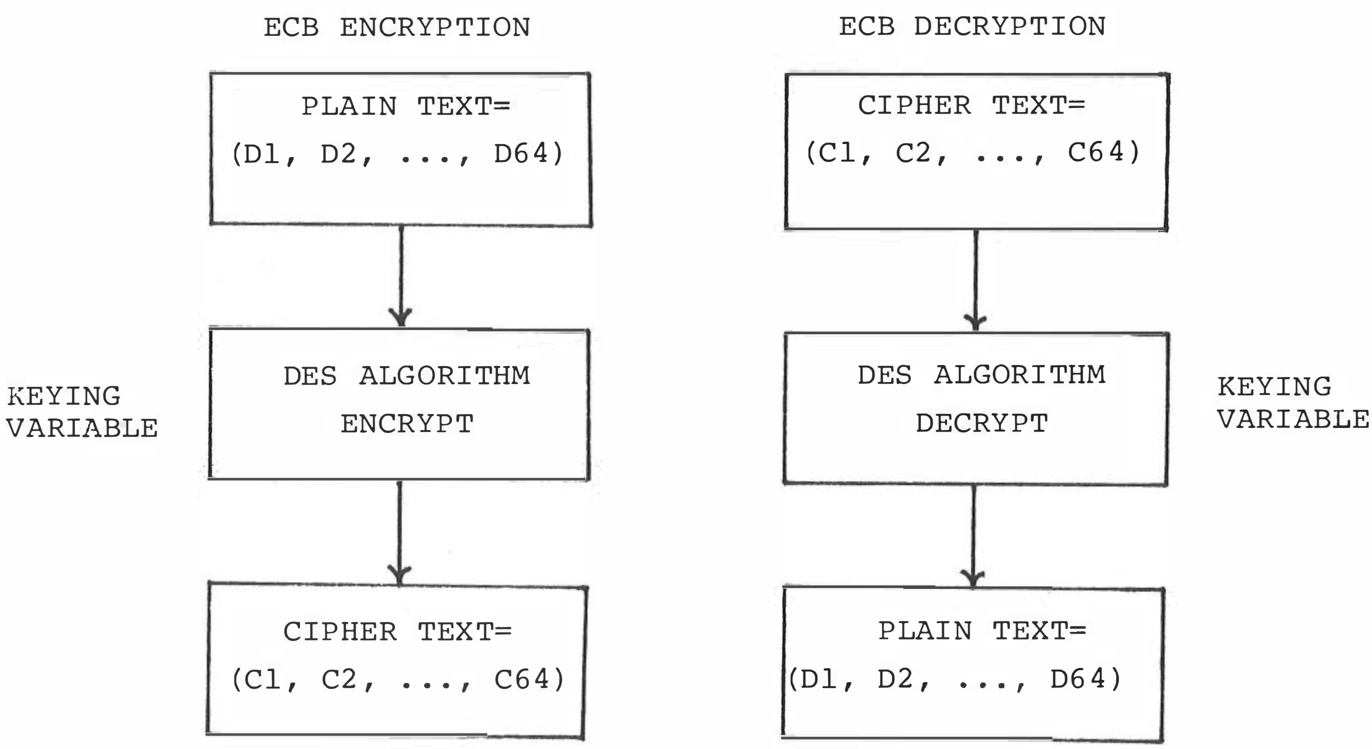


Figure 4-4. Electronic codebook (ECB) mode.

plain text each time it is transmitted as long as the same keying variable is in use. This limitation is known as the codebook analysis problem and the reason that ECB mode is only approved for encryption of isolated blocks of pseudo-random data (e.g., transmission of a keying variable or initialization vector to be used with another DES mode of operation appropriate for normal communication - cipher-block chaining, cipher feedback, or output block feedback.)

b. Cipher-Block Chaining (CBC) Mode: This mode of operation of the DES is illustrated in Figure 4-5. In the CBC mode, the plain-text input block (64 bits) is modulo-2 added to a 64-bit block of pseudorandom data prior to being encrypted by the DES device. The resultant cipher-text block is transmitted, and also fed back to serve as the "chaining" or pseudorandom block, which is modulo-2 added to the next plain-text input block. Hence the name cipher-block chaining. This process of modulo-2 adding the previous cipher text to the new plain-text block prior to encryption continues for the entire message.

The pseudorandom block added to the first plain-text block is known as an Initialization Vector (IV). The IV is required since there is no ciphertext output available to "randomize" the first plain-text input block. The IV is a randomly or pseudorandomly derived quantity.

The CBC decryption process, Figure 4-5, operates as follows. The first received cipher-text block is processed through the DES using the DES device in the decrypt mode. The result of this operation is then modulo-2 added to an identical IV as was used for encryption. This operation yields the first plain-text block. The second cipher-text block is decrypted by the DES device and added to the preceeding cipher-text block, which produces the second plain-text block. This process of decrypting the newest received cipher-text block and modulo-2 adding the result to the previous cipher-text block continues until the last cipher-text block has been received.

The CBC mode reduces the codebook analysis problem since, unlike ECB mode, the same plain text does not produce the same cipher text each time it appears as input. However, the CBC mode does have the property of error extension: This means that one or more bit errors occurring in a cipher-text block will cause multiple errors in the corresponding decrypted plain-text block (about 50% of the bits), as well as cause one or more bit errors in the plain-text block which follows it.

c. Cipher-Feedback (CFB) Mode: A third DES mode of operation is the cipher-feedback mode of operation shown in Figure 4-6. In CFB mode, the DES device is used to generate a pseudorandom binary stream (sometimes known as a keystream) which is modulo-2 added to plain text to produce cipher text. This cipher text is fed back to form all or part of the next input to the DES. One through 64-bit cipher feedback may be used.

Operation in CFB mode begins by loading an IV as the first input into the DES device. The IV is encrypted and produces a pseudorandom output block. All or part of this output block (depending on the size of the plain-text block) is modulo-2 added to a plain-text block of 64 bits or less to produce a block of cipher text. This cipher text is transmitted and is also fed back to form a new DES input block. This new input block is encrypted and modulo-2 added to the next plain-text block to form cipher text. This process of using the previous cipher-text block to form a new DES input block, encrypting this new block, and modulo-2 adding the result to the current plain-text block continues for the entire message.

A block diagram for CFB decryption is also given in Figure 4-6. Unlike the ECB and CBC modes, the CFB decryption process uses the DES in the encrypt mode. The decryption process essentially consists of generating an identical pseudorandom keystream at the receiver as was used to encrypt the traffic at the transmitter. This keystream is then modulo-2 added to the received cipher-text blocks to yield plain text.

The process begins with the encryption of an IV identical to that used at the transmitting station (for encryption). The resultant output bits are added to the first received cipher-text block to produce plain text. The first cipher-text block is then used to create a new input block which is processed through the DES device. The resultant output is added to the next received cipher-text block to yield plain text. This chaining process continues until the last encrypted block has been received and processed.

CFB mode has the property of error extension. One or more errors in a received cipher-text block will cause one or more errors in the corresponding plain-text block upon decryption. Approximately 50% of the bits will be in error in the decrypted plain-text blocks that follow the original error block until the cipher text containing the errors is eventually shifted out of the DES input block.

d. Output Block Feedback (OFB) Mode: The OFB or key autokey mode is another variation of using the DES to generate a pseudorandom stream (also known as a keystream) which is modulo-2 added to plain text to create cipher text. See Figure 4-7.

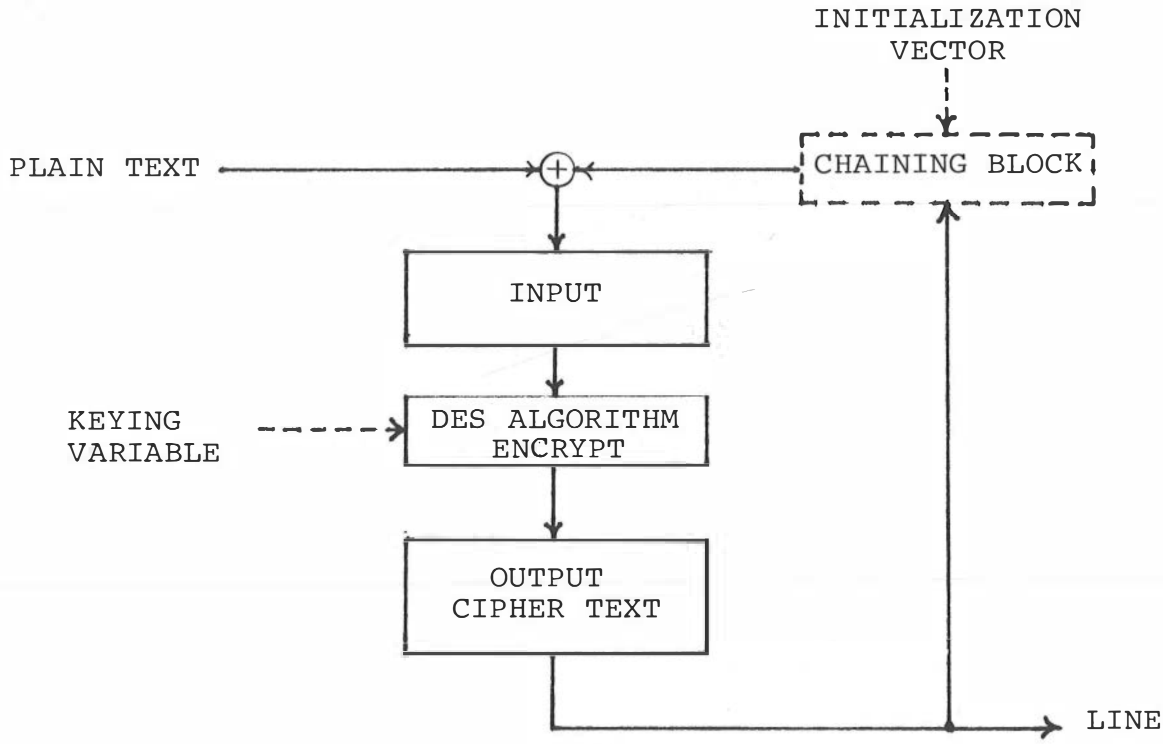


Figure 4-5a. Encryption using the cipher block chaining mode.

