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ABSTRACT

This bibliography lists publications describing the scope, time span, depth, variety, and relevance of the satellite work done by the Institute for Telecommunication Sciences from 1958 through 1976. Works cited are listed by author with six categories: propagation, antennas, modulation or signal design, electromagnetic interference and frequency sharing, system design and assessment, and noise. Authors and co-authors are interfiled alphabetically in an author index. (Author/CMV)

OT SPECIAL PUBLICATION 77-15

INFORMATION PRODUCTS RESULTING FROM SATELLITE STUDIES AT THE INSTITUTE FOR TELECOMMUNICATION SCIENCES

E.M. Gray

U.S. DEPARTMENT OF COMMERCE
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for Science and Technology

OFFICE OF TELECOMMUNICATIONS
John M. Richardson, Director

May 1977

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UNITED STATES DEPARTMENT OF COMMERCE
OFFICE OF TELECOMMUNICATIONS
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The mission of the Office of Telecommunications in the Department of Commerce is to assist the Department in fostering, serving, and promoting the nation's economic development and technological advancement by improving man's comprehension of telecommunication science and by assuring effective use and growth of the nation's telecommunication resources.

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- Conducts research, engineering, and analysis in the general field of telecommunication science to meet government needs
- Acquires, analyzes, synthesizes, and disseminates information for the efficient use of the nation's telecommunication resources.
- Performs analysis, engineering, and related administrative functions responsive to the needs of the Director of the Office of Telecommunications Policy, Executive Office of the President, in the performance of his responsibilities for the management of the radio spectrum
- Conducts research needed in the evaluation and development of telecommunication policy as required by the Office of Telecommunications Policy, pursuant to Executive Order 11556

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This bibliography describes the satellite work done by the Institute for Telecommunication Sciences, Office of Telecommunications, U.S. Department of Commerce, from 1958 through 1976. Works cited are grouped into categories of propagation, antennas, modulation or signal design, electromagnetic interference and frequency sharing, system design and assessment, and noise.

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PREFACE

The availability of the documents cited in this bibliography depends upon the medium of publication for each, and upon the age of each document cited. Requests for those documents which were published as books or journal articles should be addressed to the publisher. Documents published as NBS Technical Notes or as OT Reports should be available from many depository libraries. The OT Reports are also available for sale from the National Technical Information Service, Springfield, VA 22161. Documents which are listed with a note regarding their limited availability may sometimes be obtained by writing the author. All documents which are more than 5 years old may be difficult to obtain except by visiting depository libraries or by writing the author.

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INFORMATION PRODUCTS RESULTING FROM SATELLITE STUDIES AT THE INSTITUTE FOR TELECOMMUNICATION SCIENCES

Evelyn M. Gray*

This bibliography describes the satellite work done by the Institute for Telecommunication Sciences, Office of Telecommunications, U.S. Department of Commerce, from 1958 through 1976. Works cited are grouped into categories of propagation, antennas, modulation or signal design, electromagnetic interference and frequency sharing, system design and assessment, and noise. An author index is included.

1. INTRODUCTION

1.1 Purpose

This bibliography is designed to describe the scope, the time span, the depth, the variety, and the relevance of the satellite work done by the Institute for Telecommunication Sciences (ITS), Office of Telecommunications, U. S. Department of Commerce, Boulder, Colorado, from 1958 through 1976.

1.2 Selection of Material

One of the deciding factors for selecting papers was the goal of presenting for the reader a clear idea of what capabilities currently exist within the Institute for Telecommunication Sciences. For that reason, the following categories are included:

1. Work done by ITS staff and published in OT reports, OT technical memoranda, and OT special publications.

2. Work done by ITS staff and published in trade journals, technical journals, non-periodical publications, series, books, etc.

3. Work done by ITS staff and published by other agencies of government (e.g., Department of Transportation reports).

4. ITS contributions to CCIR satellite studies are mentioned (in a summary fashion).

*The author is with the Institute for Telecommunication Sciences Office of Telecommunications, Boulder, Colorado 80302.

ITS work which is only indirectly related to satellite studies has been included in this bibliography *if* that work represents in ITS a continuing capability in some phase of satellite-related work.

Some kinds of satellite work done at Boulder Laboratories have been excluded. Generally, the reasons for exclusion are related to a) agency reorganization, b) classification, or c) availability, as is detailed below.

1.2.1 Agency Reorganization

The Central Radio Propagation Laboratory (CRPL) was organized within the National Bureau of Standards (NBS) in 1946. The later move of CRPL from Washington, D.C., to Boulder, Colorado, was initiated in 1951. In 1965, when the Environmental Science Services Administration (ESSA) was formed, the CRPL was transferred from NBS to ESSA, and the name was changed to the Institute for Telecommunication Sciences and Aeronomy (ITSA). During the ensuing five years, further dividing of the agency was done, and in 1970, three divisions which made up the Institute for Telecommunication Sciences (ITS) were transferred to the newly formed Office of Telecommunications (OT) of the U.S. Department of Commerce. The OT/ITS now shares the Boulder Laboratories site with elements of NBS and the National Oceanic and Atmospheric Administration (NOAA). This bibliography includes only material which is related to present OT/ITS capabilities. Therefore, work done in CRPL or in ESSA-ITSA by divisions which are now in NBS or NOAA is not included. For example, the topside-sounder work for study of the ionosphere is excluded.

1.2.2 Availability of Documents

Classified documents are excluded from the bibliography since they are not available to the general public.

Talks, discussions, tapes, and other such ephemeral items are generally omitted.

Some documents which are difficult to obtain are cited. For instance, OT Technical Memoranda, NBS Reports, and ESSA Memoranda are generally of limited availability when first printed, and often out of print shortly thereafter. Those publications in these categories which have been deposited in the National Technical Information Services (NTIS) may still be obtained by writing to NTIS. Accession numbers are shown for some of these items.

1.3 Sources

Sources for this list of information products were:

1. ITS Publications Abstracts
2. NBS lists of Technical Reports
3. NBS lists of Technical Notes
4. Information Products of OT 1970-75 (OT Special Publication 75-4)
5. Boulder Library indices (author, subject, and key-words)
6. NBS Special Publications Nos. 240, 305, 305-1, 305-2, and 305-3
7. Discussions with ITS authors.

1.4 Organization of Bibliography

The references contained in this bibliography are listed first in alphabetical order by author. This listing includes author(s) name(s), date of publication, title, medium of publication, page numbers, and an abstract of the work cited. Works by the same author are listed in reverse chronological order. All entries are consecutively numbered.

The second part of the bibliography lists the same papers, grouped by subject according to the categories listed below. Only authors names, dates, titles and sources are shown in this portion of the bibliography.

The third portion of this bibliography is an alphabetical author index showing all papers in the bibliography to which each author has contributed.

The categories chosen to illustrate satellite work at ITS are as follows:

1. Propagation
   a. Ionospheric scintillation
   b. Absorption
   c. Precipitation attenuation
2. Antennas
3. Modulation and/or signal design
   a. Analog
   b. Digital
4. Electromagnetic interference and frequency sharing
5. System design
6. Noise.

2. SUMMARY

2.1 Highlights of ITS Satellite Work

When what is now ITS was part of CRPL, CRPL had primary responsibility within the Federal Government for research in the propagation of the radio waves through the atmosphere, and on the basic physics of such phenomena. In four broad areas, the programs of the CRPL had an important and close relationship to current and future space programs:

1. transmission, propagation, and reception of electromagnetic radiation to and from space vehicles for communication, navigation, and guidance;

2. interaction of space vehicles with their environment;

3. use of space vehicles as research instruments; and

4. characteristics of the various parts of the atmosphere.

Some of the most important of these programs included:

1. observing the variations of wave polarization and analyzing the refractive effects of the ionosphere on radio signals from earth satellites;

2. studying the phase stability of radio waves propagated over point-to-point paths and the effect of climatological characteristics of the troposphere on radio propagation, to determine the effects on the accuracy of guidance systems;

3. making directional scintillation and refraction studies of the ionosphere to determine the navigational accuracy of radio signals for guidance of vehicles in and beyond the upper atmosphere;

4. investigating the physics of the upper atmosphere, including the dynamics of the ionosphere, airglow emission, thermal structure, electron densities, and VLF emissions;

5. studying the effects of solar activity on radio noise, the earth's magnetic field, and the state of ionization of the ionosphere.

When CRPL was disbanded, ITSA continued to pursue the long-standing interests in satellite programs. Such interests have resulted in publications in the following areas:

Interference
- Rain-caused interference,
- Interference to Radio Astronomy,
- Satellite/Satellite interference
- Satellite/Terrestrial interference
- Desired-to-undesired signal ratios

Propagation
- Propagation predictions,
- Propagation effects
- Absorption,
- Atmospheric turbulence, refraction, and reflections.

Frequency Sharing
- International negotiations, ITU, CCIR, and WARC,
- Standards work, spectrum utilization efficiency and
- Beamwidth studies, and
- Sharing between satellite and terrestrial systems

Antennas
- Antenna design,
- Directivity measurements

Low-Noise Receiving Systems
- Signal-to-noise ratios

Terrain Shielding

Tracking Systems

Ionospheric Studies
- Using satellite beacon transmissions
- Ionospheric scintillation

System Performance Assessment
- Studies predicting interference levels for GOES.

This bibliography covers the satellite work done at what is now ITS during the years 1958 through 1976. Early CRPL satellite studies are summarized in NBS Report 7268, "Space Telecommunications and the Central Radio Propagation Laboratory," by J. W. Herbstreit (1962). Later satellite work is reported in ESSA Research Laboratories Space Science Activities," by J. H. Pope (1968). Other early information was obtained from NBS Memorandum Report DM-79-8, "Space Related Activities of the Boulder Laboratories" (1958).

2.2 CCIR Satellite Work: ITS Participation

The present Director of CCIR (International Radio Consultative Committee), and the most recent past Director of CCIR are both former employees of the Boulder ITS Laboratories. Characteristically, ITS staff have been active in CCIR committees for many years. The Chairmanship of Study Group 6 (Ionospheric Propagation) of the CCIR has always resided in ITS or its predecessor organizations. Membership lists of CCIR study groups 4, 5, and 6 (relating to satellite work) illustrates ITS involvement in the international aspects of satellite problems.

As early as 1958, Study Group VI (U.S. Committee) drafted a proposed question for study: "Protection of frequencies used by artificial earth satellites or other space vehicles for communication and positional observation." This question was approved by the US CCIR Executive committee in Doc. No. 166 of March 14, 1958.

In 1961 the only studies made by that date of the technical feasibility of spectrum sharing between space and ground-based services were made by NBS/CRPL people.

It is from these beginnings that the satellite work grew at Boulder Labs. That work is reported in the pages which follow.

3. ACKNOWLEDGMENTS

The author wishes to express appreciation to Mr. Paul I. Wells of the Boulder Laboratories for his invaluable assistance and encouragement throughout the work of compiling this bibliography. The author is also grateful for the suggestions and guidance of Dr. Peter McManamon. Appreciation and thanks are extended to the librarians at the Boulder Laboratories for their technical assistance with the literature searches.

4. PUBLICATIONS BY ITS ON SATELLITE COMMUNICATION

4.1 Alphabetical Listing by Author

1. Adams, J.E., J.R. Juroshek, W.A. Kissick, and J.P. Murray (1976), Electromagnetic compatibility of the Department of Defense Ground Mobile Forces transportable earth terminals with terrestrial systems within the 7.2-8.4 GHz spectrum, OT Report 76-99.

   The purpose of this report is to examine the small transportable earth terminal used by the Department of Defense Ground Mobile Forces. The basic aspect of this analysis is to study the electromagnetic compatibility of the small earth terminal (SET) with the terrestirla microwave systems that share the 7.25 to 8.40 GHz band. This is done by producing Restricted Area Maps (RAMs) for four specific areas of interest designated by the U.S. Army for training. Operation of an SET within the restricted regions on the RAMs will result in interference to the terrestrial systems. In addition to the compatibility analysis, the applicability of the national and international radio regulations as they currently apply, or are interpreted to apply, to the SET are reviewed. Lastly, the impact of the SET on the utilization of the geostationary orbit is examined.

2. Akima, H. (1976), Modulation studies for direct satellite communication of voice signals, OT Report 76-108.

   A study has been made on modulation aspects of a direct communication of a voice signal from a satellite to individual homes for purposes of natural-disaster warning. A reasonable voice quality required at the final destination has been determined, and required radio-frequency signal power at the receiver input has been estimated. Based on this result and the available UHF signal power measurement result, the system margin in the power budget has been discussed for certain system parameter values. The system margin depends on several factors, and the results of this study should be useful for such a discussion.

   Potential use of an existing home radio and television receiver as a part of the system under consideration has been discussed. One result of this study indicates that the possibility of such a use is very remote.

3. Akima, H. (1976), Signal-to-noise ratios in a PCM/PSK system, OT Report 76-91.

Output signal-to-noise ratios (SNR's) in a pulse-code-modulation phase-shift-keying (PCM/PSK) system are calculated. Two-phase, four-phase, and eight-phase PSK systems are considered. The calculated SNR at the demodulator output is expressed as a function of the intrinsic SNR (e.g., the ratio of signal power to noise power contained in the base-band bandwidth) at the demodulator input and parametric in the number of quantizing levels in PCM. The performance of the PCM/PSK system is compared with those of other typical systems such as single-sideband (SSB) and frequency-modulation (FM) systems.

4. Akima, H. (1975), A binary noncoherent frequency-shift-keying (NCFSK) multiple-message one-shot radio transmission system that uses a sync preamble, IEEE Trans. Comm. COM-23, No. 5, 501-509, May.

A binary noncoherent frequency-shift-keying (NCFSK) multiple-message one-shot radio transmission system is discussed where the receiver has no prior knowledge of the possible starting time of transmission. In this system each transmitted signal has a common preamble for signal acquisition and self-synchronization purposes. System design procedures are described for allowable frequency of occurrence of false alarm and probabilities of a miss and a message error specified for the system. In addition, the probability of premature response (i.e., the probability that the receiver makes an affirmative decision on acquisition of the signal when the sync preamble is only partially received) is taken into account. It is shown that the selection of sync preamble codes from randomly generated binary sequences can be a highly attractive approach. A simple, but very meaningful, criterion is suggested for aid in such a selection. The system described here can be used as a radio warning system and also as a selective call or selective interrogation system.

5. Akima, H. (1964), Error rate in a multiple-frequency-shift system and the output signal/noise ratio in a frequency-modulation and a pulse-code modulation/frequency-shift system. Proc. IEE (London) 111, pp. 547-555.

Based on the assumption of a fading-free signal and an additive white Gaussian noise, the element and symbol error rates in a multiple-frequency-shift (m.f.s.)

system and the output signal/noise ratio in a frequency-modulation (f.m.) and a pulse-code-modulation/frequency-shift (p.c.m.f.s.) system are evaluated for wide ranges of system parameters. It is shown that the required intrinsic signal/noise ratio for a given symbol error rate in an m.f.s. system can be reduced by increasing the number of frequencies in the keying. The possibility of improving the threshold of an f.m. system beyond that of a conventional one, by frequency-modulating the carrier with sampled values and demodulating the modulated wave with a band-dividing demodulator, is shown. A brief discussion on the threshold effects in the frequency-lock and phase-lock f.m. demodulators suggests that the threshold of these feedback demodulators cannot be improved beyond that of a band-dividing one. It is shown that the threshold in a p.c.m.f.s. system can be reduced by increasing the base in the coding. The comparison of a p.c.m.f.s. system with a band-dividing f.m. system shows the inferiority of the former to the latter, in so far as the minimum-power criterion of system comparison is concerned.

6. Akima, H.A. (1963), The error rates in multiple FSK systems and the signal-to-noise characteristics of FM and PCM-FS systems, NBS Tech Note 167, March.

The element and symbol error rates in multiple FSK (frequency-shift-keying) systems and the output SNR (signal-to-noise ratio) in FM (frequency-modulation) and PCM-FS (pulse-code-modulation-frequency-shift) systems are evaluated for wide ranges of system parameters, assuming that the incoming signal and noise in the demodulator are a fading-free signal and an additive white Gaussian noise, respectively. It is shown that the required intrinsic SNR for an assigned value of symbol error rate in multiple FSK systems can be reduced by increasing the number of frequencies in the keying. The possibility of improving the threshold of FM systems beyond that of conventional ones by modulating the carrier with sampled values and demodulating the modulated wave with a band-dividing demodulator is shown. The value of the intrinsic SNR at the threshold increases with the value of modulation index in band-dividing FM systems, and with the number of quantizing levels in PCM-FS systems when the base in the coding or the number of digits for each sample is kept constant. The maximum output SNR in PCM-FS systems depends only on the number of quantizing levels and not on the base, whereas the threshold decreases as the base increases. From the comparison of the threshold in band-dividing FM systems with that in PCM-FS systems it is shown that the latter cannot be lower than the former but can only approach the former when the base approaches the number of quantizing levels. Brief discussions on the threshold effects in frequency-lock and phase-lock FM demodulators suggest that the threshold of these feedback FM demodulators cannot be improved beyond that of a band-dividing one.

