

## B.S.T.J. BRIEFS

### A Three-Radiometer Path-Diversity Experiment

By R. W. WILSON

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Data from the Crawford Hill sun tracker have confirmed the expectation that frequencies above about 10 GHz experience large attenuations on an earth-space path when heavy rain is encountered.<sup>1</sup> Tillotson has proposed using frequencies of about 20 and 30 GHz for a domestic communication satellite system.<sup>2</sup> In that case, the required continuity of service would be achieved by using two or more diversity ground stations. The three-radiometer path-diversity experiment discussed here was designed to work in conjunction with the sun tracker to determine the advantage of diversity ground station pairs at these frequencies.

A common method of measuring atmospheric attenuation on earth-space paths at microwave frequencies has been to measure the brightness temperature of the atmosphere. In the absence of scattering, one can obtain the attenuation in a path through the atmosphere from the relationship between the physical temperature ( $T$ ), attenuation ( $A$ ), and brightness temperature ( $T_b$ ).

$$T_b = \left(1 - 10^{-\frac{A}{10}}\right)T. \quad (1)$$

At the frequencies of interest, however, scattering from raindrops is not negligible and, in addition, one can only estimate  $T$ . The sun tracker<sup>1</sup> is set up to measure  $T_b$  in a direction about  $2.5^\circ$  away from the sun and  $A$  in the direction of the sun simultaneously. Experience with these measurements has shown that by choosing the proper value of  $T$  (and one can do better still by making  $T$  a function of  $T_b$ ). Equation (1) and measurements of  $T_b$  will give dependable values of  $A$  up to about 12 dB (see Fig. 11 of Ref. 1). Thus, in the interest of simplicity, a 16 GHz diversity experiment has been set up using fixed-pointed radiometers rather than, say, additional sun trackers. Further advantages of this method are that all the measurements are made at the same elevation angle, and data are taken for 24 hours/day. A disadvantage is the limited measuring range (12 dB, which translates into about 36 dB at 30 GHz).

Further evidence of the ability of radiometers to measure attenuation is given in a companion paper.<sup>3</sup>

The three radiometers are located on a northwest to southeast line, the middle one being at Crawford Hill, a few yards from the sun tracker. The northwest radiometer is in Sayreville, N. J., seven miles from Crawford Hill, and the southeast one, at the time these data were taken, was located at Exit 114 of the Garden State Parkway, two miles from Crawford Hill. The antennas are pointed at an azimuth of  $226^\circ$  (approximately perpendicular to the line along which they are located) and at an elevation of  $32^\circ$ , near the center of the apparent motion of ATS-5.<sup>3</sup> The beam widths are  $1.05^\circ$  for the remote antennas and  $0.65^\circ$  for the Crawford Hill antenna.

The RF and IF parts of the radiometers are very much like those of the 16 GHz receiver on the sun tracker.<sup>1</sup> A ferrite switch, driven at 10 Hz, switches the input of the down converter between the antenna and a reference termination whose temperature is stabilized at  $30^\circ\text{C}$ . At the output of the receiver two voltages are developed on  $\frac{1}{2}$  second time constants. One is proportional to the average receiver output during the times that the input of the receiver is connected to the antenna and the other to the output while the receiver is connected to the reference termination. The level derived from the reference termination is used for an automatic gain control (AGC) loop and the difference of the two levels produces the main output.

All three radiometer outputs are brought to the Crawford Hill Laboratory for recording. The remote radiometers have their outputs (essentially dc levels) connected to voltage controlled oscillators (VCO) operating in the voice band. The VCO outputs are sent over telephone lines to Crawford Hill where discriminators convert the frequencies back to voltages for recording on strip charts.\*

The data discussed here are based on the period April 1 through August 7, 1969. Large but not perfect correlation among the attenuations is often observed for the three stations but there is usually sufficient time shift between the attenuations at the more widely separated stations to give a good diversity advantage at high attenuation.

During the period that the data were being collected, it was noticed that attenuation at Sayreville (the most northerly station) often preceded that at the other locations by a time large enough to prevent overlap of high attenuations, but that the time difference between the events at Crawford Hill and the Parkway site (two-mile separation) was insufficient for much diversity advantage.

\* The data are now also being recorded digitally on magnetic tape.

