

DEGRADATION OF HIGH FREQUENCY EARTH/SATELLITE TELECOMMUNICATION SIGNALS

Earth/satellite telecommunication traffic is becoming saturated at the standard 4 and 6 gigahertz carrier frequencies. Bands of frequencies above 10 gigahertz are therefore being implemented and others are planned. Because rain is the major degrader of signals at frequencies above 10 gigahertz, the designers of such communication links require information regarding the adverse effects caused by it. The use of radar to characterize rain, together with statistical modeling techniques, has proven useful for providing the communicator with many answers required for the design of future telecommunication systems.

BACKGROUND

Until recently, earth/satellite telecommunications have operated only at frequency bands in the vicinity of 4 and 6 gigahertz (GHz), using both domestic and internationally operated geostationary satellites. However, with increasing telecommunication traffic, bands at these frequencies are becoming saturated. Some bands at frequencies above 10 GHz are therefore being implemented and others are planned for the future. Examples of geostationary satellites operating at the higher frequencies are INTELSAT V (14 GHz uplink, 11 GHz downlink), SBS (Satellite Business Systems, 14 GHz uplink, 12 GHz downlink), and the CS2A (Japanese, 30 GHz uplink, 20 GHz downlink).

Rain is a major degrader of earth/satellite signals at frequencies above 10 GHz, where it both absorbs and scatters the propagating signal, causing an attenuation of signal strength. For frequencies as high as about 100 GHz, the earth/satellite signals attenuate monotonically with increasing frequency. Furthermore, the signals also attenuate monotonically with increasing rain intensity.

A measure of the degradation of satellite signals in the presence of rain is referred to as "rain attenuation," which is the ratio of the received power signal level at a ground station in the presence of rain to the received power level in its absence. The attenuation level is therefore equal to a number that is less than unity. Because the attenuation value may approach values very much less than unity, it is convenient to express attenuation in decibels, defined as 10 times the logarithm to the base 10 of this power ratio. Although this logarithm becomes a negative number, we frequently convert the attenuation to a positive value by considering it in an absolute sense.

Communicators interested in the design characteristics of earth/satellite links require information regarding the attenuation characteristics of rainfall. For example, they wish to know the number of minutes per year the signal level will be attenuated below a

given threshold. This information suggests the expected "downtime" for given earth terminal configurations. It is apparent that such information also translates into dollars lost when the telecommunications circuit cannot be completed. The communicator is also interested in being provided with similar information for future earth/satellite links operating at variable frequencies, path angles, geographic locations, and site geometries.

From 1972 until the present, a number of NASA-sponsored efforts have been pursued at APL that were directed toward attacking these problems. Some of the highlights of this research follow.

DEPENDENCE OF ATTENUATION ON FREQUENCY AND RAIN INTENSITY

Figure 1 shows nominal levels of attenuation as a function of frequency and rain rate.¹ These curves suggest the extent of the rain problem. Each curve gives the dependence of the attenuation coefficient on frequency for a different fixed rain rate. The rain rates considered vary between 0.25 and 150 millimeters per hour (mm/hr). By way of background, light rain lies between a fraction of 1 to about 5 mm/hr, moderate rains range from about 5 to 20 mm/hr, and heavy rains occur at rain rates greater than 20 mm/hr. The "light" and "moderate" categories are normally associated with widespread stratiform rains, and "heavy" may be associated with thunderstorms.

We observe a monotonic increase in attenuation with frequency up to about 100 GHz as well as a monotonic increase in attenuation with increasing rain rate. As an example, we note that at 30 GHz, the attenuation coefficient is approximately 1 decibel (dB) per kilometer (dB/km) at 5 mm/hr and 5 dB/km at 25 mm/hr. At Wallops Island, Va., a rain rate of 5 mm/hr has been found to be exceeded approximately 35 hours per year, and a rain rate of 25 mm/hr has been found to be exceeded 4 hours per year.² A typical 6 km earth/satellite path through rain will result

