60 GHz Band Propagation Experiments on Terrestrial Paths in Sydney and Praha

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Abstract. *Two studies of the outdoor propagation of 60 GHz microwaves are described. The focus of this paper is the relationship between rainfall and measured attenuation of the microwave signal. Experimental data are presented and the measured statistics are compared with the Recommendations of the ITU-R. Measured rain intensity statistics at the two sites were found to be in good agreement with the ITU-R Recommendations, however measured attenuations were higher than those calculated using the models provided by the ITU-R.*

Keywords

Electromagnetic wave propagation, attenuation due to rain, rain intensity distribution, rain attenuation distribution.

1. Introduction

The region of the electromagnetic spectrum between 30 and 300 GHz (the millimeter-wave region) has been under-utilized by communication and other technologies in the past. However, over the past five years, millimeter-wave radios operating around 40 and 60 GHz have become commonplace. These radios are primarily employed in cellular backhaul systems but are also finding applications in the enterprise market.

An important consideration in the design of millimeter-wave radio links is the effect of rainfall on received signal strength. Rain droplets both scatter and absorb incident millimeter-wave radiation and hence rainfall leads to attenuation of the millimeter-wave signal. Consequently, local rainfall patterns must be taken into account in the design to ensure that the link is reliable; most telecommunications carriers require links to display 99.999% availability (i.e. downtime of less than 5 minutes/year).

Unfortunately, there is little measured data [1]-[4] available at 60 GHz to validate the models of the International Telecommunication Union – Radiocommunication Sector (ITU-R) [5], [6]. These models are mainly based on studies below 40 GHz and consequently become less reliable at higher frequencies.

This paper describes two propagation studies (in Sydney, Australia and Praha, Czechia) which aim to add to the limited body of data currently available at 60 GHz.

The first study is being conducted at CSIRO's Marsfield site in Sydney, Australia. The CSIRO ICT Centre (CSIRO) is currently carrying out research into millimeter-wave radio systems operating at frequencies between 55 and 100 GHz. The aim is to create wireless systems capable of transmitting data at rates of greater than 5 Gbps over short distances (< 2 kilometers). As part of this research, CSIRO is collecting propagation and weather data at frequencies between 55 and 100 GHz, with the aim of improving the applicability of propagation models at these frequencies.

TESTCOM has been carrying out extensive experimental research in the frequency bands 19, 26, 38, 58 GHz and in the optical band 850 nm. Experimental research in the frequency band 58 GHz has been done in collaboration with the Institute of Atmospheric Physics of the Academy of Sciences of the Czech Republic (IAP AS CR) on an experimental path between IAP AS CR and TESTCOM since December 2000. This research has been focused on the attenuation due to hydrometeors (rain, snow, hail, and fog) in our specific climatic conditions.

2. Experimental Setup

In this section, the 60 GHz radio systems as well as radiometeorological facilities used at CSIRO and TESTCOM are described.

2.1 Experimental Setup at CSIRO

The experimental setup at CSIRO has been described previously [7]. The average temperature range at the Marsfield site varies from 17 – 27 ºC in January to 5 – 17ºC in July. The average annual rainfall is 1150 mm with the rainfall generally peaking during summer/early autumn (December to March) when thunderstorms are common.

CSIRO uses a commercially available 60 GHz system for rain attenuation measurement. Three tipping-bucket raingauges, an optical disdrometer and a present weather detector are used for rain intensity data measurement.

2.1.1 60 GHz Radio System

The 60 GHz link is a commercially available system operating at 60 109 MHz on a bearing of 152º and at 61 845 MHz in the opposite direction (332º); both frequencies lie near the center of the 60 GHz oxygen absorption band. The millimeter-wave links are 250 meters in length, approximately 10 meters above the ground surface and 95 meters above mean sea level. The links are vertically polarized and the data are transmitted at 125 Mbps in each direction. The transmitted and received signal strengths are monitored, along with availability and bit error rate for each 10-second interval. The measurements reported here were obtained by averaging the 10-second data over one-minute periods.

