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Dual Frequency Measurements of Rain-Induced Microwave Attenuation on a 2.6-Kilometer Propagation Path

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The ratio of attenuations measured simultaneously at 18.5 and 30.9 GHz on a common 2.6-km path during 1970 in New Jersey show that, with exceptions for special cases, the Laws and Parsons drop-size distribution adequately represents the rain on terrestrial microwave communications paths. The ratio derived from cumulative distributions of attenuation is also discussed. A rain-induced attenuation of 30 dB is found to be exceeded 0.001 and 0.01 percent of the time at 18.5 and 30.9 GHz, respectively. These results are in good agreement with attenuations derived from rain rates obtained on the Holmdel rain gauge network.

I. INTRODUCTION

Rain-induced attenuation at centimeter and millimeter wavelengths is a function of drop-size; conversely, a measure of drop-size can be obtained from multi-wavelength measurements over a common propagation path. As shown in Fig. 1, a 2.6-kilometer path, shared by both 18.5 and 30.9 GHz, extends to the southeast of Crawford Hill, Holmdel, New Jersey. Both of the receivers are located in the same building at Crawford Hill; the equipment has been reported elsewhere,[1,2] it will not be discussed here.

In addition to obtaining a measure of the drop-size distributions by examining the ratio of the 30.9-GHz attenuation to the 18.5-GHz attenuation during rainstorms, sufficient data are available for a statistical examination of the rain-induced attenuations for both frequencies. In the following, the cumulative distributions of attenuation at 18.5 and 30.9 GHz will be discussed individually and then related one to the other.

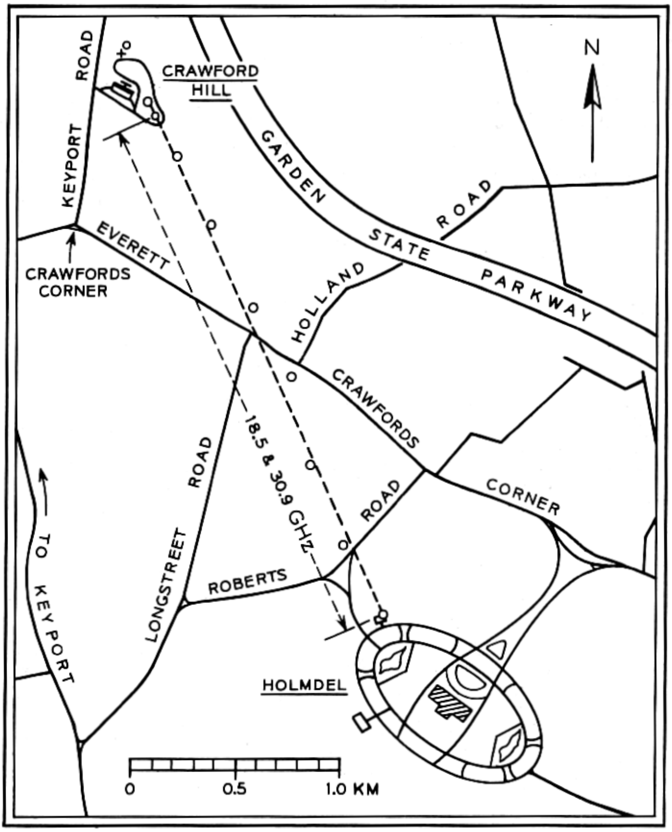

Fig. 1—Map showing the propagation path of 2.6 km used at 30.9 and 18.5 GHz.

II. VARIABILITY IN DROP-SIZE DISTRIBUTION

The variability of drop-size can be assessed by examining the data from the common propagation path, shown in Fig. 2. In this figure, the ratios of 30.9-GHz to 18.5-GHz attenuation are plotted versus the total path attenuation at 18.5 GHz (the upper plot) and versus the total path attenuation at 30.9 GHz (the lower plot). In both plots, the dashed line is the theoretical ratio of 30.9/18.5-GHz attenuation obtained using a Laws and Parsons drop-size distribution,[3,4] assuming a uniform rainfall over the path. It is apparent from the data in both plots of Fig. 2 that the theoretical ratios derived from Laws and Parsons represent the body of the data rather well, especially for path attenuations exceeding 10 dB at 30.9 GHz; in fact the least squares fit to the data is not shown because it lies so close to the theoretical curve. However, for attenuations less than about 10 dB at 30.9 GHz there is a large scatter in the measured ratios; much of the scatter is caused by two particular storms.