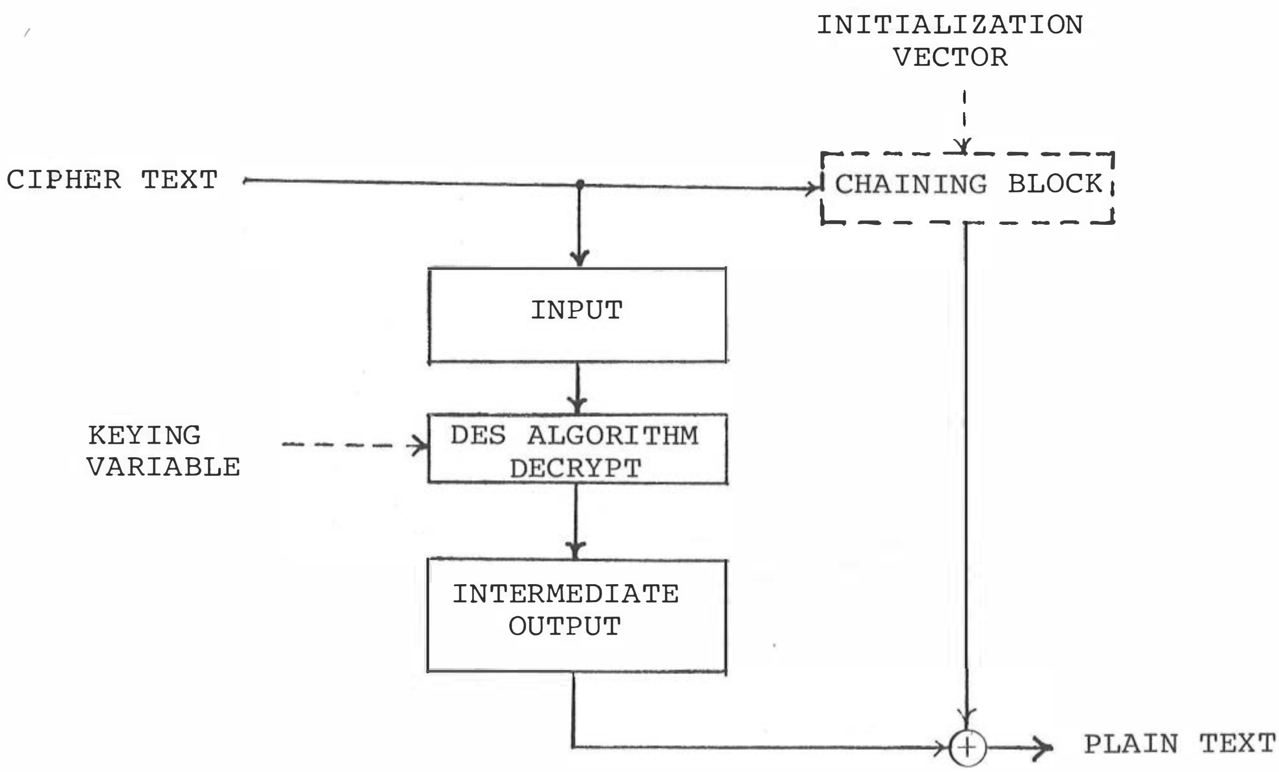
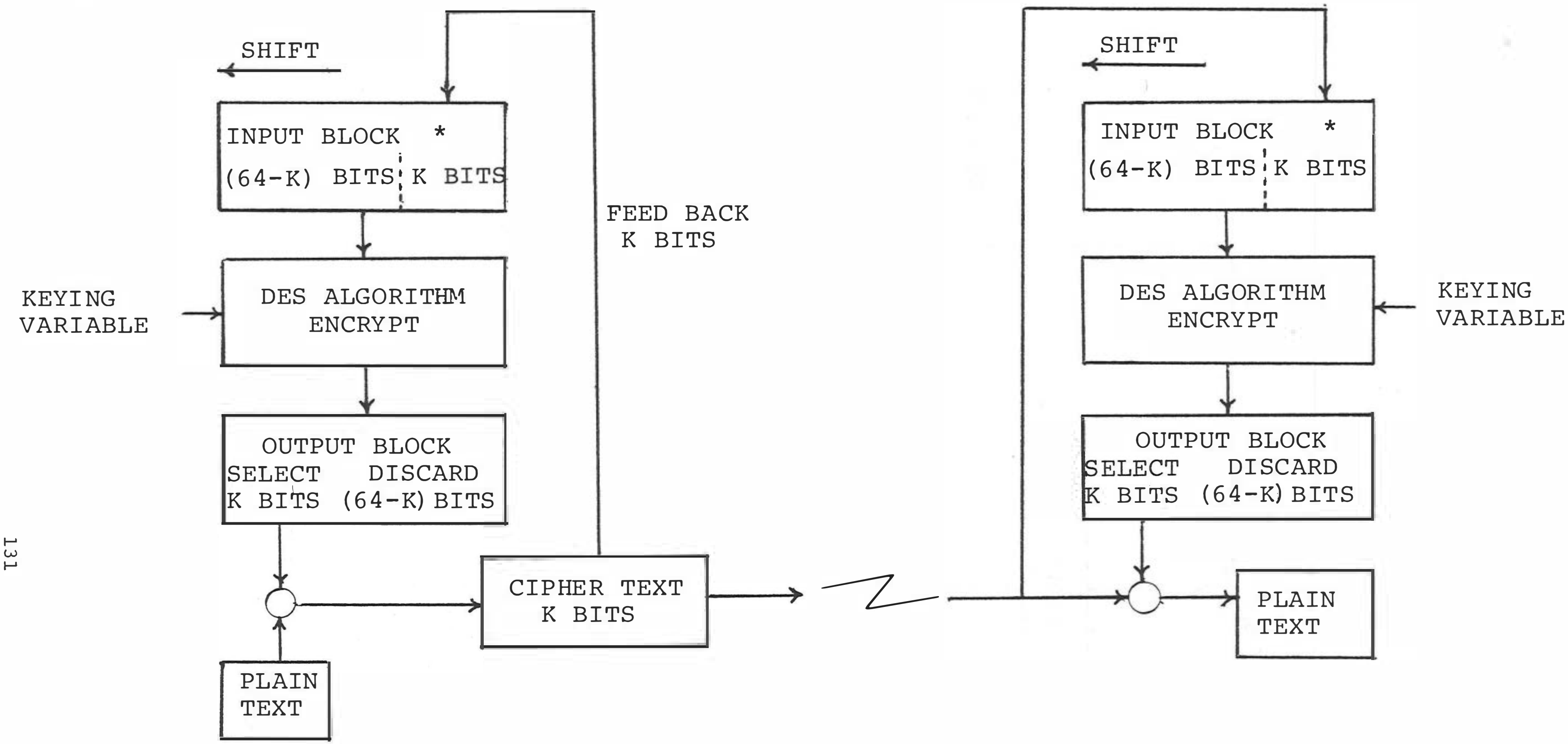


Figure 4-5b. Decryption using cipher block chaining mode.



*INPUT BLOCK INITIALLY CONTAINS 64-BIT INITIALIZATION VECTOR (IV). THIS IV IS USED TO GENERATE FIRST OUTPUT BLOCK TO ENCRYPT(DECRYPT) THE FIRST PLAIN(CIPHER) TEXT CHARACTER

Figure 4-6. K-bits cipher feedback (CFB) mode.

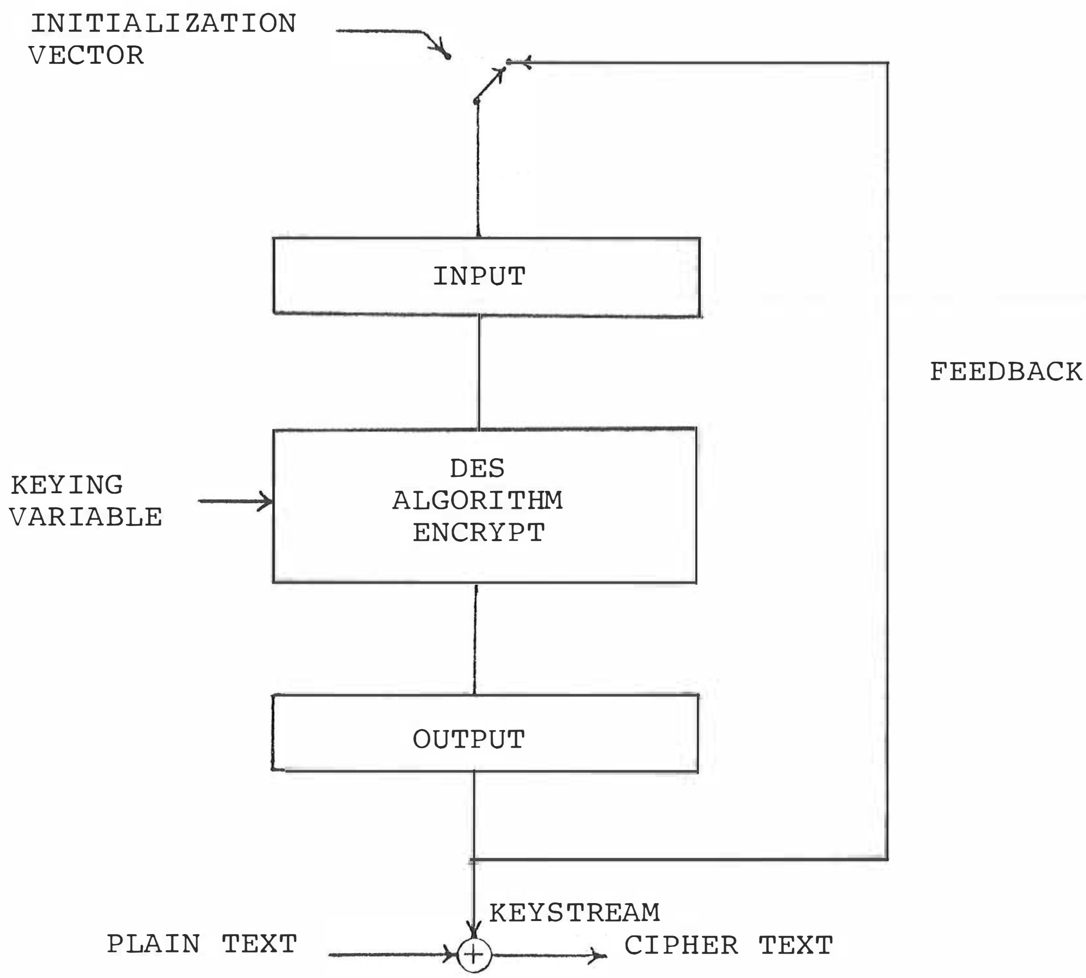


Figure 4-7. The DES in OFB mode (encryption).

Encryption begins by loading an IV as an input block to the DES. The IV is processed through the DES device operating in encrypt mode and the process yields a block of pseudorandom data. This block of pseudorandom data is added on a bit-for-bit basis to the plain text to produce cipher text. This block of pseudorandom data is fed back to form a new input to the DES and the block is encrypted, yielding another block of pseudorandom data. This block is added to the next block of plain text to form cipher text. This process is repeated for each block of plain text to be encrypted.

The decryption process, Figure 4-8, is identical to that of encryption. The pseudorandom stream, or keystream, is generated in exactly the same manner as that used for encryption. The keystream is modulo-2 added to the received cipher text to create the plain text. In order to decrypt correctly, the decryption keystream generation process must be synchronized with the encryption process. That is, the same bit of the keystream used to encrypt a particular bit of plain text must be used to decrypt the corresponding cipher-text bit.

The OFB mode has one major advantage over the other modes discussed above. Since the two keystreams are generated independently and do not depend upon the integrity of the received data, OFB mode does not cause error extension. A single bit error in the received cipher text results in a single bit error in the plain text. This property can prove useful in certain applications.

Development of protection standards will be an important and continuing area of effort in the Communications Protection Program for the next several years.

4.1.4. Public Key Cryptography and its Implementation

One of the most exciting results from public cryptographic research is the public key cryptographic system (PKCS). Generically, a PKCS is a method by which two parties can derive a common secret number quantity, e.g., a number or string of bits, without previously agreeing on anything in secret; i.e., all of the transactions are publicly disclosed. A PKCS depends upon asymmetric complexities in computation of mutually inverting operations. This curious aspect has been dubbed a cryptographic 'trapdoor.' In essence it means that, for some computations, one may proceed forward on a one-to-one mapping with relative ease and attendant small computational expense, but one is apparently faced with an enormous work factor to effect the inverse mapping in general, even though the unique inverse mapping exists.

It is believed that the various PKCS's deserve study as candidate vehicles for protected Data Encryption Standard (DES) cryptovariable transmission. Such a vehicle would complement the method provided in proposed Federal Standard (pFS) 1026. It would also allow for cryptovariables to be transferred when the pFS 1026 mode is not implementable.

4.1.5. MITRE Public Key

During the past year extensive study has been made of the MITRE Public Key Cryptographic System (MPKCS), as it is ideally suited to the ever-expanding world of digital communications. The MPKCS requires both parties to derive secret numbers, x, and y, which serve as exponents of a publicly disclosed element, α, of a finite field of 2^n elements. Exponentiation is performed modulo a GF(2) primitive polynomial (also publicly disclosed) of degree n. The first party calculates α^x and sends it to the second party. It is assumed that public disclosure also takes place. The second party computes α^y and sends it to the first party. Here it is also assumed that public disclosure takes place. The first party then exponentiates α^y to the x power and the second party exponentiates α^x to the y power. Both parties then obtain α^{xy}. An eavesdropper cannot compute α^{xy} without having x or y and x or y can only be obtained by solving for x or y given α^x or α^y. The asymmetric complexity is that given α and x one can easily compute α^x, but given α^x and α one cannot, apparently, easily recover x.

During the past year we have developed a method with which the initial exponentiations, α^x and α^y, can be performed in very short time by careful selection of α and exploitation of a finite field recursion of 'logarithmic' order which obtains upon successive squaring of α.

4.1.6. Rivest, Shamir, and Adleman (RSA) Public Key

The publication of "New Directions in Cryptography" by Diffie and Hellman has generated an increasing amount of research on public key cryptosystems. The system introduced by Rivest, Shamir, and Adleman is the subject of this project.

Briefly, the RSA scheme requires choosing two large primes, p and q, each about 100 digits long, and an encryption exponent E. Let n = pq. Then, to encrypt a message P, raise P to the power E and find the remainder upon division by n, or in symbolic form, the cyphertext C is given by

$$C \equiv P^E \bmod n. \qquad (1)$$

Decryption depends on finding a number D such that

$$C^D \equiv P \bmod n. \qquad (2)$$

The numbers E and n are made public, while the members p, q, and D are kept secret. Anyone knowing D can find p and q. Thus, the basic security of the algorithm relies on the knowledge that factoring a number n which is a product of two larger primes is presently a very difficult problem.

