Propagation of 6-Millimeter Waves*

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Summary—**One step in the exploration of a new band of frequencies for communications purposes is a study of the transmission properties of the medium involved. This paper describes the methods and results of measurements of attenuation due to rainfall and atmospheric gases at a wavelength of 0.62 centimeter.**

The one-way attenuation due to moderate rains at 0.62 centimeter is roughly 0.6 decibel-per-mile per millimeter-per-hour. The gas attenuation is probably less than 0.2 decibel per mile.

Introduction

INVESTIGATORS during the last decade have continuously improved techniques for producing and using electromagnetic waves in the centimeter region. One of the steps in the development or exploration for communication purposes of a new band of frequencies is a study of the transmission properties of the medium involved. These studies include the effects of gases, of rain, and of other liquid or solid constituents of the atmosphere, and a knowledge of the effects on propagation of reflection and refraction due to various sections of the atmosphere. The present paper deals with a few simple measurements of the first of these effects made at a wavelength of 0.62 centimeter ($f=4.8\times 10^{10}$ cycles). The measurements of rain were patterned on those made earlier at 1 centimeter and 3 centimeters by Robertson and King,[1] and by Wolf and Linder.[2] The measurements of atmospheric absorption were made by observing the path attenuation for several path lengths and comparing this with the theoretical inverse-square-law relation between power and distance.

Method

The measurements reported below were made using a modulated signal generator with a single-detection crystal receiver followed by an audio amplifier, a second rectifier, and a microammeter. The location employed was a long flat field at Holmdel, New Jersey.

The signal generator was a 1.24-centimeter velocity-variation oscillator. The cathode voltage of the oscillator was derived from the output of a square-wave amplifier, the duty cycle was 1:2, and the fundamental modulation frequency used in the tests was 10,000 cycles. The second-harmonic output was obtained from a harmonic generator and was fed directly to a paraboloidal antenna 18 inches in diameter with a gain of 45 decibels above a spherical radiator and a half-power beam width of 0.8 degree. It was located about 25 feet above the ground. The waves were horizontally polarized. The transmitted power was monitored by means of an auxiliary detector which intercepted part of the energy radiated by the antenna. The receiving antenna was a similar paraboloid located at approximately ground level at a point 1200 feet distant from the transmitter. Both antennas were shielded from the rain by structures outside the path of the beam.

The detector was developed by R. S. Ohl of the Bell Telephone Laboratories and is a silicon-crystal rectifier. The output of the receiving detector was sent through an amplifier, a rectifier and finally appeared on a microammeter. A wave-guide radio-frequency attenuator, previously calibrated against a standard intermediate-frequency attenuator in a double-detection set, was used to determine the added attenuation due to rain. In use, the receiver was adjusted for maximum received power and then radio-frequency attenuation was introduced until the received power was about twice the first-circuit noise power. As the rain introduced loss in the path, the radio-frequency attenuation was withdrawn so as to keep the output-meter reading constant. The actual amount of rain was measured at the receiving end by means of a funnel and graduate. The accuracy was such as to permit readings of rate of rainfall of about 0.3 millimeter per hour, while the path attenuation could be read to 0.1 decibel. Simultaneous readings were taken of attenuation and of rainfall, usually once a minute, but for high rates of precipitation, at half- or even quarter-minute intervals.

Atmospheric attenuation was measured by means of the same apparatus. Since it was necessary to make observations at various distances, the receiving antenna was mounted about 8 feet above the ground on a post supported on a truck. The rest of the receiving equipment was placed inside the truck. In taking the data the antennas were aligned with one another at each of the points of observation. It was possible to vary the height of the receiving antenna above the ground, and this was done at several points to check for the presence of ground reflections. No multipath effects were observed.

The method of measurement placed stringent requirements on drifts in the over-all measuring system but adequate voltage regulation and attention to details resulted in satisfactory stability. The over-all gain ordinarily varied less than 0.1 decibel per hour after the initial warm-up period. The total systems gain was such as to provide a 14-decibels working margin which proved to be adequate for the heaviest rain encountered.

It was necessary to interpret the rainfall data in light of the method of measurement. The data on rate of rainfall were based on the amount of rain water

* Decimal classification: R247×R113.501. Original manuscript received by the Institute, October 26, 1945. Presented, 1946 Winter Technical Meeting, New York, N. Y., January 26, 1946.

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[1] Sloan D. Robertson and Archie P. King, "The effect of rain upon the propagation of waves in the 1- and 3-centimeter regions," Proc. I.R.E., this issue, pp. 178–181.

