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# B. S. T. J. BRIEFS

## The Effect of Rain on Circular Polarization at 18 GHz

By R. A. SEMPLAK

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Limitations imposed by attenuation during heavy rain on the reliability of microwave systems are well known,[1] and some calculations of the depolarization of linearly[2] and circularly[3] polarized waves have been made. Recently, measurements of rain-induced rotation[4] of linear polarization at 30 GHz indicated that depolarization by large oblate raindrops[5] may limit efficient utilization of a microwave channel where orthogonal polarizations are employed. However, an advantage in using circular polarization is that less-stringent mechanical stability may be required of some antennas; also, in satellite systems, circular polarization is not affected by Faraday rotation. As the effect of rain on transmission of circular polarization had not been measured, an experiment was initiated. Data have been collected for the period June 1, 1972, through January 24, 1973.

A frequency-swept Gunn oscillator operating at a frequency of 18.5 GHz is used as a source in circular polarization on a 2.6-km path oriented in a southeasterly direction from Crawford Hill, Holmdel, New Jersey, the site of the receiver. The receiver has a ferrite switch which looks sequentially at the received fields, i.e., the desired circular polarization and then the depolarized component, the opposite sense, are observed.* Paper strip chart recordings are made of both the desired and depolarized components.

The clear-day polarization discrimination of the system is better than 32 dB. In view of the ambiguities[6] associated with measuring cross polarization below −32 dB, none of the data below −32 dB are included.

The total data obtained from the circularly polarized system are shown in Fig. 1 where the depolarized component (the field measured in the undesired sense) is plotted as a function of the rain-induced attenuation. One can see that rain has a strong depolarizing effect. For example, the very deep rain-induced attenuations of 39–40 dB have

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* The switching rate is 17 Hz; this is much faster than the changes in attenuation produced by rain.

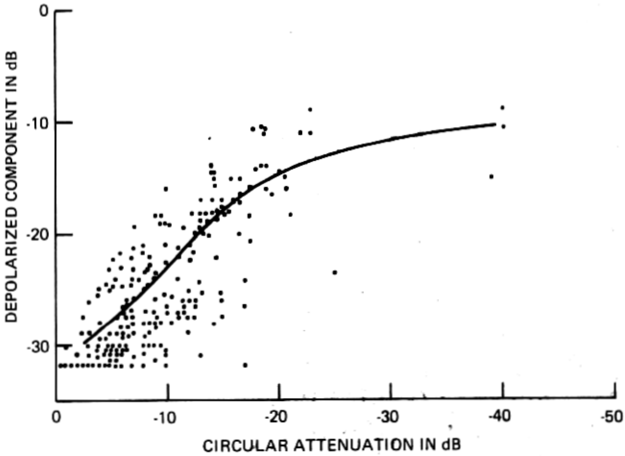

Fig. 1—Data on circular polarization from June 1, 1972, through January 24, 1973. Depolarized component plotted as a function of rain-induced attenuation.

depolarized components that are only 9–15 dB below that level. The curve shown in Fig. 1 is an estimate of the median of the data. From the figure, we observe, for example, that a rain-induced fade of 20 dB has associated with it a depolarized component with a median value of the order of −15 dB. Likewise, for a modest rain-induced fade of 10 dB, the median value of the depolarized component is about 23 dB below that level.

From measured data at 18 GHz it is concluded that there are serious polarization discrimination problems for circular polarization during periods of rain. However, circular depolarization should not be as serious for frequencies of 60 GHz and higher, since at these frequencies the small raindrops have the strongest effect on transmission, and these small drops tend to be spherical rather than oblate. Measurements not discussed here show by comparison that the attenuation of circularly polarized waves by rain lies between that for horizontally and vertically polarized waves.[7]

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6. Chu, T. S., private communication.
7. Semplak, R. A., "Effect of Oblate Raindrops on Attenuation at 30.9 GHz," Radio Sci., *5*, No. 3 (March 1970), pp. 559–564.

# Attenuation Through the Clear Atmosphere at 30, 19, and 13 GHz for Low Elevation Angles

By PAUL S. HENRY

(Manuscript received February 21, 1973)

## I. INTRODUCTION

Synchronous satellite service for Alaska, and possibly other places, requires that ground station antennas point at low elevation angles. For example, from Point Barrow (71°N, 155°W), such a satellite would never be more than 11 degrees above the horizon, and for satellite longitudes 45 degrees east or west of Point Barrow, the elevation is only 5 degrees. At such low angles, the attenuation of a nominally clear atmosphere is significant in the 18- and 30-GHz bands of proposed domestic satellite systems. There are also satellite bands near 13 GHz, where the attenuation is expected to be somewhat lower. Predictions of this attenuation have been made,[1] but as a check direct measurements have been obtained with the Crawford Hill Sun Tracker as reported below.