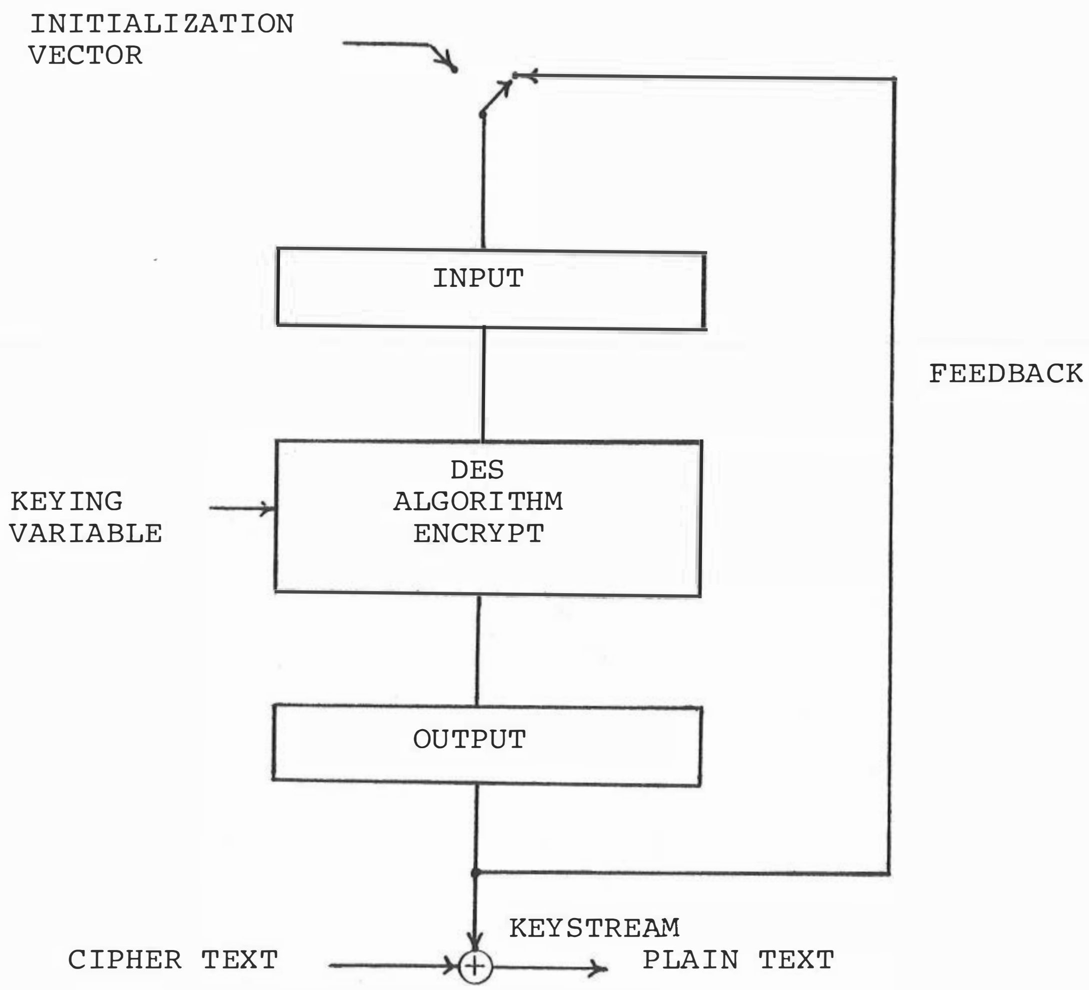


Figure 4-8. The DES in OFB mode (decryption).

One of the objectives of this project is to examine factoring methods to see if improvements are possible, and to look at other potential cryptographic weaknesses in the RSA algorithm. To date, no serious shortcomings have been found.

Two additional goals are to identify areas of application of the RSA cryptosystem and to design efficient implementations of the algorithm. One of the promising applications is for distribution of keys for conventional cryptosystems such as DES. An efficient multiprecision arithmetic software package including modular arithmetic operations is nearly completed under a contract. A report will be published at the conclusion of the project.

4.1.7. Digital Radio Studies

There are several basic approaches under consideration for protection of common carrier telecommunications information. This is because common carriers (like AT&T, MCI, etc.) employ analog FDM-FM technology for the vast majority of terrestrial and satellite microwave radio links, but are also using all-digital links to some extent, and are seriously considering the use of analog SSB-AM. The utilization of different modulation techniques adds a degree of difficulty to the search for proper protection approaches. Because of this, the Communication Protection Program has designed a two-stage study effort to ensure that all significant factors are considered before protection schemes are recommended as part of a comprehensive National Strategy Plan for protection. The first stage involves strictly a theoretical comparison of analog and digital techniques which could be used for common carrier terrestrial and satellite microwave systems. The second stage involves the practical comparisons of implementation, performance, and cost of such systems.

Stage 1 - Theoretical Comparisons: A number of techniques have been proposed to upgrade microwave telecommunication systems from analog to digital. Some theoretical work has been published in the literature, but the analysis is incomplete and fragmented. Substantial technical issues have not been addressed fully, including total link/system performance, spectrum utilization, and levels of complexity between various system schemes. A complete study must present all applicable advantages and disadvantages of analog and digital systems. The Institute is pursuing this study effort through internal ITS research, and through a contract awarded to S Consulting Services, Inc.

The study is comparing standard analog FDM/FM links against digital systems using such modulation techniques as biphase, quadrature, and M-ary PSK, binary and M-ary FSK, quadrature AM, quadrature partial response AM, and minimum shift keying. Data formats are being studied (NRZ, duobinary, etc.), as well as voice digitization techniques (compounded PCM, ADM), channel sharing (time assignment speech interpolation), diversity, error-control coding, and multiplexing (TDM, DAM, CDM, and FDM). The systems studied are being compared on the basis of quality of transmission and efficiency of spectrum utilization in the presence of thermal noise, interference, fading, and other germane factors. Assessments of voice intelligibility are being made.

The Stage 1 theoretical comparisons will be completed by February 1981.

Stage 2 - Practical Considerations: Protection provided to common carrier microwave links should be at the least cost, and cause no link performance degradation. These criteria are important both to the carriers and their customers. It is not yet clear, however, what the investment (cost) and performance tradeoffs are for implementing protection to existing analog links, analog links modified for digital transmission, or completely different new links. A study contract will provide many of the facts necessary to form a logical approach toward protection implementation.

This "real-world" study effort primarily involves three related tasks:

(1) Formulation of technical descriptions for existing common-carrier analog links, and evaluation of the relative performance of the links:

Eight different terrestrial and satellite analog links, including Bell System and CCITT types, will be specified. Baseband and radio-frequency information, multiplexing, and antenna characteristics will all be described. Block diagrams (schematics) will illustrate equipment in each system, manufacturer's part/model numbers, equipment cost, interface characteristics, input/output levels, etc. A relative level of performance will be computed for each of the analog links. That is, based on the link configuration, equipment used, modulation technique, etc., the performance the link could potentially have will be determined. Then this potential will be compared against carrier published performance. The Grade of Service concept will be used to determine minimum acceptable voice channel objectives. And the normal mix of voice, data, and facsimile traffic found on common carrier links will be determined.

(2) Theoretical transformation of the analog links described in Task (1) to digital links using various modulation techniques, and comparison of analog and digital links:

Task (2) treats the links of Task (1) as reference links and substitutes different modulation techniques in the links. The intent is to evaluate link performance, and cost impact, if some common-carrier, analog, broadband channels are converted to digital, broadband channels (while analog channels still operate adjacent to the digital channels); if some analog FDM-FM links are converted to single-sideband AM links; and if entire analog links are converted to digital links. The modulation techniques listed in the "Stage 1" effort above apply here also.

(3) Design of optimal analog and digital links to replace the links described in Task (1):

The existing common-carrier links described in Task (1) are reviewed to determine the minimum operational requirements of each link; then an FDM-FM analog, and a digital system, are designed to replace each one. The intent here is to conceptually develop links which will deliver optimum performance for mixed voice/data/facsimile traffic. Only equipment which is commercially available, or is under development and will be commercially available within three years, will be considered for the "optimum links." Optimization is assumed to be as follows. For analog systems, the number of baseband channels in the broadband channels shall be optimized while maintaining a signal-to-noise ratio at least as good as the referenced link. For the digital system, the bandwidth efficiency shall be optimized.

The Stage 2 efforts will be completed by the end of fiscal year 1981.

SECTION 4.2. SWITCHED NETWORKS

Technical Support to Common Carrier Issues. This is an introduction to the three program element descriptions which follow. The NTIA Common Carrier policy is oriented towards increasing competition, decreasing regulation, and stimulating innovative telecommunication services and productivity. As the telecommunications industry moves in these directions, there is an increasing need in NTIA for the capability to 1) address those technical issues whose understanding is integral to the formulation of sound policy, and 2) resolve those technical issues which impede the implementation of such policy.

As the central federal resource for telecommunications research and engineering, ITS is in a unique position to satisfy these needs. Increased competition implies both present and new service offerings will be supplied less by a single network which is under centralized planning and management and more by competing networks which are under different ownership. Decreased regulation implies that these networks will function in an environment which is under less government oversight and control.

Given this background, the objectives of this activity to provide technical support to common carrier issues are twofold: first to understand the interactions between competing networks, and second to facilitate the interoperability of competing networks. Pursuant to these objectives, four types of work can be defined. These are: 1) understanding the underlying technologies and methodologies, 2) modeling composite networks, 3) recommending policy changes and modifications, and 4) devising minimal remedies consistant with policy.

The Switched Networks Group of the Advanced Communication Networks Division at ITS is directly involved in the first two items, with the major support from agencies in the Department of Defense. Many of the problems encountered in the military environment are similar or identical to those found in the private sector. Understanding the advanced network technologies currently being developed by the military departments provides important insight to advanced network alternatives with commercial possibilities and to the potential policy issues which may require resolution in the future.

In the following paragraphs we describe three program elements being conducted for other agencies to support this activity. These programs involve studies of military networks having strategic, tactical, and nontactical applications.

Determination of Digital Transmission Technical Criteria. This program element, sponsored by the Defense Communications Engineering Center in Reston, Virginia, was initiated in June 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 multipler" 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.

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.

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 is contributing 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.

User-oriented parameters and values have now been developed in Phase A for one digital and one analog service mode. In Phase B, technically-oriented parameters and values must be determined for various subelement interfaces of the two systems. These can then 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.

Phase A relied 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 was a crucial step in the technical criteria development process.

The Phase A effort has resulted in an informal report entitled "Performance Parameters for Digital and Analog Service Modes," which has been delivered to the sponsor. The basic approach used in the study can only be outlined here. Some tentative results are also summarized. Details are given in the report.

The approach used for obtaining user-oriented parameters and values for two service modes is shown in Figure 4-9. The digital service mode selected for this purpose was chosen from the various AUTODIN II interactive modes. It is a high speed, 56 Kb/s, synchronous, binary, full duplex mode with the Advanced Data Communications Control Protocol (ADCCP). The transmissions employ data packets or segments which are rapidly exchanged during virtual circuit sessions. The analog service mode selected employs digital transmission of speech using a Continuously Variable Slope Delta (CVSD) waveform encoder, plus a 16 Kb/s modem for transmission of digitized voice. This analog mode permits conference calls to be protected on an end-to-end basis.

A table of parameters and the tentative values assigned to them for the digital service mode are shown in Table 4-1. One of the more difficult tasks in Phase A was defining the end user parameters for the transfer phase of an analog service mode that uses digital transmission for voice. Although a vast amount of work has been done in this area, it is difficult to specify voice quality quantitatively. Many different subjective methods have been tried, but none appear to have gained general acceptance. The authors of the report seek objective measures that satisfy criteria such as reliability, repeatability, usability, system independence, and user orientation. Five objective voice quality measures are introduced as measures of intelligibility, recognizability, and system acceptability, but it is found that additional data are needed in order to assign values to these parameters in many cases.

This report is a first attempt toward describing communication network performance from a user's viewpoint and applying these results to specific systems. The approach is new in many respects, and the results presented are not completely definitive. Some insight is given below and in the report on how this problem can be resolved.

New military systems, and commercial systems as well, normally evolve through a number of sequences or phases including concept development, validation, system development, design, production, implementation, and operation. During the concept development phase and into the subsequent validation and system development phases, a continuing iterative process is required in order to specify values for the performance parameters used in the final design and production phases. This iterative process is illustrated in Figure 4-10. The current effort is concerned with the concept development phase when initial values are assigned based on user and mission requirements. Using these values as design goals, an initial system design evolves for the validation phase. At this point, system costs can be estimated realistically and a cost/benefit analysis can be performed. Such analyses may lead to reassignment of values, redesign, and even a reanalysis. These aspects will be considered in future work by the Institute in this area.

Access Area Digital Switching System (AADSS). The U. S. Army's Communications Systems Agency (CSA) at Fort Monmouth, New Jersey, 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.

The 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 networks, (6) an evaluation of switch element capacities in access area digital switching systems, and (7) regional modeling for applying AADSS concepts to two access areas, one in New Jersey and the other in Arizona. Item 6 above was completed this fiscal year and item 7 is still in progress.

NTIA Report 79-26, "Switch Element Capacities in Access Area Digital Switching Systems," defines the parameters which determine the capacity of modern digital switching systems using stored program control. Capacity is defined in terms of the four major elements of a switch: the interface, the switching matrix, the control processor, and the signaling elements. The interrelationship between these four major elements is shown in Figure 4-11. Digital switches of the type shown in this figure provide new service features and

<table>
<tr><th colspan="2"></th><th colspan="3">USER-ORIENTED PERFORMANCE PARAMETERS</th><th colspan="3">PARAMETER VALUES FOR SELECTED MODES OF OPERATION</th></tr>
<tr><th colspan="2"></th><th>SPEED</th><th>ACCURACY/ QUALITY</th><th>RELIABILITY</th><th>SPEED</th><th>ACCURACY/ QUALITY</th><th>RELIABILITY</th></tr>
<tr><td rowspan="3">DIGITAL SERVICE</td><td>ACCESS</td><td colspan="3" rowspan="3">SUBSETS CHOSEN FROM FS 1033 PARAMETERS</td><td colspan="3" rowspan="3">TO BE ASSIGNED FOR SELECTED AUTODIN II MODE</td></tr>
<tr><td>TRANSFER</td></tr>
<tr><td>DISENGAGEMENT</td></tr>
<tr><td rowspan="3">ANALOG SERVICE</td><td>ACCESS</td><td></td><td colspan="2">SUBSETS CHOSEN FROM FS 1033 PARAMETERS</td><td colspan="3" rowspan="3">TO BE ASSIGNED FOR SELECTED AUTOVON II MODE</td></tr>
<tr><td>TRANSFER</td><td></td><td colspan="2">TO BE DETERMINED</td></tr>
<tr><td>DISENGAGEMENT</td><td></td><td colspan="2">SUBSETS CHOSEN FROM FS 1033 PARAMETERS</td></tr>
</table>

Figure 4-9. Phase A approach.

