SESSION 2F: PROPAGATION IN NEW SPECTRAL REGIONS
PAPER 2F-3

RAIN ATTENUATION AT MILLIMETER WAVELENGTHS

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Introduction

The major propagation problem confronting the use of millimeter waves for line-of-sight communication links operating through the atmosphere is hydrometeor scattering. Rain, hail, sleet, snow, and fog all can cause severe attenuation at millimeter wave frequencies. The severest problem is that of attenuation by rain. Attenuations in excess of 1 db/km are computed for frequencies in excess of 45 GHz (6.7 mm) and rain rates in excess of 0.1"/hr (2.5 mm/hr). Light rain of this intensity occurs on the average of 80 hrs/year in the New York area and is generally wide spread, completely covering typical line-of-sight ground link distances. This means that for a ground link of 50 km extent the attenuation would exceed 50 db 0.9 percent of the time for frequencies above 45 GHz.

The problems of hydrometeor scattering have been recognized for years. Measurements have been made at centimeter and millimeter wavelengths to confirm the results of computations of rainfall attenuation. A survey of propagation measurements made prior to 1965 showed particularly poor agreement between measurements and calculations especially at frequencies near 35 GHz (8.6 mm). Recent measurements reported in the literature tend to support the conclusions that the current theory is not sufficient to adequately predict attenuation.

Computations of Attenuation Due to Rain

The computations of attenuation due to rain have been made using the assumptions that the raindrops are spherical, the dielectric constant of the water in the drops is uniform and known, that single scattering theory is sufficient to evaluate scattering from a volume of raindrops, and that the effect of scattering by the rain-filled medium can be described by an effective index of refraction of the medium. Using these assumptions the attenuation coefficient is determined from the imaginary part of the effective index of refraction of the medium and is proportional to the sum of the total scattering and absorption cross section per-unit volume averaged over the drop-size distribution applicable to the unit volume. The attenuation coefficient thus obtained describes the behavior of the expected value of the amplitude of the wave propagating through the medium or the so-called coherent signal propagating through the medium.

Incoherent Energy Propagation Through Rain

Of the assumptions used to make the computations for comparison with measured data, the one most suspect is that of neglecting the incoherent energy propagating through the medium. The energy received after propagation through the medium is the sum of the coherent and incoherent energy. The incoherent energy describes the variance of the expected value of the amplitude of the wave about its mean value or the fluctuations in apparent attenuation. For each drop, part of the energy lost to the propagating wave is absorbed by the drop and part is rescattered. The ratio of the energy rescattered to that lost is called the single albedo. For small values of albedo most of the energy is absorbed and the incoherently scattered signal reaching the receiver will be negligible; for values near one the opposite may be true. For frequencies below 5 GHz less than 5 percent of the energy lost to the propagating wave is rescattered. For frequencies above 45 GHz the single scattering albedo for a unit volume is greater than .45 and more than 45 percent of the energy lost is available for multiple scattering.

The propagation of incoherent energy through the rain-filled medium may be described using radiative transfer theory. A criterion for the use of the coherent attenuation to describe both coherent and incoherent transmission through rain can be made from the ratio of the incoherent energy transmitted along the line-of-sight to the coherent energy received. Computations for a value of the ratio of .1 show that the incoherent signal is greater than .1 of the coherent signal for rain rates greater than .1"/hr for distances greater than 50 km for a frequency of 22.5 GHz (1.3 cm), greater than 10 km for a frequency of 37.5 GHz (8. mm), and greater than 2 km for a frequency of 75. GHz (4. mm).

The use of the computed attenuation coefficient to estimate the performance of a millimeter wave system in rain depends upon the effect of the incoherent signal present with the coherent signal at the receiver. It is expected that the incoherent signal will vary slowly with time and for many systems will represent an added fluctuation of the received signal or an apparently fluctuating attenuation, the amplitude of the fluctuation of attenuation depending upon storm structure, antenna beamwidth, and other relevant parameters of the receiving system.

Effects of Storm Structure

Another source of discrepancy between measured and computed attenuation values is the effect of spacial and temperal changes in rainfall intensity. Radar and radiometric measurements of rainfall structure show large changes in intensity over distances of the order of 500 meters in both wide spread and showery rain. Most experimental measurements are made using rain gauges as the source of rain intensity data. The rain gauges sample rainfall intensity only for a limited region about each gauge. The data does not apply to the entire path unless the gauges are spaced at distances less than the distance over which rainfall intensity can vary significantly. The inadequate instantaneous sampling of rain intensity along the path can lead to errors in the estimated average attenuation along the path, hence to a discrepancy between measured and computed attenuation.

Results of Measurements at 8 GHz

An investigation of the discrepancies between measured and computed attenuation was conducted at M.I.T., Lincoln Laboratory at a frequency for which the single scattering solution to the radiative transfer equation is valid. The experiment compared predicted values of brightness temperature due to rain at 8 GHz (3.7 cm) computed from radar measurements of rain intensity with measured values. The results indicate that except for the difference in beamwidths between the radar and the radiometer system, the data was within the rms deviation of expected results computed using the measurement uncertainty of the radar and the uncertainty of the drop-size distribution.

Conclusions

The results of the radar, radiometer comparison measurements show that when single scattering theory is valid and adequate spacial resolution is available in the estimate of rain intensity agreement is found between computations and measurements. The results of the analysis also show that at millimeter wave frequencies the estimation of the effect of rain on a communications link is much more difficult because of the incoherent energy present at the receiver. The effect of the rain depends not only on the rain intensity, but on the path length, receiver-antenna beamwidth, and the modulation system used. For the adequate estimation of rain effects on a given system, more than just the coherent attenuation is required. A more complete channel characterization must be used.

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