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The Influence of Rain on Design of 11-GHz Terrestrial Radio Relay

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Three salient factors governing attenuation of 11-GHz waves propagating through rain on a terrestrial radio path are discussed: magnitude of attenuation as a function of rain rate, relationship between attenuation and path length, and dependence of attenuation on polarization. Background material is given pertinent to the companion papers in this issue which develop procedures useful for radio system design.

I. INTRODUCTION

Terrestrial radio systems employing the 10.7–11.7 GHz common carrier band have been in use for many years. For example, analog TJ and TL radio are used for short-haul applications, and TL has served in cross-band diversity as protection for a 6-GHz system. However, new emphasis is being placed on autonomous 11-GHz systems, wideband digital implementations such as 3-ARDS[1] being attractive in many applications. It is therefore meaningful to re-examine the effects of rain on the propagation of 11-GHz signals; hop-length limitations imposed by rain have impact on the cost of service. Multipath fading, readily accommodated by antennas operated in space diversity, is not discussed. In the interest of designing reliable systems, our prime intent here and in the companion papers of this issue is to determine the limitation on hop lengths imposed by rain attenuation for given fading margin and annual outage time objectives for systems in the United States.

Three major factors are involved in this determination:

(*i*) The 11-GHz attenuation statistics must be properly associated with the rain rate statistics as determined by measurements at a point. There are two reasons for this: (a) It is only by virtue of long-term measurements of point rain rate, from sources such as the National Climatic Center, that a sufficient quantity of data can be obtained to provide reliable temporal statistics for calculation of the path attenuation. (b) It is only from measurements of point rain rates at numerous locations throughout the country, such as those compiled by the National Climatic Center, that the rain environment at arbitrary locations where radio systems may be installed can be suitably determined.

(*ii*) The spatial extent of rain associated with a given point rain rate must be accounted for; this is necessary, especially in the case of the intense showers which produce large attenuation, because the hop length may or may not exceed the dimension of the shower. This interdependence between storm dimensions and loss has the effect of producing a nonlinear relationship between attenuation and hop length, for a given point rain rate.

(*iii*) Dependence of rain attenuation on the polarization of 11-GHz transmission must be understood. Vertically polarized waves are attenuated less than those which are horizontally polarized because of the oblate shape of large raindrops; this results in different outage durations for vertical and horizontal polarization on a hop. In the design of a system involving many hops, a sequencing of polarization may therefore be desirable to equalize annual channel outage times.

The above three factors are dealt with in detail in companion papers;[2,3] here, the background material that forms the basis for these investigations is discussed.

II. MEASUREMENTS OF ATTENUATION BY RAIN

In 1956, a transmission experiment[4] was mounted at 11 GHz on colinear contiguous paths of 20 and 44 km at Mobile, Alabama. The measured attenuation caused by rain was compared with attenuation calculated[5] from the rain rate measured by 14 gauges along the 44-km path, and, although scatter in the data was large, agreement was fairly satisfactory. Therefore, by scaling annual distributions of 1-hour point rain rates of more than 25 mm/hr, obtained in other regions of the U.S., to the Mobile data, a set of contours defining constant hop length for a fixed outage time was developed. In 1965, an article[6] comparing theoretical calculations with rain attenuation measured at various microwave frequencies in several countries pointed out that serious deficiencies existed in the ability to predict path attenuation from point rain rates.