7. Akima, H. (1963), Theoretical studies on signal-to-noise characteristics of an FM system, IEEF Trans. Space Electronics and Telemetry SET-9, 101-108.

The essential signal-to-noise characteristics of an FM system are studied theoretically, assuming that the transmitted wave is frequency-modulated by a discontinuous signal, which is made by sampling from the original information signal at every sampling point equally spaced by a Nyquist interval and by boxcarring the sampled value over the following interval. Studies are made with a simple model of an FM demodulator of a new type, which may be called the band-dividing FM demodulator. As a result of these studies a limit to the degree of improvement in the threshold of an FM system is obtained. The result obtained here again suggests that it is possible to improve the threshold of the system beyond that of a so-called conventional FM demodulator. It is also shown that the value of the intrinsic signal-to-noise ratio (the ratio of the incoming signal power to the incoming noise power in the baseband bandwidth) at the threshold is not constant but increases with the value of the modulation index. Brief discussions on the threshold effects in the so-called phase-lock and frequency-lock FM demodulators are also given.

8. Akima, H., and M. Nesenbergs (1973), Performance of a coherent communication system with constant amplitude interference, OT TM 73-123. (Limited availability.)

The output signal-to-noise ratio is derived and numerically evaluated for phase-shift-keying (PSK) modems in presence of noise and continuous wave (CW) interference. The corresponding error probability performance is expressed in a form suitable for future computation. The CW carrier is angle modulated with band-limited Gaussian noise. The results are applicable to satellite, aero mobile, instrument landing system, and other interferences that affect the proposed Collision Avoidance System (CAS) operation in the 1600 MHz band.

9. Ax, G.G., and R. D. Jennings (1972), Electromagnetic compatibility of radar altimeters with proposed maritime satellite and aeronautical satellite systems, OT TM 101 (limited availability).

Prior to the 1971 ITU World Administrative Radio Conference for Space Telecommunications (WARC-ST), the Aeronautical Radio-navigation band at L-band extended from 1557.5-1637.5 MHz. Operating nominallly within this band are several models of radar altimeters, tunable as well as fixed-tuned, which have only conditional (temporary) allocations. There are, of course, other existing/planned systems which do/will operate within the band, i.e., the Collision Avoidance Systems (CAS) and the Defense Navigation Satellite System (DNSS).

By action of the 1971 WARC-ST the Aeronautical Radio-navigation band was narrowed slightly to 1558.5-1636.5 MHz, and allocations were provided on either side of this band to accommodate the Aeronautical Mobile (R) and Maritime Mobile-Satellite communication, surveillance, and navigation requirements (see Figure 2.1 for graphical depiction) for which systems are now being planned and developed.

10. Bean, B.R., and G.D. Thayer (1969), Reply to a letter by Robert H. Paul, IEEE Trans. Aerospace & Electron. Sys., March.

Apparent discrepancies between two methods of estimating the direction angle error of radio "interferometers" are analyzed. The analysis shows that both yield correct results, but they have mutually exclusive domains of applicability. Paul's result is correct under conditions of short baselines and target positions where flat-earth geometry is permissible; the author's previous result is correct for conditions of curved-earth geometry and deep-space tracking where the incoming radio wavefront is nearly planar. A more general result is given here, which is valid under either set of conditions.

10a. Bean, B.R., and E.J. Dutton (1966), Radio Meteorology, NBS Monograph 92.

This volume brings together in book form the work done in radio meteorology over the past decade at the National Bureau of Standards' Central Radio Propagation Laboratory, and adds results obtained in other laboratories both in the United States and abroad. Specifically, the book deals with the refraction of radio waves and the refractive index structure of the lower atmosphere on both synoptic and climatic scales.

The text contains chapters on the radio refractive index of air, measuring the radio refractive index, tropospheric refraction, *N* climatology, synoptic radio meteorology, and applications of tropospheric refraction and refractive index models. Additional chapters cover transhorizon radio-meteorological parameters and the attenuation of radio waves by atmospheric gases, clouds, rain, hail and fog. The final chapter consists of 50 pages of radio-meteorological charts, graphs, tables, and sample computations, invaluable aids for all radio and communications engineers, electrical engineering students and teachers, and other users of the book.

11. Bean, B.R., R.L. Abbott, and E.R. Westwater (1963), Design of experiments for remote microwave probing of the atmosphere, NBS Report 7682.

The purpose of this report is to summarize progress to date on studies of the feasibility of remotely probing the atmosphere at microwave frequencies to determine atmospheric pressure and temperature structure. This will involve first summarizing the work to date on atmospheric absorption of radio waves and the thermal noise properties of the atmosphere. Analysis of computed values of thermal noise has indicated promising experimental procedures to be followed in actually determining atmospheric temperature and humidity structure.

12. Bean, B.R., R.L. Abbott, and E.R. Westwater (1962), Analysis of thermal noise temperature as a remote probe of atmospheric structure--Phase II, NBS Report 7293.

This report is an analysis of thermal emissions in the microwave region by atmospheric gaseous components. It contains an analysis of how this thermal noise energy may be used as a probe for atmospheric structure. It contains a discussion of the absorption of microwaves by O_2 and H_2O vapor and the reliability of these values insofar as they affect thermal noise as a probe of atmospheric structure. Practical methods of calculating the basic integrals are discussed. In an appendix the ray tracing techniques used in the calculations are given. As examples of the thermal noise temperatures to be expected, numerous profiles representing widely divergent types are calculated and graphs prepared showing the results. A discussion of these results is given along with the recommendations for future work.

13. Bean, B. (ed.) (1960), CCIR Commission 3: Ionospheric radio propagation, Review of U.S.A. activity in the fields of interest of URSI Commission 3 during the trennium 1957-1959: 4 - Satellite beacon studies. J. Research NBS, Vol. 64D, Nov.-Dec. 1960, p. 630.

Section #4 (Satellite beacon studies) of this report summarizes the literature in the field. Theories and applications of Faraday rotation, signal weakening, signal enhancements, and some unusual effects in the propagation of satellite signals are mentioned in a brief, annotated bibliography.

14. Bergman, R. R., P. L. Rice, and M. J. Miles (1973), Advances in computer model predictions for ATS-F radio frequency interference experiment at 6 GHz, OT Tech Memo 73-158 (limited availability).

Refinements and simplification of the ITS mathematical computer prediction model described by Bergman et al. (1972), resulted in better quality and lower cost predictions for signal noise levels and spectral power flux densities expected from terrestrial 6 GHz microwave communication networks at synchronous orbit.

Input data for the computer program are derived from various government frequency management sources. New predictions are presented for NASA Advanced Technology Satellite, Series F (ATS-F), for all assigned frequencies between 5925 and 6425 MHz. These predictions appear on Hollerith data cards for computer use. Results are based on assigned terrestrial transmitter locations, power levels, antenna patterns, azimuths and assumed signal polarizations.

Signal noise level predictions were made with a satellite antenna having a maximum gain of 49 dB and a half-power beamwidth of about 1°.

Work is presented showing the verification of assumptions relative to the accuracy of the idealized pencil beam antenna model described by Rice et al. (1970), when applied to the subject computer prediction process.

A better understanding of the problems influencing predictions was derived from studies involving 6 GHz carrier bandwidth and expected location of these carrier centers when compared to their frequency assignments.

15. Bergman, R. R., P. L. Rice, and M. J. Miles (1972), Mathematical computer model and predictions for ATS-F radio interference experiment at 6 GHz, OT Tech. Memo. 107 (limited availability).

A mathematical model for calculating radio frequency interference (REI) levels at synchronous orbit from common carrier microwave systems in the 5925-to-6425 MHz common carrier band is described. The input data for the resulting computer program are derived from various government frequency management sources. The expected spectral power flux density levels at synchronous orbit position for the NASA Advanced Technology

Satellite, Series F (ATS-F) are presented for separate 20-MHz band segments and an evaluation of predicted RFI intensity versus system sensitivity is shown. Results are based on assigned terrestrial transmitter locations, power levels, average antenna patterns, assigned and random azimuths and assumed signal polarizations.

Maximum and minimum signal intensities resulting from aligning all terrestrial antennas (at 0° elevation angle) with the great circle path and positioned towards and away from the satellite were calculated for representative cases. Predictions for signals expected from stations near the optical horizon are orbital positions of 40° to 0° west longitude. Signal intensity predictions were made with a satellite antenna having a maximum gain of 49 dB and having a half power beamwidth of about 1°. A number of calibration frequencies for satellite systems calibration were selected, based on band occupancy.

16 . Brown, F. W. (1958), Relative suitability of various frequency bands for outer space communications, unpublished letter to Lt. Colonel Earl J. Holliman, Signal Corps Chief, U.S. Army Radio Frequency Engineering Office. (Unavailable.)

In general, it may be stated that the most suitable frequencies for communication between the earth and outer space within the direct optical line of sight of the earth terminal, would be those which lie in the range above the frequencies trapped by the ionosphere (greater than approximately 80 Mc) and those which are not greatly attenuated by absorption due to the constituents of the atmosphere (e.g., oxygen and water vapor attenuation bands).

17 . Chadwick, R.B., and D.S. Irwin (1973), Technical and economic trade-offs for the geostationary orbit communications resource, OT Report 73-8.

The effects of certain trade-offs in utilizing the geostationary orbit communications resource are discussed. This resource, sometimes called the electrospace, has three important dimensions, time, frequency and spatial angle. The communication capability or utility obtained from a unit volume of the resource is of fundamental importance since it is the basic efficiency with which the resource is utilized. This quantity is termed the utility density and has units of bits per Hertz per second per degree. Assuming a white Gaussian channel, an upper limit on the utility density can be obtained. The special case where the mutual interference is large is studied, and numerical results for the general case are presented as plots of utility density vs. antenna diameter or ground station cost. These results are then used to obtain an economic value which can be attached to portions of the resource. The summary gives a concise list of specific results.

18. Cottony, H. V. (1972), Scaled-model-measurements on rf sensor antennas for outer planet grand tour (TOPS) project, OT Tech Memo 86 (limited availability).

Launchings of four Thermoelectric Outer Planet Spacecraft (TOPS) for outer space exploration are projected by the National Aeronautics and Space Administration for 1976, 1977 and 1979. Among the planned experiments is that for the detection and measurement of rf radiation by planets to be visited (Jupiter, Saturn, Uranus, Neptune, and Pluto). Scaled-model measurements were carried out on two-types of sensor antennas suggested for this experiment.

Two 1/10 full-scale models of spacecraft were constructed. Model No. 1 was equipped with a pair of crossed dipoles consisting of four monopole elements each one meter long. Model No. 2 used the four quadrants of the 42.7-cm reflector as the sensing antennas. The nominal frequency band for the full-scale spacecraft antennas is 0.1 to 30 MHz. The impedances and the radiation patterns on scaled-model antennas were measured over the 30 to 300 MHz band corresponding to 3 to 30 MHz full-scale.

The sensor antennas on model No. 1 were found to have a degree of electrical imbalance and some lobing at the higher end of the frequency band. The input impedance of the quadrant antennas of model No. 2 was found to have a high voltage-standing-wave ratio. The use of model No. 1 with only one half of each of the crossed dipoles was also tried as a possible alternative.

19. Crombie, D. (ed.) (1976), Lowering barriers to telecommunitions growth, OT Special Publication 76-9.

This report contains the findings and recommendations of the Science and Technology Telecommunications Task Force of the U. S. Department of Commerce. The Task Force was formed to explore how barriers to the application of telecommunication technology might be lowered so that new domestic products and services would become more widely and more rapidly available.

(N.B. One chapter and one appendix of the report are devoted entirely to direct satellite communications.)

20. Crow, E. L. (1974), Confidence limits for digital error rates, OT Report 74-51.

Confidence limits for error rates (probabilities of an error) of digital communication systems are derived and implemented under the assumptions that the error rate is constant and the trials are independent. Four types of samples are considered: prescribed sample size (binomial sampling), prescribed number of errors (inverse binomial sampling), both sample size and number of errors bounded (truncated binomial sampling), and truncated binomial sampling with sample size also bounded below. Both exact confidence limits and good approximations for them in the communications situation of very small error rates are presented. Point as well as interval estimates are presented. The planning of the experiment is discussed.

21. Dutton, E. J., H. T. Dougherty, and R. F. Martin, Jr. (1974), Prediction of European rainfall and link performance coefficients at 8 to 30 GHz, U. S. Army Communications Command Technical Report No. ACC-ACO-16-74

The Rice-Holmberg prediction model for surface rain rate distributions is extended to the whole of Europe, including the European USSR. A data base from 249 European stations is used to determine the input parameters for the rainfall prediction model, and rain rate predictions are presented for t-minute periods of an average year in each of the 10 European zones.

The geographical variations in rainfall within the European zones are illustrated by contours of 1 min rain rates mapped on Europe for 1, 0.1, and 0.01% of an average year. A modification of the prediction model is described to permit determination of the temporal, year-to-year, variation of rainfall in Europe. Estimates of this variation of rain rate for 1, 0.1, and 0.01% of any year are given from estimates of annual precipitation and its long-term standard deviation.

The mean terrestrial-link performance coefficients, rainfall attenuation rate and rainfall reflectivity, are predicted for the frequency range of 8 to 30 GHz for each of the European rainfall zones.

22. Dutton, E. J., and H. T. Dougherty (1973), Modeling the effects of clouds and rain upon satellite-to-ground system performance, OT Report 73-5.

A state-of-the-art engineering model is described for estimating the expected performance degradation of satellite-to-ground microwave systems because of atmospheric gases, clouds, and rain. The model incorporates an allowance for a vertical structure of atmospheric gases, clouds, and rain as well as local and regional rainfall statistics. The estimates are in terms of attenuation and scintillation, as well as the volume reflectivity which contributes to co-channel interference. A composite prediction is given for 15 GHz, as representative of microwave signals, for 1.0, 0.1, and 0.01 percent of an average year. This prediction is a function of location and the angle-of-arrival at ground stations on the central east coast of the U.S.

23. Dutton, E. J. (1971), A meteorological model for use in the study of rainfall effects on atmospheric radio telecommunications, OT Report 24.

The commonly used relations between radio scattering (or attenuation) and rainfall are statistical relations determined from rainfall rate at the ground versus a scatter or attenuation factor observed at some average height, usually unknown, above the ground. Thus these relations should more properly contain a height dependency by determining the rain dropsize distribution,

first at the surface, making use of surface rainfall rates, and then aloft by considering the meteorological influences changing this dropsize distribution with height. This produces a model of dropsize distribution at the height of interest. It should be emphasized that the modelling is primarily oriented toward solution of the telecommunication problems of scatter and attenuation rather than toward solution of a problem in cloud and precipitation physics.

The first part of this report is devoted to finding dropsize distribution parameters at the earth's surface. The second and third parts are devoted to methods of ascertaining the dropsize distribution in the cloud itself using an approach for analysis of data (radiosonde) taken during a known rainstorm and then using an approach that involves only surface data.

24. Einaudi, F., and R. R. Wait (1971), Analysis of the excitation of the earth-ionosphere waveguide by a satellite-borne antenna. II. Can. Jour. of Phys. 49, No. 11, pp. 1452-1460.

The analytical expressions for the fields at the earth surface due to a satellite-borne horizontal dipole are derived for an idealized model in which the Earth's magnetic field is vertical and the medium is divided into plane, parallel slabs. Although nonlinear phenomena in the neighborhood of the antenna are not analyzed, the problem is circumvented by defining an equivalent infinitesimal dipole whose external fields are the same as those of the actual antenna. Finally, a numerical example is given in which the fields of such a horizontal dipole are compared with those of a vertical dipole operating in the same conditions.

25. FitzGerrell, R.G., and L. L. Haidle (1976), Two ways to plot sidelobe patterns, Microwaves, July 1976, pp. 59-60.

Two methods for analyzing antenna sidelobe power-gain data are compared. One is best for EMC studies, while the second is well suited for determining frequency sharing criteria. The oldest method of presenting and calculating sidelobe power-gain characteristics, the probability plot, is most useful for EMC studies for which antanna pointing is arbitrary. The second method, obtained by plotting power gain against the angle measured from the antenna's electrical boresight, is most useful for determining coordination procedures and criteria for frequency sharing among terrestrial and satellite communication stations.

26. Gallawa, R. L. (1976), Current development in fiber waveguide components (unpublished study).

The purpose of the study is to investigate the pos-
The purpose of the study is to investigate the possible use of fiber waveguides to replace radio and conventional cable communication techniques in the innerconnect facility (ICF) between the technical control facility and the satellite earth terminal in the Defense Satellite Communication Systems (DSCS). A key question, addressed in the report, is whether components are ready for deployment in a fieldable system.