The two specific sets of data are shown in the two plots of Fig. 2

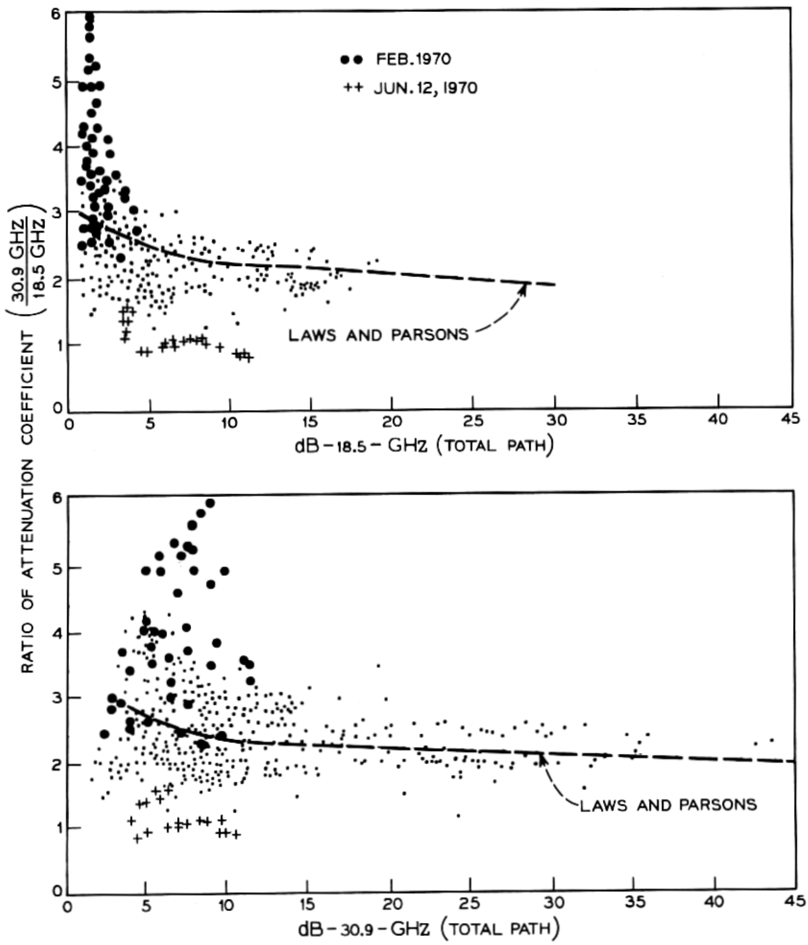

Fig. 2—The ratio of attenuation at 30.9 GHz to that at 18.5 GHz plotted, in the upper graph, versus the 18.5-GHz total path attenuation and, in the lower, versus the 30.9-GHz total path attenuation. The dashed curve in each plot is the theoretical ratio using Laws and Parsons drop-size distribution.

by distinctive symbols; these data were measured during periods of the month of February, and on the twelfth day of June, 1970. Suffice it to say that these are special cases where the large ratios obtained in February are due to light rains composed of more small drop diameters than accounted for by Laws and Parsons, whereas the lower ratios obtained in June are the results of drops larger than that given by the Laws and Parsons drop-size distribution. If these two special cases are removed, the remaining data are well represented by the line labeled Laws and Parsons. The spread in the measured data is due not only to variations in drop-size distributions but also to a lack of homogeneity in the rainfall intensity along the propagation path.

III. CUMULATIVE DISTRIBUTIONS OF 30.9- AND 18.5-GHZ RAIN-INDUCED ATTENUATION

A sample of 6432 hours of recording on the dual-frequency experiment was obtained during the period January 1, 1970 through September 25, 1970. During this period a total of thirty-six individual showers occurred. Of these thirty-six, attenuation measurements were obtained at both 18.5 and 30.9 GHz for thirty-four. The remaining two storms were missed; in one instance, there was an equipment failure at 18.5 GHz, in the other, a failure at 30.9 GHz.

Percent-of-time distributions for 18.5- and 30.9-GHz rain-induced attenuations are shown in Fig. 3 (by the solid curves) for the recording period of 6432 hours, *not* a full year. However, based on earlier work,[2] this period is known to include the months of heaviest rain rate, therefore the sample contains essentially all of the high attenuations which occur in a full year.

Examination of the solid curves of Fig. 3 shows that for this 2.6-kilometer path and a 0.01-percent probability level, the 18.5- and 30.9-GHz rain-induced attenuations exceeded 15 dB and 30 dB, respectively. Thus, these levels of attenuation were exceeded for a total of 38 minutes of the 6432-hour recording period. Similarly, if one examines the 0.001-percent probability level, which for this sample is equivalent to about 4 minutes, one finds that the attenuation at 18.5 GHz exceeded 30 dB whereas at 30.9 GHz, using some extrapolation,* the attenuation exceeds 57 dB.

As stated earlier, the likelihood that the 18.5- or 30.9-GHz attenuation would have exceeded 30 and 57 dB for the remainder of the year, beyond the 6432-hour sample, is remote. If the percentage level is

* The measuring range at 30.9 GHz is 48 dB.