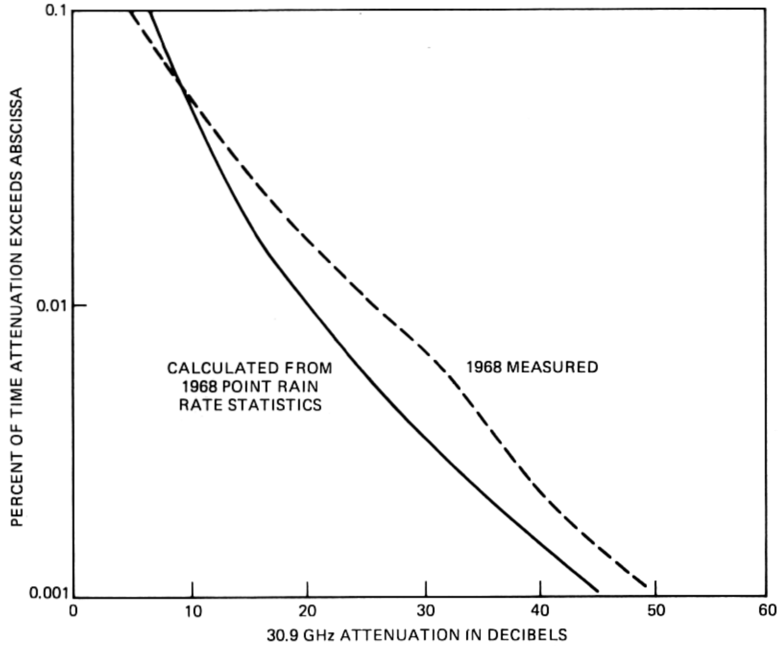

Fig. 1—Rain attenuation measured on a 1.9-km path in New Jersey compared with calculation based upon rain rate measured at a point on the path.

In 1967, an experiment involving 100 rain gauges arranged in a fine-grained network over a 410 km^2 area was performed at Holmdel, N.J.; these data[7] showed that the high microwave attenuation events[8] were produced by intense showers of limited size which resulted in nonlinear dependence of attenuation on path length, as noted in factor (*ii*) above. Simultaneous measurements[9] at 18 and 31 GHz on a 2.6 km path showed that the size distribution of the raindrops in heavy showers is adequately represented by the Laws-Parsons size distribution[10] which has been used for theoretical calculation[12] of attenuation by uniform rain on a path. Direct comparison of attenuation measurements on *short* paths with attenuation calculated from measured point rain rates is fairly satisfactory. In the example shown in Fig. 1, a cumulative distribution of 31 GHz attenuation measured[11] during 1968 on a 1.9-km path in New Jersey is compared with calculated results based upon point rain rates measured near the center of the path. In this early experiment, the predicted values of attenuation are somewhat less than the measured values. However, more favorable comparisons were obtained later in measurements on short paths,[13] and are discussed in a companion paper;[2] these are important in accounting for factor (*i*) of the introduction.

During that same series of experiments, measurements[14] at 31 GHz

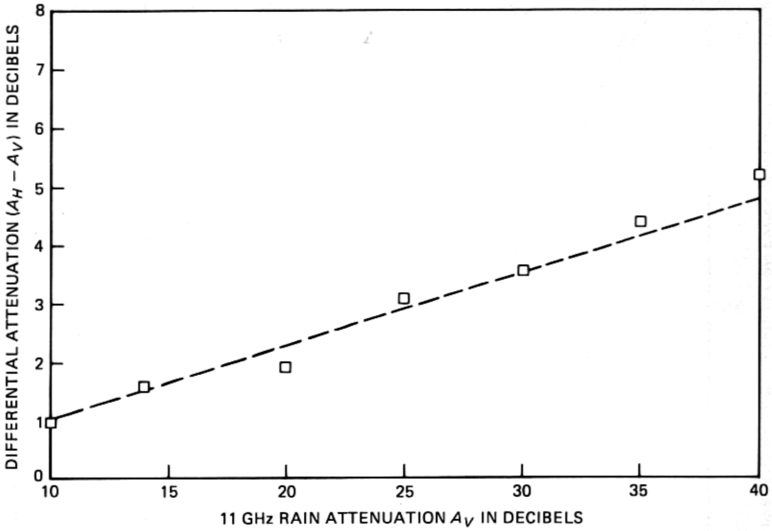

Fig. 2—Difference between attenuation of horizontally and vertically polarized waves measured at 11 GHz on a 23.4-km path in Pennsylvania during 1974. The attenuation on abscissa includes wet radome loss.

showed that horizontal polarization was attenuated about 15 percent (in decibels) more than vertical polarization. More recently, measurements of differential attenuation have been obtained at 11 GHz on a 23 km path at Harrisburg, Pennsylvania. As shown in Fig. 2, the difference amounts to about 12 percent; the effect has been investigated theoretically,[15,16] and good agreement with experimental data is found.[17] These results are used in companion papers, Refs. 2 and 3, to take factor (*iii*), above, into account.