The study considers the components required to meet various operational telecommunications needs for the Army. Particular emphasis is on a fiber link which could be incorporated in the DSCS/ICF. The study includes discussions of availability, reliability, cost, and an analysis of components available off the shelf. It includes consideration of developmental work and research being conducted by various military agencies. Components are examined with regard to adaptability, maintenance, logistics and design parameters required to provide reliable communications between the satellite earth terminal and the technical control facility.

27. Gierhart, G. D., and M. E. Johnson (1973), Computer programs for air/ground propagation and interference analysis (0.1 to 20 GHz), FAA Report # FAA-RD-73-103.

This report describes three computer programs for use in predicting the service coverage associated with air/ground radio systems operating in the frequency band from 0.1 to 20 GHz. Power density, station separation and service volume programs are used to obtain computer-generated microfilm plots. These are: (1) power density available at a particular altitude versus distance from a ground-based transmitting facility; (2) the desired-to-undesired signal ratio, D/U, available at an isotropic receiving antenna versus the distance separating desired and undesired facilities; and (3) constant D/U contours in the altitude versus distance space between the desired and undesired facilities. A detailed discussion of the propagation model involved and program listings are included in the appendicies.

28. Gierhart, G. D., and M. E. Johnson (1972), UHF Transmission loss estimates for GOES, OT Tech. Memo. 109 (limited avail.)

This report describes a computer method for predicting transmission loss over nominal line-of-sight earth/satellite telecommunication links, and provides predictions for the GOES satellite system. The method is applicable to radio frequencies from about 0.1 to 6 GHz and includes allowances for (a) average tropospheric ray bending, (b) horizon effects, (c) antenna gains, (d) long-term power fading, (e) surface reflection multipath, (f) tropospheric multipath, and (g) ionospheric scintillations. Comparisons of predictions with experimental data are included.

29. Gierhart, G. D., R. W. Hubbard, and D. V. Glen (1970), Electrospace planning and engineering for the air traffic environment, DoT Report, FAA-RD-70-71.

Service limitations imposed upon VHF/UHF/SHF radio communication links by cochannel and adjacent-channel interference is the primary subject, but limitations imposed by intermodulation and noise are also discussed. Methods for predicting available desired-to-undesired signal ratios (protection ratio) and determining the required protection ratio are summarized. Appendices on frequency sharing with air traffic control satellite, modulation characteristics, and system performance measurements are included. The primary purpose of this report is to illustrate the application to interference predictions for air traffic control systems of (a) the available desired-to-undesired ratios as predicted, (b) the transmission loss atlas, (c) the required protection ratios derived from measurements and (d) the analysis of modulation characteristics.

30. Gierhart, Gary D. (1967), Frequency sharing with air traffic control satellites, IER Tech. Memo. 26 (limited availability).

Technical information relevant to the solution of frequency sharing problems in the VHF band that are associated with the use of VHF for the aircraft/satellite link of a synchronous satellite air traffic control system is included in this report. Specifically, estimates are given of (1) the desired-to-undesired RF signal ratios available at the satellite when interference from a multitude of conventional air traffic control facilities is considered, and (2) the extent to which the service range of conventional air traffic control facilities may be reduced because of interference caused by transmissions from a satellite.

31. Glen, D. V., H. Akima, and E. C. Bolton (1976), Evaluation of the GOES-data-buoy interrogation link, OT Report 76-106.

Assessment and testing of the Geostationary Operational Environmental Satellite Data Collection Platform Interrogation link using the Synchronous Meteorological Satellite (SMS-2) has been completed.

Bit error rate tests and radio set interrogations were made from the Command and Data Acquisition Station, Wallops Island, Virginia, to Boulder, Colorado, via the SMS-2 to measure performance. It was determined that (1) the received signal level was too low for reliable operation of the Data Collection Buoy Radio Set using a low-gain omnidirectional data buoy antenna and (2) the interrogation channel is subject to severe interference from non-government land mobile transmitters which have primary frequency allocation at 468.825 MHz.

Improved performance was demonstrated through the use of a higher-gain antenna and the insertion of a low-noise amplifier in separate tests. The latter is recommended as an immediate solution to provide improved performance. Use of a 12.5 kHz offset to the interrogation frequency is recommended to minimize land mobile interference.

32. Glen, D.V., E.C. Bolton, J.C. Blair, and P.M. McManamon (1976), Circuit status for multiple-satellite-hop user reaction tests, OT Special Publication 76-8.

The Office of Telecommunications/Institute for Telecommunication Sciences (OT/ITS), under an agreement with the Federal Communications Commission, served as the Technical Management Organization (TMO) for Multiple-Satellite-Hop User Reaction Tests. These user reaction tests involved voice telephone communications that were relayed one, two, or three times through the Westar satellite. The types of connections for the voice transmission involved Common Control Switching Arrangements, Foreign Exchange, and Tandem Tie Lines services. Circuits for testing were primarily provided by American Satellite Corporation, American Telephone and Telegraph, and the Western Union Telegraph Company.

Subjective and objective measurements of circuit quality were made. The objective measurements, for which OT/ITS was the TMO, were confirmed as being within the criteria established for the tests.

33. Glen, D.V., and M.J. Miles (1976), Spin modulation statistics of the GOES data collection system, OT Report 76-81.

This report presents the results of statistical analyses of the interrogation and data reply carrier signals transmitted through a Geostationary Operational Environmental Satellite (GOES) between a Data Collection Platform Radio Set (DCPRS) and the Command and Data Acquisition (CSA) station. Both were located at Wallops Island, Virginia. Normalization has been attempted for the carriers that contain spacecraft spin modulation.

Statistical parameters included are the mean and standard deviation of the signals, the computer plots of a) data during one revolution of the spacecraft, b) mean values from 1000 revolutions of the spacecraft, c) the differences between the sample and the mean values, and d) the mean values for 1000 differences. These parameters have been determined for the output of the Data Collection Platform Interrogate (DCPI) phase detector, the output of the Data Collection Platform Reply (DCPR) phase detector, and the DCPR amplitude ripple. Using this approach to normalize the effect of spacecraft spin modulation to study ionospheric scintillation is not recommended.

34. Glen, D. V., and P. M. McManamon (1974), GOES data collection system measurements, OT Report 74-49.

This report presents results of measurements for the interrogation and data reply communications between Data Collection Platform Radio Sets (DCPRS) and the Command and Data Acquisition (CDA) station demodulators using recorded and simulated signals with and without ± 70 degree Manchester encoded Phase-Shift-Keying modulation transmitted through a Geostationary Orbiting Environmental Satellite (GOES) transponder prior to launch. Bit Error Rate (BER) measurements are used to compare performance for one or three DCPRS and give estimates of degradation due to spacecraft spin modulation and simultaneous operation of other satellite communication subsystems. Post-launch measurements were made and are compared to the pre-launch measurements.

35. Gray, E. M. (1974), Anik, IEEE Comm. Soc. 12, No. 1, 3-5.

"Anik," an Eskimo word meaning "brother", is the name given to the world's first domestic communications satellite in synchronous orbit. The article describes the Telesat Canada satellite communications system including the baseline network of earth stations.

36. Haakinson, E.J., and D.E. Skinner (1977), Power and beam pointing restrictions for geostationary orbit avoidance: program ORBITCHECK user's manual (in preparation).

Internationally established power and antenna beam pointing restrictions have been placed on fixed and mobile terrestrial systems which share common frequency bands with geostationary satellites. The restrictions were designed to limit the level of in-band and/or adjacent-channel interference power from the terrestrial system to the space systems.

A computer program has been developed to automatically check the compliance of fixed terrestrial stations with the stated requirements. Specifically, the program checks frequency applications and assignments against the regulation stated in Section 8.2.34 of the Office of Telecommunications Policy's Manual of Regulations and Procedures for Frequency Management, and Article 7 Section VII of the International Telecommunication Union's Radio Regulations. It is written in UNIVAC FORTRAN V language for use in an interactive (time-sharing) mode on the UNIVAC 1108 computer.

This manual explains the execution of the program, the choice of input values, the alteration of input values, and the interpretation of output results. Sample executions of the program also are provided.

37. Haakinson, E.J., D.E. Skinner, K.P. Spies, and G.J. Bridgewater (1977), Automated computing and plotting of geostationary satellite earth footprints: program FOOTPRINTS user's manual (in preparation).

Earth footprints are contours of constant antenna gain from antennas aboard geostationary satellites. Footprint plots are used by design engineers as an aid in maximizing satellite antenna coverage over a particular portion of the earth's surface while minimizing the effects of interference to other telecommunication systems. Similarly, the plots aid international regulatory bodies in coordinating deployment of satellite systems so as to minimize interference.

We have written a computer program that automatically computes and plots footprints. This program is flexibly designed to accommodate a broad range of user-supplied input details, from minimal information to highly detailed antenna pattern data. It is written in UNIVAC FORTRAN V language for use in an interactive (time-sharing) mode on the UNIVAC 1108 computer.

This manual explains the execution of the program, the choice of input values, the alteration of input values, and the interpretation of output results. Sample executions of the program are also provided.

38. Haidle, L. L., and R. G. FitzGerrell (1977), Hemispherical power gain pattern measurements at 7.5 GHz (to be published).

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

39. Halton, J. H., and A. D. Spaulding (1960), Error rates in differentially coherent phase systems in non-Gaussian noise, IEEE Trans. Commun. Tech., Vol. COM-14, pp. 594-601.

A theoretical analysis of the differentially coherent phase-shift keying systems acting under a wide range of noise and signal conditions is given. In addition to the elemental error rate, it is desirable to know the error rates for sequences of errors, since there is intersymbol dependency in this system. To determine the probability of a sequence of r errors requires, at most, integrations over volumes up to 2r + 2 dimensions, which are performed by Monte Carlo techniques. The analysis and computational schemes are such that any noise and signal statistics, as well as the use of nonlinear devices (noise suppression equipment), can be taken into account in calculating the error rates (for a k-phase system) as long as the resulting joint distributions of the instantaneous SNR at the phase detector can be determined in some form. A sequence of r errors requires knowledge of the (r+1)st-order distribution. Since nothing is known of the joint densitites of atmospheric or other non-Gaussian interference, and since many systems have slow enough bit rates for the noise to be independent from one integration period to the next, examples are given for the independent case for Gaussian noise and characteristic samples of atmospheric noise. Results for both constant and slow, flat, Rayleigh fading signal for the two and four phase systems are given, and comparisons of experimental results with the theoretical error rates are made. Also, for comparison, expressions are derieved and results given for the error rates corresponding to the above for the coherent PSK systems.

40. Hargreaves, J. K. (1966), The coverage of satellite passes from a ground station, Planet. Space Sci. 14, 617-622.

For studies of the upper atmosphere which require the simultaneous detection of phenomena on a satellite and from the ground, it is necessary to ensure good coverage of the satellite orbit from the ground station. With this in mind, the present note computes the number of satellite revolutions whose projection passes within a specified distance of a ground station. The results are presented in graphical form and provide a ready indication of the observational statistics which may be expected from any proposed comparison of satellite and ground-based data.

41. Harr, T. A., Jr., and W. M. Roberts (1974), Calculations of interference potential between geostationary satellite networks: program WARC 71.A29 user's manual, OT Tech. Memo. 74-161 (limited availability).

This user's manual contains a program description of what the "WARC 71.A29" does, a sample calculation, explanations, and instructions for the use of the program. Guidance is provided as to the various sources of information needed to operate the program and as to the applicability and limitations of the various classes of data. Procedures applicable in the early analysis and coordination of new foreign and domestic space systems are outlined and flow diagrams are furnished as guidance to potential users of the program.

42. Harr, T. A., Jr., K. E. Bechard, and J. J. Stephenson (1973), Space/terrestrial radio service coordination areas: Program WARC 71.A28 user's manual, OT Tech. Memo. 73-139 (limited availability).

This manual describes a computer program ("WARC 71.A28") that implements the procedure (outlined in Appendix 28 of the World Administrative Radio Conference for Space Telecommunication, Geneva 1971) for determining the co-ordination area around an Earth Station in frequency bands between 1 and 40 GHz shared by Space and Terrestrial Radio Communication Services. This program is written for use on the OEP/UNIVAC-1108 computer in UNIVAC FORTRAN V language, but can easily be converted for use on any computer. The manual explains how to access the computer program, how to run the computer program, how to change the input values for subsequent runs of the computer program, and how to interpret the results.

43. Hartman, W. J. (1971), Study and forecast of the electromagnetic spectrum technology, part 3. OT Tech. Memo. 25. NTIS Access. No. COM-71-00658.

Some factors which could or should affect frequency allocations and assignments in the future are considered. These include propagation predictions, modulation, coding and information processing. In addition a forecast of the use of cables as replacements for Broadcast TV and microwave relay is presented.

44. Hartman, W. J., and G. A. Hufford (1966), On the general problem of frequency sharing, Telecommun. J. 33, No. 8, 287-293.

It is shown that, in a very general sense, one can define a best or optimal choice of radiated powers for systems sharing frequencies. For this definition the condition of optimality determines the relative radiated powers uniquely and these can be calculated in a straightforward manner. One interesting result of the study is that under optimum conditions, all of the systems under consideration will be equally well off in that they will suffer from equally, hopefully slight interference.

(N.B., This article was published in English and was translated into French and Spanish.)

45. Hartman, W. J. (1966), Feasibility of communication with a satellite by means of tropospheric scatter, IEEE Trans. Commun. Technol. COM-14, No. 3, 251.

Theoretical methods are developed for predicting the transmission loss over a tropospheric scatter path from a point on the earth to a satellite. The results indicate that presently available equipment allows reliable communication to only very slightly beyond the radio horizon. Some of the difficulties encountered in designing experiments to test the theoretical predictions are investigated.

46. Hartman, W. J., and M. T. Decker (1963), Mutual interference between surface and satellite communication systems, NBS Tech Note 126.

Estimates of the mutual interference expected to occur between the ground terminals of space communications systems and surface point-to-point systems are presented

in a fashion suitable for engineering applications. These estimates are obtained from recently developed methods for predicting the transmission loss over tropospheric paths in terms of parameters such as geographic separation, elevation angle of the antenna, antenna patterns, and frequency. It is concluded that these systems can share the same frequency assignment under suitable conditions.

47. Hartman, W. J., and M. T. Decker (1962), Experiments for feasibility study of tropospheric scatter propagation between the earth and satellites, NBS Report 7625, NTIS Access. AD 414-280 or AD-414 771.

The proposed experiments described in this report are designed to obtain information concerning the feasibility of tropospheric scatter transmission between an earth terminal and a satellite. These experiments are suggested in lieu of experiments utilizing orbiting vehicles primarily because of the problem of obtaining adequate power aboard satellites.

48. Hartman, W. J., and S. G. Lutz (1962), Antenna beam elevation angle for control of tropospheric interference between space/earth and terrestrial stations, paper presented at the WESCON Conference (unpublished).

By controlling the path antenna gain along tropospheric interference paths, excessive separation distances can be avoided between space/earth stations ("terminals") and surrounding microwave relay or other surface radio services using the same frequencies. Surface communication antennas are directed at the horizon, whereas beams directed at satellites are usually elevated. Early satellite communication systems require a minimum beam elevation of 5° to 10° to obtain satisfactory performance. It was assumed in early studies of frequency sharing that this minimum beam elevation would be sufficient to suppress tropospherically propagated interference via the main beam and thus justify an isotropic approximation. This paper compares tropospheric scatter transmission loss via the elevated main beam of a 60-ft terminal antenna to that for an isotropic terminal antenna. For 10-ft, 6-ft, and isotropic surface antennas, calculations are given for beam elevation angles to 15°, path lengths to 350 miles and for frequencies between 1Gc/s and 10Gc/s. It is shown that when the remote antenna is isotropic, the terminal beam elevation angle which suppresses the beam gain is essentially independent of frequency, but that it increases with distance, from about 4° at 50 miles to nearly 9° at 250 miles, based on median losses. When the remote antenna has a 10-ft aperture directed at the terminal, the beam elevation angle versus distance relationship becomes increasingly frequency-sensitive at greater distances, thus requiring greater angles at the higher frequencies.

Even through satellite communication systems of the future may have much stronger signals and therefore may not be constrained by earth-temperature and atmospheric noise, tropospheric interference may limit their minimum beam elevation and prevent tracking satellites to the horizon.

49. Hartman, W. J. (1962), Feasibility of communication with satellites by means of tropospheric scatter, NBS Report 7243, NTIS Access. No. AD 405-801.

Theoretical methods are developed for predicting the transmission loss over a tropsopheric scatter path from a point on the earth to a satellite. The results indicate that presently available equipment allows reliable communication to only very slightly beyond the radio horizon. Some of the difficulties encountered in designing experiments to test the theoretical predictions are investigated.

50. Hartman, W. J., and M. T. Decker (1961), Mutual interference between surface and satellite communication systems, J. Research (D. Radio Propagation), National Bureau of Standards 65D, 433-436.

