MILLIMETER WAVELENGTH PROPAGATION STUDIES

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FINAL REPORT 2374-18

July, 1974

Grant No. NGR 36-008-080

National Aeronautics and Space Administration
Goddard Space Flight Center
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ABSTRACT

This final report summarizes the investigations conducted under NASA Grant No. NGR 36-008-080 entitled Millimeter Wavelength Propagation Studies during the period December, 1966, to June 1974.

These efforts included the preparation for the ATS-5 Millimeter Wavelength Propagation Experiment and the subsequent data acquisition and data analysis. The emphasis of the OSU participation in this experiment was placed on the determination of reliability improvement resulting from the use of space diversity on a millimeter wavelength earth-space communication link; this effort represented the first attempt to perform space diversity measurements using an actual earth-space communication link operating above 10 GHz. Related measurements performed as part of this experiment included the determination of the correlation between radiometric temperature and attenuation along the earth-space propagation path.

Along with this experimental effort a theoretical model was developed for the prediction of attenuation statistics on single and spatially separated earth-space propagation paths. And, finally, a High Resolution Radar/Radiometer System and a Low Resolution Radar System were developed and implemented for the study of intense rain cells in preparation for the ATS-6 Millimeter Wavelength Propagation Experiment.

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INTRODUCTION

This program was motivated by the desire to extend our usage of the electromagnetic spectrum to frequencies above 10 GHz. Historically, the utilization of the electromagnetic spectrum advanced upward to higher and higher frequencies until the microwave region, 1-10 GHz was reached. At this point it was found that natural sources of noise were minimized in the microwave region of the spectrum and, hence, this portion of the spectrum is called the quiet region. Furthermore, it was realized that absorption due to atmospheric gases and precipitation increased significantly as frequency is increased beyond 10 GHz. These two factors encouraged system planners and designers to exploit the microwave region to its fullest potential and to delay the development of the millimeter wavelength portion of the spectrum, 10-300 GHz. Eventually this emphasis coupled with increased demand for channel capacity led to saturation of the microwave region and necessitated the use of the millimeter wavelength portion of the spectrum.

It should be pointed out that the terminology millimeter wavelength, as used in this report, will apply to the frequency range 10-300 GHz in contrast with the traditional range of 30-300 GHz. The reason for this definition is the physical fact that atmospheric and precipitation absorption became significant system design factors at frequencies above approximately 10 GHz. Thus, in terms of physical phenomena it is more convenient to associate the frequencies between 10 and 30 GHz with millimeter wavelength rather than microwave characteristics.

The advantages associated with utilization of the millimeter wavelength portion of the spectrum should not be overlooked. These include: the realization of high antenna gains using relative small physical apertures, increased data rates which do not require dramatically increased percentage bandwidths, and, of course, a large expanse of unused spectrum. Fortunately, the development of components for this frequency range has progressed to the point where it is feasible to take advantage of these characteristics.

The disadvantages associated with this portion of the spectrum include: absorption due to atmospheric gases, absorption due to precipitation, and scatter interference due to precipitation. The first of these, absorption due to atmospheric gases, is not a major problem unless frequencies quite close to the water vapor and oxygen absorption lines at 22 and 60 GHz, respectively, are utilized. The attenuation due to these molecular resonances, shown as a function of frequency in Fig. 1, is present at all times and, thus, must simply be taken into account when specifying the link power budget. The second disadvantage, that of absorption due to precipitation, is much more severe. This attenuation, due to the presence of liquid water in the atmosphere, increases monotonically with frequency in the range of interest as shown in Fig. 1. It may be noted that this attenuation reaches severe levels in the presence of high rain rates. Since these high rain rates occur only sporadically in time and space, the system

