NASA CR-122438

Final Technical Report

ATS-5 Millimeter Wave Experiments

Contract No.: NAS5-10387

# ATS-5 Signal Charateristics at 15.3 GHz and Related Experiments at 15 and 35 GHz

## Part I

## Basic Features of the Experiments and Primary Results

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for

Goddard Space Flight Center

Greenbelt, Maryland

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## Abstract

This paper presents the results of observations by The University of Texas of the 15.3 GHz experiment associated with the ATS-5 satellite and of related experiments designed to provide information on earth-satellite communication links at 15.3 and 31.65 GHz.

The 15.3 GHz transmissions were observed at Austin, Texas over an eighteen month interval primarily during periods of rain. Measurements were also made at Mount Locke, near Fort Davis, Texas but only for a period of two months.

Essentially continuous measurements were made at Austin, Texas of the sky temperature at 35 GHz looking in the direction of the ATS-5 satellite over an interval of four months.

Point-to-point transmissions over the earth's surface at 15 and 35 GHz and various meteorological parameters were studied as possible means of predicting performance over a satellite-earth path.

The basic features of the experiments and the primary results are presented in the first section which is intended to be an independent unit. More detailed descriptions are given in the second section with substantiating data for conclusions stated in the first section.

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Part I

## Basic Features of the Experiments and Primary Results

### I. ATS-5 15.3 GHz Test Configurations

The ATS-5 satellite operating in a near equatorial synchronous orbit at 105° west longitude provided a CW signal at 15.3 GHz. Failure in the stabilization of the satellite resulted in a horizontal spinning rate of 76 rpm. The signal at the earth stations was therefore pulsed at this rate. The spacecraft hardware, the details of launch and the operational experience with the satellite have been given by Ippolito [1970a, 1971] and will not be repeated here.

At The University of Texas sites, the receiver used was one made by Martin Marietta Corporation specifically for this program. This phase lock unit and the modifications necessary to accommodate the pulses have also been described by Ippolito [1970a, 1971].

The Austin site was at 97.7° west latitude and 30.4° north longitude at an elevation of approximately 700 feet above sea level. Two ten foot parabolas operated in tandum gave a resulting antenna pattern with half power beamwidths of 0.17° in azimuth and 0.46° in elevation. The mean elevation angle was 54°. The output of a peak detector was recorded on magnetic tape and on a paper strip chart. The resulting output signal-to-noise ratio ranged from 10 to 15 dB depending on the power level transmitted by the satellite and the daily level variations described later.

The site near Fort Davis was on Mount Locke at an elevation of 6,600 feet above sea level at 104.0° west latitude and 30.7° north longitude. A 16 foot parabolic reflector was used with individual pulse levels recorded on a paper chart. The signal-to-noise ratio was approximately 25 dB. The mean elevation angle was 55°.

## II. Transmission Characteristics in the Absence of Rain Clouds

In the period after the initial reception of the 15.3 GHz transmission, continuous recordings were made of the signal level over extended time intervals. In the absence of rain or rain clouds no rapid fluctuations or long term fades were experienced which resulted in signal changes greater than one dB. This is in contrast to point-to-point observations on a ten mile link over the earth's surface [Straiton, Bailey and Vogel, 1970]. On this path rapid variations up to 10 dB were noted at the time of the passage of a cold front and slow fades up to five dB occurred on occasions during early morning hours.

The stability of the satellite transmission is attributed to the fact that the path length through regions where the clear air refractive index may be disturbed due to water vapor inhomogeneities is very limited. Clouds except those of the heavy cumulus type showed no measureable change in signal level nor resulted in fluctuations or fades.

Simultaneous observations by various groups indicated correlated daily variations of the received power with a range of 3 to 4 dB. These combined tests have been described by Sukhia [1971] and attributed to north-south movement of the satellite.