Estimates of the mutual interference expected to occur between the ground terminals of space communications systems and surface point-to-point systems are presented in a fashion suitable for engineering applications. These estimates are obtained from recently developed methods for predicting the transmission loss over tropospheric paths in terms of parameters such as geographic separation, elevation angle of the antenna, antenna patterns and frequency. It is concluded that these systems can share the same frequency assignment under suitable conditions.

51. Hatfield, D. (1971), A general analysis of domestic satellite orbit/spectrum utilization. NTIS Access. No. PB 207 397.

This report evaluates the geostationary orbit/spectrum utilization of the U.S. domestic communication satellite system applications. It provides information for considering the scarcity of the orbit/spectrum resource and DOMSAT policy recommendations.

52 Hayden, E. C. (1971), Planning for telecommunication system development in Alaska, Vol. 1 (text), Vol. 2 (appendices), OT AR 1.

An examination was made of alternate concepts for message-carrying networks which could provide the required or desired services at minimum price. One important conclusion drawn was that there are unique technical advantages which satellite signal relay offers for the solution of Alaska's particular problem and which are probably within economic reach in the very near future.

Six areas for future work are identified which merit priority attention. They are:

1) A hearing on utility rate base and tariff structure.
2) The preparation of appropriate rules and regulations for the administration of the regulatory function.
3) The institutionalizing of the public telecommunications planning and advocacy functions.
4) The assembly and analysis of an integrated statement of the demand or requirement for communications within Alaska and between Alaska and outside points.
5) The innovative generation of alternate concepts which might be the basis for Alaska's long-lines network, especially concepts for the use of satellite technology.
6) The provision of interim consulting and advisory services during the period of stress produced by the impact of the ACS transfer process on Alaska's nascent public institutions.

53. Haydon, G. W., and R. K. Rosich (1973), Technical considerations in the efficient use of the spectrum, Part 1, Terrestrial-surface power flux density limits for services using satellites, OT Report 73-19.

The role of power flux density limitations at the earth's surface in the efficient use of the spectrum is examined. The effective initiation of some newly emerging services such as disaster warning, educational TV, and direct broadcasting, and the expansion of established services such as point-to-point communication and environmental sensing appear to be dependent upon the relaxation of power flux density limitations at the earth's surface for these services whenever feasible. Computer routines have been developed to examine the probable impact of various levels of power flux density at the earth's surface upon terrestrial systems as a function of percentage of terrestrial systems affected.

The use of these routines is illustrated by an examination of terrestrial systems between 6 GHz and 10 GHz in the state of Colorado.

Tabulations and graphs show the percentage of terrestrial systems expected to be seriously affected by satellite signals as a function of satellite location and permissible power flux density level. Relationships between maximum tolerable power flux density and satellite elevation angle and the significance of terrestrial receiving antenna point to the satellite are illustrated. It is concluded that power flux density limits appear too stringent, particularly for satellite signals arriving at vertical angles above 25°.

54. Haydon, G. W. (1971), Analysis of VHF and UHF aviation satellite systems, OT Tech. Memo. 58 (limited availability).

Possible UHF (1540-1600 MHz) and VHF (118-136 MHz) aviation synchronous satellite systems have been analyzed stressing the effects of propagation and other natural phenomena upon the capability of these systems to achieve their operational objectives.

It is concluded that even under the quasi-ideal conditions of undistorted free space propagation and negligible external noise contributions to the receiving system, neither the VHF nor UHF system considered will fully attain the voice intelligibility desired. Both systems, however, under these quasi-ideal conditions would achieve the desired data handling capability with a small but possibly insignificant margin in favor of the UHF system.

The significant difference between the UHF and VHF system appears to lie in the role of the natural phenomena which may markedly degrade the VHF system by both signal level variations due to its passage through the ionosphere and by possible increases in the effect of the noise.

55. Haydon, G. W. (1962), Technical considerations in the selection of frequencies for communication with, via and between space vehicles, NBS Report 7250.

Technical considerations in the selection of frequencies for communication via satellites as prepared as an appendix for "Preliminary Views of the United States of America," May 17, 1961, and "Final Preliminary Views of the United States of America," as submitted by the Federal Communications Commission, September 7, 1961; are revised in accordance with the Interim Meeting of CCIR IV, Space Systems, Washington, D.C., 1962), and expanded to include a consideration of passive systems, communication between space vehicles, and between space and earth terminals when each use an omnidirectional antenna.

56. Haydon, G. W. (1960), Optimum frequencies for outer space communication, J. Res. (D. Radio Propagation), 64D, No. 2., 105-109.

Frequency dependence of radio propagation and other technical factors which influence outer space communications are examined to provide a basis for the selection of frequencies for communication between earth and a space vehicle or for communication between space vehicles.

57. Haydon, G. W. (1959), Optimum frequencies for outer space communication, Journal of Research, Section D, 64D, No. 2, 105-109 (Also published in FCC Hearings).

Frequency dependence of radio propagation and other technical factors which influence outer space communications are examined to provide a basis for the selection of frequencies for communication between earth and a space vehicle or for communication between space vehicles.

N.B. The basic material in this paper was unanimously adopted by the International Radio Consultative Committee at the IX Plenary Assembly in Los Angeles, April 1959, and was issued as CCIR Report No. 115, Factors affecting the selection of frequencies for telecommunication with and between space vehicles. In addition, this material has been published in full twice within the text of the same FCC hearings.

58. Haydon, G. W. (1958), Optimum frequencies for outer space communication, Space/Aeronautics Research and Development Handbook, 1960-1961, pp. D18-D22. (Published by Office of Chief Signal Officer. N.B. This article is a condensation of the above article of the same title and author published in the NBS Journal of Research, Section D, 64D, No. 2, 105-109, Mar-April 1960.)

Frequency dependence of radio propagation and other technical factors which influence outer space communications are examined to provide a basis for the selection of frequencies for communication between earth and a space vehicle or for communication between space vehicles.

59. Hefley, G., R. F. Linfield, and R. H. Doherty (1960), Timing and space navigation with an existing ground-based system, for: Avionics Panel Meeting of the Advisory Group for Aeronautical Research and Development (AGARD), 3-8 October 1960, NBS Report 6721.

New synchronization techniques have been developed with accuracies which make feasible the use of an inverse hyperbolic system for determining the position of space vehicles.

The National Bureau of Standards had developed a Loran-C clock which provides timing and synchronizing accuracies of one microsecond or better and stabilities of 0.1 microseconds or better anywhere within a Loran-C navigation chain. Synchronization of other chains could provide base line lengths equal to an earth's diameter.

Having established a common time base, short pulse transmissions from space vehicles are measured relative to this base. Differences in the time of arrival of these pulses at various ground stations permit space fixes at great ranges.

The time synchronization scheme is discussed along with fix accuracies obtainable as a function of synchronization accuracy and system geometry.

60. Herbstreit, J. W. (1962), Space telecommunications and the Central Radio Propagation Laboratory, NBS Report 7268.

The Central Radio Propagation Laboratory of the National Bureau of Standards has been active in the field of study and research on the propagation and frequency problems of space communcations. This report summarizes work in that field and emphasizes the urgent need to obtain basic propagation information as a prerequisite to intelligent negotiation of frequency allocations for space telecommunications systems and as a basis for optimizing the equipment and techniques to be incorporated in such systems.

61. Herbstreit, J. (1961), Frequency allocations for space communications, a report of the Joint Technical Advisory Committee, Proc. IRE 49, 1009-1015.

The report examines the technical aspects of space communications with special attention to the use of satellites for commercial trunking purposes. The problems of frequency allocation and frequency utilization are examined. The report contains a compilation of recommendations and conclusions concerning the allocation of the radio-frequency spectrum for space communications.

62. Herbstreit, J. W. (1961), Mutual interference between surface and satellite communication systems, Ch. 5 of Frequency Allocations for Space Communications, a report of the Joint Technical Advisory Committee of IRE-EIA. (Chapter V was written by the National Bureau of Standards, Central Radio Propagation Laboratory, and Mr. Herbstreit was a member of the Ad Hoc Subcommittee 60.2 of the JTAC of the IRE and the EIA.)

This report examines the technical aspects of space communication with special attention to the use of satellites for commercial trunking purposes. The problems of frequency allocation and of the influence of system design on frequency allocation and frequency utilization are examined.

Many of the problems of mutual interference between proposed satellite communication systems and surface communication systems can be investigated in terms of available theories. The primary purpose of this chapter is to predict the conditions under which a service will be interference-free for a given percent of the time. The prediction methods that are developed are intended to have a wide range of applicability. Examples which illustrate the use of the method for specific systems are included.

63. Herbstreit, J. W., and M. C. Thompson, Jr. (1958), Continuous phase difference measurements of earth satellites (letter), Proc. IRE 46, No. 8, 1535.

The Radio Propagation Engineering Division of the National Bureau of Standards, Boulder Laboratories, conducted a series of observations of both satellites using a continuous phase-difference measuring technique developed earlier for studying atmospheric turbulence in the troposphere. The records contain information on two types of mechanisms. One is the effect of gross geometrical changes and the second is the relatively irregular effect of ionospheric turbulence.

64. Hill, D. A. (1974), A survey of earth-to-satellite propagation factors between 2.5 and 275 GHz, OT Report 74-43.

Propagation factors for earth-to-satellite paths are reviewed for frequencies between 2.5 and 275 GHz. Although molecular absorption by water vapor and oxygen limits the use of this frequency range near 22.2, 60, 118.8 and 183.3 GHz, the subject is sufficiently well understood for systems considerations. It is concluded that

rain attenuation is the most serious limiting factor and that considerable progress has been made in understanding the theory of rain attenuation and in collecting data on surface rainfall rates. However, lack of data on rain rate and drop size distribution as a function of height prohibits the determination of statistics on earth-to-satellite attenuation required by the systems engineer. The only direct satellite measurements of rain attenuation have been provided by the Applications Technology Satellite (ATS-5) at 15.3 and 31.65 GHz. Other forms of precipitation are available between 110 and 313 GHz.

65. Hubbard, R. W. (1974), Measurement and prediction of bistatic radio scattering due to precipitation, Special Issue of Journal de Recherches Atmospheriques.

This paper describes an experiment conducted to measure the temporal statistics of radio energy scattered by precipitation in the 4 and 8 GHz bands. These data are compared with measurements of surface rain rates to test the applicability of surface statistics in predicting interference between satellite and terrestrial microwave systems that share these frequency bands. The prediction method is shown to provide good engineering results for common-volume scattering up to elevations of 10,000 feet (3 km).

66. Hubbard, R. W., J. A. Hull, P. L. Rice, and P. I. Wells (1973), An experimental study of the temporal statistics of radio signals scattered by rain, OT Report 73-15.

A fixed-beam bistatic CW experiment designed to measure the temporal statistics of the volume reflectivity produced by hydrometeors at several selected altitudes, scattering angles, and at two frequencies (3.6 and 7.8 GHz) is described. Surface rain gauge data, local meteorological data, surveillance S-band radar, and great-circle path propagation measurements were also made to describe the general weather and propagation conditions and to distinguish precipitation scatter signals from those caused by ducting and other non-hydrometeor scatter mechanisms. The operating characteristics of the various system components used in the experiment are presented. The data analysis procedures were designed to provide an assessment of a one-year sample of data with a time resolution of one minute. The results to date cover the time interval of September 15, 1970 to January 31, 1971. The cumulative distributions of the bistatic signals for all of the rainy minutes during this period are presented for the several path geometries. These cumulative distributions of amplitude-time durations of hydrometeor scatter signals are compared with measured cumulative distributions of surface rain-rate measurements obtained for the same time periods. The surface rain-rate statistics are compared with long-term excessive precipitation data available for the southeastern United States.

67. Hubbard, R. W., J. A. Hull, G. D. Thayer, and P. L. Rice (1971), An experimental study of the temporal statistics of radio signals scattered by rain, OT/ITSTM 37 (limited availability).

A fixed-beam, bistatic cw experiment designed to measure the temporal statistics of the volume reflectivity produced by hydrometeors at several selected altitudes, scattering angles and at two frequencies (3.6 and 7.8 GHz) is described. Surface rain gauge data, local meteorological data, surveillance S-band radar and great-circle path propagation measurements are also made to describe the general weather and propagation conditions and to distinguish precipitation scatter signals from those caused by ducting and other non-hydrometeor scatter mechanisms. The results to date cover the time interval September 15, 1970, to January 31, 1971. The cumulative distribution of rainy minutes for which the path loss signal exceeds a given value above system sensitivity is presented for the several path geometries. These cumulative distributions of amplitude-time durations of hydrometeor scatter signals are compared with measured cumulative distribution of surface rain rate measurements obtained for the same time period. The surface rain rate statistics are compared with long-term excessive precipitation data available for the southeastern United States.

68. Hubbard, R. W., G. D. Thayer, and J. A. Payne (1970), An experiment for the study of earth station-terrestrial station interference--Part II-Statistical data summary for the RIPP fixed beam experiment at Langley, Virginia, U. S. Dept. of Commerce, OT/ITSTM 14 (limited availability).

The data processing and analysis procedures for the RIPP fixed beam experiment have been implemented, tested and applied to the assimilation of data for the period 15 September to 7 December 1970. This includes: 1. A/D conversion of the analog field measurement tapes to digital processing tapes. 2. The preparation of digital data archives tapes from the computer distribution analysis. 3. Compilation of clock-minute signal distribution data in a computer program. 4. Computer program to assimilate clock-minute median data, and to compute cumulative distribution functions. 5. Plotting routine to present the distribution functions on microfilm. 6. Program to compute

the cumulative distribution function for measured rain rates. The primary value of this report is to indicate what the long-term trends in these data are, and to illustrate the manner in which the data are to be assimilated in the overall conduct of this experiment.

69. Hubbard, R. W., and D. V. Glen (1968), Required protection ratios for frequency sharing in a VHF air traffic control communications system with a satellite terminal, ESSA TM ERL TM-ITS 140 (limited availability).

This report presents the results of laboratory tests conducted to make preliminary determination of the required protection ratios for satisfactory sharing service in a VHF ATC communications system. The data given may be used to predict a quantitative measure of performance for any voice communication system in the VHF band and including a satellite terminal.

The principal results of the work are data from performance tests on typical ATC equipment to determine required desired-to-undesired signal ratios (D/U) for various grades of service. Percent intelligibility is plotted against D/U. The ATC controller is very skilled in reading typical ATC messages under severe interference conditions. There is a sharp threshold in intelligibility followed by rapid degradation in performance for both AM and FM systems.

70. Hufford, G. A. (1972), A user's guide to path loss computations, OT Tech. Memo. 104 (limited availability).

The user's guide defines, describes, and explains input parameters and output values of the path loss between 20 MHz and 20 GHz.

71. Hull, J. A., P. L. Rice, R. W. Hubbard, and G. D. Thayer (1970), An experiment for the study of earth station-terrestrial station interference, Part I - Interference model for rain scatter and fixed-beam experiment, OT/ITS TM 14 (limited avail.).

Raingauge data measured at the sub-common volume points when converted to an equivalent radar reflectivity and plotted in terms of a cumulative distribution correlates well with the similar cumulative distributions for the bistatic reflectivity for the 5 K, 10 K, and 20 K ft altitudes for which data are available. The accumulation of long-term statistical data requires that strong attention be directed toward achieving maximum reliability of operation

in order that short-term events ($p=10^{-4}$) be recorded during the "typical" year of measurement. The extrapolation of the measurements made at the present site to other locations will depend on models being developed to relate the time and space statistics of radar reflectivity, Z.

The present fixed-beam configuration of the experiment is providing critically needed measurements of interference phenomena which must be assessed in terms of cumulative distributions for the given fixed configurations as a function of season and for a total seasonal variation of a "typical" year. It is necessary that this accumulation of data proceed without interruption to provide the inputs required for the use of interference probability models required for domestic and international sharing criteria.

72. Janes, H. B. (1969), Atmospheric errors in electromagnetic distance measurements: ESSA Hawaii experiments 1966-7, AGARD Conf. Proc. No. 33, Phase and Frequency Instabilities in Electromagnetic Wave Propagation, Ankara, Turkey, Oct., p. 628.

For several years, the National Bureau of Standards and its successor in this area the Environmental Science Services Administration have been studying the errors contributed by the lower troposphere to microwave measurements of distance and angular position. Primary emphasis has been placed on measurements involving ground-to-air propagation paths such as those used in microwave tracking systems. The experimental technique has, in general, consisted of placing equipment simulating the rocket or satellite transponder on a mountain top and recording continuously the apparent variations in position as observed by a simulated tracking system located at a lower altitude.

A series of experiments was undertaken in 1966 and 1967 using overwater propagation paths in Hawaii to establish the relevance of the overland data to existing systems, most of which are at coastal locations. The purpose of this chapter is to describe these experiments briefly and to show some preliminary results of the analysis.

73. Janes, H. B., M.C. Thompson, Jr., W. B. Grant, A. W. Kirkpatrick, and D. Smith (1969), Experimental evaluation of several refractivity correctors for microwave slant-range data, ERL TM-ITS 174 (limited availability).