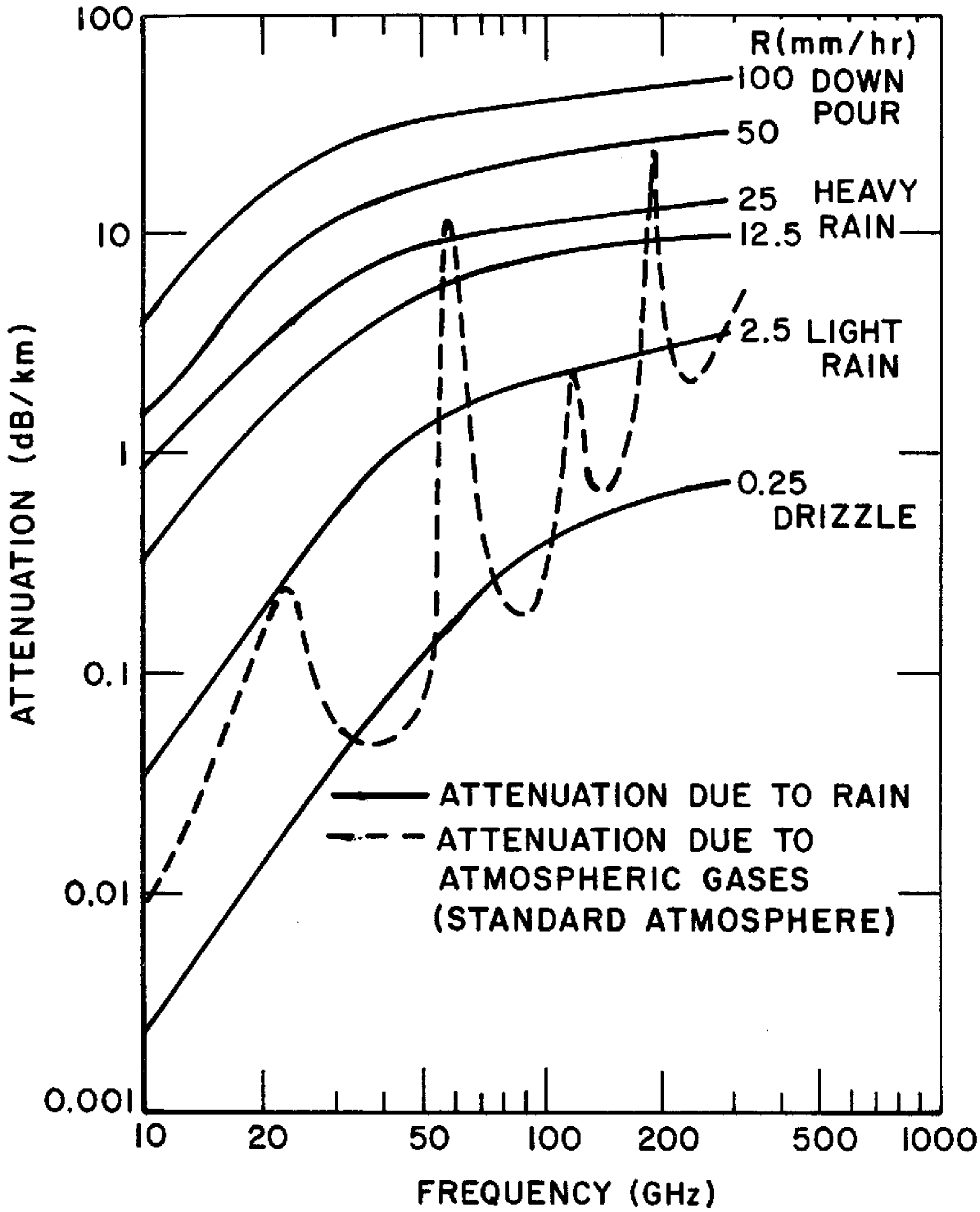

Fig. 1. Attenuation due to atmospheric gases and rain.

designer is faced with a major trade-off decision between link power requirements and link reliability. It is precisely this problem to which the effort under this grant has been directed. Finally, the presence of liquid water droplets in the atmosphere provides a physical mechanism for the production of scatter interference in the event that frequency reuse is implemented on spatially separated links. Since the effects of both gaseous and liquid water have been noted it should be pointed out that ice and snow, i.e., water in its solid form, do not produce significant absorption in this frequency range but may scatter effectively.

The remainder of this report summarizes the experimental and theoretical efforts conducted under NASA Grant NGR 36-008-080 and directed toward a more complete understanding of the characteristics of attenuation produced by intense rain rates and the implications of these characteristics in terms of millimeter wavelength communications system design.

ATS-5 MILLIMETER WAVELENGTH PROPAGATION EXPERIMENT

Two ground terminals were implemented by OSU for reception of the 15.3 GHz beacon signal from the ATS-5 synchronous satellite. One of these terminals was fixed and the other was fully transportable. During 1970, the two terminals were located 4 Km apart along a baseline oriented approximately along a NNW-SSE line. During 1971 the terminals were separated by 8.3 Km along the same baseline. These terminals, which were very nearly identical, were capable of recording both the amplitude of the received 15.3 GHz signal and the 15 GHz radiometric temperature viewed along the earth-satellite propagation path as well as other supporting data. More complete discussions of the instrumentation utilized in this experiment will be found in References 3, 4 and 10.