Table 4-1. Tentative Values for the Primary FS-1033 Parameters

Function	Performance Criterion: Efficiency or Speed	Performance Criterion: Accuracy	Performance Criterion: Reliability
Access	1. Access Time 0.10 sec. (Mean) 0.15 sec. (90%)	2. Incorrect Access Probability 10^{-10}	3. Access Denial Probability 10^{-3} (at 0.3 sec.)
Bit Transfer	4. Bit Transfer Time 0.5 sec.	5. Bit Error Probability 10^{-10} 6. Bit Misdelivery Probability 10^{-11} 7. Extra Bit Probability 10^{-11}	8. Bit Loss Probability 10^{-11}
Block Transfer	9. Block Transfer Time 0.5 sec.	10. Block Error Probability 10^{-9} 11. Block Misdelivery Probability 10^{-9} 12. Extra Block Probability 10^{-10}	13. Block Loss Probability $3 \cdot 10^{-11}$
Message Transfer	14. Bit Transfer Rate 8510 b/s 15. Block Transfer Rate 8510/n* blocks/s 16. Bit Rate Efficiency 50% 17. Block Rate Efficiency 50%		
Disengagement	18. Disengagement Time 0.05 sec. (Mean) 0.10 sec. (90%)	19. Disengagement Denial Probability 10^{-3} (at 0.15 sec.)	

*n = number of bits per block.

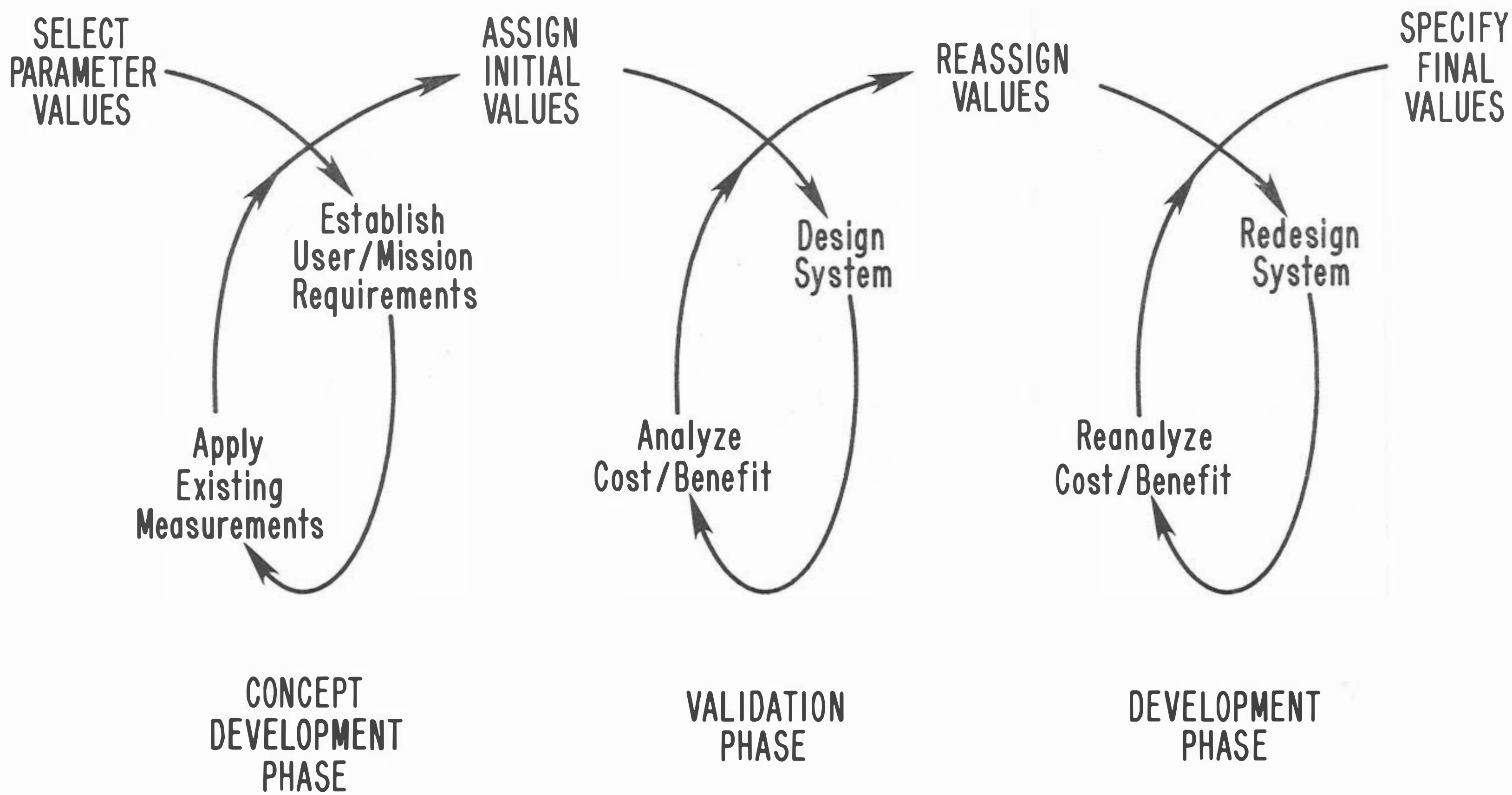


Figure 4-10. Iterative process for assigning values to user-oriented performance parameters.

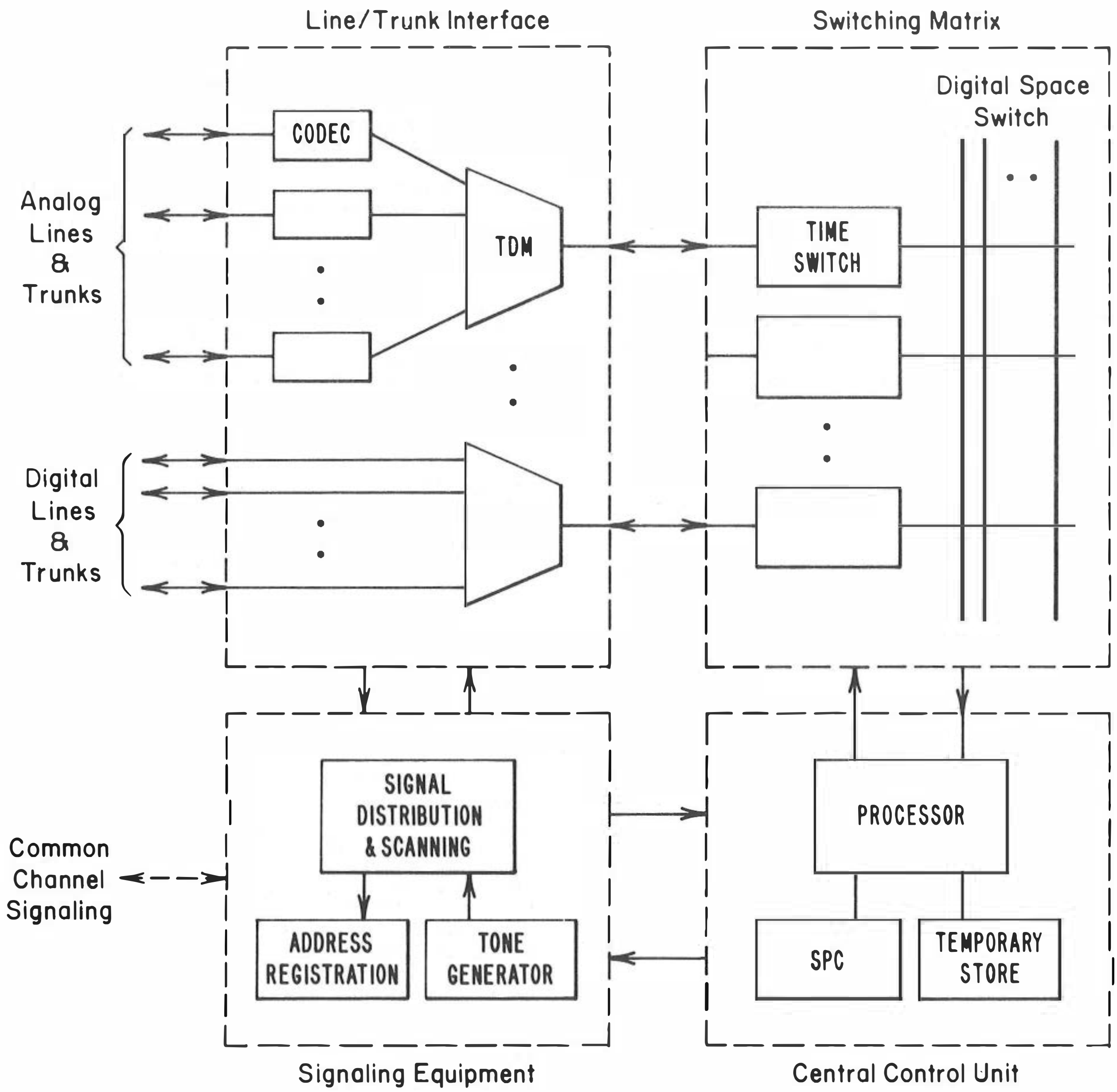


Figure 4-11. Digital switching system with T-S-T switching matrix.

functions to the user and at the same time permit reduction in space, power, and eventually operating and maintainance costs. When augmented with digital transmission facilities, the application of digital switching technology to military access area posts, camps, and stations extends the digitization process from the DCS long haul backbone to the local level.

Figure 4-12 indicates the interrelationship between capacities of various switch elements in quantitative terms. The overlay on this figure provides an example of how it can be used for evaluating various switch configurations. This is essential in order to compare switch characteristics, since different switch manufacturers specify switches in different ways. For example, the TTC-39 switch is specified for 3,300 call attempts per hour, 180 Erlangs of switched matrix load, and 600 terminations. Plotting these capacity values on Figure 4-12 yields a traffic intensity per termination of 0.6 Erlangs. Using the figure, it can be seen that this corresponds to 11 call attempts per hour per termination assuming an average holding time per call of 3.3 minutes. The dash lines on the figure indicate the characteristics of another military tactical switch, the TTC-38 (300 line version).

The regional modeling study initiated this year is concerned with reducing DCS access line costs, or at least reducing the direct homing from each military installation to the backbone network. This involves remote concentration elements and a concentrating switch (the AADSS) that are capable of handling all of the distance traffic to and from a single regional area. One network configuration for such a regional area, consisting of a number of contiguous bases, is shown in Figure 4-13.

In order to size the various concentration, switching, and transmission elements in an access area as shown in Figure 4-13, it is necessary to resolve a number of traffic engineering issues. It is apparent that in military access areas, as in many commercial installations, the telecommunications traffic passes through several concentration and switching stages. Traffic loads to server facilities (trunks) are formed through mergers and branch outs of offered traffic substreams. Blocking of calls is known to occur in many ways throughout these networks.

In NTIA Report 80-34, "Three Phases of Teletraffic Congestion in Military Access Areas," an effort is made to represent the access area grade of service (i.e., the probabilities of blocking for different substreams) in more realistic ways than has been done before. The message flow process is structured into three representative contention phases which are realistic and occur often in military networks. All three phases possess queueing models and analytical properties distinct from the conventional Engset, Erlang, and other classical models. Their blocking probabilities also differ significantly.

The report demonstrates several applications to access area telephony. These results and those obtained from the previous study on switch capacity are being used to develop regional access area models for subsequent performance and cost evaluations. This effort is expected to continue during the next fiscal year.

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 has taken 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 was sponsored by the U. S. Army's Communication Electronic Equipment Installation Agency (CEEIA) at Fort Huachuca, Arizona. The prime objective was to provide a functional design and specification of a bus-type transmission system to replace currently used wire pair cables used in transportable tactical command posts. During the course of this program, ITS collected a considerable amount of information relating to command post signaling centers and bus-type distribution centers. This was accomplished by literature search, discussions with congnizant personnel, and by visits to tactical field exercises at Fort Huachuca, Arizona, and Fort Hood, Texas.

This effort has now been completed and a final report has been prepared. NTIA Report 80-36, "Command Post/Signal Center Bus Distribution System," was submitted to the sponsor in April 1980. This report is divided into two major parts. The first part is concerned with command post operational requirements, and reviews the facilities currently used to meet these requirements. The second part of the report describes the application of new technologies such as time division multiplexing, voice digitization, and bus-type transmission facilities. In order to meet the conflicting requirements of deployment time and survivability, the concept of hierarchal structuring is introduced. A three-phased improvement plan is described so that bus-type system alternatives can be evaluated in terms of their evolution from existing architecture, through a transitional architecture, and to the final architecture. This three phased improvement program is assumed to occur at 5 year intervals. The three phases involve 1) imbedding transparent bus-type links into the existing network structure, 2) merging these links with digital switches, and 3) changing the network topology by adding new switching nodes to enhance survivability. Using this evolutionary process, the functional design tradeoffs are described and a preferred alternative selected on the basis of eight criteria including deployment time, capacity, performance, development risk, cost, etc.