An evaluation of three refractivity variables in terms of their value in correcting microwave slant-range data for atmospheric effects is described. Experiments were conducted in Hawaii in 1967 on a fixed, 65 km overwater propagation path. The data output from 14-day runs consisted of continuous recordings of microwave range variations, surface refractivity from meteorological data taken at the lower path terminal, and average path refractivity computed both from radiosonde data and from airborne refractometer data. Correlation coefficients between range and each of the several refractivity variables ranged from 0.5 to 0.8, with the radiosonde and airborne refractometer data showing slightly higher correlations than did the surface refractivity. The correlation analysis is discussed in terms of the implied value of the several refractivity variables as slant-range correctors.

74. Janes, H. B., M. C. Thompson, D. Smith, and A. W. Kirkpatrick (1968), Comparison of simultaneous line-of-sight signals at 9.6 and 34.5 GHz, ERLTM-ITS 152. IEEE Trans. Ant. and Prop. AP-18, No. 4.

Signals at 9.6 and 34.52 GHz propagated simultaneously over a slant, line-of-sight, overwater path are analyzed. The phase data at the two radio frequencies exhibited nearly identical power spectra from 0.01 to 5 Hz and very high coherence from 0.01 to 0.1 Hz. The coherence dropped rapidly above 0.1 Hz and was in most cases less than 0.4 above 0.5 Hz.

The power spectra of fading were similar in shape at the two frequencies, but the fading spectral density from 0.1 to 5 Hz was consistently higher at 34.52 GHz than at 9.6 GHz. The shape of the coherence function for fading was similar to that of the corresponding phase coherence function, but the fading coherence was lower at the low spectral frequencies. The possible effect of the small spatial separation of the propagation paths on the coherence analysis is discussed.

75. Janes, H. B., and M. C. Thompson, Jr. (1966), Observed phase-front distortion in sumulated earth-to-space microwave transmissions, NBS Tech. Note 339.

An experimental study has been made of the time and space statistics of the phase-front distortion of microwave signals sent from a ground terminal to an elevated terminal. These phase-front characteristics are important in systems involving phase measurements between a ground station and a moving airborne or space terminal. To isolate atmospheric errors from random motion of the upper terminal, the latter was simulated by a series of mountain-top antenna arrays. Phase-front distortion was analyzed in terms of time variations in radio range on a single path and in first and second range differences from pairs of paths. The cross-correlations of (1) range variations on adjacent paths, and (2) range difference variations on both adjoining and separated pairs of paths are investigated, including the strong dependence of correlation on the portion of the power spectrum included in the data. The effect of the mountain-top terrain on the spatial homogeneity of the phase-front was examined and found to be insignificant. A diurnal pattern in the variance of 15-minute range difference samples was observed, with minimum variance in the early morning hours. This pattern was not observed in the range variances, nor were the range and range difference variances significantly correlated with refractive index, air temperature, pressure or wind speed data at the lower terminal.

76. Janes, H. B., and M. C. Thompson, Jr. (1965), Observed phase-front distortion in simulated earth-to-space microwave transmissions, NBS Report 9140. (Limited availability.)

An experimental study has been made of the time and space statistics of the phase-front distortion of microwave signals sent from a ground terminal to an elevated terminal. These phase-front characteristics are important in systems involving phase measurements between a ground station and a moving airborne or space terminal. To isolate atmospheric errors from random motion of the upper terminal, the latter was simulated by a series of mountain-top antenna arrays. Phase-front distortion was analyzed in terms of time variations in radio range on a single path and in first and second range differences from pairs of paths. The cross-correlations of (1) range variations on adjacent paths, and (2) range difference variations on both adjoining and separated pairs of paths are investigated, including the strong dependence of correlation on the portion of the power spectrum included in the data. The effect of the mountain-top terrain on the spatial homogeneity of the phase-front was examined and found to be insignificant. A diurnal pattern in the variance of 15-minute range difference samples was observed with minimum variance in the early morning hours. This pattern was not observed in the range variances, nor were the range and range difference variances significantly correlated with refractive index, air temperature, pressure or wind speed data at the lower terminal.

77. Janes, H. B., and M. C. Thompson, Jr. (1964), Preliminary report on experimental studies of atmospheric errors in microwave tracking systems, NBS Report 8237.

A series of experiments is described which were designed to study certain errors contributed by the atmosphere in range and range difference (angular position) measurements made with baseline-type microwave missile tracking systems. Results of a preliminary analysis of data obtained during the summer of 1963 are presented along with a brief discussion of plans for further analysis of these and subsequent measurements.

78. Jennings, R. D., L. E. Vogler, and J. J. Stephenson (1976), Statistical frequency-distance curves, initial model, OT Report 76-84.

This report describes an initial computer program that produces statistical frequency-distance curves. The computer program has been developed as a tool for use by the frequency managers' community of OTP/IRAC.

The statistical frequency-distance curves estimate the minimum distance separation that is required between a victim receiver and an interfererer as a function of the frequency offset between them. The curves are parametric in the probability or percent of time that interference is permissible. The model uses statistical variations in antenna gain and propagation loss to compute the probability interference. Appendices of the report describe the propagation loss and antenna gain models and the method used to combine them to produce the statistical frequency-distance curves. Operating instructions and several sample applications also are included as appendices.

79. Jennings, R. D. (1972), Electromagnetic compatibility of collision avoidance systems with proposed maritime satellite and aeronautical satellite systems, Office of Telecommunications Tech. Memo. 110 (limited availability).

Conclusions:
1. Spectrum splatter from a time-frequency CAS can cause interference to the MARSAT system's shipboard receivers and to the AEROSAT system's aircraft receivers on other aircraft at spatial separations less than about 117 nmi. About 100 dB isolation is required between systems on the same aircraft.
2. Spectrum splatter from a transponder technique CAS (SECANT) will not cause harmful interference to the MARSAT system's aircraft receivers on the same and/or other aircraft.
3. Neither CAS will cause harmful interference to the satellite receivers due to spectrum splatter or spurious emission.
4. CAS spurious emissions which are reduced to a level 80 dB less than the fundamental emission can cause interference to the MARSAT system's shipboard receivers when separated from a time-frequency CAS by less than 12.5 nmi or from a transponder technique CAS by less than 1.6 nmi.
5. Spectrum splatter from a satellite transmitter of either system will not cause harmful interference to the collision avoidance system's receivers.

80. Johler, J. R. (1973), The impact of the choice of frequency and modulation on radio navigation systems, Conference sponsored by Institute of Navigation with participation of Office of Telecommunications Policy, Executive Office of the President, Washington, D.C., November 13-15.

The choice of frequency for radio navigation is a subject of considerable depth and is inextricably intertwined with requirements for range, accuracy, reliability, cost and impact on competitive services using radiowaves. The basic information for passing judgment on these items comprises the limitations imposed by nature on the system. These limitations are the laws of physics governing the propagation of radio waves.

We note in particular that great ranges and hence large coverage areas can be obtained at opposite ends of the spectrum in the OMEGA and SATELLITE systems. We find that great accuracy is accomplished with the ground wave propagation mechanism in the form of LORAN-C and LORAN-D. We observe that the choice of modulation is critical if high accuracy of position is an objective or requirement.

We conclude that the most important single subject bearing upon the choice of frequency concerns the propagation of the radio waves that the navigation systems utilize.

81. Juroshek, J. R. (1976), Performance of digital modems with cochannel interference and gaussian noise, OT Report 76-82.

An approximate method for estimating the performance of digital systems operating with cochannel interference and Gaussian additive noise is described in this report. The method uses Monte-Carlo techniques and an approximation, based on the geometrical characterization of signals, to estimate the error rate of a variety of digital systems as a function of signal-to-noise ratio and signal-to-interference ratio. Curves are presented that show excellent agreement between the estimates and theoretical predictions at symbol and bit error rates as low as 10^{-9}. Computer programs are included that estimate error rate for multiphase coherent phase-shift keyed (CPSK), noncoherent frequency-shift keyed (NCFSK), differentially coherent phase-shift keyed (DCPSK), and coherent amplitude-phase-shift keyed (CAPK) systems. The programs can handle single as well as multiple cochannel interference, and examples are given that show error rate in both environments.

82. Juroshek, J. R., P. M. McManamon, M. Nesenbergs, and D. A. Hill (1974), Study of satellite frequency requirements for the U.S. postal service electronic mail system, Volume III, Technology studies, OT Report 74-27.

Optimum frequency allocations are recommended for electronic mail distribution by digital data transmission from a geostationary satellite to 125 locations in the continental United States, Alaska, Hawaii, and Puerto Rico. Frequency allocations for the fixed-satellite service from 4 GHz to 50 GHz have been reviewed for 700 Mbps transmission rate. This rate was estimated to be sufficient to enable the distribution of an average of 82 million mail pieces per day. Point-to-point digital data transmission requirements have been investigated and system performance requirements outlined. The influence of these requirements as well as network design on the selection of an optimum frequency allocation is demonstrated.

This volume includes reviews of satellite frequency allocations, restrictions, and requirements. The performance of a number of candidate network designs, the state of the art of existing and proposed satellite telecommunication systems, multiple access techniques, power tubes, modems and antenna systems are described. Propagation effects, including rain attenuation, are summarized and are included in determination of requirements for satellite EIRP and ground station antenna diameter.

83. Juroshek, J. R. (1970), A brief analysis of FSK, MSK, CSK and pseudo-random signalling techniques, OT Tech. Memo. 17 (limited availability).

A brief survey of the available literature was made to determine the performance of four phase-continuous, digital signalling techniques. The first three techniques (FSK, MSK, and CSK) are described using a geometrical approach to the classification of signals, while the fourth technique (pseudo-random modulation) is analyzed in terms of the correlation coefficient between the two binary signals.

84. Kissick, W. A., and D. N. Rebol (1977), "Orbit prints"--contours of power density at the geostationary orbit due to a terrestrial emitter: A program description, proposed OT Report (in preparation).

The theory is developed to calculate the power density at (or near) the geostationary orbit due to radiation from a terrestrial emitter. This development assumes free-space propagation and the geometry includes an arbitrary direction for the emitter antanna aim. The computer program does the above calculations for an array of points on a region defined on the inside surface of the sphere that contains the geostationary orbit. This array of power density values, when contoured at constant levels, is the primary output of the program. Several antenna patterns are included as subroutines for the terrestrial emitter. The program was designed to run on the CDC 6600 computer facility at the Department of Commerce, Boulder (Colorado) Laboratories.

85. Liebe, H. J. (1975), Studies of oxygen and water vapor microwave spectra under simulated atmospheric conditions, OT Report 75-065.

Atmospheric radio wave propagation in the 40 to 140 GHz band is influenced by microwave spectra of oxygen (O_2-MS) and water vapor. The report treats the complementary roles of controlled laboratory experiments and computer analysis for providing detailed molecular transfer characteristics. A pressure-scanning differential refractometer was operated at fixed frequencies between 58 and 61.5 GHz. The variability of O_2 and H_2O spectra with frequency, pressure, temperature, and magnetic field strength was studied under conditions which occur in the atmosphere. Results obtained (a) for oxygen and air on the 9^+ line, the $7^+/5^-$ and $3^+/9^-$ doublets, and the continuum spectrum and (b) for water vapor on nonresonant effects are reported. The experimental O_2-MS data are used in theoretical analyses of attenuation and dispersion rates which are extended to other lines, to frequencies identified for remote sensing applications, and to temperature and pressure sensitivities between 40 and 140 GHz.

86. Liebe, H. J. (1975), Molecular transfer characteristics of air between 40 and 140 GHz, IEEE Trans. Microwave Theory Tech. MTT-23, No. 4, 380-386.

Radio wave propagation in the 40-140-GHz band through the first hundred kilometers of the clear atmosphere is strongly influenced by many (>30) lines of the oxygen microwave spectrum (O_2-MS) and to a lesser extent by water vapor. A unified treatment of molecular attenuation and phase dispersion is formulated whereby results of

molecular physics are translated into frequency-, temperature-, and pressure-dependencies. The propagation factors are developed for O_2 continuum-- ($h < 10$ km) and line-- ($h > 20$ km) spectra taking into account pressure-broadening ($h < 40$ km), Zeeman-splitting ($h > 40$ km), and Doppler broadening ($h > 60$ km). The influence of water vapor is discussed briefly. The filter characteristics of dry air are evaluated for various path models. Examples of computer plots of attenuation and dispersion rates are given as a function of altitude h for homogeneous, zenith, and tangential path geometries through the 1962 U.S. standard atmosphere.

87. Liebe, H. J., and W. M. Welch (1973), Molecular attenuation and phase dispersion between 40 and 140 GHz for path models from different altitudes, OT Report 73-10.

Radio wave propagation in the 40 to 140 GHz band through the first hundred kilometers of the atmosphere is strongly influenced by the microwave spectrum of oxygen (O_2-MS). A unified treatment of molecular attenuation and phase dispersion is formulated. Results of molecular physics are translated into frequency, temperature, pressure, and magnetic field dependencies of a complex refractive index. The intensity distribution of the O_2-MS undergoes several changes with increasing altitude: when $h < 10$ km, all lines, but one at 119 GHz, are merged to a continuum spectrum under the influence of pressure-broadening; when $h > 30$ km, a line spectrum with isolated Lorentzians is displayed; when $h > 40$ km, Zeeman-splitting of each line occurs due to the influence of the earth's magnetic field; for $h > 60$ km, a Voigt profile governs the transition to a Gaussian line shape and eventually the Doppler-broadened line spectrum vanishes. The influence of water vapor is discussed separately.

Attenuation and dispersion rates for path models are evaluated by computer routines. Examples of computer plots are given as a function of altitude for homogeneous, zenith, and tangential path geometries. Molecular resonances of minor atmospheric gases are discussed briefly, as in the noise which originates from the O_2-MS.

88 . Liebe, Hans J. (1969), Laboratory studies of microwave dispersion caused by atmospheric gases, Summaries of Papers, Symposium on Atmospheric studies to Satellite Trans., Sponsored by Ionospheric Physics Lab., AFCRL, Boston, Mass., September 3-5, 1969.

The propagation of radio signals through the earth's atmosphere for frequencies beyond about 15 GHz is strongly affected by molecular resonances of water vapor, oxygen, by a residual contribution of the entire H_2O and O_2 spectra extending into the far-infrared, and possibly by some pressure-induced polarization in water vapor. Spectroscopic laboratory studies provide knowledge of line shapes, of the temperature and pressure dependence of line parameters, and of nonresonant background effects of concern in the "window" regions.

The dispersometer was first applied to investigate the self and foreign gas-broadening properties of the water vapor line. Precise measurements of foreign gas-pressure broadening have been performed and the results are given.

Laboratory experiments have provided the spectroscopic parameters necessary to calculate the attenuation and dispersion caused by the 22-GHz H_2O line. The integrated resonance dispersion was calculated in 0.2 km increments for a simple vertical path model and using the Gross shape function, and the results are presented. Finally, a preliminary result for pressure-induced dispersion is given for water vapor between 11 and 22 GHz.

89. Linfield, R.F. (1975), Simulation of avionics line-of-sight radio transmission channels, OT/TM 75-204 (limited availability).

As the state of communication technology advances, there is an increasing interest in developing real-time transmission channel simulators capable of reproducing multiplicative effects of the propagation medium. Such simulators permit system calibration, checkout, and performance comparison to be made at considerably less cost than on-the-air testing. Meaningful simulations can only be obtained, however, if the characteristics and perturbations of real channels can be reproduced accurately, reliably, and repeatably.

This tutorial report discusses some basic concepts for simulating the multiplicative and convolutional disturbances on avionics line-of-sight transmission channels in frequency bands from 240 MHz to 38 GHz. The principal systems of concern are digital data links between airborne terminals and the ground or to synchronous satellites.

90. Lucas, D. L, and G. W. Haydon (1964), Preliminary feasibility study of Apollo spacecraft to earth HF transmissions, NBS Report 8716.

Maximum Usable Frequencies (MUF), Optimum Traffic Frequencies (FOT), and available signal-to-noise ratios as calculated by an electronic computer are used to estimate the expected signal strength of high frequency transmissons from an Apollo spacecraft to selected earth terminals. Diurnal and geographic contour charts of expected signal-to-noise ratios are shown for summer and winter in a period of moderate solar activity (SSN 50).

91. McManamon, P.M. (1976), Network capacity and queue aspects of USPS electronic message systems, USPS-1702-114. NTIS Access. No. PB-252 690/3WZ.