In view of these studies and those conducted by other groups, it is concluded that the atmosphere will have no significant effect on 15.3 GHz transmissions at the elevation angles used in the absence of rain and heavy rain clouds.

III. Attenuation Levels vs Probability of Occurrence

A. Austin, Texas

After it had been confirmed that no appreciable losses are to be expected in the absence of water drops along the path, the continuous recordings were considered to be unnecessary. Further, power limitations on the satellite prevented simultaneous operation of the 15.3 GHz transmitter and other experimental packages aboard the satellite. The procedure was then established that the satellite transmitter would be turned on only when rain was eminent at one of the recording stations. Because of uncertainties in weather forecasting and occasional unavailability of the satellite for the experiment, it was not possible to measure the effects of all of the rain that occurred.

During the interval from January 1970 through June 1971 the level of the 15.3 GHz transmission was recorded for 7555 minutes during which a total of 6.53 inches of rain fell. Analyses of these data indicated that losses due to rain or rain clouds exceeded 5 dB for 313 minutes and 10 dB for 129 minutes. The longest continuous duration of the 10 dB loss was 56 minutes.

For station design purposes, it is desirable to extrapolate the measured data to the probability of occurrence of these attenuation levels to an annual basis. In the absence of detailed information on the distribution of drops along the actual path during rainstorms, very reliable extrapolation is impossible. However, a crude approximation was made by assuming that the duration of occurrence of various attenuation levels was directly proportional to the total rain recorded. When the average annual rainfall in Austin of 33.6 inches is considered, the times of occurrence of attenuations in excess of 5 and 10 dB are estimated to be 1620 minutes and 663 minutes per year, respectively. These correspond to probabilities of 0.3% and 0.12%. Comparing these results with those of other observers, it is concluded that Austin, Texas is one of the least desirable places for an earth-satellite path receiver at 15.3 GHz.

B. Mount Locke, Texas

After completion of the recording period in Austin, the receiver was taken to the Millimeter Wave Radio Astronomy Observatory in West Texas. Data were recorded in September and October 1971 during the rainy season for that region. Data were taken for 670 minutes when 1.9 inches of rain fell in seven rain showers. During these measurements, losses in excess of 1 dB were noted during only one rain period and the maximum was only 4 dB.

The amount of data is inadequate to assume that attenuation greater than 4 dB never occurs at Mount Locke. However, it can be concluded that the "seeing" of the satellite at Mount Locke, Texas will be many times better than that at Austin in spite of the fact that the amount of annual rainfall is approximately half of that in Austin.

In comparison with other receiving locations, the site at Mount Locke appears to be a very desirable one from the probability of occurrence of 5 and 10 dB attenuation levels.

IV. Path Attenuation at 35 GHz from Sky Temperature Measurements

An auxiliary method of obtaining information on earth-satellite path attenuation is to measure the sky radiation at the receiver. The sky temperature can then be converted to total attenuation along a path through the atmosphere in the direction of antenna pointing. The necessary assumptions are that the effects of scattering by the atmosphere are negligible and that the atmosphere may be represented by a mean temperature. Bell Telephone Laboratories [Wilson, 1969] showed that good agreement exists between attenuation values found by sun tracking and those obtained by radiometric sky measurement at 15 and 35 GHz.

The usefulness of the method is limited to attenuations no greater than approximately 12 dB because the opaqueness of the atmosphere results in near saturation for larger losses.

Since a 35 GHz radiometer was available at the start of the ATS-5 experiment, it was decided to correlate observations of the sky temperature at this frequency with the satellite tests at 15.3 GHz. The data obtained in this manner is felt to provide complementary material for the uplink test performed by GSFC at 31.65 GHz.

The radiometer was mounted in a weather-proof box in the vicinity of the 15.3 GHz receiving system with the antenna pointed in the direction of the satellite. A 4 inch horn was used which resulted in a half power beamwidth of 3°. This is a significantly wider beam than used for observing the satellite signal and the significance of the wider beam will be noted later.