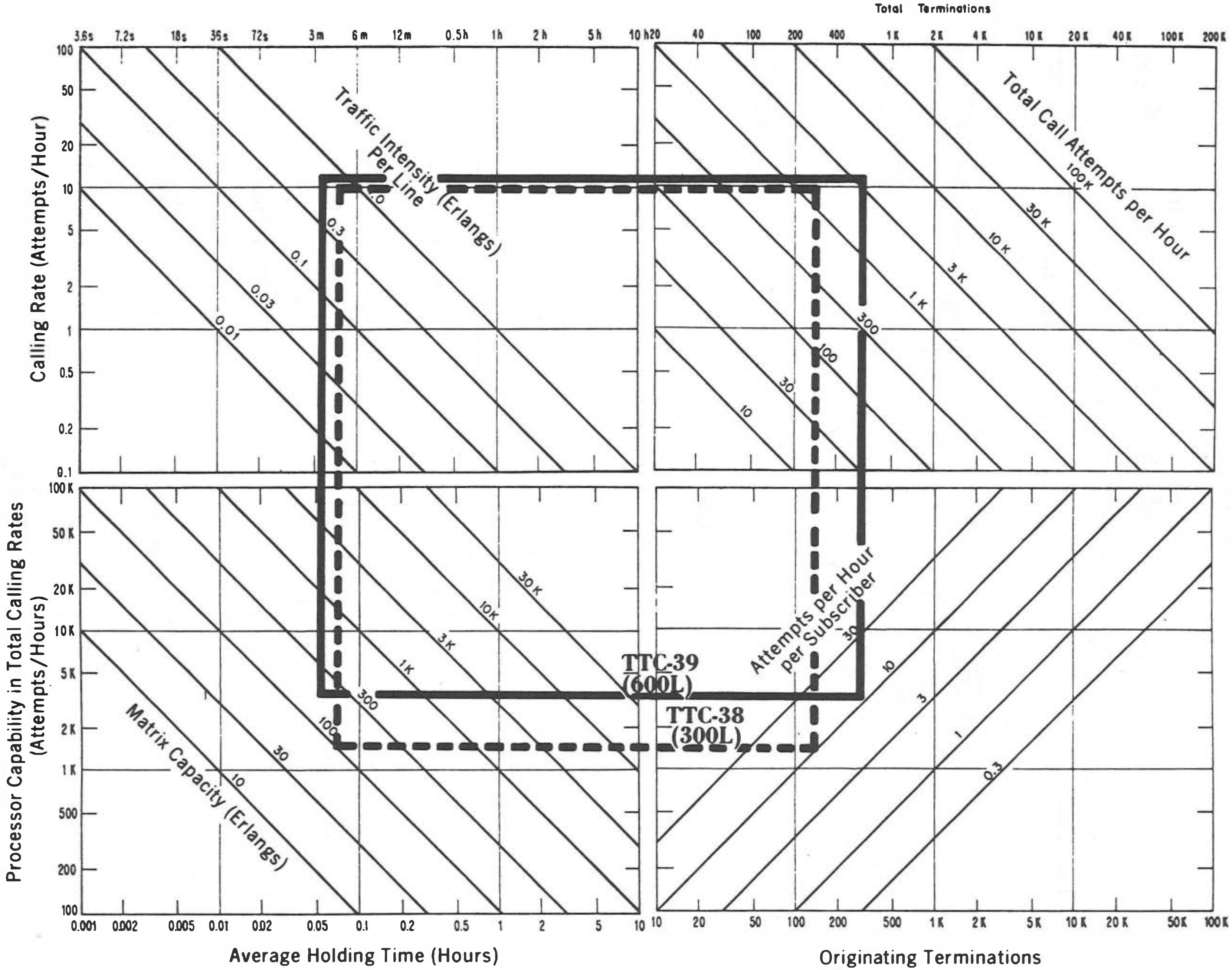


Figure 4-12. Overlay demonstrating capacity of tactical switch.

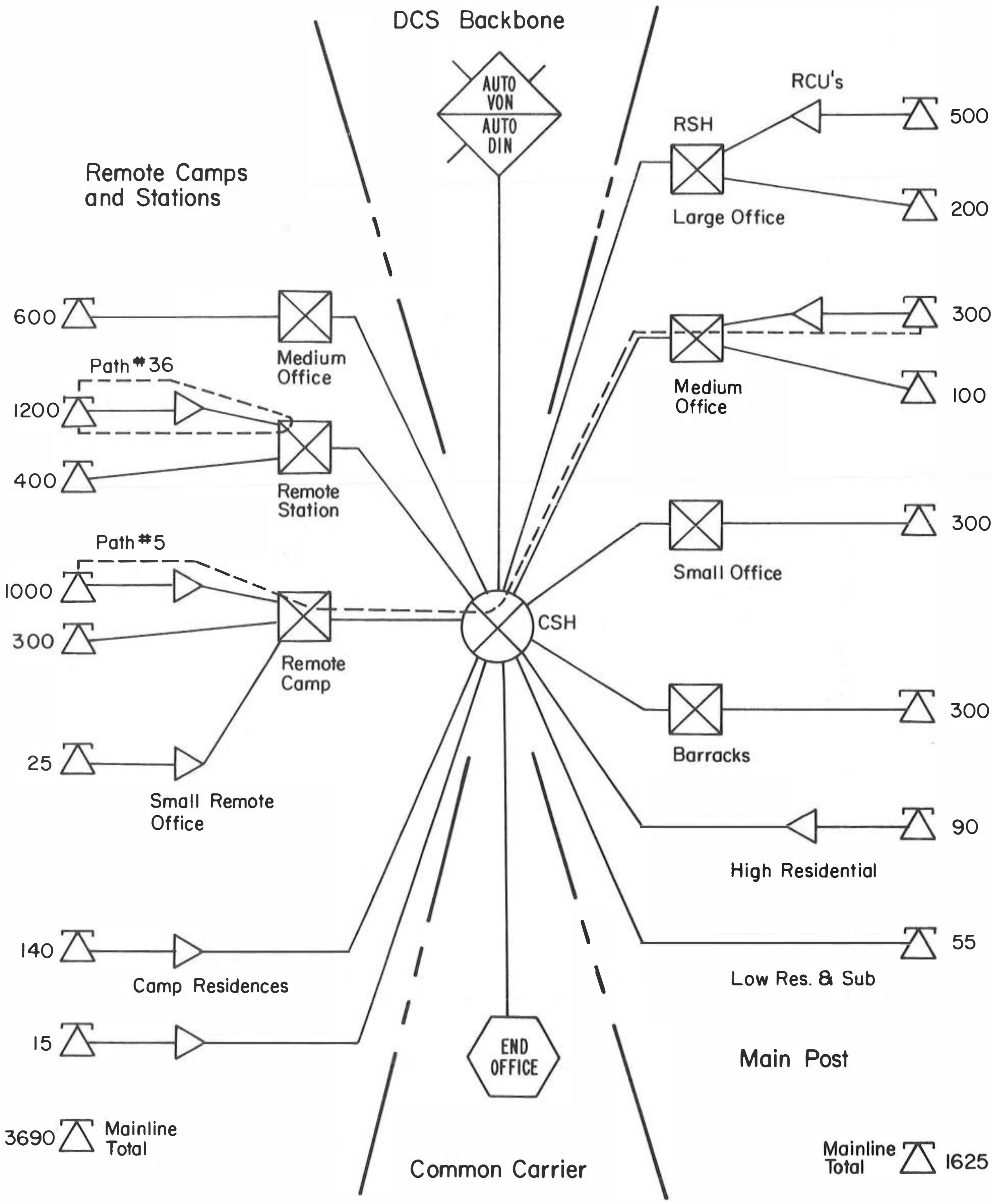


Figure 4-13. Illustrative example of an access area communications network.

Figures 4-14 and 4-15 illustrate the functional and physical form of the alternative that was recommended from the five alternatives considered. This preferred alternative is compatible with digital switching, but requires demultiplexing and conversion to the analog baseband voice channel for switching with existing analog methods. The basic T-carrier concept is a proven technology which can be adapted for tactical use at reasonable cost. Other transmission links can also be used such as coaxial cable using phase shift keying (PSK) for carrier modulation or fiber optical cable using a pulsed light emitting diode. This alternative offers considerable flexibility in the choice of analog to digital conversion technique, binary encoding, as well as the choice of transmission media. Digital time-division multiplexing (TDM) is transparent to encrypted voice and could be link encrypted if desired. This alternative is also compatible with future transitions to all digital operations, either with CVSD at 16 or 32 Kb/s or with PCM at 48 Kb/s and 64 Kb/s.

USPS Electronic Message Service System. NTIA/ITS provides support for the development of the Electronic Message Service System (EMSS) by the United States Postal Service (USPS). ITS provides technical expertise, system analysis, and necessary support documentation. The USPS/ITS agreement calls for participation in providing assistance to the USPS in the preparation of a Statement of Work (SOW) for an electronic message test network and developing computer modeling of the EMSS in the form of dynamic message flow simulation for the entire system.

ITS has provided assistance in the concept formulation and selection of the candidates that will best meet the overall USPS objectives for initial implementation and subsequent development for a mature national electronic message system including all 50 states and Puerto Rico. The services to be provided would accept messages on magnetic tape, paper for fascimile transformation, and electronic input from public terminals and user terminals (business inputs). The USPS objective is overnight delivery on the next working day of 95% of the messages input to the EMSS. This would use common carrier leased services for electronic message input and for the message transfer with the system. The EMSS planned operation is shown in Figure 4-16.

The input messages are converted at the EMSS stations for transmission via leased common carrier services such as satellite and terrestrial links to the EMSS destination station. On message receipt at the EMSS station, the messages would be stored in computer memory, sorted, and then printed and enveloped for carrier delivery. The messages would be distributed to the customer by truck or mail carrier as is the current practice. This would be done in accordance with Presidential guidance received in July 1979 which states that no direct electronic messages would be delivered directly to the customer.

During the past year ITS has developed a dynamic simulation model of the EMSS stations and the telecommunications network for the system. This required an extensive evaluation of simulation languages that were available. The recently developed Simulation Language for Alternative Modeling (SLAM) was selected and has been implemented. SLAM provides the organizational structure for building event, process, and continuous models of systems.

A structured analysis of the station operation was formulated to assist the simulation development. All messages that were to flow through the system had to be determined and defined. These included the customer-generated messages as well as internally generated messages for system support. The number of each type of message was then estimated as well as the message size. Message flow through the system was determined, and overall system schematics were developed.

System requirements were formulated for each major phase of message processing. These major phases consisted of input message conversion, message transfer, and output message conversion for delivery. This information was then translated into message flow and system requirement, and used as a basis for formulating the SLAM simulation model.

Special performance measures had to be developed to determine individual station and network performance for each major phase of operation as well as over all system performance. Work is also in progress to develop a user manual for use of the EMSS simulation model.

The simulation model provides some unique capabilities and state-of-the-art development. The simulation has been set up with the capability to analyze the system and optimize the selection of station and telecommunications network resources to meet input specified performance requirements. This is done by an "Auto Search" process within the analysis mode. Specified criteria were developed to provide this capability and thus greatly reduce the number of runs that are needed to specify station and network resources. The simulation has also been set up in compartments so that segments of the operation can be reviewed in detail without having to run the total program.

Follow-on work with the simulation model will provide overall system tradeoffs, system sensitivities, and the capability of evaluating contractor proposals for EMSS development.

ITS has provided the technical support to the USPS for the development of a draft Statement of Work for an electronic message test network. This will provide for the initial phase of system development of EMSS.

Support will also be provided in establishing software support requirements with the EMSS and at the major system interfaces. This will include message processing, message sorting, control, and bookkeeping functions. This will also include the telecommunications network functions of interfaces and trunk requirements. Link requirements will be determined and network controls will be investigated.

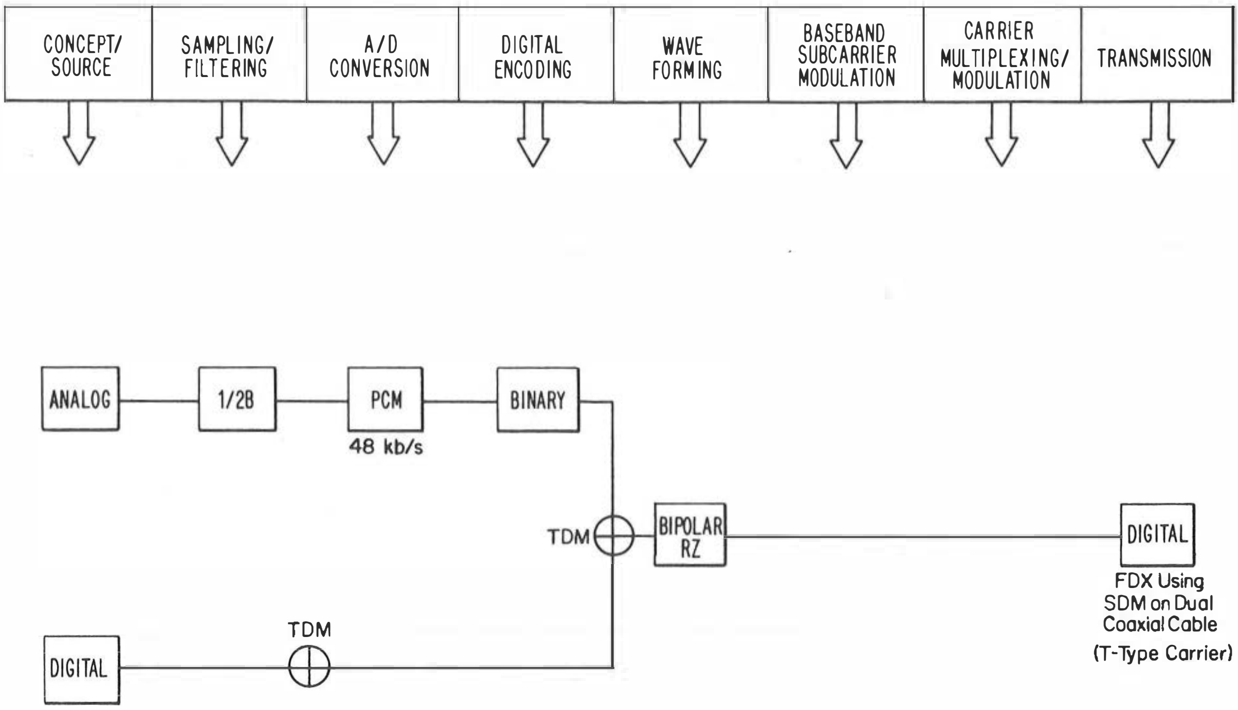


Figure 4-14. Alternative III for CP/SC link structure.