A geostationary orbit satellite communications network is developed parametrically for 125 station application to USPS Electronic Message Service. The satellite is based on the Atlas-Centaur launch vehicle with a 9-zone antenna coverage of the continental U.S. Other multiple zone configurations are considered. Earth stations with 5.0 meter diameter antennas are assumed to have a total average traffic load of 91,312,000 messages/day. The queueing analysis is based on 4th order Erlangian arrival and service statistics with an average bits/message considered parametrically up to 1,200,000. Message delays are presented parametrically so that the results for networks up to 123 stations and traffic loads up to 100,000,000 messages/day may be evaluated. For 123 stations and 617,000 bits/message, a nearly state-of-the-art single satellite network appears feasible to support a 91,312,000 messages/day traffic load with average message transmission delays of 2.5 seconds/message or less.

92. McManamon, P.M. (1975), A digital telecommunication conversion model for electronic message mixtures, U.S. Postal Service Report, April. NTIS Access. No. PB 252-183.

A mathematical model is developed to estimate the digital bits/message for message mixtures which arrive at a digital telecommunication network station for conversion to electronic messages and transmission. Digital data on tape or cards, and alpha-numeric and graphic messages on paper, are assumed to be converted to digital bits by one of five conversion processes; digital data, character reader, black and white graphic binary or N-ary, or color graphics. The model

allows parametric studies and incorporates the message size reductions from data compression technology. Results are given for the mean, standard, deviation, and probability functions of the number of bits/message for 11 mixture cases for 3 different sets of data compression ratios. Graphics scanner resolutions from 50 to 600 lines per inch are considered.

93. McManamon, P. M., R. K. Rosich, J. A. Payne, and M. J. Miles (1975), Performance criteria for digital data networks, OT Report 75-54.

There is a need for a "user-oriented" approach to the development of telecommunication network performance criteria. This report uses a survey of presently accepted engineering-oriented performance criteria as a vehicle for the logical development of such a user-oriented approach. On the basis of this survey, a set of user-oriented performance crieteria is developed and related to digital data transmission networks in general. The set of criteria is compared to the ANSI and another recently proposed set of performance measures. Lastly, the results of a simulation of these criteria are presented for a simple network as an illustrative example. The user-oriented performance criteria are accessibility, accuracy, delay, efficiency, reliability, security, and transparency.

94. McManamon, Peter M. (1974), Study of satellite frequency requirements for the U.S. Postal Service electronic mail system, Volume 1, Summary, OT Report 74-27.

Optimum frequency allocations are recommended for electronic mail distribution by geostationary satellite digital data transmission to servie 125 locations in the continental United States, Alaska, Hawaii, and Puerto Rico. Frequency allocations for the Fixed Satellite Service from 4 GHz to 50 GHz have been ranked in preferential order on the basis of frequency allocation restrictions, feasible network designs using available satellite and earth station technology, conversion of mail pieces to digital data, system performance requirements including a bit error probability of 1×10^{-12}, and expected frequency assignment limitations. A 650 to 700 megabit/second transmission rate was established for distribution of an average of 82 million mail pieces per day. The relationships between a definition of an electronic mail service, system performance and requirements and selection of an optimum frequency allocation have been outlined.

95. McManamon, P. M., J. R. Juroshek, and M. Nesenbergs (1974), Study of satellite frequency requirements for the U.S. postal service electronic mail system, Volume II, Frequency allocations and network designs, OT Report 74-27.

Optimum frequency allocations for electronic mail distribution by geostationary satellite digital data transmission to serve 125 locations in the continental United States, Alaska, Hawaii, and Puerto Rico are considered. Frequency allocations for the Fixed Satellite Service from 4 GHz to 50 GHz have been reviewed on the basis of restricitons, network designs with available technology, conversion of mail pieces to digital data, system performance requirements including a bit error probability of $1x10^{-12}$, and expected frequency assignment limitations. A 700 megabit/second (Mbps) transmission rate was established for distribution of an average of 82 million mail pieces per day. The relationships between a definition of an electronic mail service, system performance and requirements and selection of an optimum frequency allocation are outlined.

This volume summarized the available frequency allocation restricitons and limitations. Candidate satellite telecommunication system networks are described with different time division, frequency division, and space division multiple access techniques with both pre-assignment and demand-assignment operating protocols. Network transmission rates including overhead bits and network performance estimates are developed. Error control techniques are included in performance estimates for satellite power and ground station antenna diameter.

96. McManamon, P. M., J. R. Juroshek, and M. Nesenbergs (1974), Digital data satellite systems, 1974 IEEE International Conf. on Comms. (ICC'74), Minneapolis, Minnesota, June 17-19.

Fixed-Satellite Service frequency allocations from 4 GHz to 50 GHz have been investigated for 700 Mbps digital data satellite transmission from over 100 earth stations in the United States. Nine candidate satellite networks have been evaluated for bit error rates as low as $1x10^{-12}$, based on currently available technology and using earth station antenna diameters as small as 10 feet. Different time division, frequency division, and space division multiple access techniques have been investigated along with error control coding. The effects of rain-loss attenuation were included.

97. McManamon, P. M., and W. F. Utlaut (1973), A survey of technical requirements for broadband cable teleservices, Vol. 5, System interconnections, OT Report 73-13, Vol. 5, COM-73-11590.

The interconnection of existing and future CATV systems for two-way transfer of audio/video and digital data signals has been surveyed. The concept of interconnection is explored relative to existing and proposed CATV systems and broadband teleservice networks, common carrier services, facilities and growth projections, and the technical-economic state-of-the-art of the required technology. The need for interconnection is reviewed. Satellite and line-of-sight microwave transmission in addition to digital versus analog transmission systems, aspects are considered in terms of interconnection. Some potentially significant queueing problems are identified.

98. McManamon, P. M. (1973), GOES data collection system performance estimates, OT Tech. Memo. 73-125 (limited availability).

This report presents performance estimates and recommended measurements for the interrogation and data reply transmissions between the remote Data Collection Platform Radio Sets and the Command and Data Acquisition station through the GOES transponder. Transmission losses with ionospheric scintillation fading and multipath, man-made noise, crosstalk and intermodulation are included to give carrier-signal-energy to noise-power density ratios over the GOES geographical area of coverage up to central angles of 70°.

99. Middleton, D. (1976), Statistical-physical models of man-made and natural radio noise, Part II: first order probability models of the envelope and phase, OT Report 76-86.

Most man-made and natural electromagnetic interferences are highly non-gaussian random processes, whose degrading effects on system performance can be severe, particularly on most conventional systems, which are designed for optimal or near optimal performance against normal noise. In addition, the nature, origins, measurement and prediction of the general EM interference environment are a major concern of an adequate spectral management program. Accordingly, this second study in a continuing series (cf. Middleton, 1974) is devoted to the development of analytically tractable, experimentally verifiable, statistical-physical models of such electromagnetic interference.

Here, classification into three major types of noise is made: Class A (narrowband vis-a-vis the receiver), Class B (broadband vis-a-vis the receiver), and Class C (=Class A + Class B). First-order statistical models are constructed for Class A and Class B cases. In particular, the APD (a posteriori probability distribution) or exceedance probability, PD, of the envelope are obtained. These results are canonical, i.e., their analytic forms are invariant of the particular noise source and its quantifying parameter values, levels, etc. Class A interference is described by a 3-parameter model, Class B noise by a 6-parameter model. All parameters are deducible from measurement, and like the APD's and pdf's are also canonical in form; their structure is based on the general physics underlying the propagation and reception processes involved, and they, too, are invariant with respect to form and occurrence of particular interference sources.

100. Middleton, D. (1974), Statistical-physical models of man-made radio noise, Part I. First-order probability models of the instantaneous amplitude, OT Report 74-36.

A general statistical-physical model of man-made noise processes appearing in the input stages of a typical receiver is described analytically. The first-order statistics of these random processes are developed in detail for narrow-band reception. These include, principally, the first-order probability densities and probability distributions for a) a purely impulsive (poisson) process, and b) an additive mixture of a gauss background noise and impulsive sources. Particular attention is given to the basic waveforms of the emissions, in the course of propagation, including such critical geometric and kinematic factors as the beam patterns of source and receiver, mutual location, doppler, far-field conditions, and the physical density of the sources, which are assumed independent and poisson distributed in space over a domain Λ.

Apart from specific analytic relations, the most important general results are that these first-order distributions are analytically tractable and canonical. They are not so complex as to be unusable in communication theory application; they incorporate in an explicit way the controlling physical parameters and mechanisms which determine the actual radiated and received process; and finally, they are formally invariant of the particular source location and density, waveform emission, propagation mode, etc., as long as the received disturbance is narrow-band, at least as it is passed by the initial stages of the typical receiver.

The desired first-order distributions are represented by an asymptotic development, with additional terms dependent on the fourth and higher moments of the basic interference waveform, which in turn progressively affect the behavior at the larger amplitudes.

This first report constitutes an initial step in a program to provide workable analytical models of the general non-gaussian channel ubiquitous in practical communications applications. Specifically treated here are the important classes of interference with bandwidths comparable to (or less than) the effective aperture-RF-IF bandwidth of the receiver, the common situation in the case of communication interference.

101. Middleton, D. (1970), Electromagnetic interference by scattering from clouds, NASA Contract NAS-12-2219.

A first-order electromagnetic scattering model for atmospheric clouds is constructed, in order to assess quantitatively the interference such scattering may introduce into communication links not connected with the primary transmission mode. For the latter it is also desired to determine the role of such scattering in attenuating and corrupting the transmitted signal. For an adequate treatment it is essential to obtain explicitly the scattered (and any ducted) waveforms observed at the receiver and to determine as well their energy and other appropriate statistics, e.g., the covariance functions of the received waves. Geometry plays a critical part in such problems: not only the relative geometries of source, receivers, and scatterers (in the cloud(s)), but also the transmitting and receiving beam patterns. These features must be explicitly incorporated into any criterion for measuring interference effects in the communication process.

This preliminary memorandum outlines and illustrates with some detailed examples and results:

(a) the first-order scatter model, in the bistatic situation

(b) (optimum) receiver performance under such scatter, in the particular case of (slow) Rayleigh fading of a desired (deterministic) signal, incoherently received.

Enough technical detail is provided to indicate the elements that must be considered for an adequate analysis and guide to, and interpretation of, experiment.

102. Miles, M.J. (1975), Analysis of a digital telecommunications message model. U.S. Postal Service Report, April, NTIS Access. No. PB 252-184.

The general expression for the probability density function of the number of bits in a telecommunications message is derived. Some key random phenomena are assumed to have the normal distribution, and their distribution parameters are assigned plausible values. The expressions for the mean and standard deviation of bits per message are derived. The number of pages/message is assumed to have the Poisson distribution truncated at zero, and the resulting distribution is examined.

103. National Bureau of Standards (1958), Areas of mutual interest between NBS-Boulder Laboratories and the National Aeronautics and Space Administration, an NBS Report (no number).

This report describes those technical activities in which the Boulder Laboratories are already contributing to the objectives defined for NASA, and proposes new activities which are in the currently defined objectives of the Boulder Laboratories and which will contribute in a major way to the objectives of the NASA.

104. Nesenbergs, Martin (1975), Study of error control coding for the U.S. Postal Service electronic message system, U.S. Postal Service Report, NTIS Access.No. PB 252-689.

A U.S. Postal Service (USPS) electronic mail system could incorporate many types of error control coding, or no coding at all. This report reviews a variety of possible codes, lists their advantages and disadvantages, and selects a preferred alternative. It turns out to be a concatenation of an inner convolution (rate 1/2 to rate 3/4) code with Viterbi decoding, and an outer long block, high efficiency code. The two codes have separate functions, in the sense that the inner code performs forward error correction and the outer code does error detection only. The report describes the structures, properties, and implementations of the coding hybrid. After that, the performance of the preferred coding scheme is estimated. The resultant error probability gains, which are shown to be considerable, are balanced against system slowdown and bandwidth expansion.

105. Nesenbergs, M. (1975), Scintillation channel characterization and MPSK performance estimation, 1975 IEEE International Conference on Communications (ICC '75), San Francisco, CA., June 16-18, IEEE Cat. #75-CH-0971-2 CSCB, 15/1-15/5.

Relatively familiar theoretical techniques seem applicable to assess the ionospheric scintillation effects on satellite data link performance. We review one such error probability expansion technique, well suited for digital computation, as it pertains to a Multiple-Phase-Shift Keying (MPSK) modem operating in the 1 Mb/s to 1 Gb/s range. Unfortunately, the usefulness of the technique suffers for lack of adequate characterization of the scintillation medium. Factors like correlation bandwidths, power delay spreads, probabilities of amplitude and phase excursions, etc. appear only vaguely known. Realistic and reliable scintillation statistics are desired to estimate the achievable data rates and performances on proposed satellite channels.

106. Nesenbergs, M. (1974), A first look at certain wideband detection problems, OT TM 74-175 (limited availability).

Consideration is given to a wideband detection problem where the number and structure of the received signal set is arbitrary. A particular spectral weighting approach is taken and the processing results are found to be inadequate. The search for substantially better detectors, in particular for those with optimal features, is initiated. An outline of future work is provided in the conclusion.

107. Nesenbergs, M. (1974), Ionospheric scintillation as it affects satellite communication - Part III: Scintillation channel characterization and MPSK performance estimation, OT TM 74-190 (limited availability).

This memorandum is concerned with scintillation effects on digital multiple phase shift keying (MPSK) channels in the presence of additive Gaussian noise. The basic channel statistics, such as the correlation bandwidth and related spreads, are introduced first. Later, the function of the demodulator is reviewed and the most popular digital performance index, the bit error probability (P_e), is pursued. A particular approach, starting from Taylor series and ending in Gram-Charlier expansions, is elaborated in detail. A number of useful P_e expansions are given. The choice of a preferred expansion depends on existing

knowledge of scintillation statistics, notably the extent of the power delay density, the fading character in the time-frequency domain (such as flat-flat, or other), and the gross magnitudes of the intersymbol interference moments at the detector. The memorandum concludes with an overview of the general intersymbol interference case, as it pertains to scintillation distortions on satellite MPSK links. More realistic radio wave statistics are needed to estimate the modem performance reliably.

108. Nesenbergs, M., R. H. Ott, and L. C. Walters (1972), Performance of a coherent communication system with pulsed interference, OT TM 89 (limited availability).

The error probability and output signal-to-noise ratio performance of binary PSK and Manchester PSK systems are derived and numerically evaluated in the presence of pulsed interference. The results are directly applicable to a coherent Collision Avoidance System (CAS).

109. Nesenbergs, M. (1971), Optimum reception of coded multiple frequency keying in presence of random variable phases, IEEE Trans. on Comm. Tech. COM-19, No. 5, pp. 707 ff.

Wide-band multiple frequency-shift keyping is perturbed by random phases in the M>2 frequency slots. We consider a coded digital system, where the M phases can be treated as mutually dependent random variables. If their joint distribution is known, the optimum (maximum-likelihood) receiver is shown to be in general very complicated. We show that there are a few phase distributions and signal-to-noise-ratio extremes for which the optimum receiver and its performance can be simply described. If the joint phase distribution is not known, we give an appropriate minimax receiver with a guaranteed performance. This performance is evaluated for orthogonal coding, white Gaussian noise, and non-fading signals. It is valid for all joint phase distributions.

110. Nesenbergs, M. (1970), A two-signal primer for Fourier analysis of a random access communication system, ESSA TR ERL 178-ITS 113.

The detectability parameter, i.e., the acquisition signal-to-noise ratio is derived for an elementary two-signal multiple access channel. The basic Fourier series approach requires no approximations, and the methodology should be useful in a forthcoming rigorous analysis of a more realistic random access satellite repeater.

The channel model consists of an ideal hard limiter and Gaussian noise. Carrier phases are mutually independent and uniform over $(0, 2\pi)$. The relative delays and frequency deviations can be treated as deterministic or as random variables. We have derived second order statistics (means and variance) for the word correlation outputs.

Three properties that emerge in the above two-signal case and may very well be valid in the general M signal case, are the following. First, reasonable frequency drifts and departures from a true carrier do not seem to increase the distortion variance in a drastic fashion. The same conclusion appears to be valid for slow message FM or PM. Second, the variance of the correlator outputs contains a substantial term that is entirely independent of cross-modulations for the assumed 0 to π modulations. Third, waveform and coding departures from orthogonality do not necessarily affect the detectability parameter by robustly scaling down the signal mean.

111. Norton, K. A. (1965), Effects of tropospheric refraction in earth-space links (1965), in Progress in Radio Science 1960-1963, 2, ed. F. du Castel, 186-210 (Elsevier, New York).

Methods are first given for predicting the expected values of the bending and the electrical path length of radio waves in propagation between the surface and arbitrary heights in the troposphere for radio waves leaving the surface at specified angles of elevation. Variances of these predicted values are also given. Comparisons of the predicted with the observed values of both the bending and its variance show excellent agreement.

An extensive analysis is given of the spectrum of the variations of both electrical path length and range rate with time. The regions of applicability of geometrical and wave optics are outlined. A discussion is given of the correlation of the variations in electrical path lengths for different radio frequencies. Formulas are given for the influence of antenna apertures and path length on the spectrum of both path length and range rate.

An indication is given of applications of these results to radio guidance systems and standard frequency dissemination.