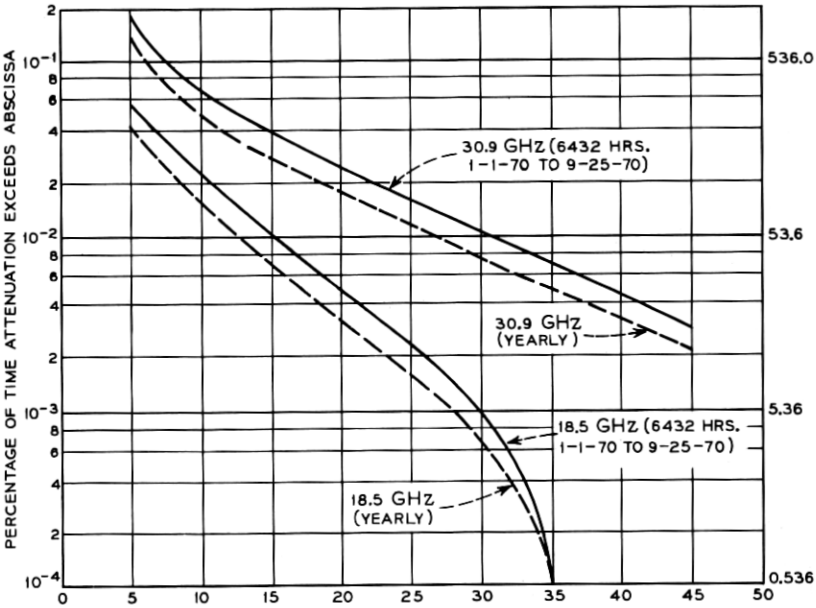

Fig. 3—Percent-of-time distributions of the rain-induced attenuations for both 18.5 and 30.9 GHz. The solid curves are based on 6432 hours of data, the dashed curves are projected yearly distributions.

computed on a yearly basis, it is found that the attenuation at 18.5 GHz exceeds 28 dB 0.001 percent of the time, approximately 5 minutes per year, and the attenuation at 30.9 GHz exceeds 54 dB for 5 minutes of the year. The yearly attenuation distributions are shown by the dashed curves of Fig. 3.

An interesting comparison can be made between the data points just discussed and the attenuation computed[5] from the rain rates measured on the Holmdel rain gauge network. Figure 4 is a reproduction from Ref. 5 of the curves of computed rain attenuations exceeded 0.001 percent of the year (Fig. 4a) and 0.01 percent of the year (Fig. 4b), as a function of path length. These computed curves are based on average path rain rates from the 1967 rain gauge network data. The current 1970 data at the 0.001-percent probability level for both 18.5 and 30.9 GHz are shown as crosses on Fig. 4a;* the agreement is quite

* Figure 4 also shows measurements for the two probability levels at 18.5 and 30.9 GHz taken on 6.4- and 1.9-km paths during 1967, 1968, and 1969.[2]