The radiometer was operated essentially continuously from February through June 1971 with complete coverage of nearly all rain events. For this time interval, the probability that the path attenuation exceeded 5 dB was 0.3 percent and for 10 dB was 0.14 percent. As in the case of the 15 GHz attenuation statistics, the data were extrapolated to the mean annual rainfall by assuming the time of occurrence of various attenuation levels to be proportional to the total rain occurring.

On the basis of this study, it is estimated that for an "average" year at Austin, Texas, the probabilities that the 35 GHz attenuation will exceed 5 and 10 dB are 1.05% and 0.53%, respectively. This corresponds to times of 5920 minutes and 2860 minutes per year respectively. These periods are approximately four times as great as the corresponding times for 15.3 GHz.

## V. Correlation of 15.3 GHz Satellite Losses with 35 GHz Sky Temperature Observations

Several groups participating in the ATS-5 millimeter experiment made sky temperature measurements at nearly the same frequency of the satellite transmission and with highly directive antennas. They found that very good correction was obtained between simultaneous values of attenuation level obtained both ways for losses less than 10 dB.

The University of Texas radiometer differed both in the frequency and the antenna beamwidth. The 35 GHz radiometer was more sensitive to rain and rain clouds because of its higher frequency. Thus its usefulness in predicting the 15.3 GHz losses would be limited to only 3 to 4 dB at the lower frequency.

The wider beamwidth used with the 35 GHz radiometer resulted in integration of the received sky radiation over a significant volume of the sky. As a result, rapid fluctuations in the satellite signal did not have correspondingly rapid variations in the sky temperature as measured by the radiometer.

The sky temperature observations made do provide good statistical information of the level of attenuation which might be experienced at 35 GHz for various fractions of the total time.

It is concluded that sky temperature observations are an excellent adjunct to the direct satellite loss data. The observations should be made at the frequency of the satellite channel for best results up to 10 dB. If estimates are to be made of greater losses, radiometric measurement might be made at lower frequencies and extrapolated to the satellite frequency by use of a storm model.

## VI. Correlation of Satellite Path Losses with Rain, Rain Rate and Surface Path Attenuation

Substantially all of the losses at 15.3 GHz on an earth-satellite path results from the number and size distribution of the drops along the path. The resulting fading characteristics are quite different for different types of rain. There is danger of over simplification of meteorological models, but for this discussion two types of rain will be considered.

For wide-spread general rains, the liquid water content of the atmosphere is fairly evenly distributed both horizontally and vertically. The vertical extent of such rains is not as great as for thunderstorms. Attenuation levels of the satellite signal measured in this type of rain were less than 5 dB. Rain amounts, rain rate and point-to-point surface losses were all found to have a direct relationship to satellite fading for wide spread general rains but this relationship is not of practical significance because of the relatively low fading level associated with them. It is to be expected that the satellite loss will be dependent on "look angle" for this type of rain distribution.

The nature of thunderstorms is in sharp contrast to that of the general rains. The convective process which builds up the storms frequently results in condensation at elevated levels. The rainfall may be substantially displaced. The areal extent of the storm may be quite limited. The vertical extent is of approximately the same range as the horizontal dimension and is much greater than for the more general rain.

As a result, the fades greater than 5 dB were associated with thunderstorms. Attempts to correlate these fades with rain rates, rain amounts, or surface attenuation indicate that these parameters are inadequate to predict satellite path performance. It is to be expected that thunderstorm effects should be relatively independent of "look angle" because of their comparable horizontal and vertical extents.

## VII. Correlation of Satellite Path Losses with Thunderstorm Heights

As indicated in the preceding section, fades of the 15.3 GHz satellite signal in excess of 5 dB were all associated with clearly defined thunderstorms. Storm heights for Austin, Texas, Columbus, Ohio, Rosman, North Carolina, and Orlando, Florida were obtained from Weather Bureau teletype records for storms for which significant fades were reported for these locations by The University of Texas, Ohio State University [Bohley and Hodge, 1970] [Grimm and Hodge, 1971], Goddard Space Flight Center [Ippolito, 1970b] and Martin Marietta Corporation [Sukhia, 1971].