Since the satellite beacon was not available on a 24 Hr/day basis, data was acquired during periods when significant precipitation was likely and the satellite was available. Although this mode of operation made extrapolation of the resulting attenuation data to an annual base extremely difficult, it was found that the diversity gain data were very meaningful. Diversity gain is defined here as the reduction of the effection fade depth for a specified percentage of time when space diversity is utilized. The resulting diversity gain data are shown as a function of separation distance in Fig. 2 along with data generated from radiometric temperature measurements by the Bell Telephone Laboratories. These data demonstrate that little reliability improvement is realized for terminal separations greater than approximately 10 Km. Furthermore, it was shown that the diversity gain realized with a separation distance of 10 Km was within 1.5 dB of the optimum diversity gain which would result if the terminals were spaced extremely far apart such that the correlation between the rain rates at the two terminals was zero. It was also established that little improvement would result from the use of three or more ground terminals in a space diversity mode. Thus, one may conclude that two

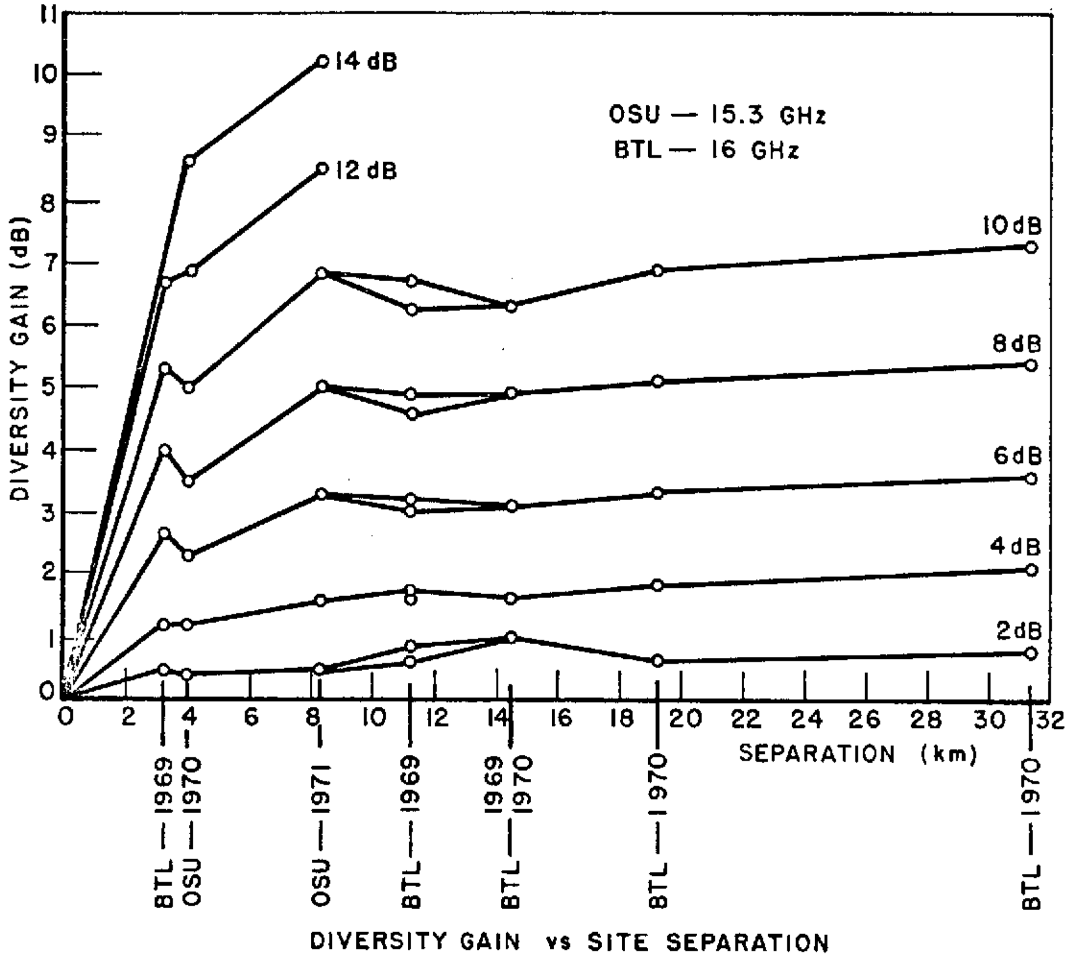

Fig. 2. Diversity gain vs. site separation.

ground terminals spaced approximately 10 Km apart will provide very nearly the maximum achievable improvement in system reliability. This improvement would correspond to a reduction in the duration of 6 dB fades at 15 GHz by more than two orders of magnitude. These data and results, as well as those discussed below, are described more thoroughly in References 6, 7, 9, 12, 13, 15, 17, 20, 24, 25, 27 and 28.