112. Ott, R. H. (1975), A numerical method for generating earth coverage footprints from geostationary antennas, U.S. Postal Service Report, May, NTIS Access. No. PB 252-688.

An algorithm is described for generating earth coverage footprints on a microfilm output from geostationary satellite antennas. A separate algorithm for determining whether given stations are included in or excluded from a particular footprint is described. The antenna beam can be elliptic in cross-section with an arbitrary orientation of semi-minor and semi-major axes. Several examples of the use of the algorithms are presented.

113. Ott, R. H. (1975), Bandwidth limitations in EM transmission imposed by clear air turbulence, 1975 IEEE International Conference on Communications (ICC '75), San Francisco, CA., June 16-18; IEEE Cat. #75-CH-0971-2 CSCB, 15/6-15/9

A solution of the appropriate parabolic wave equation is used to derive the transfer function for a medium characterized by a complex random refractive index with Gaussian statistics and a non-zero complex mean. We compute its mean and its two-frequency correlation function. The statistics are shown to depend on the temperature spectra of the random media. The results for the two-frequency correlation function indicate that close to sea level the oxygen spectrum (frequency dependent part of refractive index) does not limit the bandwidth of a channel in the 50 GHz to 70 GHz range. That is, the bandwidth in this frequency range is only limited by the static (frequency independent) refractive index.

114. Ott, R. H. (1974), Ionospheric scintillation as it affects satellite communication - Part II: A transfer function for ionospheric scintillations, OT-Tech. Memo. 74-187 (limited availability).

The Born approximation is used to derive a general expression for a radio wave passing through a random medium. The medium is characterized by a random index of refraction. An explicit transfer function is derived using the Fremouw and Rino

model for the index of refraction. The bandwidth of the channel is derived in terms of the variance of the index of refraction.

115. Rice, P. L., and N. R. Holmberg (1973), Cumulative time statistics of surface-point rainfall rates, IEEE Trans. on Comm. 21, No. 10, pp. 1131-1136.

Statistics on rainfall rates near and above the earth's surface are needed in order to estimate the percentage of time of absorption, or scattering of radio waves that affect radio system design and electrospace management. The most useful averaging time for computing such rates is on the order of 1 min or less. This paper extrapolates excessive short-duration precipitation data to provide such statistics from data routinely reported by the National Weather Service. For the 8766 h in an average year, and for a median or random location in any part of the world, the model described here estimates the fraction of time during which 5-minute average rainfall rates exceed any given value.

116. Samson, C. A. (1976), Refractivity and rainfall data for radio systems engineering, OT Report 76-105.

Information on refractivity gradients and rainfall rates is provided for application to the planning and engineering of microwave line-of-sight radio systems. The 100-m refractivity gradients calculated from radiosonde observations at 15 U.S. and 49 foreign stations are presented in the form of an indication of the diurnal variability of the gradients, separate distributions are shown for each of two daily observations at 29 stations, and for four daily observations at 4 stations. Point rainfall rate distributions, based on recording rain gage statistics, are given for 29 stations in various climatic areas of the world, including 8 locations in the U.S.

117. Samson, C. A. (1975), Atmospheric considerations in radio system engineering at 10 to 30 GHz, OT Report 75-66.

The effects of the atmosphere on radio propagation at frequencies of 10 GHz to 30 GHz include attenuation and depolarization by precipitation, absorption by water vapor and oxygen, and multipath fading related to refractivity gradients in stratified layers. Information is presented on the probable magnitude of the various weather-related effects, considering the differences in radio

frequency, geographical location, and climate. The limitations of climatological data are discussed, as well as methods of using the available data in system engineering.

118. Seitz, N. B., and P. M. McManamon (1976), Performance measures for digital communication services, Business Comm. Rev., March-April, 26-33.

Six general criteria have been proposed for describing digital communications system performance: accessibility, accuracy, efficiency, reliability, security, and transparency. Specific performance parameters have been proposed for the first four criteria.

The suggested measures clearly are not "ideal" from the standpoint of the "desired attributes" defined. Nevertheless, they do provide communications users with a practical means of expressing their communication needs; comparing service alternatives and monitoring delivered performance. The utility and precision of the suggested measures will increase as they evolve in response to the stresses of actual use.

119. Smith, D., and F. G. Kimmett (1975), Measurement of interference effects between TDM-FM and FDM-FM microwave systems, OT Tech. Memo. 75-194 (limited availability).

Following the alignment and tuning of an analog FM microwave radio to handle a 12.6 Mb/s, 3-level partial response base-band, the effects of various types of interference on system performance were investigated. Since TDM-FM and FDM-FM microwave systems will be operating in the same frequency band, the mutual interference effects were investigated to determine the degree of degradation of system performance for each type of transmission. Bit-error-rate and orderwire signal-to-noise ratio were used as indices of TDM-FM system performance, and noise power ratio was used as the index for the FDM-FM system evaluation. These measurements indicate that the TDM-FM system can operate at higher interference levels than the FDM-FM system when subjected to TDM-FM interference.

120. Smith, E. K. (1975), Radio wave propagation in the ionosphere - 1972-1974, OT Tech. Memo. 75-197 (limited availability).

This survey of published literature has been prepared at the request of Prof. Chalmers Sechrist, Editor Commission III, URSI Triennial Report. Ionospheric propagation is treated by frequency (ELF-VLF, LF-MF, HF, and VHF on up) and also by topic (e.g., ionospheric scintillation, ionospheric modification, and theory).

121. Smith, E. K. (1974), A study of ionospheric scintillation as it affects satellite communication - Part I: Geophysical Aspects, OT TM 74-186 (limited availability).

This study concerns ionospheric scintillation as it affects satellite communications between about 100 MHz and 30 GHz. It is divided into three parts. The first part reviews the pertinent physics and suggests some boundaries and values for some of the critical geophysical parameters needed to make communications estimates. The second part is concerned with the derivation of the channel transfer function based on the suggested parameters from Part 1. The third part develops the relations necessary to assess the effect of ionospheric scintillation on typical satellite modulations and bit rates.

122. Snider, J. B. (1968), A proposed program for the study of atmospheric attenuation of satellite signals, ESSA Technical Report RL 62-WPL 1.

The theory of absorption and emission of radio frequency energy by atmospheric constituents is reviewed. Theoretical limitations and the problem of predicting atmospheric effects upon satellite communications systems are discussed. A program is outlined to investigate experimentally atmospheric absorption and emission with emphasis placed upon rainfall phenomena using simultaneous measurements of satellite-earth transmission loss and meteorological parameters, including radar measurements of precipitation.

123. Spaulding, A. D. (1976), Man-made noise: the problem and recommended steps toward solution, OT Report 76-85.

Man-made noise causes interference which is, quite often, the limiting factor in communications/electronics system performance. This interference results in communication systems being required to use excessive powers and/or spectrum space, thereby hampering the efficient utilization of the limited spectrum resource. It is the purpose of this report to specify the "man-made noise problem" in detail and recommend required remedial actions. Specifically, the aim is to:

1) assess the adequacy of information presently available and being collected,
2) define and assess the adequacy of present abatement measures,
3) make specific recommendations on additional required abatement measures, and
4) make specific recommendations as to necessary additional research.

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

Programs for noise measurement, analysis, and model development are summarized, and recommendations for the attaining of required additional information on the noise environments are given. In addition, the role that better information on the noise environment should play in the proper management of the spectrum resource is covered.

124. Spaulding, A. D. (1975), Effects of noise in system performance, Review of Radio Science, 1972-1974, URSI, Brussels, Belgium, [illegible]32

This paper is a summary of advances worldwide for the years 1972-1974 in determination of the effects of noise and interference on system performance etc. This contribution is combined with others in the noise area by the URSI Commission VIII editor and appear as Commission VIII's contribution to the URSI Triennial Review of Progress in Radio Science.

125. Spaulding, A. D., R. T. Disney, and A. G. Hubbard (1975), Man-made radio noise, Part II: Bibliography of measurement data, applications, and measurement methods, OT Report 75-63.

The Office of Telecommunications, Institute for Telecommunication Sciences (OT/ITS), over the past several years, has accumulated a data base of man-made radio noise measurements in the frequency range from 250 kHz to 250 MHz taken in a number of geographical areas. Man-Made Radio Noise, Part I (OT Report 74-38) gives the results of the analysis of this base and provides estimates of the man-made noise levels and characteristics to be expected in typical locations.

This part of the report (Part II) is a compilation of references relating to man-made radio noise. This bibliography is divided into five sections: Section I, Measurements and Data; Section II, Applications to Systems and Mathematical Modeling; Section III, Measurement Experiemtns and Methods; Section IV, General, and Section V, Atmospheric Radio Noise.

126. Spaulding, A. D., and D. Middleton (1975), Optimum reception in an impulsive interference environment, OT Report 75-67.

Since communications systems are seldom interfered with by classical white Gaussina noise, Middleton's recently developed physical-statistical model of impulsive interference is applied to real world communications channels.

The main impulsive interference models that have been proposed to date are summarized, and Middleton's model is specified in some detail, giving the statistics required for the solution of signal detection problems. Excellent agreement of these statistics with corresponding measured statistics is shown.

Middleton's model for narrow-band impulisve interference (a subset of the overall model) is applied to a class of optimal signal detection problems. Optimum detection algorithms are given for coherent and incoherent binary detection. The three basic digital signaling waveforms are considered; i.e., antipodal, orthogonal, and ON-OFF keying. Performance bounds are obtained for these signaling situations. Since it is known that in order to gain significant improvement over current receivers, the number of independent samples of the received interference waveform must be large, the performance results are given parametrically in the number of samples, or equivalently, the time-bandwidth product. Performance of the current suboptimum receivers is obtained and compared to the optimum performance. It is shown that substantial savings in signal power and/or spectrum space can be achieved.

Since physical realization of the completely optimum detection algorithms cannot, in general, be economically obtained, the corresponding locally optimum or threshold receivers are derived and their performance given. These threshold receiver structures are canonical in nature in that their structure is independent of the form of the interference. They are also adaptive in that they must be able to adjust to the changing interference environment. Locally optimum structures are given here for coherent and incoherent detection with constant signal levels and various kinds of fading. The case in which phase estimation is used (partially coherent reception) is also considered.

127. Spaulding, A.D., and R. T. Disney (1974), Man-made radio noise, Part I: Estimates for business, residential, and rural areas, OT Report 74-38.

The Office of Telecommunications, Institute for Telecommunication Sciences (OT/ITS), over the past several years, has accumulated a data base of man-made radio noise measurements in the frequency range from 250 kHz through 250 MHz taken in a number of geographical areas. This data base has been analyzed to provide estimates of the expected characteristics of man-made radio noise in business, residential, and rural areas. The parameters used are the average available power spectral density, the ratio of the rms to the average voltage of the noise envelope, and the ratio of the rms to the average logarithm of the envelope voltage. The variation of these parameters as a function of frequency, location, and time are shown and discussed. Examples of amplitude and time statistics of the received man-made radio noise process also are shown and discussed. examples of amplitude and time statistics of the received man-made radio noise process also are shown and discussed. The use of the estimates is shown (principally by references in Part II, Bibliography) in the solution of problems encountered in frequency management and telecommunication system design.

128. Spaulding, A. D., L. L. Proctor, and A. F. Barghausen (1973), DSCS Airborne earth terminal - terrestrial microwave measurements in the 7.25-8.40 GHz Band, OT Tech. Memo. 73-143 (limited availability).

The majority of the 7.25-8.40 GHz band has been allocated, on a shared basis, to both satellite communications and fixed and mobile terrestrial communications, primarily microwave radio relay systems. The Office of Telecommunications, Institute for Telecommunication Sciences, has conducted tests to assess the nature of the interaction between a prototype airborne satellite terminal (AN/ASC-18) and microwave radio relay systems (FAA RML-4 links). This report presents the measurement procedures and results of those tests under actual operating conditions.

129. Spies, K. P., and E. J. Haakinson (1977), Calculation of geostationary satellite footprints for certain idealized antennas, proposed as an OT Report (in preparation).

This report describes methods for calculating, under certain simplifying assumptions, footprints (contours of constant power density) for idealized models of several common types of transmitting antennas (circular aperture, elliptical aperture, rectangular aperture, and helical antennas), and for antenna beams of specified but rather arbitrary shape. The transmitter is mounted on a satellite in a prescribed geostationary orbit and has its main-lobe axis directed toward a given aim point on the earth.

Formulas are first derived for calculating the intersection of the earth with a ray emanating from a given geostationary satellite and having a prescribed direction in space. For each idealized antenna type, procedures are next discussed for finding those directions in space where the relative power density has a specified constant value; intersection formulas are then applied to locate the corresponding footprint. Far-field patterns are approximated for aperture antennas by evaluating Fourier transforms of assumed aperture illumination distributions, and for the helix by assuming it radiates in the axial mode. Owing to gross discrepancies between actual and ideal side-lobe patterns, the analysis is confined to the main lobe of idealized antenna models.

130. Steele, F. K., and S. F. Van Horn (1975), A bibliography of recent work on propagation in the radio spectrum from 10 to 100 GHz, OT Report 75-57.

References are presented on the subject of recent (1971 to mid-1974) work on radio propagation through the atmosphere at frequencies from 10 to 100 GHz. The references are separated into six major categories covering propagation through precipitation, multipath propagation, propagation through non-turbulent-clear and turbulent-clear atmospheres, measurements/data and a general category.

131. Stewart, A.C., L.L. Haidle, R.D. Jennings, S. Murahata, and D. Vandermade (1976), Electromagnetic compatibility measurements and analysis of systems in the 1535-1660 MHz band, U.S. Dept. of Transportation Report No. FAA-RD-75-229.

Laboratory measurements and a statistical analysis were made to determine the electromagnetic compatibility of systems occupying or proposed to occupy the frequency spectrum from 1535 to 1660 MHz. Three proposed collision avoidance systems, five radar altimeters, and a simulated satellite communication system were measured. The results obtained in the measurement program were combined with an estimate of the aircraft population that might be expected in the year 1982 in the Los Angeles Basin to produce a statistical model. This model, and computations of "worst case" scenarios involving two aircraft were used

to determine the possibility of altimeter interference to other systems in an operation environment. It was concluded that the altimeters will cause interference to systems proposed to operate in the band.

132. Tary, J. J., R. R. Bergman, and G. D. Gierhart (1971), GOES telecommunication study - 1971, OT TM 64 (limited availability).

A telecommunication study for the GOES/SMS satellite system. The effects of propagation phenomena, radio frequency interference, and noise for the 400 MHz communication system link performance are considered.

133. Thayer, G. D., and B. R. Bean (1962), An analysis of atmospheric refraction errors of phase measuring radio tracking systems--Part I: An analysis of the refraction errors to be expected in a horzontally homogeneous atmosphere and a method for their systematic correction, NBS Report 7254, NTIS Access. No. AD 292-046.

In Part I of this report the atmospheric refraction errors experienced by phase-measuring radio-baseline tracking systems are examined, and a general method for their correction is presented. The correction method consists of a system of linear equations that are to be used to predict the most likely value of the range error experienced at each antenna location of the system, as a fucntion of the surface value of refractive index and the target range and height. The correction method yields residual rms range errors of only 1% to 3% of the uncorrected values, and the method is suitable for real-time use if desired. The correction method is applied to some limited experiemtnal data, and the comparison is found to be satisfactory. Possible limitations on the use of the correction method are discussed, and extensive tables are given in an Appendix which serve to define the system of equations used for the corrections.

In Part II of this report the effects of horizontal gradients of the refractive index on long-baseline tracking systems are investigated briefly and the results are compared with the predictions supplied by the correction method derived in Part I. The comparison is found to be acceptable.

134. Thompson, M.C., L.E. Wood, H.B. Janes, and D. Smith (1975), Phase and amplitude scintillations in the 10 to 40 GHz band, IEEE Trans. Ant. Prop. AP-23, No. 6, 792-797.

Simultaneous measurements of phase and amplitude variability were made on a 64 km slant path using five radio frequencies: 9.55, 19.1, 22.2, 25.4, and 33.3 GHz. The three middle frequencies were chosen for their relation to water vapor absorption.

The amplitude data show occasional fades in excess of 20 dB superimposed on ubiquitous smaller scintillations of several decibels. The latter generally increased with radio frequency and the fluctuations at the different frequencies were only moderately correlated (e.g., < 0.7). Neither phase nor amplitude variability shows effects on the molecular resonance of water vapor.

135. Thompson, M.C., Jr. (1973), A review of propagation information needed for the effective use of the 1- to 40-GHz band, OT Report 74-30.

An inquiry was sent out to 60 persons engaged in research, engineering, or system applications in the 1- to 40-GHz band. This report summarizes the propagation-related problems identified by these people and also indicates where work is being done to provide additional information for system design.

136. Thompson, M. C., Jr., L. E. Wood, and H. B. Janes (1972), Phase and fading characteristics in the 10- to 40-GHz band, OT/ITS unpublished report.