2.1.2 Rain Intensity Measurement

Because variations in rainfall can occur on scales less than the link length (100 meters or less), a number of rain gauges are used to ensure that the rainfall data collected give a true measure of rainfall intensity along the link.

Three tipping-bucket raingauges were installed, one at each end of the link and a third at the midway point. In addition, an optical disdrometer is operated at one end and a present weather detector (PWD) at the other end of the link. These latter two devices provide rain rate data for each 10 and 15-second interval respectively, however data are averaged over a one-minute period in the measurements reported here.

The three tipping bucket rain gauges were all of identical construction. A collecting area of 200 mm diameter collects the rainfall, which is strained by a metal gauze before being passed to the tipping bucket measuring system. Tips of the bucket occur with each 0.2 mm of rainfall collected.

The Scintec Parsivel optical disdrometer consisted of a 3 mW, 780 nm infrared laser, optics to spread the beam into a horizontal plane (27 mm wide, 180 mm long and 1 mm thick), optics to focus the beam and a detector (a single photodiode). When particles passed through the light beam, they obscured part of the beam and reduced the amount of light arriving at the detector. The drop in signal amplitude was used to estimate the particle size and the transit time used to estimate the particle velocity. The sensor has a threshold of 0.01 mm/h (0.000167 mm in one minute), below which rainfall is not recorded.

The VAISALA Present Weather Detector (PWD11) uses a combination of capacitive and scattering measurements to estimate precipitation rates. The capacitive device consists of thin wires protected by an insulating glass coating. The presence of water on the glass coating changes the capacitance of the device. The scattering device consists of an infrared transmitter and a receiver about 30 cm apart and oriented at an angle of 45° to each other. In such a configuration light from the transmitter could only reach the receiver if it was reflected off particles along its path. A near-infrared LED with a wavelength of 875 nm and a peak power of 60 mW supplied the infrared light. Rapid changes in the scattered signal were identified as precipitation droplets and the droplet data were used to estimate precipitation intensity.

Dust was differentiated from precipitation using the signal from the capacitive sensor. Where particles were identified but there was no change in capacitance, the particles were identified as dust. Where a change in capacitance was also recorded, the particles were identified as precipitation.

Fig. 1. One end of the experimental link at CSIRO in Sydney.

2.2 Experimental Setup at TESTCOM

TESTCOM uses a commercially available 60 GHz system for rain attenuation measurement. A heated siphon raingauge and PWD are used for rainfall intensity measurement. The average annual temperature at the nearest meteorological station Praha-Karlov [8] is 9.3 °C and the average annual rainfall is 431 mm. Thunderstorms and heavy rains occur mostly during the hotter months – from April to September.

2.2.1 60 GHz Radio System

NOKIA MetroHopper equipment has been used at TESTCOM in Praha. The equipment was modified with special 60-cm diameter, off-set antennas that were manufactured at TESTCOM. The path length is approx. 850 m, the frequency used is 57 650 MHz with V polarization.

Records of received signal were processed statistically and cumulative distributions of attenuation due to hydrometeors were obtained for individual months of the one-year period of observations January 2004 - December 2004. The recorded attenuation values were compared with the concurrent meteorological data [8] and the PWD data, and this made it possible to distinguish between attenuation due to rain, snow, fog, rain with snow and rain with hail. Cumulative distributions of attenuation due to rain for the worst month over the one-year period as well as for the whole year period of observation were obtained.

Fig. 2. The end site of the experiment in Praha at IAP AS CR.

2.2.2 Rain Intensity Measurement

Rain intensity data measured by a heated siphon rain-gauge at TESTCOM were used for obtaining the average one-minute rain intensities. Cumulative average one-minute rain intensity distributions were obtained for individual months, for the worst month over the one-year period and for the whole year.