Considerable interest has been shown in the prediction of attenuation statistics based upon radiometric temperature measurements. Therefore, simultaneous measurements of path attenuation and radiometric temperature were performed as part of the ATS-5 Millimeter Wavelength Propagation Experiment. It was found that the attenuation calculated from the radiometric temperature generally agreed with the measured attenuation over the useful dynamic range of this technique. A sample scatter diagram showing this agreement is presented in Fig. 3. The correlation between the attenuation and radiometric temperature was found to be on the order of 0.9; this value is probably somewhat pessimistic since small antenna pointing errors could significantly influence the attenuation measurement while having little effect on the radiometric temperature measurement. Thus, one may conclude that this technique is, indeed, useful over the 10-12 dB dynamic range and at frequencies up to 15 GHz. The effect of scattering at higher frequencies remains to be determined.

THEORETICAL PREDICTION OF ATTENUATION STATISTICS

Ultimately, a system designer must be able to extrapolate existing propagation statistics to the frequency and climate appropriate to his system. Since techniques for this purpose were not currently available an approach was developed to meet this need. A cylindrical rain cell model was chosen to represent the region of intense rain rate usually associated with the convective cells which produce severe fading. This rain cell model was intended to represent the rain environment in a statistical rather than an instantaneous, physical sense. The emphasis in the development of this approach was placed upon the flexibility, tractability, and ease of application of the approach. In addition, attention was concentrated on the utilization of readily available information, e.g., hourly rainfall accumulation rather than instantaneous rain rates, so that the approach would have wide applicability.

The resulting approach permits specification of many system and climate parameters including: frequency, path elevation angle, rain rate distribution, and rain cell dimensions. Application of the procedure developed yields the fade distribution and the joint fade distribution for space diversity terminal pairs.

This procedure was tested by calculating the anticipated fade distributions at the NASA Rosman and OSU ATS-5 ground terminals. These distributions were then compared with the actual fade distributions measured at these sites. A sample of the comparison is shown in Fig. 4;