A statistical summary of the measurements taken for the two-, seven- and nine-mile spacings is shown in Fig. 1. What is plotted is the percentage of the measuring period (3080 hours) that the attenuation shown on the abscissa was exceeded. Data from the three radiometers are plotted individually in Curves (1), (2) and (3) and in combination as the three possible diversity pairs in Curves (4), (5) and (6). One sees explicitly that the seven- and nine-mile separations result in a large diversity advantage whereas the two-mile spacing results in

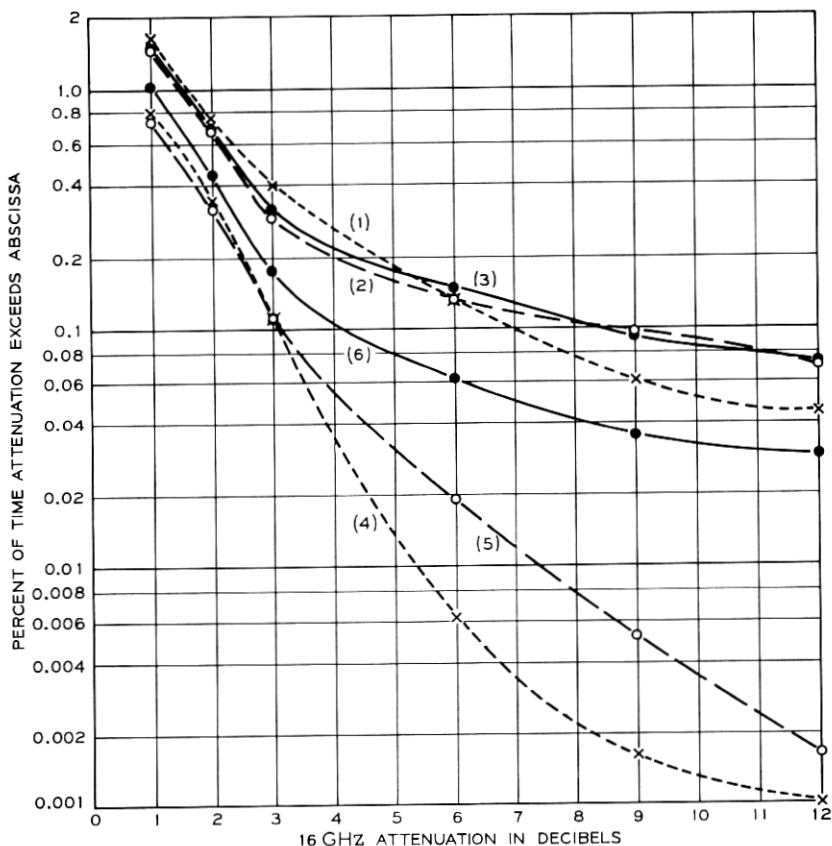


Fig. 1—16 GHz radiometer rain data, April 1, 1969 through August 7, 1969; total time 3081 hrs. Distributions of attenuation for the individual stations: (1) x---x Sayreville; (2) o---o Crawford Hill (3) o---o Parkway. Distributions of attenuation for pairs of stations in diversity: (4) x---x Crawford Hill to Sayreville, 7 miles; (5) o---o Parkway to Sayreville, 9 miles; (6) o---o Parkway to Crawford Hill, 2 miles.

much less. For example, at the 12-dB level, the data from the diversity pairs separated by seven and nine miles show about a factor of 50 improvement over the individual distributions. The difference between the curves near the bottom of Fig. 1 should not be taken as very significant since the data in those portions of the curves are from only a few rains. The attenuation scale for Fig. 1 is based on  $T = 273^\circ$  which is a good fit to 1968 sun tracker data. During the 129 days used for this data sample, 15.26" of rain fell at Crawford Hill.

Thus, spacings of from five to ten miles provide considerable diversity advantage on earth-space paths at 16 GHz. The experiment is continuing but the Parkway station has been moved from two miles to twelve miles southeast of Crawford Hill. This will make available diversity data for spacings of seven, twelve and nineteen miles.

#### REFERENCES

1. Wilson, R. W., "Sun Tracker Measurements of Attenuation by Rain at 16 and 30 GHz," B.S.T.J., 48, No. 5 (May-June 1969), pp. 1383-1404.
2. Tillotson, L. C., "A Model of a Domestic Satellite Communication System," B.S.T.J., 47, No. 10 (Dec. 1968), pp. 2111-2137.
3. Penzias, A. A., "First Result from 15.3-GHz Earth-Space Propagation Study," B.S.T.J., this issue, pp. 1242-1245.

## First Result from 15.3-GHz Earth-Space Propagation Study

By A. A. PENZIAS

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Consideration is being given to the use of frequencies well above 10 GHz for satellite communication. One of the problems encountered in the use of these high frequencies is the attenuation caused by precipitation. A considerable amount of pertinent data has been obtained in the 16- and 30-GHz sun tracker and 16-GHz radiometer programs underway at the Crawford Hill Laboratory.<sup>1,2</sup> From the data obtained from radiometer measurements, one may calculate the attenuation expected on an earth-space path. Such attenuation calculations have been shown to be in good agreement with sun tracker measurements.<sup>1</sup> The present experiment was designed to check further the validity of the radiometer results by a direct comparison of the data obtained from a 16-GHz radiometer with the attenuation measured by transmission from a