3. Experimental Results

Experimental data obtained from both the rain intensity and rain attenuation measurements were statistically processed. Results are given in the following paragraphs.

3.1 Cumulative Distributions of Rain Intensities

The cumulative distributions of average one-minute rain intensities for individual months of the one-year period of observation obtained at CSIRO are shown in Fig. 3. The distribution for the worst month is composed of distributions for September (127 mm/h < R(1) ≤ 174 mm/h), and October (R(1) ≤ 127 mm/h).

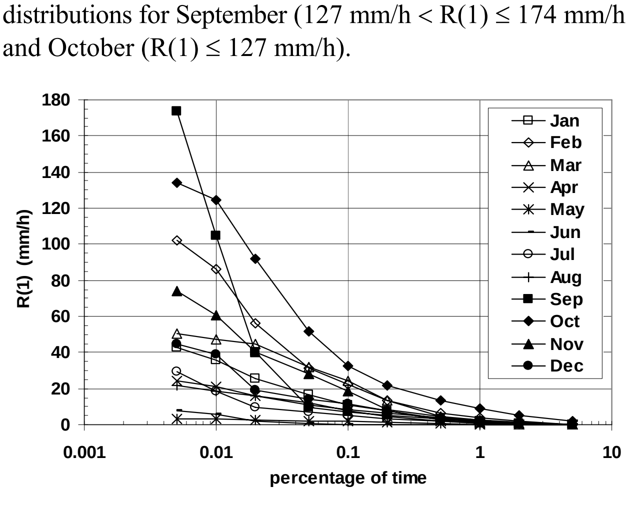

Fig. 3. Cumulative distributions of rain intensities obtained at CSIRO in 2004.

The cumulative distributions of average one-minute rain intensities for individual months of the one-year period of observation obtained at TESTCOM are given in Fig. 4. The distribution for the worst month is composed of distributions for July (49 mm/h < R(1) ≤ 61 mm/h), August (3 mm/h < R(1) ≤ 49 mm/h), and June (R(1) ≤ 3 mm/h).

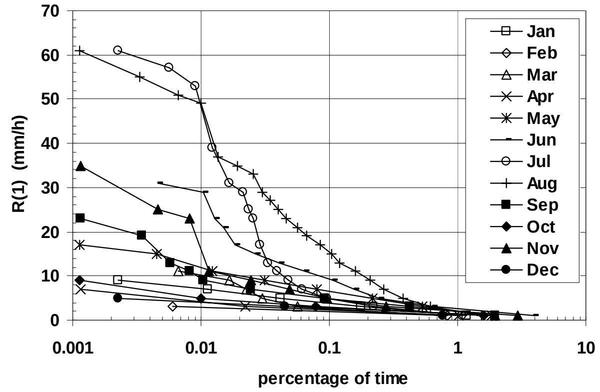

Fig. 4. Cumulative distributions of rain intensities obtained at TESTCOM in 2004.

3.2 Cumulative Distributions of Attenuation due to Rain

The cumulative distributions of attenuation caused exclusively by rain for individual months of the one-year period of observation (January 2004 – December 2004) at CSIRO are shown in Fig. 5.

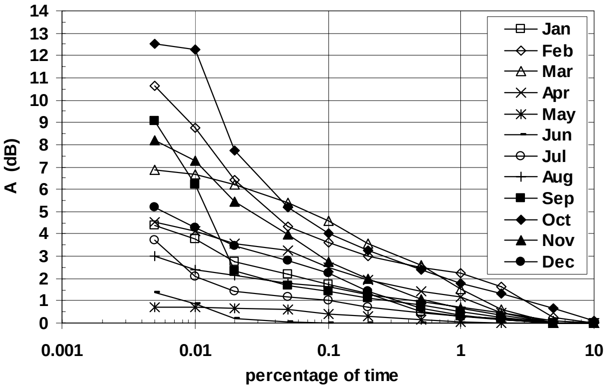

Fig. 5. Cumulative distributions of attenuation due to rain obtained at CSIRO in 2004 (60 109 MHz, 250-meter path length).