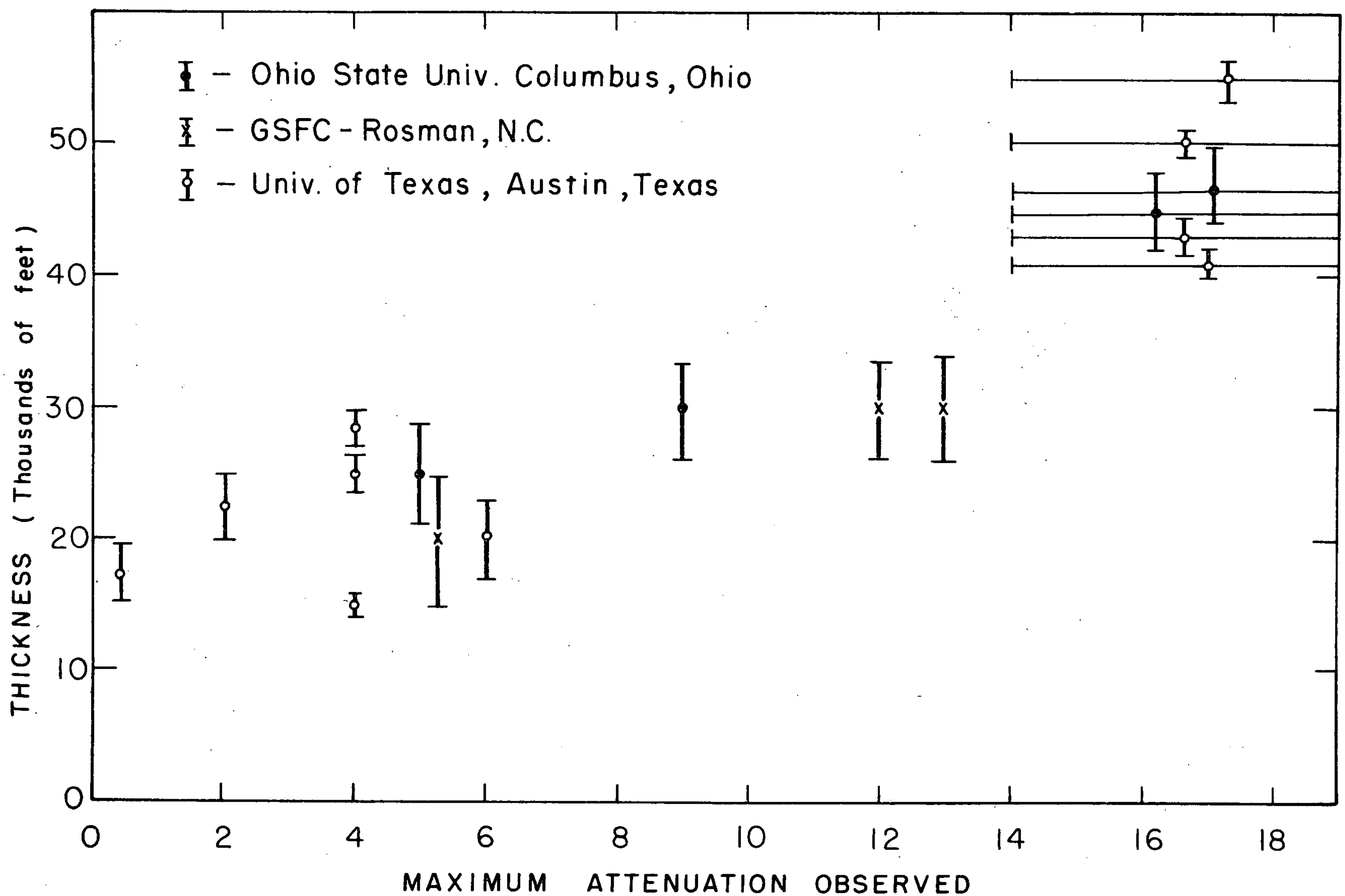
Fig. 1 shows the magnitude of the recorded attenuation as a function of cloud height. All losses in excess of 14 dB were associated with storms which rose to a height in excess of 40,000 feet.