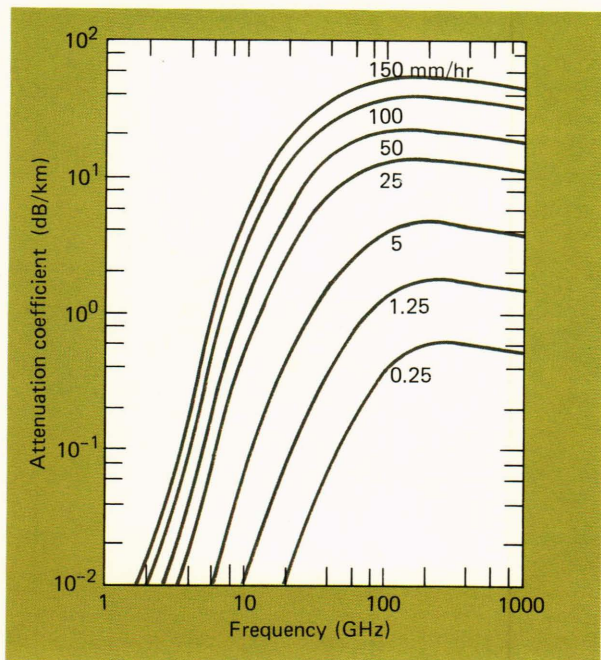


Figure 1 — Attenuation coefficients (in decibels per kilometer) versus frequency (in gigahertz) for a family of rain intensities.¹

in 6 dB at the lower rain rate and 30 dB at the upper one. It is apparent that individual earth/satellite, 30-GHz telecommunication systems will become inoperative at these higher rain rates unless special techniques are employed to overcome the problem. One such technique is described.

SINGLE-TERMINAL PATH ATTENUATION STATISTICS

An experimental program to monitor and understand the rain environment has been pursued at Wallops Island. The program uses a high-resolution ground-based radar operating at 3 GHz, 0.4° beamwidth, and a peak power of 1 megawatt. The rain radar data are recorded on magnetic tape along with other in situ rain measurements such as rain rate and rain drop-size distributions.³ These data are reduced and analyzed by means of numerical modeling techniques. Consequently, attenuation statistics at approximately 30 GHz have been derived for Wallops Island.^{4,5}

In Fig. 2 are curves showing examples of the results of the experimental and modeling procedures.⁵ The ordinate represents the percentage of the year the attenuation exceeds the abscissa value, where 1% of the year represents approximately 88 hours; 0.1%, 8.8 hours; and so on. The attenuations are expressed in positive decibel values. One curve in Fig. 2 represents the directly measured statistics at the same location, and the other, the modeled results obtained using radar measurements. The directly measured statistics were obtained by monitoring a beacon signal emanating from a geostationary satellite named COMSTAR. The COMSTAR signal was monitored continuously

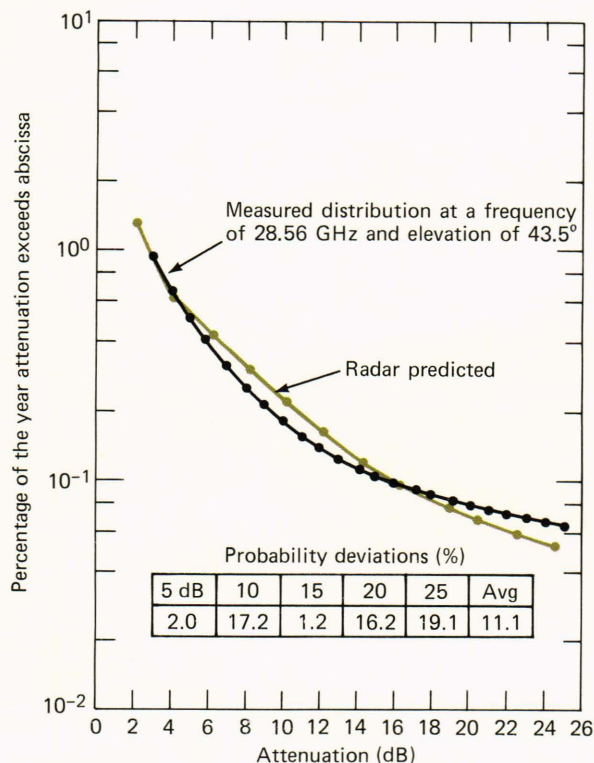


Figure 2 — Comparison between radar-predicted attenuation distribution and directly measured distribution obtained by monitoring the COMSTAR geostationary satellite.^{5,6}

over a three year period.⁶ We note that there is very close agreement between the directly measured results and those derived from the radar data and modeling procedures. Figure 2 indicates that for 8.8 hours of the year, the signal degrades by more than 15 dB.

SITE DIVERSITY

Figure 3 shows a configuration of the ground terminals located a distance d apart. Because rain cells in thunderstorms tend to be highly localized, terminal 1 is shown to experience more path length through rain than terminal 2. Terminal 1 correspondingly experiences more attenuation. We assume that both stations are communicating with the same geostationary satellite at the same time and that they are linked to each other with superimposed logic that enables the larger of the two signals to be received and distributed to the land lines. Because rain is laterally nonuniform, when the path attenuation for terminal 1 becomes prohibitively large, the likelihood is high that terminal 2 will experience less attenuation and communications will still be received. The technique represented by this configuration is called "site diversity."