[2] Irving Wolf and E. G. Linder, "Transmission of 9-centimeter electromagnetic waves," *Broadcast News*, no. 18, pp. 10–13; December, 1935.

collected over one-minute intervals, whereas the attenuation reading was the instantaneous value taken at the end of each interval. In order to compare the two measurements properly, it was necessary to average the values of attenuation over at least one-minute intervals. Also, since the rainfall measurements were made at one end of the path, the peak rainfall did not always coincide with the peak of attenuation. To take care of this displacement, sections of the data were selected which satisfied two criteria. First, the rainfall was substantially uniform over the interval chosen. Second, the edges of the interval were well defined. Samples of the data and

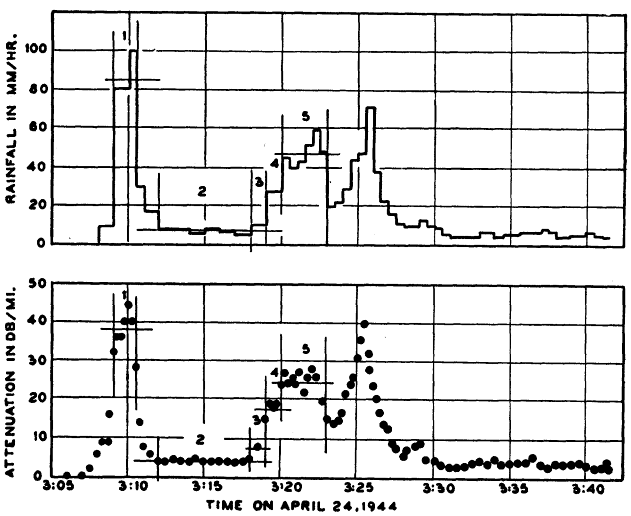

Fig. 1—Sample of data and method of interpretation.

method of averaging are shown in Fig. 1. Here the light vertical construction lines indicate the boundaries of the averaging intervals, and the horizontal lines indicate the average value chosen. For convenience of comparison, the corresponding intervals of rainfall and attenuation are numbered consecutively. The points plotted in Fig.

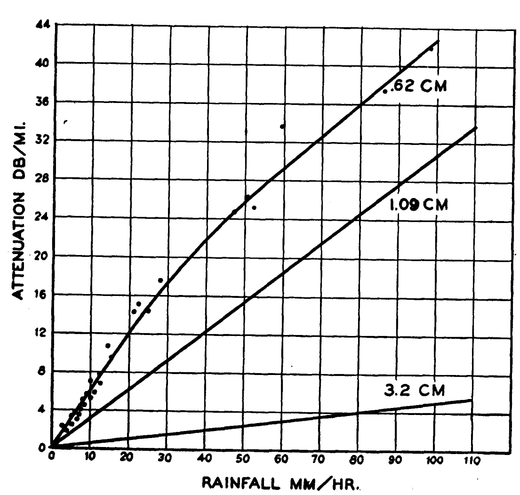

Fig. 2—Attenuations due to rainfall.

2 were obtained from some thirty such intervals taken from the data covering the rainfall on three days (15, 24, and 27) in April, 1944. This method of reducing the data leads to a considerable decrease in the scattering of points, largely due to the improved correlation of the two types of data. However, it does introduce a possibility of error, for it integrates out the effects of variation in drop size taking place during any one averaging interval.

Results

In Fig. 2 the attenuation in decibels per mile due to rainfall at 0.62 centimeter is shown. Comparison curves for 1-centimeter and 3-centimeter wavelengths from the paper of Robertson and King[1] are included.[3] The effect of a change in wavelength for a given rainfall is made

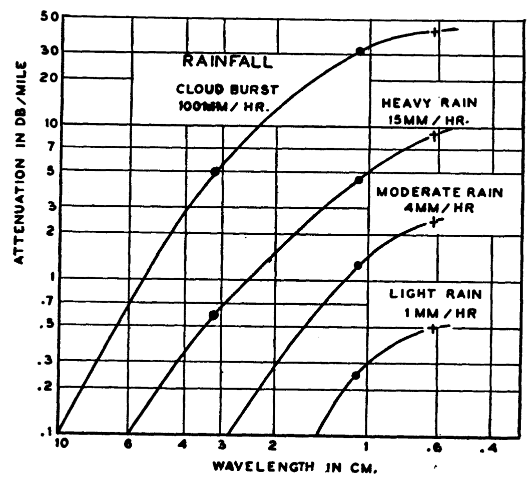

Fig. 3—Effect of wavelength on attenuation due to rain.

more evident by Fig. 3 which is a rearrangement of the data of Fig. 2 on an attenuation-wavelength basis.

It is apparent from the data of Robertson and King[1] that the decibel attenuation for a given rain at 1 centimeter is six or seven times as large as that at 3 centimeters. If the attenuation increased at the same rate, for a given rainfall the loss at 0.6 centimeter would be almost three times the 1-centimeter loss while the measurements show it to be approximately twice as large. This drop in the rate of increase of attenuation may be explained as follows.

From the theoretical work of Mie,[4] Fränz,[5] and Stratton[6,7] it would seem that the attenuation due to rain is composed of two parts The first is due to scattering and the second is due to absorption by the water in the drop.