In 1970, a substantial experiment[18] including 11 GHz propagation was started near Atlanta, Georgia. In particular, the 11-GHz rain attenuation was measured simultaneously on three hops of quite different length; cumulative distributions of path attenuation measured over long periods of time could then be compared directly. The comparison was made by choosing a (small) time interval of interest to system outage, 30 minutes per year for example, and noting the rain attenuations on the three distributions at this level of incidence; a certain measured point rain rate is also associated with the chosen time interval. These attenuations, when plotted versus hop length, are found to increase nonlinearly with distance, the slope of the curve decreasing with increasing hop length.[2] If such a plot were to reach an asymptote, attenuation then being constant with hop length, the interpretation would be straightforward, namely, that well-defined uniform storms with dimensions much smaller than the hop length were producing the attenuation. However, this asymptote is never reached because the probability of a shower intersecting a path continues to increase as the path length is increased. In reality, rain storms are not well defined geometrically, nor is the rain rate uniform throughout, therefore calculations[19] involving spatial correlation of the rain have been made; comparison with the 11-GHz attenuations measured at Atlanta is described in Ref. 3.

III. RAIN ON ANTENNAS

In addition to attenuation on the path per se, rain on various parts of an antenna produces enough attenuation to be of concern. This problem is especially serious in unprotected paraboloids fed from the prime focus, in which case water can form on the aperture of the feed as a layer or as drops. Since water introduces both loss and phase shift[20] at 11 GHz, its presence at the feed aperture where the power density of the wave is high causes considerable degradation in antenna performance by way of loss, reflection, and distortion of the phase of the wavefronts. These antennas therefore are usually protected by weather covers which enclose the paraboloidal reflector as well as the feed. Thus the problem is relegated to transmission through a weather cover wetted by rain; similar considerations apply to horn-reflector antennas.

Measurements have been made at 20 GHz on transmission through the water layer produced by various rain storms on a radome;[21] attenuations from 4 to 8 dB were observed, depending on factors such as the rain rate, wind velocity, and the nature of the surface of the radome. At 11 GHz, these values scale to between 3 and 6 dB. Measurements at 11 GHz have been made on a short hop employing paraboloids with hemispherical weather covers. After the rain on the path was accounted for through calculation, each weather cover was found[22] to contribute at least 3 dB of attenuation during heavy rain. Horn-reflector antennas fortunately are equipped with flat weather covers pitched somewhat beyond vertical; recent measurements during rain storms using a pair of closely spaced horn reflectors indicate that an attenuation of 4 dB per hop should be allowed[23] in the fading margin of an 11-GHz system to account for water on the weather covers. Note that the attenuation caused by water on weather covers is considered part of the fading-margin allowance rather than part of the attenuation caused by rain on the path per se. This allowance is discussed further in Ref. 3.

IV. SUMMARY

If the factors discussed above are taken into account, the 11-GHz rain attenuation statistics on a hop of arbitrary length can be estimated from measured point rain rate statistics as described in the companion papers. In all, estimates of annual attenuation have been carried out for 226 locations in the United States by properly processing point rain rates obtained from the National Climatic Center. The occurrence of intense rain is, of course, not the same from year to year at a given location; the resulting attenuation behavior will therefore also vary. It has been found necessary to use point rain rates measured over periods of 20 years or more to generate stable statistics. The deviation of data taken over 1- and 5-year periods (from the 20-year value) is discussed in Refs. 2 and 3. Reference 3 deals with application of the results to radio-path engineering, and an illustrative example of a tandem-hop situation is given. In calculating the performance of a system involving two or more hops, it is assumed that no two hops will simultaneously experience very deep fading as a result of rain attenuation. This assumption of lack of correlated outages to rain attenuation leads to slightly pessimistic estimates for the outage of a system.

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