Fig. 2 shows the length of time during each of the storms for which the loss due to rain exceeded 10 dB versus cloud height. The time during which the loss occurred increases consistently with cloud height.

It is therefore concluded that thunderstorm cloud heights are a useful indicator of the intensity and duration of fades. A good knowledge is required, however, of the storm shape and its path if extrapolation between stations is attempted.

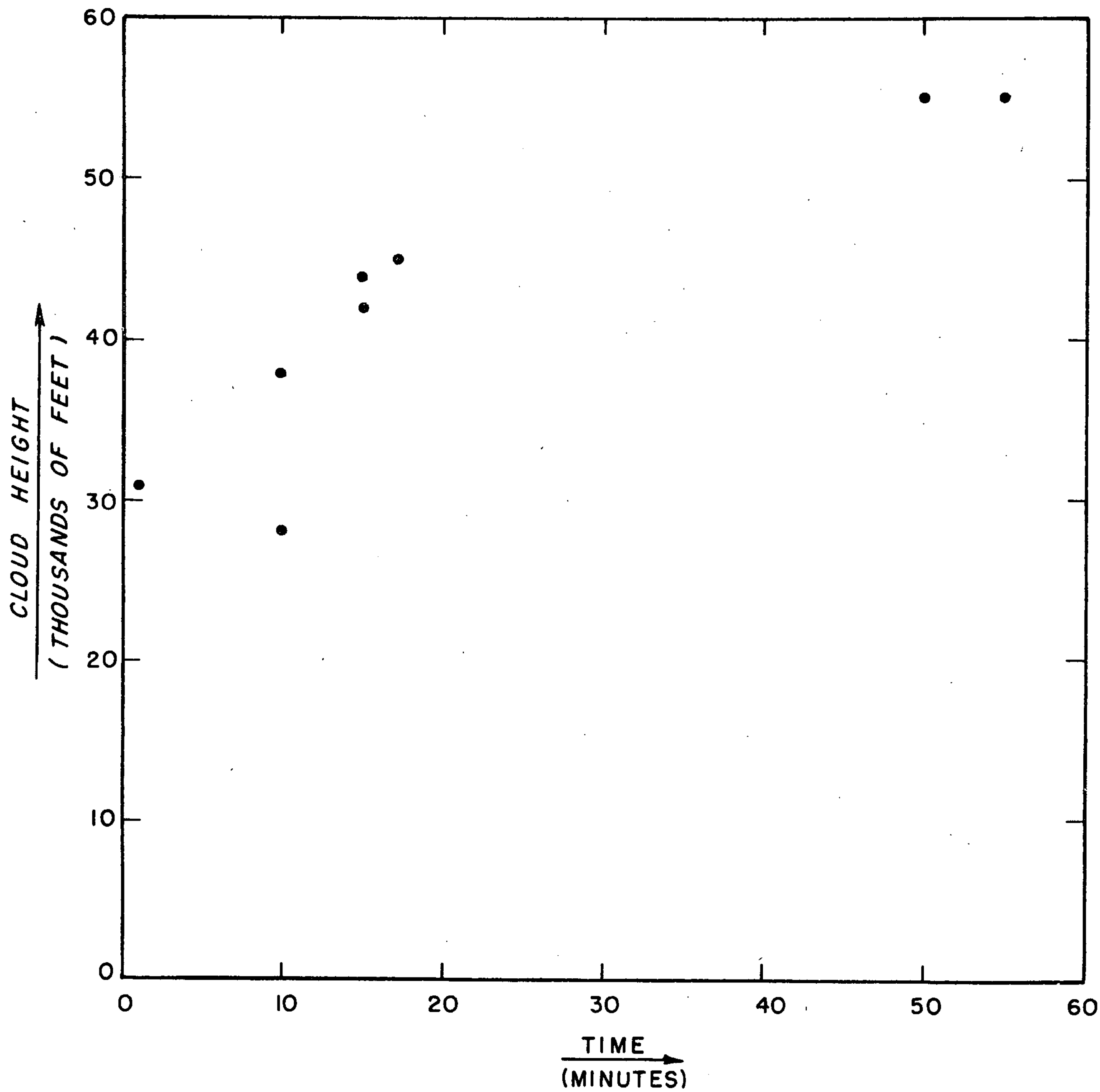
## VIII. Recommendations on Frequencies for Earth-Satellite Frequencies