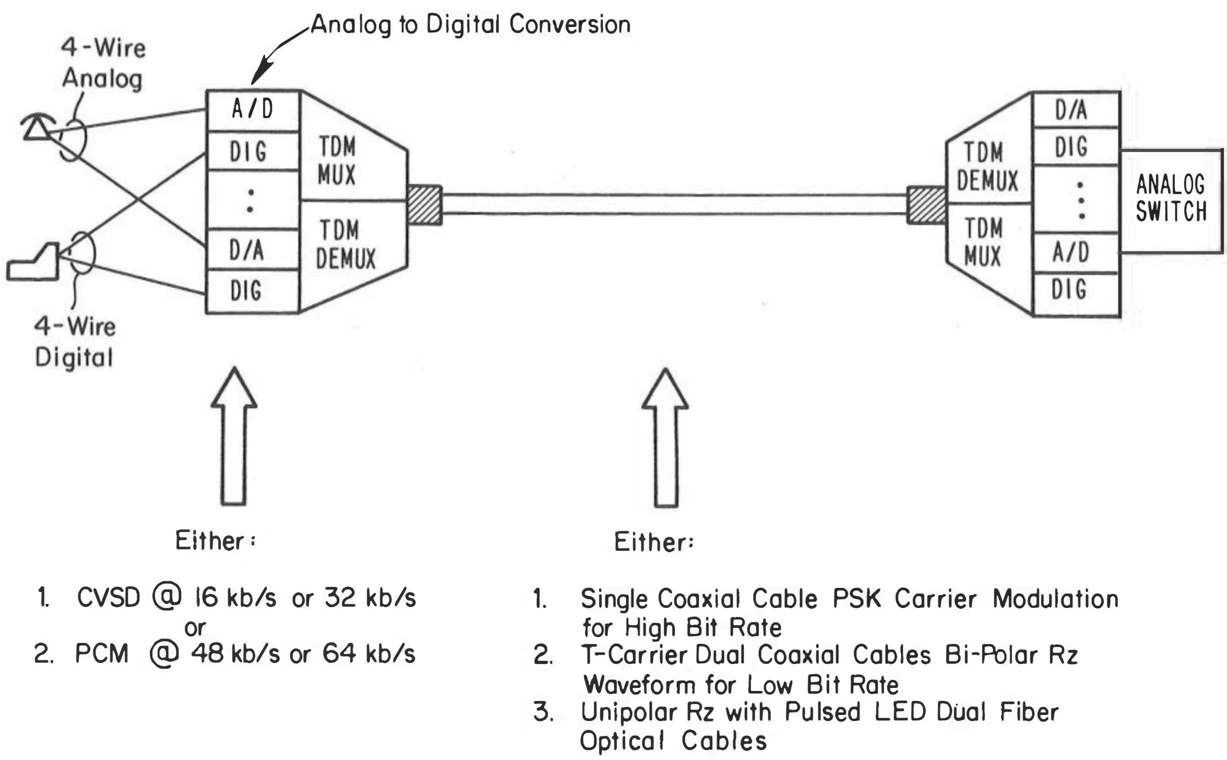


Figure 4-15. CP/SC Alternative III canonical bus distribution system.

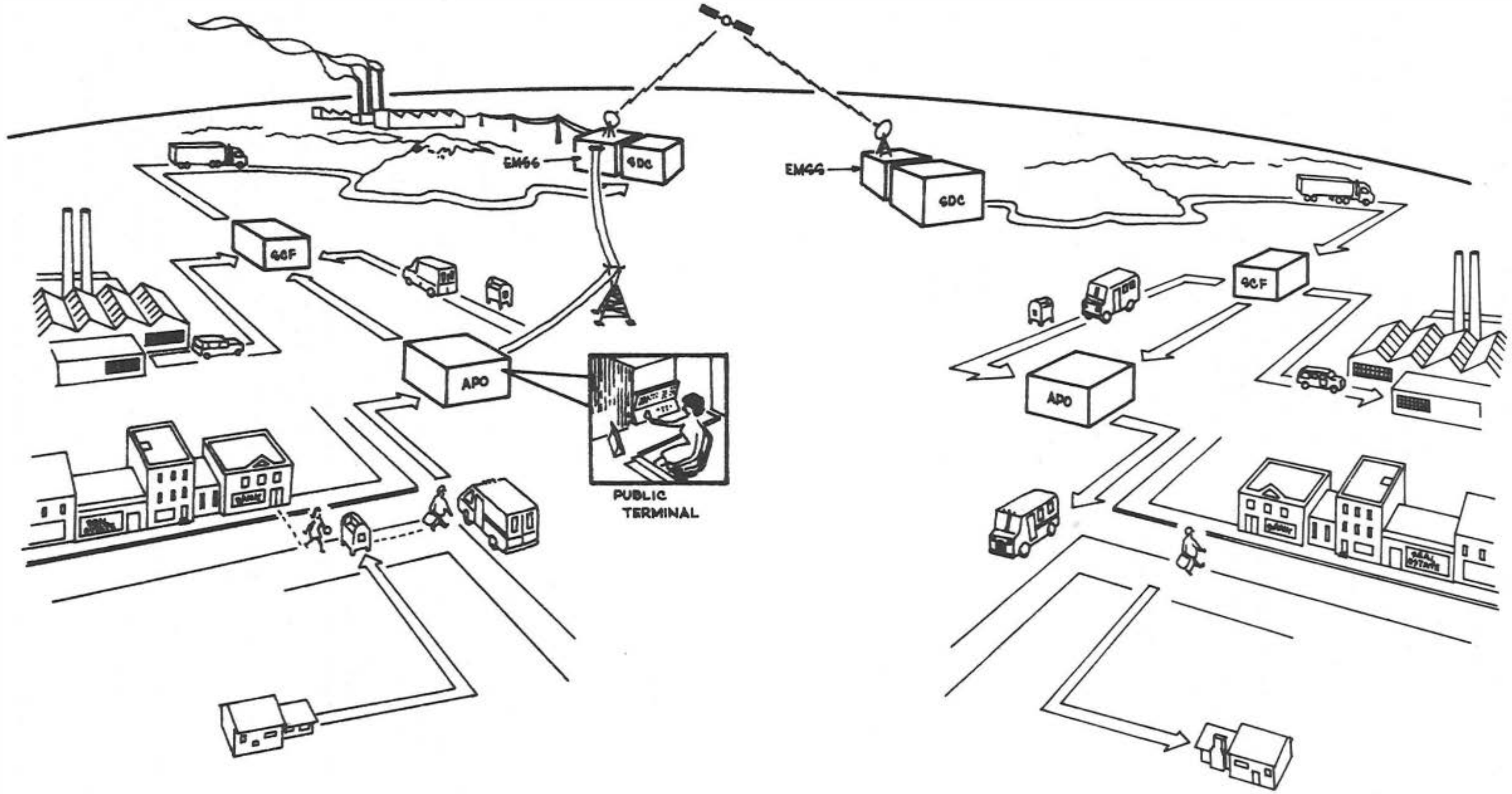


Figure 4-16. EMSS message routing.

A new task was undertaken for the USPS EMSS during the past year. It's purpose is to initiate identification of standards which will ensure that businesses can interconnect with the planned mail delivery system through telecommunications common carriers. This requires an American National Standards Institute (ANSI) standard.

This work is in response to a Presidential Policy Statement (July 19, 1979) which established the role of the USPS in electronic mail. Specifically, one of the administration conditions states,

"To ensure that interconnection with the mail delivery system is available to all companies, technical interconnection standards should be developed through a cooperative effort by the American National Standards Institute, the USPS, the private carriers, and an impartial arbiter, if needed."

Thus far, planning for and initial development of the work has taken place. This planning is composed of several elements, which include:

1. determination of the scope of the present EMSS network planning,

2. identification of terminal devices and associated interface standards,

3. identification of local telecommunication input lines, and

4. initiation and maintaining of contacts and activities with the ANSI.

Work in all of these areas has started, including the establishment of contacts with the ANSI.

A presentation which described the potential USPS EMSS was made to ANSI Technical Committee X3S3, Data Communications. Subsequently, the EMSS project work was assigned to ANSI Task Group X3S37, Public Data Networks. Working in cooperation with X3S37 will lead to the identification of existing standards applicable to the EMSS, and also, the possible identification of unique standards requirements for the EMSS which may need development. The result of this work will be an ANSI applications standard which may become an ANSI national standard.

The identification of the standards is based on the International Organization for Standards (ISO) Open System Interconnection (OSI) architecture of interface layers. The OSI is a seven layer reference model (Figure 4-17). As shown, the layers are: 1) Physical, 2) Data Link, 3) Network, 4) Transport, 5) Session, 6) Presentation, and 7) Application.

The first four layers are related to the telecommunications transport service for messages, while users of the transport service are concerned with the fifth through seventh layers. These latter layers relate to message usage, formatting, and file access or transfer. These are transparent to the first four layers, which deal with physical interconnection, control of physical connections at end points, message routing (multiplexing/demultiplexing), and network topology, including point-to-point, multi-drop, and alternate paths for an EMSS communications network.

The current work is concerned specifically with the interconnection standards required for electronic message inputs, but identification of these local telecommunications network standards will have a bearing on the trunk network system protocols. The trunk network will be for the message transmission between EMSS stations located at cities across the continental United States, Alaska, Hawaii, and Puerto Rico.

Parameters in the selection of interface standards relate to coding (ASCII, EBCDIC), clocking (synchronous, asynchronous), protocols (bit- or character-oriented), and switching (circuit, message, or packet), in addition to methods of message connection and transmission to the EMSS.

A result of this work will be the establishment of government and industry standards for the use of the USPS EMSS.

SECTION 4.3. SATELLITE COMMUNICATION SYSTEMS

In the Executive Order that established the National Telecommunications and Information Administration (NTIA) in 1978, the Department of Commerce was charged with developing and setting forth "telecommunications policies pertaining to the Nation's economic and technological advancement" (EO 12046, Section 2-406). This charge was elaborated with regard to communications satellites in the Administration's National Civil Space Policy Presidential Directive (PD) 42. In that Directive, NTIA was given three interrelated missions: (1) to aggregate the potential public service users of communications satellite services; (2) to stimulate research and development of inexpensive satellite technologies and services appropriate to the low-volume public service users; and (3) to translate the agency's experience in market aggregation and R&D into programs for lesser developed countries. These three missions form the cornerstone of the Dispersed Users Satellite Program, administered by NTIA's Office of Telecommunications Applications (OTA), and supported technically by NTIA's ITS through their Satellite Communications Systems' Program.