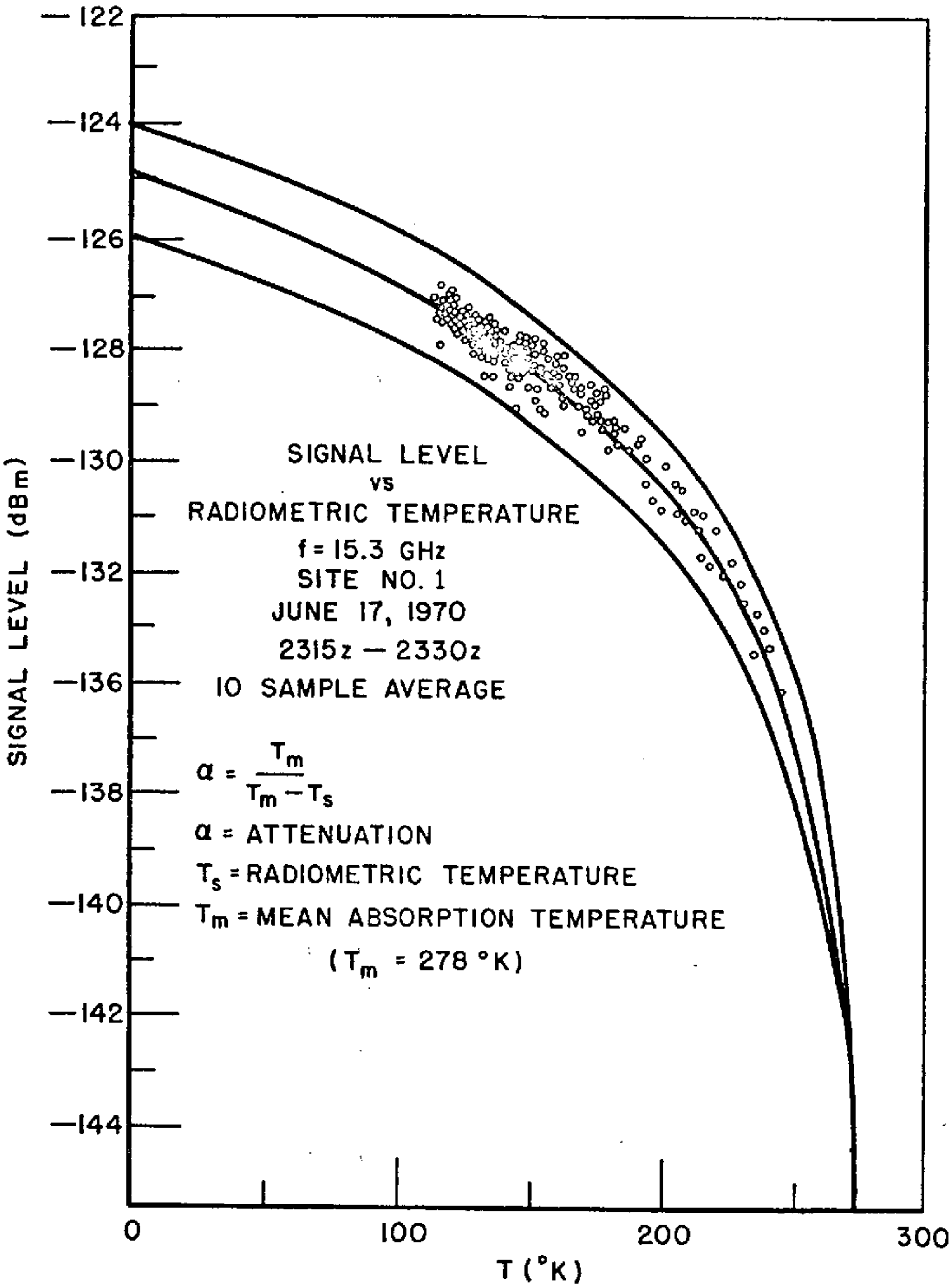

Fig. 3. Received signal level vs radiometric temperature.