These configurations are mainly experimental. To optimize a design for such a system, the communicator engineer requires a knowledge of the best spacing between sites, the effect on frequency, the path elevation angle, and the best azimuth pointing angle rela-

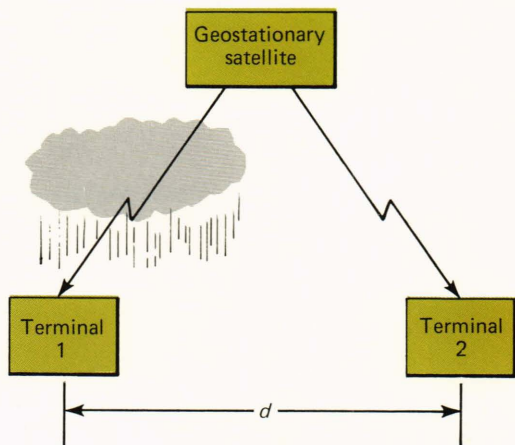


Figure 3 — A two-ground-terminal site diversity configuration, showing greater path attenuation for terminal 1 as a result of a thunderstorm.

tive to the line connecting the two terminals (baseline direction).

Here again, the radar rain-environment data were used together with numerical modeling procedures to obtain information related to the space diversity questions.^{7,8}

Figure 4 illustrates the improvement in earth/satellite communication achieved for various values of spacing, d , between two ground terminals. Radar data and numerical modeling procedures were combined to determine the probability of encountering different levels of attenuation, assuming one could select the strongest signal from either of two ground terminals. For comparison, the $d = 0$ km curve represents the probability distribution for a single station. The curves labeled $d = 2$ km, etc., represent the joint probability distributions for two sites separated by the distances indicated.

As an illustration of the significance of the curves in Fig. 4, consider the 0.1%, or 8.8 hour, case. We note that at that fixed level, a single terminal fade of 15 dB is exceeded. On the other hand, for the case of two sites operating in a site diversity mode with a spacing of 35 km, the minimum of the fades that is exceeded for this same time percentage is approximately 9 dB. In other words, the site diversity configuration has gained 6 dB over the single terminal case for the same percentage of time. Such results demonstrate the utility of employing a site diversity configuration.

CONCLUSIONS

Radar data of rain structure may be efficiently reduced and analyzed. By using numerical modeling techniques coupled with other phenomenological measurements, the attenuating effects of signals propagating along earth/satellite paths may be derived both on a case-by-case basis and statistically.⁹

Such results are useful to the communicator interested in designing earth/satellite links at frequencies exceeding 10 GHz. The techniques used obviate the need for direct experiments, which of necessity would require many geostationary satellites and ground termi-

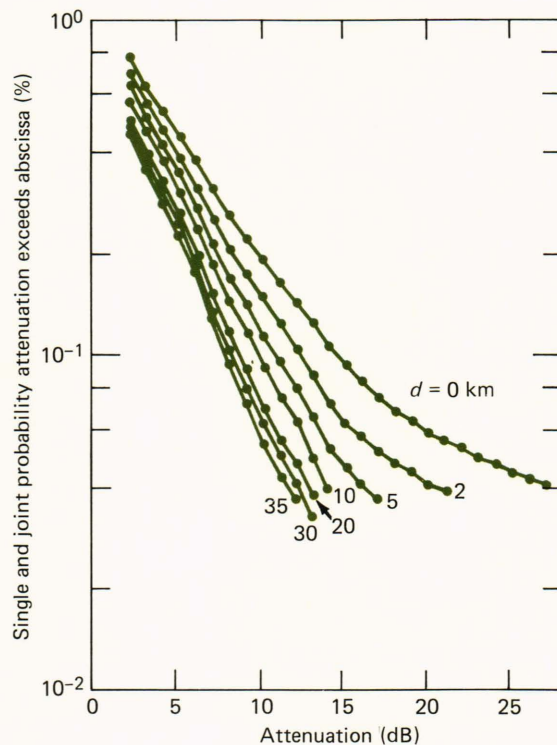


Figure 4 — Single and joint terminal attenuation distributions obtained by using radar data of rain and statistical modeling techniques⁷ ($d = 0$ represents single terminal; $d = 2, 5, 10, \dots, 35$ km represents different spacings between two terminals).

nals. This would result in enormous expenditures of money and manpower and take a relatively long time. On the other hand, the use of radar enables the three-dimensional rain structure to be captured on magnetic tape or disk. By using numerical modeling procedures, the path attenuation characteristics may be derived for variable frequencies, path angles, geographic locations, and site diversity configurations.

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