## II. APPARATUS AND PROCEDURE

The experimental setup, described in detail elsewhere,[2] is briefly this: the antenna temperatures of the sun and a nearby patch of sky are compared by means of a radiometer. The temperature difference, $\Delta T$, is related to the excess attenuation above the solar noon value, $A$, by the formula

$$A(\mathrm{dB}) = 10 \log [\Delta T/\Delta T_0], \tag{1}$$

where $\Delta T_0$ is the antenna temperature difference at solar noon on a clear day. As the antenna follows the setting sun, attenuation as a function of elevation angle is measured directly.

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The measured attenuations are increases above the noontime value. Thus the absolute attenuation is the measured value plus the atmospheric attenuation at noon; the latter has been estimated to be 0.3, 0.3, and 0.1 dB at 30, 19, and 13 GHz.[1] For the remainder of this paper, quoted attenuations are referred to noontime as the zero of attenuation.

A small correction must be applied to the Sun Tracker raw data to account for different antenna temperatures in the "sun" and "sky" positions due to differences in atmospheric radiation. This correction is readily determined by measuring $\Delta T$ for low elevation angles of the antenna beam, while the sun is high in the sky and thus out of the beam. The magnitude of the correction is less than 3 percent of the measured attenuation in dB for elevations of 5 degrees or greater. Below 5 degrees, the correction rises to a maximum of 8 percent at 3 degrees elevation.

## III. DATA

The measured attenuations, corrected as described above, are shown as a function of elevation angle in Fig. 1. The data, collected during four sunsets in August 1972, are shown as bars spanning the full range of the values observed. During the measurements the absolute surface humidity was about 12.5 gm/m³, which is typical of summertime New Jersey. The curves through the bars represent the average behavior of the data. At 5-degree and 10-degree elevations are indicated the

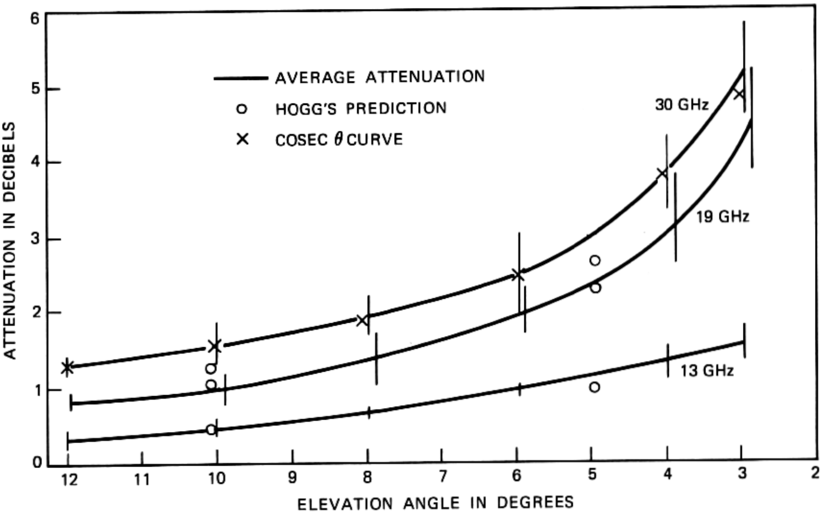

FIG. 1—Attenuation vs elevation angle, normal summer weather (average humidity 12.5 gm/m³).

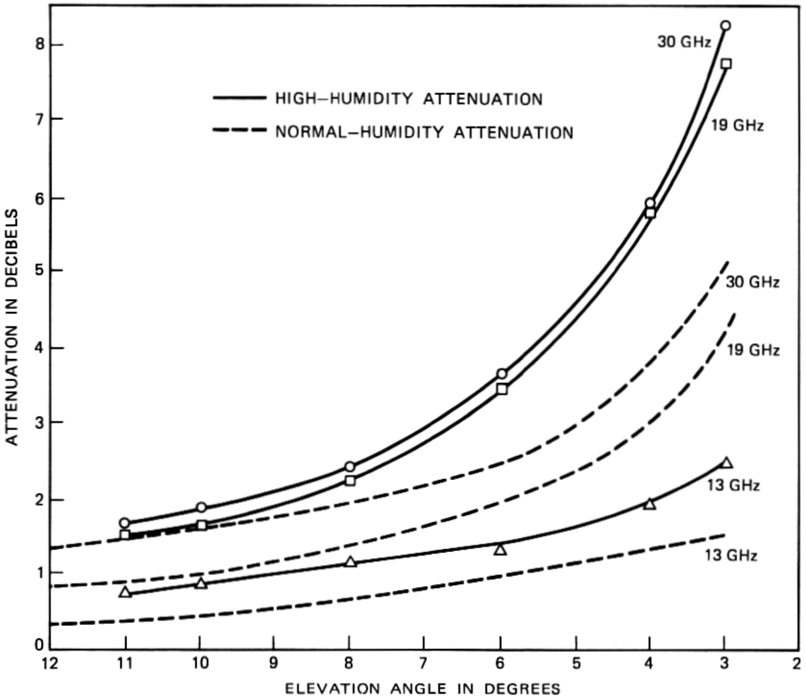

FIG. 2—Attenuation vs elevation angle, humid weather (August 7, 1972, humidity 23 gm/m$^3$).

attenuation predictions of Hogg, normalized to zero dB at noon. Also shown for the 30-GHz attenuation are the points corresponding to a cosec $\theta$ law, normalized to agree with observation at 10 degrees and 12 degrees.