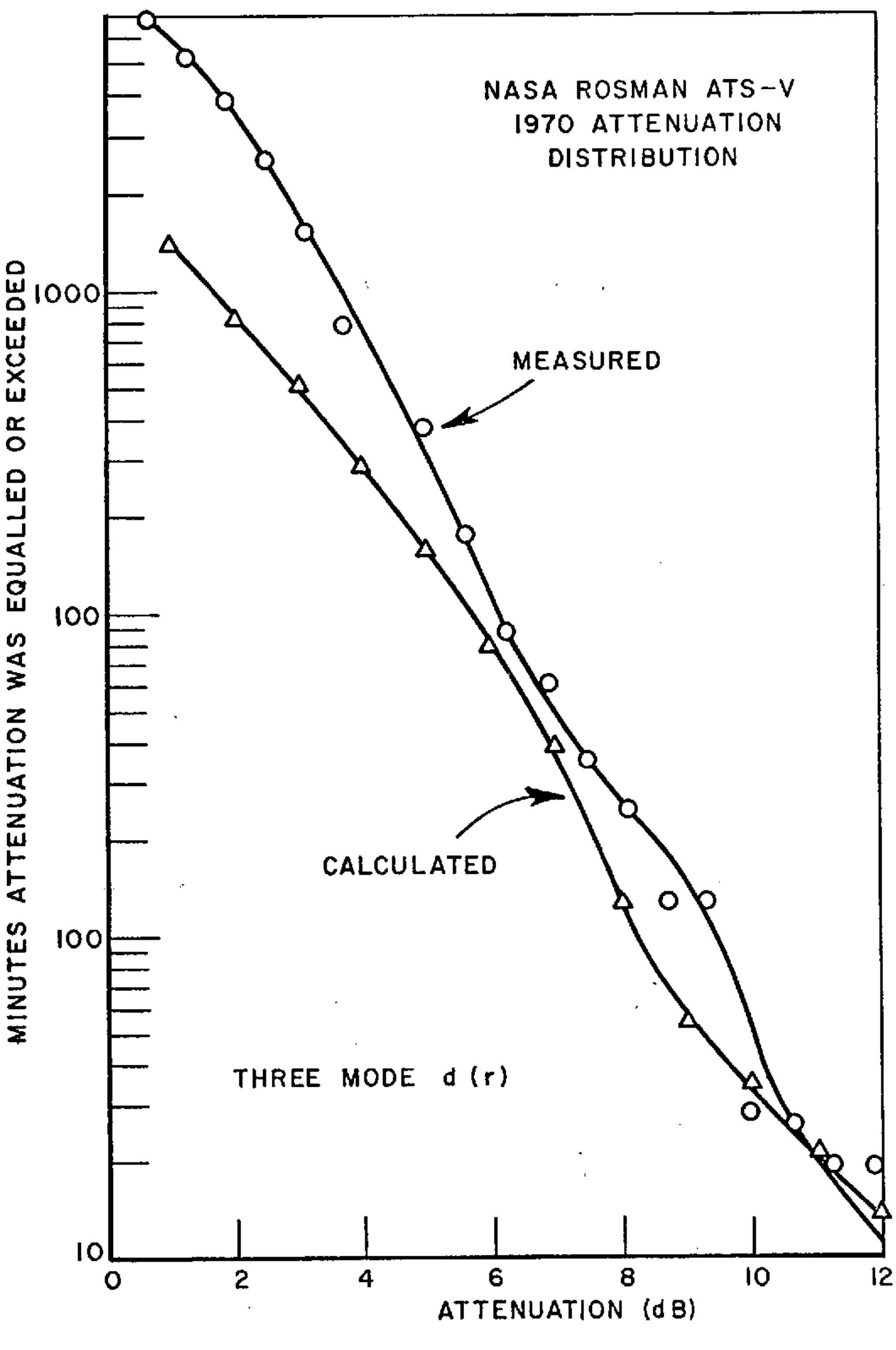

Fig. 4. Calculated and measured fade distributions.

the agreement was within 1 to 2 dB in general. Therefore, a reasonably simple technique is now available for the prediction of fade statistics due to precipitation. This procedure is described in detail in References 11, 13, 14 and 16.

The procedure described above does require a knowledge of the relationship between rain cell size and rain rate for the climate in which the ground terminal is located. Consequently, as a side issue, a simple, inexpensive method using only 2 rain gauges was developed for the purpose of determining this relationship in regions where extensive radar data is not available. This technique is described in References 22 and 23.

RADAR/RADIOMETER MEASUREMENT OF RAIN CELLS

During the course of the efforts described above it became apparent that there was a paucity of information concerning the spatial and temporal statistics of rain cells and their associated rain rates. Therefore, in preparation for the ATS-6 Millimeter Wavelength Propagation Experiment, basic facilities were developed from the remote measurements of these characteristics. These facilities include a High Resolution Radar/Radiometer System for the measurement of the fine scale structure of individual cells and a Low Resolution Radar System for the determination of gross cell size, location, and motion properties.

The High Resolution Radar/Radiometer System consists of three radar/radiometer pairs operating in the S, X, and K_u-bands. The S and X-band radar/radiometer pairs each share a 9.1 m parabolic antenna as shown schematically in Fig. 5. The K_u-band radar/radiometer pair shares a 4.6 m parabolic antenna. Thus, simultaneous measurements of radar backscatter and radiometric temperature at each of three different frequencies are obtained and recorded digitally. The spatial resolution is on the order of 200 m at a distance of 40 Km. A sample of the raw data as photographed on the interactive CRT display is shown in Fig. 6.

The Low Resolution Radar System is a conventional X-band weather radar system. This radar has been interfaced to a dedicated SDS-910 computer so that the video data may be digitized and recorded on an unmanned, 24 Hr/day basis.

Both of these systems became operational during 1973 and will be fully utilized in support of the ATS-F Millimeter Wavelength Propagation Experiment. These systems are described in detail in Reference 19.