The results of these tests indicate that frequencies near 15 GHz should be satisfactory for earth-satellite links except for the losses resulting from intense thunderstorms. The effects can be reduced by (1) locating




THUNDERSTORM THICKNESS VS. ATTENUATION

Fig. 1




THUNDERSTORM VERTICAL EXTENT VS. TIME 10 dB ATTENUATION EXCEEDED

Fig. 2

the receiver where thunderstorms are fewer, (2) locating where the effects of the thundershowers are not significant as at the higher elevation of Mount Locke in West Texas, (3) using space diversity or (4) matching the transmitter and receiver power and gain to the minimum outage time requirements.

The precipitation loss increases as the frequency increases above 15 GHz. However, satisfactory communication to satellites should be attained in the absence of thundershowers for frequencies up to around 40 to 50 GHz. The power and gain requirements compared to that of 15.3 GHz must be increased by a factor of about 3 for 35 GHz and more for higher frequencies for the same tolerated outage time.

The water vapor absorption line at 22 GHz is less of a detriment than is the increased precipitation loss at higher frequencies. Above 50 GHz the oxygen absorption becomes serious.

For frequencies above the oxygen absorption region (65-105 GHz), the satisfactory earth-satellite propagation conditions should be limited to time relatively free of precipitation.

## References


Bohley, P., and D. B. Hodge, 1970: A millimeter wave diversity propagation experiment, Fall 1970 URSI Meeting, Columbus, Ohio.

Grimm, K. R., and D. B. Hodge, 1971: A 15.3 GHz satellite-to-ground diversity propagation experiment using a terminal separation of 4 kilometers, The Ohio State University ElectroScience Lab., Tech. Rept. 2 374-7, Grant No. NGR 36-008-080.

Ippolito, L. J., 1970a: Millimeter wave propagation measurements from the applications technology satellite (ATS-V), IEEE Trans. Antennas Propagat., AP-18, 4, 535.552.

Ippolito, L. J., 1970b: Millimeter wave propagation experiments utilizing the ATS-5 satellite, Paper from the Fall 1970 URSI Meeting, Columbus, Ohio, Goddard Space Flight Center X-751-70-428, 1-1-1-56.

Ippolito, L. J., 1971: Effects of precipitation on 15.3 and 31.65 GHz earth-space transmissions with the ATS-V satellite, Proceedings of the IEEE, 59, 2, 189-205.

Straiton, A. W., C. R. Bailey and W. Vogel, 1970: Amplitude Variations of 15 GHz radio waves transmitted through clear air and through rain, Radio Sci., 5, 3, 551-557.

Sukhia, Darius E., 1971: ATS-V satellite propagation measurements at Orlando, Florida, Martin Marietta Corporation Rept. OR 11,800, Orlando, Fla., 87 pp.

Wilson, R. W., 1969: Measurement of attenuation by rain at 16 and 30 GHz with a sun tracker, Bell Systems Technical Journal, 48, 1383-1404.