Figure 2 is a plot of measured attenuation versus elevation for very humid air. These measurements were made on August 7, 1972, shortly after a rainstorm when the atmosphere had cleared. The surface humidity was 23 gm/m$^3$ at the time of observation. For comparison, the curves from Fig. 1 also are shown. The increased attenuation is clearly visible. Even larger attenuations are possible. Hogg and Semplak[3] have calculated that very humid weather can result in attenuations more than double those shown in Fig. 2.

## IV. EXTRAPOLATION TO OTHER ATMOSPHERIC CONDITIONS

The atmospheric attenuation is due primarily to oxygen and water vapor. In summertime New Jersey, the fraction of the total attenuation attributable to water vapor is roughly 50, 75, and 50 percent at

30, 19, and 13 GHz, respectively.[1] Thus one can convert attenuations measured at one humidity to values corresponding to a different water vapor content. For example, we can predict the attenuations that should have been observed under the conditions of Fig. 2 (23 gm/$m^3$) by doubling (very nearly) the contributions due to water vapor in Fig. 1 (12.5 gm/$m^3$). This simple extrapolation rule predicts the observed attenuation to an accuracy of 10 to 15 percent.

Compared with New Jersey, the Point Barrow atmosphere contains essentially no water. In winter the humidity is 0.5 gm/$m^3$ and in summer 5 gm/$m^3$.[4] Therefore, a first approximation for conversion of the attenuations of Fig. 1 to Alaskan conditions consists in neglecting the water vapor entirely and simply reducing the observed attenuations by 50, 75, and 50 percent at 30, 19, and 13 GHz.

## V. ERRORS

There are two main sources of systematic error. The first is occultation of the setting sun by objects near the horizon. At the Crawford Hill location the Sun Tracker has a clear view down to about 3 degrees elevation. The second error is an increase in antenna beamwidth in the vertical plane due to the gradient of atmospheric refraction within the antenna beam.[5] The forward gain of the antenna is thus reduced, resulting in an apparent increase in attenuation. The magnitude of this effect depends on the size of the source being observed. A "point" source, such as a synchronous satellite, would show an attenuation about 0.1 dB above the values reported here.

Strictly speaking, the points calculated by Hogg shown in Fig. 1 should not be compared directly with the data. Although the attenuation at solar noon has been subtracted from them (they are normalized to 0 dB at noon), they still do not correspond to the conditions of this experiment. Hogg assumed a humidity of 10 gm/$m^3$—a value 20 percent below the prevailing humidity during the observations. A rough correction to Hogg's values would involve scaling his attenuations (in dB) up by 10, 15, and 10 percent at 30, 19, and 13 GHz.

Fluctuations in the data are attributable to three sources: (*i*) error in reading attenuations on the chart recorder, (*ii*) error in reading the time on the chart, and (*iii*) changes in humidity over the course of the observations. The first-mentioned error, called $\delta A$ below, is estimated to be about 0.2 dB rms, one-fifth of the smallest chart division. The timing error is significant because it leads to an uncertainty in the elevation angle, $\delta\theta$ below, at which a particular measurement was made.

A reasonable estimate for this error is 1 minute rms, which means $\delta\theta$ is 0.25 degree. Finally, the diurnal changes in humidity, $\alpha$, were about 20 percent. All these errors add in quadrature to give a resultant overall error estimate

$$E^2 = (\delta A)^2 + S^2(\delta\theta)^2 + (f\alpha A)^2, \tag{2}$$

where $S$ is the slope of the attenuation versus elevation angle curve (see Fig. 1), $f$ is the fraction of the attenuation due to water vapor, and $A$ is the measured attenuation. The errors represented by the three terms of eq. (2) are of comparable magnitude. Thus the noise in the data must be ascribed to both instrumental and "external" sources.

The rms fluctuations predicted by eq. (2) can be compared with the observed scatter in the measurements at various frequencies and angles. Typically the two differ by only 0.2 to 0.3 dB, indicating that the stochastic processes operating in this experiment are reasonably well understood.

## VI. CONCLUSIONS

The 13-, 19-, and 30-GHz attenuation of a clear atmosphere at low elevation angles has been measured by the Crawford Hill Sun Tracker. The results are in good agreement with predictions. Extrapolation of the measurements to Alaskan conditions yields attenuations substantially below those measured in New Jersey. A significant improvement in the measurements using the Crawford Hill Sun Tracker can be made only under conditions of reduced and/or more stable atmospheric water vapor content.

## VII. ACKNOWLEDGMENTS

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