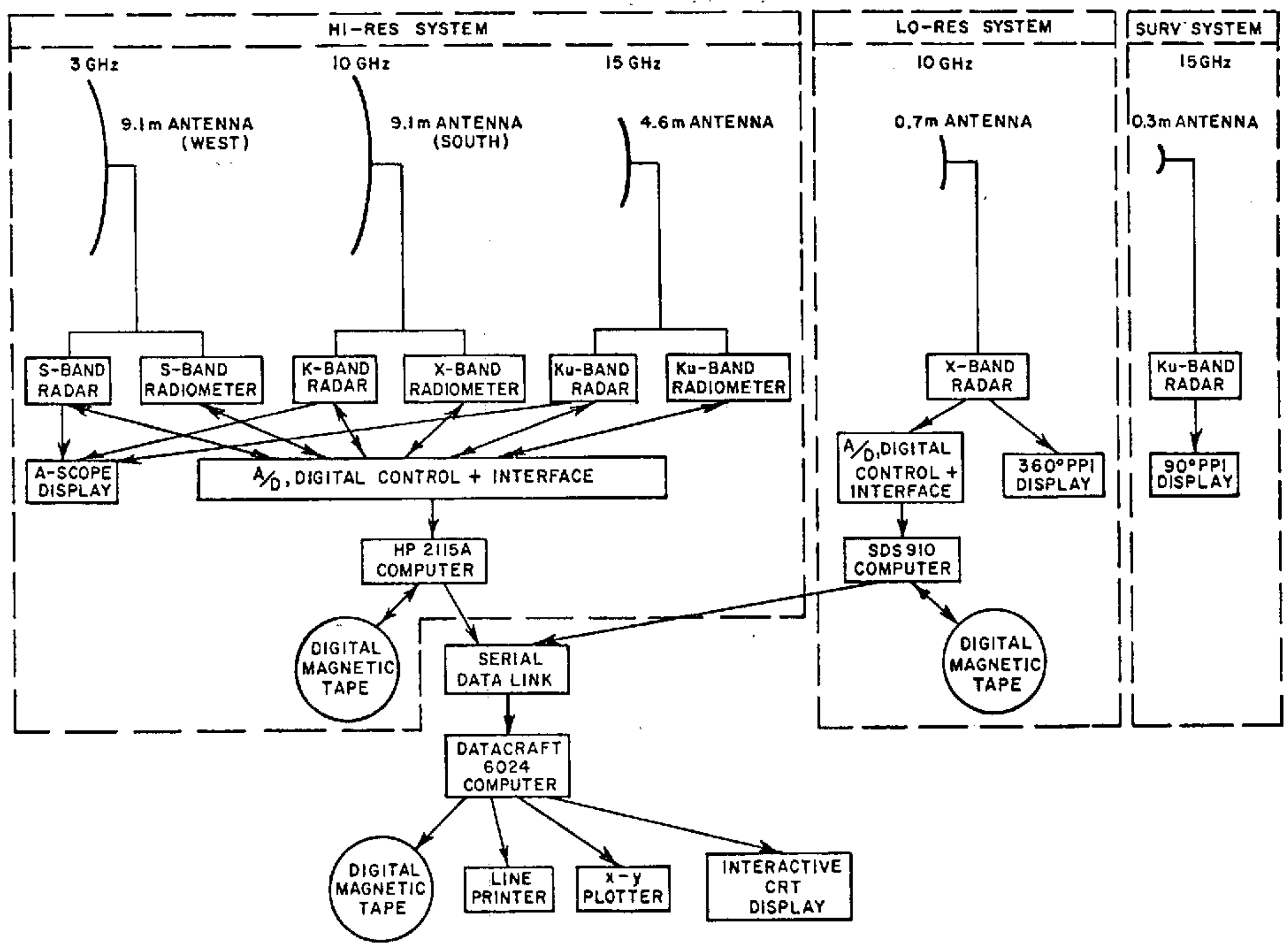

Fig. 5. OSU Radar/Radiometer facilities.