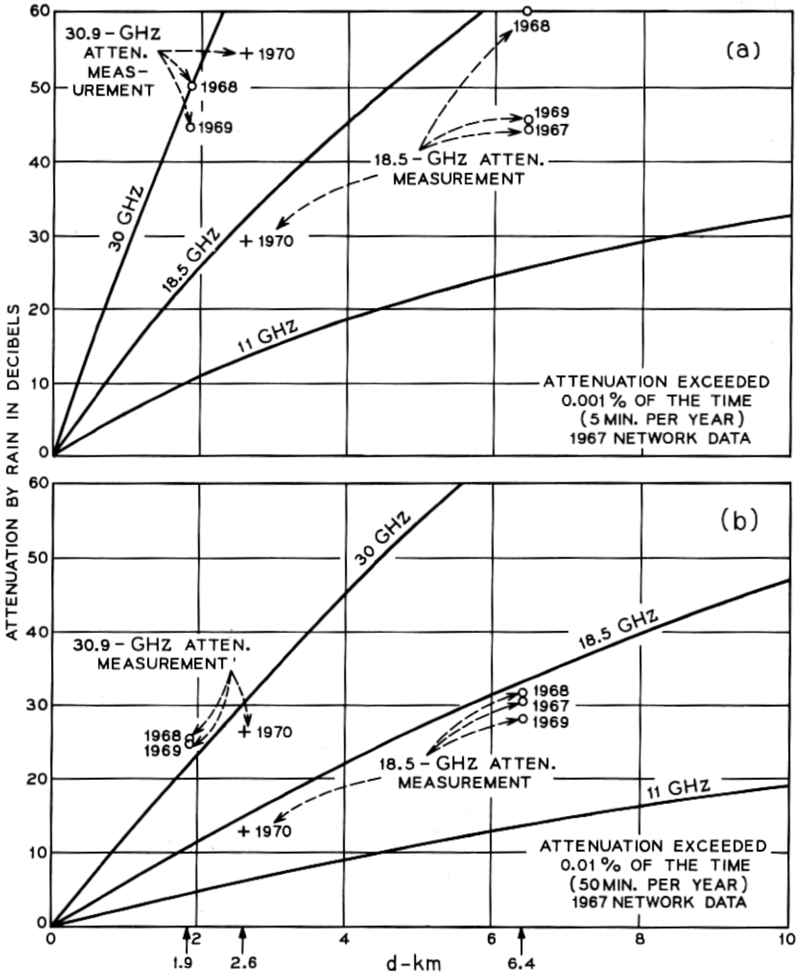

Fig. 4—Attenuation as a function of path length at 11, 18.5, and 30 GHz (1967 Holmdel rain gauge network data) for (a) 0.001 percent probability and (b) 0.01 percent probability along with measurements on paths of length 1.9 km (30.9 GHz), 2.6 km (18.5 and 30.9 GHz), and 6.4 km (18.5 GHz).

good at 18.5 GHz but at both frequencies the computed curves predict a value somewhat larger than the measurements.

A similar comparison at the 0.01-percent probability level can be made if one is willing to assume that no attenuations exceeding 15 and 30 dB at 18.5 and 30.9 GHz, respectively, occurred for the remainder of 1970, beyond the 6432-hour recording period. This is not an overly hazardous assumption since experience has shown that the tail of the distribution for the measuring period discussed here contains essentially all the high attenuation data for a year. This assumption was made with the 1970 data for both 18.5 and 30.9 GHz and the results (12.5 and 27 dB) for the 0.01-percent probability level are shown by crosses on Fig. 4b. Agreement between computations and measured data is fairly good, the curves computed from the rain gauge network data again being somewhat conservative.

IV. RELATIONSHIP BETWEEN THE TWO ATTENUATION DISTRIBUTIONS

In view of the fact that the 18.5- and 30.9-GHz attenuations are measured on a common path, the received signal levels at the two frequencies are always attenuated by the same volume of rain and therefore fade together. One is justified in attaching significance to the ratio of the attenuations at a given percent-of-time level.

Ratios of 30.9- and 18.5-GHz attenuation for various percentage levels (from Fig. 3) are plotted as solid dots in Fig. 5 versus the total path attenuation at 18.5 GHz; the theoretical ratio[4] of 30.9/18.5-GHz attenuation obtained using a Laws and Parsons drop-size distribution is plotted as the solid curve on this figure. Again, as in Fig. 2, there is

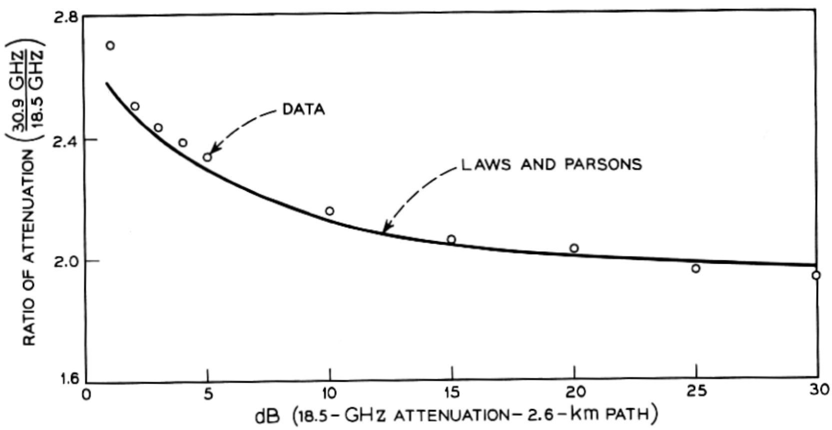

Fig. 5—The ratio of measured attenuation from the 30.9-GHz and 18.5-GHz distributions of Fig. 3, plotted as solid dots, versus the measured 18.5-GHz total path attenuation. The solid curve is the theoretical ratio using Laws and Parsons drop-size distributions.

good agreement between the ratios obtained from the measured attenuation and the theoretical distributions based on the Laws and Parsons drop-size distribution; thus, it appears that the Laws and Parsons distribution holds on the average. The least squares fit to the measured ratios has not been plotted in Fig. 5 because of its proximity to the computed curve.

V. CONCLUSION

Our measurements of the instantaneous ratio of 30.9- to 18.5-GHz attenuation appear to be consistent (Fig. 2) with computations based on the Laws and Parsons raindrop-size distribution. The attenuation ratios have also been derived from the cumulative distributions of attenuation (Fig. 3) and these are in very good agreement (Fig. 5) with the theoretical computations. Relative values obtained from cumulative distributions of attenuation at two frequencies (or more) on common paths therefore proves to be a valuable technique for probing the rain environment.

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