The Federal Government has long been committed to satellite communications and to the growth of a vigorous commercial satellite industry. That industry has benefited greatly from Government-funded R&D efforts, such as those of the Department of Defense (DoD) and the National Aeronautics and Space Administration (NASA), and indeed has emerged to serve domestic and international needs. However, the existing commercial systems have not developed satellite technologies and services appropriate to large portions of the public service sector. They are presently designed to serve high-volume, geographically centralized

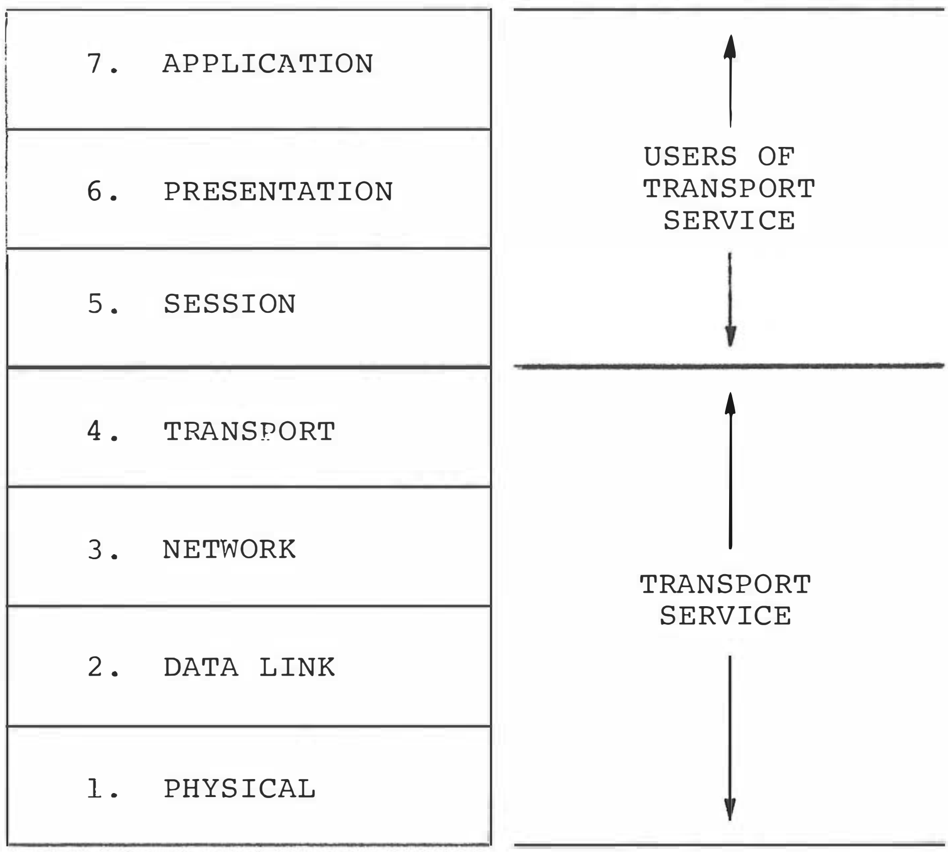


Figure 4-17. Open system interconnection model.

communications users in major urban areas. In contrast, many public service users have short-term, intermittent, and low-volume communications demands, commonly referred to as "thin-route" traffic, among dispersed agencies and offices. Available commercial technologies are not compatible with the inexpensive satellite ground systems essential to serving many rural areas and decentralized agency users. Public service users with low-volume, intermittent communications needs cannot afford the sophisticated and expensive systems now in use; nor has it been considered profitable by the commercial carriers to launch high-power satellites to serve this community. Where available technology could be used, service to this disaggregated market has not been seen as a profitmaking venture, and therefore commercial satellite carriers have not offered to the public sector the benefits that distance-insensitive communications could provide.

The major activities of the NTIA/ITS Program reflect its three missions -- market aggregation, technical studies of relatively inexpensive technologies, and international applications.

The Institute has been providing input to these three missions in the form of technical studies and international applications.

Existing commercial services, even if made available to the public sector through successful aggregation efforts, may not fully satisfy public service needs. New technology development may be required to provide very low cost services for part-time users. Since the President's Directive assigned to NASA responsibility for undertaking R&D in public service satellite technologies, the NTIA Satellite Program has deferred to NASA's experience and expertise. The efforts of ITS focus on developing technical means to improve the efficiency and cost effectiveness of services and on providing a technical base for the development of policies to encourage the evolution of new satellite communications technologies with significant public service benefits. Specifically, ITS is defining options for the application of low-cost, small-antenna earth stations; developing plans for orbit/spectrum utilization; and conducting studies of advanced ground terminal systems for rural areas and other thin-route services.

The ITS program was divided into three projects for management purposes. The three projects' concerns are reflected by their titles: "Frequency/Orbit Resource Study," "Public Service Satellite Support," and the "AID Rural Satellite Systems."

Frequency/Orbit Resource Study. The Frequency/Orbit Resource Study is concerned with the activities of CCIR, World Administrative Radio Conferences (WARC), FCC actions, etc. which have impact upon the rules and regulations for the use of the radio spectrum and the application of small-antenna earth stations (SAES) that are critical to the public service and thin route satellite users. The Institute has been active in these forums either by direct participation in their activities such as CCIR Study Groups or have provided input to the 1979 GWARC and various FCC actions. Formally the ITS activities have resulted in a report (to be published as an NTIA Report) on the results of the 1979 GWARC and its impact on the public service user and a major contribution to NTIA's Task Force Report on the Direct Broadcast Satellite. Among the technical issues dealt with in the report were an assessment of the frequency-orbit capacity available for direct-to-home broadcasting satellite services, the output of the 1979 GWARC, and an estimate of the probable frequency-orbit capacity that may be available to the U.S. for a DBS (direct broadcast satellite) system.

Since many of the issues related to the DBS issue require detailed analysis and study, ITS has contracted with ORI, Incorporated for the modification of a computer program called Spectrum Orbit Utilization Program. This program was designed to compute the mutual interference between large numbers of satellite communications links which use satellites in geostationary orbit. The modification will allow each transmitter and each receiver to use its own individual antenna pattern so the benefits of shaped antenna beam technology may be properly considered. The antenna patterns will be specified either by equations or by constant gain contours.

Public Service Satellite Support. Public Service Satellite Support provides the direct technical support to NTIA's effort to develop the environment for a new generation of commercial services to meet the public service needs. The ITS support has included investigations on existing transponder and earth station availability for this purpose. We have also looked into the factors associated with satellite service for the Pacific Basin and the requirements for an American Indian Public Radio Network.

AID Rural Satellite Systems. AID Rural Satellite Systems is funded by the Agency for International Development, Department of State. This ITS project is a small part of a larger and new AID program to test the cost-effectiveness of satellite communications in rural development.

The basic premise of the program is that new satellite technologies will make possible the establishment of reliable communications systems in many rural areas of the developing world. Once established, reliable communications in rural areas potentially represent a new development tool of importance. This AID program is designed to guide the use of that tool toward serving a number of fundamental development objectives, and to test its utility when so used.

The Institute is providing technical support to this AID program in the form of four studies or developments. The AID objectives are to provide an initial limited facility for satellite-transmitted, voice-grade circuits to remote areas of the less-developed countries where trunk communications are non-existent or limited to less-than-fully-reliable, high-frequency links. It is the expectation that, in countries which are equipped with one or more

AID-supplied satellite ground stations, an expanding network and plant will evolve.

The ITS studies are directed primarily to the requirements of this evolution; they consist of examination of the following areas --

- Demand-assigned multiple access (DAMA) technology
- Frequency converter technology
- Solar power sources
- Slow-scan television.

The latter two of these topics were undertaken and reported on in the early part of the year.

The findings in the solar power study revealed that, while the costs of solar cell production are declining and are expected to continue this decline as a result of increased volume and improved techniques, nonetheless, the overall costs of complete solar power systems will decrease no more than 20% from current prices and then will rise in response to inflation. The reason for tnis is that a very significant part of a continuous-supply solar system is the investment in storage batteries which are required to provide power during periods of non-insolation, i.e., at night and during bad weather. To meet the power requirements of a conventionally-designed satellite station, i.e., with capability for expansion of services to 200 or more voice channels, and with cost and effectiveness trade-offs between antenna dish size and power amplifier, costs of a solar power source of appropriate capacity would equal that of the satellite station. The study results indicated that notable economics could be affected by including consideration of the solar power source -- if one is to be used -- in the overall system design of the satellite ground station.

In other work, a survey was made of commercially available slow-scan television equipment. Slow-scan TV uses digital storage techniques to accumulate and hold a video image and transmit it at a rate which can be transmitted by voice-grade circuits. At the receiving point, the image is reconstructed as the video information comes in, and can be displayed as a frozen image or replaced as each new image is completed. The replacement time is approximately 30 to 60 seconds. While this interval is far too long for motion display, the system can have great value in information transmitted for purposes of education, emergency medical information, and, indeed, any long-range consultation where some visual information is pertinent.

In continuing work, ITS will be examining technology of earth-station frequency converters from the point of providing more economical implementation for this significant ground-station component. Also, investigations of demand-assigned systems are being conducted in anticipation of the expected evolution noted for LDC use of satellite communications. DAMA is a technology which permits the expansion of an existing network by providing a capability to automatically search among existing channels for unused ones. Such systems exist at the present time and, while they are economically desirable for high-volume networks, are marginal for thin-route applications.

ANNEX I
ITS PROJECTS FOR FY 80
ORGANIZED BY DEPARTMENT AND AGENCY

AGRICULTURE, DEPARTMENT OF

Project	Title	Leader
9104384	Communication Support Program	Morrison
9104427	Shasta-Trinity Telecommunication Study	Skerjanec
9104434	Data Communication Support Program	Gates

COMMERCE, DEPARTMENT OF

Maritime Administration (MARAD)

Project	Title	Leader
9102419	MARAD Assistance	deHaas

National Bureau of Standards (NBS)

Project	Title	Leader
9103551	IACP/NBS Test Program	Bolton

National Telecommunications and Information Administration (NTIA)

Project	Title	Leader
9101131	FM/TV Increased Capacity	Adams
9101132	TV Broadcast Spectrum Strategy	Berry
9101133	Broadcast Spectrum Technology/Policy Analysis	Murray
9101134	900 MHz Technology	Berry
9101135	FM Performance in Interference	Spaulding
9101136	Protection Ratios	Rush
9101137	Analysis Services Transfer	Hufford
9103107	International Data Communications	Williams
9103108	Common Carrier Communications	Williams
9104131	Data Communications	Seitz
9104132	Guided Wave Communications	Bloom
9104133	Telecommunication Architecture	Gates
9104162	Frequency/Orbit Study	Hanson
9104163	Public Service Satellite Support	Hanson
9105109	Common Carrier Project	Lemp
9105110	Standards Project	Pietrasiewicz
9105111	Terminal Evaluation	Pomper
9105193	Video Text Technology	Bloom
9106104	Protection Ratios	Rush
9107104	Technical Subcommittee Support (FSSM)	Hull
9107136	Spectrum Engineering Development Support	Adams
9107137	Noise Levels	Spaulding
9107167	RSMS Operations (FSSM)	Matheson
9107168	RSMS Development (FSSM)	Matheson
9108101	MF Skywave Propagation	Washburn
9108102	VHF/UHF Measurements	Grant
9108103	Multipath Fading (Model)	Ott
9108104	Knowledge Gaps: Data Base	Washburn
9108105	Multipath Fading (Tests)	Lucas
9108106	Frequency Assignment in ERF Level	Dougherty
9108107	Engineering Models UHF/VHF	Hufford
9108108	Protection Ratios	Rush

DEFENSE, DEPARTMENT OF (DOD)

Air Force Communication's System (AFCS)

Project	Title	Leader
9103484	Automatic Measurement System Upgrade	Wortendyke
9104380	LOS Fade 8-GHz System	Hause

Air Force Systems Command (ESD)

Project	Title	Leader
9103479	EFAS/PEP II Program	Skerjanec
9103564	CONUS OTH-B Propagation	Rosich
9104371	TRC Tropographic Tests	Hubbard
9104373	EFAS/PEP II Program Analysis	Skerjanec
9104419	HF Ducted Propagation	Violette

Air Force Systems Command (RADC)

Project	Title	Leader
9103562	HF Ground Wave	Wait

Air Force Miscellaneous

Project	Title	Leader
9103441	MSR-T1 Multiple Receiver System	Barghausen
9103492	TAC-Signal Analysis System	Barghausen

DEFENSE, DEPARTMENT OF (DOD) (Continued)

Air Force Miscellaneous (Continued)

Project	Title	Leader
9103563	Polar Ionospheric Predictions	Rosich
9103565	Topside HF Noise	Rush
9103569	OHD Target Detection	Ott
9104418	MSR-T1 Maintenance	Marler
9104430	AN/TRC-170 Digital Tropographic Tests	Hubbard
9104431	SC-2R ECM Receiver	Barghausen

Army Communication Command (USA/CC)

Project	Title	Leader
9103382	Army Mobile Automatic Receiver System	Carroll
9103427	EMC Van, Part II	Carroll
9103434	Access Area Digital Switch	Linfield
9103446	Application Software	McLean
9103474	Automated Digital Tropographic Data Techniques	Adams
9103478	EMC Van, Part III	Carroll
9103491	Follow-on Maintenance	Stewart
9103505	Automated Field Intensity Measurement System	Haakinson
9103507	TAEMS Noise Measurement	Spaulding
9103511	Voltage Tuned Filter	Grant
9103513	TAEMS Repair Parts	Stewart
9103531	ADRES System Upgrade	Adams
9103532	15 GHz LOS Fading	Hause
9103538	Verification Test Set	Smith
9103550	DM-4/Calculator Software	Matheson
9103557	TAEMS Field Measurement Consulting	Matheson
9103561	Command Post/SIG CTR Bus	Linfield
9104390	NBS Antenna Interface	Grant
9104412	Automated Digital System Engineering Model	Hause
9104413	Selective Fading	Hubbard
9104416	TAEMS PTE Update	Stewart
9104426	TAEMS Application Software/Satellite	McLean
9104432	HF Antenna Simulation	Lloyd

Army Research Office (ARO)

Project	Title	Leader
9103470	EMC Remote Extension	Marler
9104405	MM Wave Attenuation	Liebe

Army Miscellaneous

Project	Title	Leader
9103527	Frequency Extension of Spectrum Monitoring Capabilities	Jennings
9103555	30-300 GHz Communication Links	Thompson
9104377	Jammer S/1 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
9104414	AADSS Regional Models	Linfield
9104423	MM-Wave Vegetation	Violette

Naval Research Laboratory (NRL)

Project	Title	Leader
9102370	Project Nonesuch	Warner

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
9104429	Digital MW Radio Evaluation	Hubbard

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
9104424	Spectrum Distribution Measurements	Hause
9104435	DCS Transmission Study	Hause