Simultaneous measurements of phase and amplitude variability were made on a 64-km overwater slant path using 5 radio frequencies: 9.5, 19.1, 22.2, 25.4, and 33.3 GHz. The data show relatively small differential time delay variations over this 24-GHz spectral interval. Amplitude scintillations generally increased with radio frequency and the fluctuations at the different frequencies were not highly correlated (e.g., < 0.7).

Periods were observed in which all signals experienced nearly simultaneous fades of 10 dB or more.

137. Thompson, M. C., Jr., L. E. Vogler, H. B. Janes and L. E. Wood (1972), A review of propagation factors in telecommunications applications of the 10- to 100-GHz radio spectrum, OT Report 34.

This paper discusses systems applications in the 10- to 100-GHz frequency band, propagation factors pertinent to the design of these systems, and recommendations for future action. Consideration is given to the complementary roles of experiment and analysis in providing the information necessary for optimum utilization of EHF frequencies.

138. Thompson, M. C., Jr., and H. B. Janes (1971), Effects of sea reflections on phase of arrival of line-of-sight signals, IEEE Trans. Ant. Prop. AP-19, No. 1, 105-108.

Continuous wave signals at 9.6 GHz were propagated over a 97-km overwater path extending from an elevation of 80 m to 3000 m mean sea level (msl). Variations in phase of arrival of the signals received by antennas having 1.2° and 5° beam widths were recorded simultaneously. With the nominal path elevation angle of 1.2°, the broad-beam antenna received a contribution reflected from the sea surface, while the narrow-beam antenna largely discriminated against such reflections. The spectra of phase variations for the two cases were compared, and their coherency was computed. The broad-beam signal displayed consistently higher spectral density than did the narrow-beam signal over the fluctuation frequency range from 0.1 Hz to the limit of the analysis at about 10 Hz. The relatively large effect of multipath phase noise on range rate measurements is discussed.

139. Thompson, M, C., Jr., and H. B. Janes (1971), Sea multipath effects on microwave range and velocity measurements, Symposium on App. of Atmos. Studies to Sat. Trans., Boston, September 1969.

Accuracy of microwave systems for making slant range and velocity measurements is limited by random phase noise contributed by the propagation medium. Most are caused by spatial and temporal variations in atmospheric refractive index along the path. For low elevation angles, additional noise can result from signal components reflected from earth or sea or from associated low-level atmospheric refractive index gradients. Signals received simultaneously with two antennas of differing beam widths, one broad enough to pick up sea multipath and the other a narrow-beam antenna that excluded sea-reflected components. Multipath could pose serious problems for tracking at low elevation angles.

140. Thompson, M. C., Jr., and H. B. Janes (1970), Measurements of phase-front distortion on an elevated line-of-sight path, IEEE Trans. Aerospace Electron. Sys. AES-6, No. 5, pp. 645-656.

An experimental study has been made of phase-front distortion in microwave signals sent over a slanted path. This distortion is important in systems involving phase measurements between a ground station and

a moving upper terminal. To insure path stability, the upper terminal was simulated by a series of mountaintop antenna arrays. Phase-front distortion is analyzed in terms of time variations in radio range on a single path and in terms of first and second range differences between pairs of paths. The cross correlations of pairs of range and range difference records are discussed, and the strong dependence of correlation on fluctuation frequency is emphasized. Mountaintop terrain effects on the spatial homogeneity of the phase front are found to be insignificant. Some of the phase-front statistics are found to be weakly dependent on time of day and on wind velocity at the lower terminal.

141. Thompson, M. C. (1969), Tropospheric propagation effects on precise electromagnetic measurement of distance, 1966-67 AGARD Conf. Proc. No. 33, Phase and Frequency Instabilities in Electromagnetic Wave Propagation, Ankara, Turkey, Oct. pp. 613-627.

The question of phase stability of signals propagated through the atmosphere has become important recently as more and more precision is required from radio and optical location systems. In most of these systems the basic operation consists of measuring the transit time of a signal over the path in question. The conversion of this time interval to distance requires knowledge of the velocity of the signal through the medium.

The use of these techniques in terrestrial geodesy has become well established during the past decade. Several systems have been developed commercially and the effects of atmospheric limitations on such systems have been investigated. The same basic limitations become important in missile and satellite tracking as greater precision is required in these applications.

Since the propagation velocity is a function of the density and composition of the atmosphere, the velocity and phase exhibit a wide spectrum of time fluctuations. These include certain effects which are more or less systematic, such as diurnal and seasonal variations. In many cases these changes are highly correlated with velocity, or refractive index, measurements at one or more "points" in the general vicinity of the path. In such cases it is practical to apply appropriate correction methods and obtain quite precise (e.g., 1 in 10^6) distance estimates. In addition, atmospheric turbulence results in random phase variations of a signal propagated through the atmosphere. Because of its random nature, this component of the variation, often referred to as "phase noise", is unpredictable from moment to moment and can only be described in statistical terms. The development of electronic devices and techniques has reached a stage where this phase modulation introduced by the atmosphere is a serious factor in their utilization. It becomes important then to study the magnitude and nature of both the systematic and random atmospheric effects and to examine carefully the possibilities of making effective corrections for the systematic effects and averaging out the random effects. In the following we will describe some of the measurement techniques and discuss some of the results from field experiments to date.

142. Thompson, M. C., and H. B. Janes. (1969), Effects of sea reflections on phase of arrival of line-of-sight signals, ERLTM-ITS 163 (limited availability).

Continuous wave signals at 9.6 GHz were propagated over a 97-km over-water path extending from 80 miles to 3000 miles above mean sea level. Variations in phase of arrival of the signals received by antennas having 1.2° and 5° beamwidths were recorded simultaneously with a nominal path elevation angle of 1.2°. The broadbeam antenna received a contribution reflected from the sea surface, while the narrow beam antenna largely discriminated against such reflections.

The spectra of phase variations for the two cases were compared, and the coherence between the phases was computed. The broadbeam signal displayed consistently higher spectral density than did the narrow beam signal over the fluctuation frequency range of from 0.1 Hz to the limit of the analysis at about 10 Hz.

143. Thompson, M. C., Jr., L. E. Wood, and H. B. Janes (1969), Use of radio-optical dispersion to study radio range errors on moving paths, ITS Technical Memorandum, ERLTM-ITS 190 (limited availability).

Supported by data taken over a 65-km slant path with fixed terminals, this report suggests exploitation of the dispersion between radio and optical signals for studying the atmospheric errors in radio range measurements over propagation paths with a moving terminal. Correlations between the microwave range variability and the microwave-optical dispersion are heavily concentrated near unity. The variations of the dispersive range difference very closely approximate the corresponding atmospheric variation on the microwave range.

For a number of years the National Bureau of Standards and, since 1965, the Environmental Science Services Administration, has been studying experimental time-varying errors introduced by the troposphere in microwave distance measurements, especially with regard to ground-to-air or ground-to-space systems involving aircraft, missiles, or satellites. These studies have been based on measurements over fixed, slanted propagation paths with the upper terminal located on a mountain top. This arrangement has permitted long-term, continuous measurements of apparent range variations without contaminating the data with real range changes introduced by random motion of an airborne upper terminal.

144. Thompson, M. C., Jr., H. B. Janes, and W. B. Grant (1965), Study of atmospheric errors in microwave tracking systems, NBS Report 9139.

An experimental program was conducted to study further aspects of atmospheric effects on radio tracking systems. This series included measurements near Boulder, Colorado, and on the island of Maui, Hawaii. Four specific points were investigated: 1) effect of antenna aperture size on range noise, 2) dependence of range difference noise on baseline length, 3) correlation of range variations with radio refractive index obtained both from surface and airborne instruments, and 4) the use of auxiliary atmospheric properties to predict the expected noise level (from atmospheric effects). All measurements were made at 9.4 GHz. Antenna aperture size effect was found to be insignificant. Baseline length dependence was determined for baselines ranging from 4.5 to 1653.4 meters. Generally poor correlations were found between range and surface refractive index, but good correlation appeared between range index data obtained from about 1000 to 2300 meters (MSL). No clear relationship was found between the level of range noise and any of the supplementary quantities measured during these experiments.

145. Thompson, M. C., Jr., and D. M. Waters (1958), Comparison of phase difference and Doppler shift measurements for studying ionospheric fine structure using earth satellites, Proc. I.R.E. 46, No. 12, p. 1960.

In using signals from earth satellites to investigate ionospheric fine structure, it would appear that at least two approaches might be used. One is the technique of measuring continuously the phase difference of signals received over slightly different paths (space receiving antennas), and the second is that of examining the Doppler shift on the frequency of a single signal. The basic differences in the two techniques are examined.

146. U.S. Army Radio Frequency Engineering Office, Office of the Chief Signal Officer (1958), Optimum Frequencies for Outer Space Communication, unnumbered report, July 1958, 30 pp. (principal contributors were personnel of NBS CRPL, G. W. Haydon et al.)

The work summarizes the frequency dependence of radio propagation and other technical factors which influence outer space communications and provides a basis for the selection of frequencies for communication between earth and a space vehicle or for communications between space vehicles.

Communications between earth and outer space is theoretically possible in both the VHF and UHF bands. The upper limit is dependent upon tropospheric conditions and the lower limit depends upon ionospheric conditions. The optimum frequency, therefore, is not sharply defined, but is dependent upon geographic location and time of operation. For communication for most of the time to most any earth terminal location, any frequency above 70 Mc/s may be used. The optimum freuqency will depend upon the specific communication service required and will be a compromise between the maximum practical antenna size, the minimum beamwidth which will permit acquisition or tracking and radio noise levels.

147. Utlaut, W. F. (1975), Review of important problems in wave propagation affecting future telecommunication systems performance, Conference Proceedings, World Telecommunications Forum, Geneva, Switzerland, October 1975, 3.1.8.1-3.1.8.8.

Radio propagation factors play an important role in determining telecommunication system performance limitations. This paper summarizes some of the radio propagation factors about which there is insufficient knowledge in view of the trends with which telecommunication systems are developing. These include ionospheric affects on earth-space communications, tropospheric radio meteorology, urban and irregular terrain environments and ionospheric modification resulting from high power transmitters.

148. Utlaut, W. F. (1973), Ionospheric scintillations: a potential limitation to satellite communications - important unknown scintillation factors, American Institute of Aeronautics and Astronautics 12th Aerospace Sciences Meeting, Washington D.C., January 30 - February 1, Paper No. 74-56.

The phenomenon of ionospheric scintillations has long been observed by radio astronomers and physicists. Their observations have been valuable in describing certain

aspects of the phenomenon. Questions for which they sought answers were not necessarily framed to provide adequate information about scintillation effects for today's satellite system designer. Factors needing better understanding relative to scintillations include: signal, amplitude and phase, time and frequency characteristics in relation to geographic location and period in time: probability of occurrence, degree of severity, geographical extent of scintillation effects; relationship of scintillations to other geophysical phenomena, that may permit prediction capacity; and others.

149. Violette, E. J. (1974), Wideband digital communication satellite system, OT Report 74-50.

A wideband digital communications satellite system is investigated using a time-division, multiple-access approach to establish a high capacity, nationwide network. State-of-the-art bit-rate capacity is estimated for digital data transmission in the entire frequency bands of each assumed frequency allocation in one geostationary orbital slot.

150. Vogler, L. E., and S. F. Van Horn (1972), Bibliography on propagation effects from 10 GHz to 1000 THz, OT Report 30.

A bibliography on electromagnetic wave propagation over line-of-sight paths through the troposphere at frequencies about 10 GHz. The references are divided into three main categories covering the area of propagation through non-turbulent clear atmosphere and precipitation.

151. Welch, W. M. (1974), Intermodulation effects in space-qualified type traveling-wave tubes, OT Report 74-55.

Characteristics of space-qualified traveling-wave tubes are summarized. The nonlinear behavior of these tubes is outlined, and the results of experimental and theoretical investigations of several authors are given. Recent advances which will influence satellite communication systems are discussed.

152. Wells, P. I., D. A. Hill, A. G. Longley, R. G. FitzGerrell, L. L. Haidle, and D. V. Glen (1975), An experiment design for the measurement of building attenuation, OT Technical Memorandum 75-199 (limited availability).

An experiment has been designed by the Office of Telecommunications, Institute for Telecommunication

Sciences, to study the attenuation of ultra-high frequency signals by buildings. This program was sponsored by the Lewis Research Center of the National Aeronautics and Space Administration and is a part of a study to determine the feasibility of a future disaster warning satellite system.

This report first discusses some previous, related research and the results of some theoretical studies of the behavior of electromagnetic signals in buildings. These are followed by a description of the recommended experiment approach, the instrumentaion system to be used in the building attenuation measuremtns and the measurement procedures, and the reduction of the building attneuation data. It is recommended that the ATS-6 satellite be used as a signal source for the building attenaution measurements. Finally, the results of preliminary building attenuation measurements are presented to show the viability of the recommended experiment approach.

153. Wells, P. I., and P. V. Tryon (1976), The attenuation of UHF radio signals by houses, OT Report 76-98.

This paper presents the results of a measurement program which was conducted to determine the attenuation of UHF radio signals penetrating to the inside of a typical house. This program is part of a study to determine the feasibility of using direct satellite communication to disseminate disaster warning messages. The measurements were made in a manner to determine the building attenuation as a function of frequency, construction type, climate, and the elevation angle to the signal source.

Attenuation measurements were made in five cities: Boulder, Colorado; Duluth, Minnesota; Kansas City, Missouri; Little Rock, Arkansas; and Houston, Texas. The measurements were made at three frequencies, 860 MHz, 1550 MHz, and 2569 MHz, using the ATS-6 geosynchronous satellite as a signal source. Most measurements were made on two principal house types, wood frame with a wood outside surface and a wood frame brick veneer outside surface.

A brief description of the measurement program and an analysis of the measurement results are presented.

154. Westwater, E. R. (1967), An analysis of the correction of range errors due to atmospheric refraction by microwave radiometric techniques, ESSA TR IER 30-ITSA 30.

The accuracy of systems which measure range to missiles or satellites is limited by atmospheric refraction. The MARCOR technique corrects for range errors due to the wet component of atmospheric refraction by using thermal emission measurements in the vicinity of the water vapor resonant line at 22.235 GHz.

The effect of reasonable estimates of error in the MARCOR process is evaluated and given in tables. The analysis is based on a limited sample of two meteorological profiles, though nothing in the work indicates that the results would be radically different for other profiles.

Under the assumptions of this report, the MARCOR technique further reduces the refraction error already corrected by radiosonde data by a factor of 1.5 to 3 for elevation angles greater than 3°.

155. Wood, L. E., and M. C. Thompson, Jr. (1970), Oscillator synchronization via satellite, Radio Sci. 5, No. 10, pp. 1249-1252.

A technique is proposed for the synchronization of widely separated microwave oscillators via satellite transponder. As a result of calculations of the phase shifts over the paths, computation of expected signal-to-noise ratios, and experiments on a 15-km line-of-sight path, synchronization to within 0.05 cycle rms for 10-GHz oscillators should be possible.

156. Zacharisen, D. H., R. T. Disney, L. D. Schultz, A. F. Barghausen, and R. J. Matheson (1971), Interference compatibility monitoring and measurements for UHF satellite earth terminals, OT TM 69 (limited availability).

This report summarizes the work performed for the National Environmental Satellite Services from June through September 1971. Emissions in two UHF bands, centered on 468.825 and 1690 MHz were monitored and analyzed at four GOES system Data Utilization Stations (DUS) to determine the RFI/EMC environment. The data collection technique and the measurement/monitoring system instrumentation are discussed. Distributions and tables showing diurnal and geographic variations of spectrum usage in the lower band are presented along with photographs of emissions observed in the higher band.

4.2 Subject Listing

This portion of the bibliography contains authors names, dates, titles, and sources arranged by subject according to the following categories: Propagation (ionospheric scintillation, absorption, and precipitation attenuation); Antennas; Modulation and/or Signal Design (analog or digital); Electromagnetic Interference and Frequency Sharing; System Design; and Noise. Within each category, the papers are listed in alphabetical order by author. The number at the left of each entry below refers to the citation number for each reference cited beginning on page 7 of the text.

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10a. Bean, B.R., and E.J. Dutton (1966), Radio Meteorology, NBS Monograph 92.

11. Bean, B.R., R.L. Abbott, and E.R. Westwater (1963), Design of experiments for remote microwave probing of the atmosphere, NBS Report 7682. NTIS Access. No. AD 404-207.

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73. Janes, H.B., M.C. Thompson, Jr., W.B. Grant, A.W. Kirkpatrick, and D. Smith (1969), Experimental evaluation of several refractivity correctors for microwave slant-range data, ERL Tech. Memo. TM-ITS 174.

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4.3 Author Index

All authors and co-authors of works cited in this bibliography are listed alphabetically below. The numbers following each name refer to the citation number for each reference cited, beginning on page 7.

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