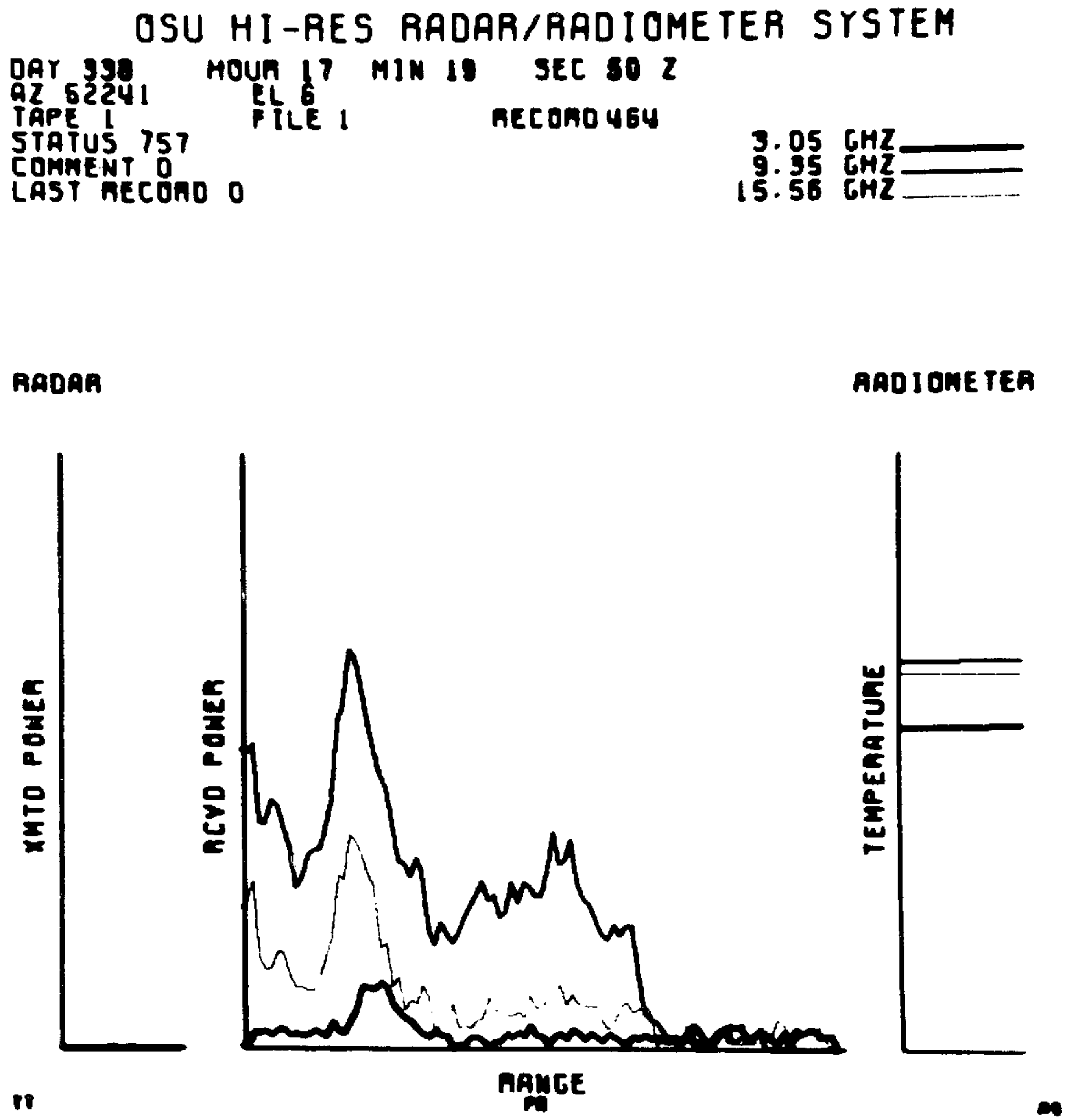

Fig. 6. Sample of raw radar/radiometer data.

REPORTS AND PUBLICATIONS

The reference list included in this report contains all reports, oral papers, and publications resulting from the studies conducted under NASA Grant NGR 36-008-080. This list includes 18 progress and technical reports published by OSU (References, 1, 2, 3, 4, 6, 8, 9, 10, 13, 16, 17, 18, 19, 21, 23, 25, 26, 29), 6 oral papers (References 5, 11, 12, 20, 22, 24), 3 papers included in NASA published reports (References 7, 14, 15), and 2 publications (References 27, 28).

During the course of these studies this grant provided support for 2 Ph.D. students and 4 M.S. students.

SUMMARY

The research conducted under NASA Grant NGR 36-008-080 has provided the first space diversity performance statistics on an actual earth-space communication link operating above 10 GHz. These results show that significant reliability improvement can be achieved through the use of space diversity. The high degree of correlation between measured attenuation and radiometric temperature at 15.3 GHz was also established using the ATS-5 synchronous satellite.

A simple, yet versatile, model was developed for the prediction of fade distributions produced by intense rainfall. This technique was used successfully to predict the fade distributions observed on the ATS-5 15.3 GHz earth-space link.

Finally, radar and radiometer facilities were developed for the measurement of intense rain cell characteristics in conjunction with the ATS-6 Millimeter Wavelength Propagation Experiment.

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13. D. B. Hodge and L. R. Zintsmaster, Semiannual Status Report, "Millimeter-Wavelengths Propagation Studies," Report 2374-9, May 1972.

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