Project	Title	Leader
DEFENSE, DEPARTMENT OF (DOD) (Continued)		
	Defense Nuclear Agency (DNA)	
9104428	Trace Gas Attenuation at 35 GHz	Liebe
	National Security Agency (NSA)	
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
9104420	DM-4 Operational Development	Spaulding
ENERGY RESEARCH & DEVELOPMENT ADMINISTRATION (ERDA)		
9103536	SPS RFI/EMI Analysis	Grant
9104379	SPS Ionospheric Effects	Rush
9104388	DoE Platteville Heating	Violette
9104404	SECOM System Enhancement	Morrison
9104421	SPS Ionospheric Heating	Rush
9104422	SPS EMC Assessment	Grant
FEDERAL COMMUNICATIONS COMMISSION (FCC)		
9103520	TV Coverage Maps	Kissick
9104394	FCC Channel Simulation	Watterson
9104425	Planning for FCC	Washburn
9104433	So. California Propagation Planning	Hufford
9104439	Statistical Analysis/TV Broadcast Data	Jennings
INTERNATIONAL COMMUNICATION AGENCY (ICA)		
9101501	Improved Prediction Formats and Maps	Agy
9103540	VOA Consulting	Agy
9103542	Remote Access Computer	Agy
9104436	VOA Support	Agy
9104437	HF WARC Study Program	Haydon
NATIONAL AERONAUTICS & SPACE ADMINISTRATION (NASA)		
9104391	Radio-Optical Refractometer	Thompson
9104438	NASA SPS Heating	Carroll
TRANSPORTATION, DEPARTMENT OF (DoT)		
	Federal Aviation Administration (FAA)	
9103489	Technical Support/Propagation & 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)	
9101532	Consulting USCG	Kissick
9104395	Puget Sound Coverage	Kissick
9104410	Omega Propagation Study	Steele

Project	Title	Leader
U.S. POSTAL SERVICE		
9104389	U.S.P.S. Electronic Message Service	Thompson
OTHER		
9101583	LF Models	Berry
9101585	GOES Equipment Certification	Bolton
9101586	Tropographic Predictions	Johnson
9101587	Numerical Predictions Service MFA	Agy
9102580	Analysis Services	Adams
9102586	Ionocap Requests	Teters
	Miscellaneous Federal Agencies	
9101504	HF Consulting	Haydon
9103466	Saudi Arabia HF Predictions	Teters
9103482	SECOM Communication Analysis	Morrison
9104400	EM Waves in Mines	Wait
9104411	AID Assistance	Bogle
9104442	Technical Operations Improvement Options	Williams
	Miscellaneous Non-Federal Agencies	
9102378	Mobile Aids	Hufford
9103521	Bell Consulting	Spaulding
9104387	Voice Performance Measurement	Matheson
9104409	LASL	Violette
9104417	Consult 4 & 6 GHz	Dougherty
9104440	Refractometer Repair	Marler

ANNEX II

ORGANIZATIONAL DIRECTORY

INSTITUTE FOR TELECOMMUNICATION SCIENCES

NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, DEPARTMENT OF COMMERCE
325 Broadway, Boulder, Colorado 80303
(303) 497 + extension (FTS dial 320 + extension)

Name	Ext.	Room
DIRECTOR'S OFFICE (O/D)		
CROMBIE, Douglass D. - Director	5215	3020
UTLAUT, William F. - Deputy Director	3500	3020
O'DAY, Val M. - Assistant to the Director for Program Development	3484	3014
WALTERS, William D. - Budget and Accounting Officer	3811	3019
STONER, Russell B. - Publication and Technical Information Officer	3572	3009
DIVISION 1 - SPECTRUM UTILIZATION		
MURRAY, John P. - Associate Director	5162	4533
1.1 Spectrum Analysis, Modeling & Services ADAMS, Jean E.	5301	4517
1.2 EM Environment Characterization MATHESON, Robert J.	3293	3420
1.3 Spectrum Planning Methodology HUFFORD, George A.	3457	4525
DIVISION 2 - SYSTEMS TECHNOLOGY AND STANDARDS		
HULL, Joseph A. - Associate Director	5136	2034
2.1 Evaluation of New Technology Developments HULL, Joseph A. - Acting	5136	2034
2.2 Systems Requirements Definition MORRISON, Ernest L., Jr.	5386	2223
2.3 Systems Performance Criteria GATES, Harvey M.	3589	2213
DIVISION 3 - APPLIED ELECTROMAGNETIC SCIENCE		
LUCAS, Donald L. - Associate Director	3821	3421
3.1 EM Propagation Research and Analysis BOGLE, Robert W.	3130	3443
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	2245
4.1 Communications Protection McMANAMON, Peter M. - Acting	3570	2245
4.2 Switched Networks LINFIELD, Robert F.	5243	2241
4.3 Specialized Networks HANSON, D. Wayne	3977	2223

ANNEX III
INSTITUTE FOR TELECOMMUNICATION SCIENCES
NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION
DEPARTMENT OF COMMERCE
Alphabetical Listing of ITS Employees
September 1, 1980

Name	Ext.	Room
ADAMS, Christopher D.	3749	4517
ADAMS, Jean E.	5301	4517
AGY, Vaughn L.	3659	3430A
AKIMA, Hiroshi	3392	2244B
ANDERSON, David P.	3506	2237M
ARCHULETA, Stephanie L.	3485	2245
AUSTIN, J. Jay	5732	2210M
AX, Carole J.	3748	2236B
BARGHAUSEN, Alfred F.	3384	3451
BEASLEY, Keith R.	3731	4528A
BEERY, Wesley M.	3501	3463
BERRY, Janet S.	5129	4516B
BERRY, Leslie A.	5474	4528D
BLOOM, Louis R.	3485	2245A
BOGLE, Robert W.	3130	3443
BOLTON, Earl C.	3104	2234M
BROOKS, Ferminia	5281	2030
BYERS, John D.	5125	4520B
CANADAY, Lois S.	3562	3413
CANDELARIA, Virginia A.	3291	3420
CARROLL, John C.	3601	3445
CHAVEZ, Richard	3584	3450B
CHILTON, Charles J.	3815	3459
COLEMAN, Susan J.	3702	3450
CROMBIE, Douglass D.	5215	3020
CRONIN, Daniel H.	5191	4516G
CROW, Edwin L.	3452	2210A
CUNNINGHAM, Charlene E.	5738	2237
deHAAS, Thijs	3728	2030
DOUGHERTY, Harold T.	3913	3417
DUTTON, Evan J.	3646	3430B
EDGAR, Catherine L.	5628	3421
EDWARDS, Mai E.	3798	3409
ESPELAND, Richard H.	3882	3442
FALCON, Glenn D.	5361	3420
FARROW, Joseph E.	3607	2230
FLETCHER, Christopher M.	5802	4524
FORRESTER, Sibelan E.	5179	3422M
FRITZ, Olive M.	3778	2213
GALLAWA, Robert L.	3761	2217
GATES, Harvey M.	3589	2213
GAMAUF, Kenneth J.	3677	2246C
GEISSINGER, Marcia L.	5216	3020
GIBSON, Beverle J.	5215	3020
GIERHART, Gary D.	3292	4520C
GLEN, Donald V.	3893	2242B
GODWIN, John R.	5859	4520D
GOODNIGHT, Frank A.	5627	3442
GRANT, William B.	3729	3447
GRAY, Evelyn M.	3307	2210
HAAKINSON, Eldon J.	5304	4511
HAIDLE, Leroy L.	3233	4524B
HALE, William K.	3907	4528F
HANSEN, Ruth B.	3513	3441
HANSON, A. Glenn	5449	2223

Name	Ext.	Room
HANSON, D. Wayne	3977	2235
HARMAN, John M.	3655	2030
HARTMAN, William J.	3606	2210E
HAUSE, Laurance G.	3945	2230B
HAYDON, George W.	3583	3426A
HERSHEY, John E.	3600	2236M
HIEBERT, Jorgeann	5618	2223
HILL, David A.	3472	2209
HUBBARD, Robert W.	3414	2213
HUFFORD, George A.	3457	4523
HULL, Joseph A.	5136	2034
HUNT, H. David	5734	2210B
HUTCHINS, Wendell	3175	2230
HYOVALTI, Duane C.	3447	3450A
JEFFREYS, Charlene E.	5414	3021
JENNINGS, Raymond D.	3233	2233
JOHNSON, Mary Ellen	3587	4520F
JUNEAU, Robert I.	5202	3420
JUROSHEK, John R.	5362	3455
KISSICK, William A.	5258	4520
KOBAYASHI, Herbert K.	3358	3450
KOLDEWYN, Katherine	5163	4527
LANGER, Susan K.	5337	3013
LAWRENCE, Vincent S.	3951	3420
LAYTON, Donald H.	5496	3454A
LEMP, John, Jr.	3713	2238A
LIEBE, Hans J.	3310	3426B
LINFIELD, Robert F.	5243	2241
LLOYD, John L.	3701	3419M
LONGLEY, Anita G.	3470	4521
LUCAS, Donald L.	3821	3425
MADONNA, Nancy	3627	3411M
MARLER, F. Gene	5321	3458A
MARLOW, Michael M.	3175	2230
MARTIN, William L.	3195	3426
MATHESON, Robert J.	3293	3420
MAYEDA, Kathy E.	5116	2239
MELLECKER, Carlene M.	3330	3430M
MILES, Martin J.	3567	2246D
MILLER, Charles M.	3702	3450C
MINISTER, Carl M.	3805	2242
MITZ, Albert R.	5627	3442
MOLLARD, Jean R.	3821	3421
MONTIS, Emmett A.	3883	3449
MORRISON, Ernest L., Jr.	5386	2223
MURRAY, John P.	5162	4533
McCARROLL, Patricia A.	3883	3449
McCOY, Elizabeth L.	5162	4527
McLAURIN, James E.	3562	3422M
McLEAN, Robert A.	3262	3454C
McMANAMON, Peter M.	3570	2245
NESENBERGS, Martin	3337	2246A
O'CONNOR, Rosemary C.	3786	4515
O'DAY, Val	3484	3014
OGAWA, Craig S.	5125	4520B
OLSON, Marylyn N.	5136	2030
OTT, Randolph H.	3513	3441

Name	Ext.	Room
PAULSON, S. Jean	3774	4519
PAYNE, Judd A.	3296	3458C
PIETRASIEWICZ, Val J.	3723	2238B
POKEMPNER, Margo	3825	3424M
POMPER, William J.	3730	2240B
PRATT, Lauren E.	3826	2218M
REASONER, Rita K.	3184	4520A
RUSH, Charles M.	3460	3411
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SAMORA, Charles	3367	3417M
SANCHEZ, Patricia A.	5166	2243
SANDERS, Frank H.	3951	3420
SARRAZIN, David B.	3668	3415M
SEITZ, Neal B.	3106	2214
SEXTON, Alma B.	3883	3449
SHELTON, Lenora J.	3572	3011
SKERJANEC, Richard E.	3157	2230
SMILLEY, John D.	5218	3420
SMITH, Dean	5458	3467
SOWELL, Roland J.	5202	3420
SPAULDING A. Don	5201	2217
SPIES, Kenneth P.	3829	2214A
STEARNS, Charles O.	3883	3449
STEELE, F. Kenneth	5626	3458C
STEWART, Arthur C.	3998	3419
STEWART, Frank G.	3336	3469
STOEBE, Suzanne M.	3627	3411M
STONEHOCKER, Garth H.	3364	3413M
STONER, Russell B.	3572	3009
TETERS, Larry R.	5410	3442
THOMPSON, Ray E.	3352	2246B
TVETEN, Lowell H.	3621	3453
UTLAUT, William F.	3500	3020
VAN STORY, Carol B.	3267	3017
VIOLETTE, Edmond J.	3703	3442
VOGLER, Lewis E.	3556	2234C
WALTERS, William D.	5811	3019
WARNER, Billie D.	5496	3454B
WASHBURN, James S.	3798	3415
WASSON, Gene E.	3584	3450B
WILLIAMS, Michael O.	5275	4516C
WILSON, Debra A.	5812	3015
WORTENDYKE, David R.	5241	2210F

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ANNEX V

GENERAL AND HISTORICAL INFORMATION OF ITS

The Institute for Telecommunication Sciences (ITS), 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, 1980) a full-time permanent staff of 104 and other staff of 57. In FY 1980, its support consisted of $3.7 million of direct funding from Commerce and $6.0 million in work sponsored by other Federal agencies.

The Boulder Laboratories include research and engineering components of the National Bureau of Standards, the National Oceanic and Atmospheric Administration, and the National Telecommunications and Information Administration. Common administrative services are the rule in the Boulder Laboratories. The Radio Building, which houses ITS, is on the U.S. Department of Commerce 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 the Institute's 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, DC, 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) telecommunications 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 chaired by members of ITS (U.S. Study Groups 1, 5, and 6), and staff members of ITS participate in many of the other Study Groups. ITS actively supports the Interdepartment Radio Advisory Committee (IRAC), and the chairman of its Standards Working Group (J. A. Hull) is a member of ITS management.

The work which ITS does for other agencies in the government derives its legal authorities from 15 U.S.C. 272(3) "Advisory Services to Government Agencies on Scientific and Technical Problems" and 15 U.S.C. 272(f) "Invention and Development of Devices to Serve Special Needs of Government." As a matter of Federal policy, NTIA does not accept work more appropriately done by other non-government or government organizations. It is also a matter of policy that all sponsored work reinforce NTIA's overall program and that it be clear that other agencies, industries, or universities could not serve equally well or better.

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