[3] It will be noted that the measurements of Robertson and King used horizontal polarization at 3.2 centimeters while they used vertical polarization at 1.09 centimeters. The present measurements used horizontal polarization. It is believed that the attenuation due to rain is independent of the spatial orientation of the polarization. This is a consequence of the fact that individual raindrops are very nearly spherical.

[4] G. Mie, "Beiträge zur Optik trüber Medien, speziell kolloidaler Metallösungen," Ann. der Phy., vol. 25, pp. 377–445; 1908.

[5] K. Fränz, "Die Schwachung sehr kurzer electrischen Wellen beim durchgang durch Wolken und Nebel," Hochfrequenz. und Electroakustic, vol. 55, pp. 141–143; May, 1940.

[6] J. A. Stratton, "The effect of rain and fog on the propagation of very short radio waves," PROC. I.R.E., vol. 18, pp. 1064–1074; June, 1930.

[7] J. A. Stratton, "Electromagnetic Theory," McGraw-Hill Book Company, New York, N. Y., p. 563; 1941.

The water resonance which causes the absorption loss lies in the vicinity of 2 centimeters and, although it is very broad, in going from 1.0 to 0.6 centimeter there should be a decrease in the second derivative of the absorption loss with respect to wave length. Scattering loss varies directly with the dielectric constant, with the power factor, and with the ratio of drop diameter to wave length. In the 0.6-centimeter region, the dielectric constant and power factor are decreasing with wave length while the drop diameter, in wavelengths, is increasing. These factors tend to balance so that the scattering loss should not increase rapidly with shorter wavelengths. Qualitatively then, one would expect further decreases in the rate of increase of attenuation as one goes to still shorter wavelengths.

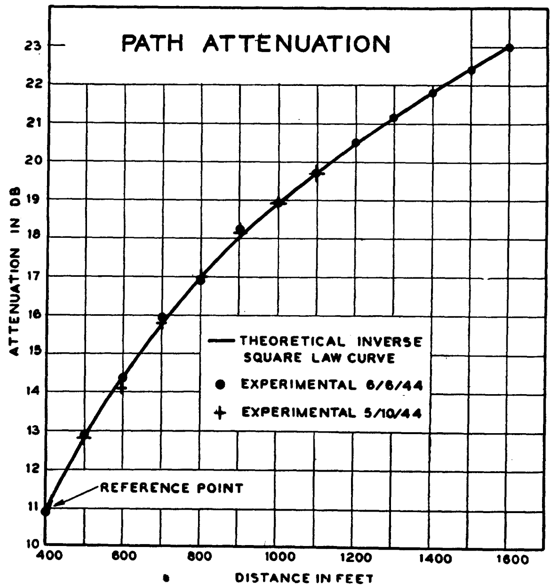

Fig. 4—Curve showing path attenuation.

In Fig. 2, it may be seen that for large values of rainfall the slope of the 0.6-centimeter attenuation seems to be comparable with that at 1 centimeter. The amount of data is small and the errors may, in fact, be large enough to account for the change in slope. One of the more likely causes is uneven rainfall over the transmission path. It should be noted, however, that this path was only a quarter-mile long and that it was directed at right angles to the prevailing storm winds.

The scattering of points on the graph is probably due in large part to the variation in drop size. Experimental errors, the unevenness of rainfall discussed above, and the method of interpretation also contribute to the spread of the points. The scattering is somewhat less than that obtained in the earlier 1-centimeter measurements, but this is almost wholly a result of the averaging process used in reducing the data.

The results of the atmospheric absorption measurements are shown as points in Fig. 4. The solid curve is a plot of the inverse square law using as a reference the signal received at 400 feet. If attenuation had been present the experimental points would have fallen above the theoretical curve, in effect increasing the rate of increase of attenuation with distance. No trend of this kind can be observed. The standard deviation of the observed results from the theoretical curve has been calculated and found to be 0.035 decibel. Since the longest path change is a quarter mile, this corresponds to a probable error of ± 0.14 decibel per mile. Assuming there are no systematic errors, it is reasonable to set the value of the upper limit of any atmospheric absorption that may be present at twice the standard deviation, or 0.28 decibel per mile. Since there was no definite indication of atmospheric absorption, no attempt was made to assess the relative effects of humidity and of gases.

Conclusions

The attenuation of 0.6-centimeter waves by moderate rainfalls is approximately twice that of 1 centimeter. However, this statement should be correlated with the frequency at which given rains occur before its seriousness is evaluated. In terms of the average rainfall in the middle temperate zone, the one-way loss will be less than 0.5 decibel per mile 97 per cent of the time, less than 1.5 decibels per mile 98 per cent of the time, and less than 6 decibels per mile 99 per cent of the time. Stated in terms of intensity, the one-way attenuation for most rains will be roughly 0.6 decibel-per-mile per millimeter-per-hour. An attenuation of 40 or more decibels per mile may be obtained in cloudbursts of 100 millimeters per hour rate of fall.

The attenuation due to atmospheric absorption is probably less than 0.2 decibel per mile, which is small in comparison with the losses due to rain.