The distribution for the worst month is composed of distributions for October (5.5 dB < A ≤ 12.5 dB), March (2.4 dB < A ≤ 5.5 dB), February (1 dB < A ≤ 2.4 dB), and October (A ≤ 1 dB).

The cumulative distributions of attenuation caused exclusively by rain for individual months of the one-year period of observation (January 2004 – December 2004) at TESTCOM are shown in Fig. 6. The distribution for the worst month is composed of distributions for August (6 dB < A ≤ 28.5 dB), May (3.5 dB < A ≤ 6 dB), and June (A ≤ 3.5 dB).

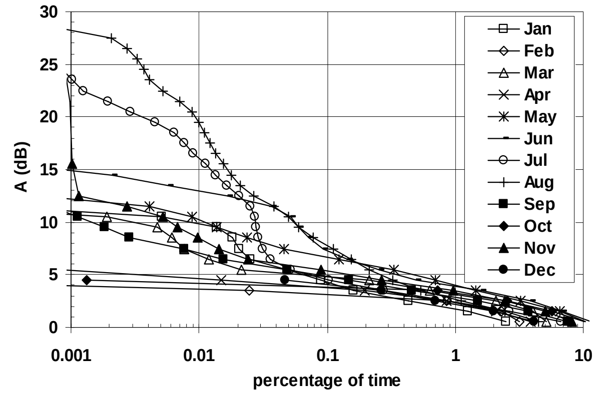

Fig. 6. Cumulative distributions of attenuation caused exclusively by rain for whole year period at TESTCOM (57 650 MHz, 850-meter path length).

3.3 Comparison with ITU-R Predictions

3.3.1 CSIRO, Sydney

The measured cumulative distributions of rain intensity for the one-year period and the worst month over this one-year period are presented in Fig. 7. For comparison, the corresponding distributions calculating using the relevant ITU-R Recommendations [5], [9] are also shown. The measured data are in very good agreement with the ITU-R Recommendations at lower rain intensities (< 50 mm/h). At higher rain intensities, the measured intensities are greater than those calculated using the ITU-R Recommendations; these high rain intensity data were obtained during unusually heavy storms in September and October.

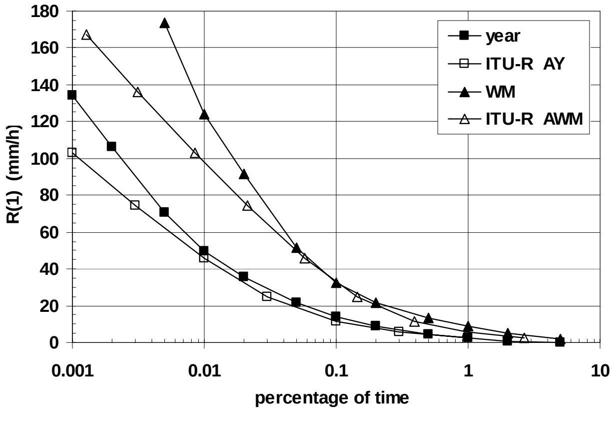

Fig. 7. Obtained cumulative distributions of rain rate for the whole year period and worst month obtained at CSIRO.

The measured cumulative distributions of attenuation for the one-year period and the worst month over this one-year period are presented in Fig. 8. For comparison, the cumulative distributions of attenuation due to rain for the average year and average worst month calculated in accordance with [6], [9] for the one-year period of observation are also shown (ITU-R Recommendation 530-11 [6] is only intended for use below 40 GHz, however there is currently no alternative at higher frequencies). The cumulative distributions were calculated using the measured value for the one-minute rain intensity exceeded 0.01% of the time ($(R(1)_{0.01} = 49.5$ mm/h). The measured attenuations were higher than those calculated using the ITU-R Recommendations at all time percentages.

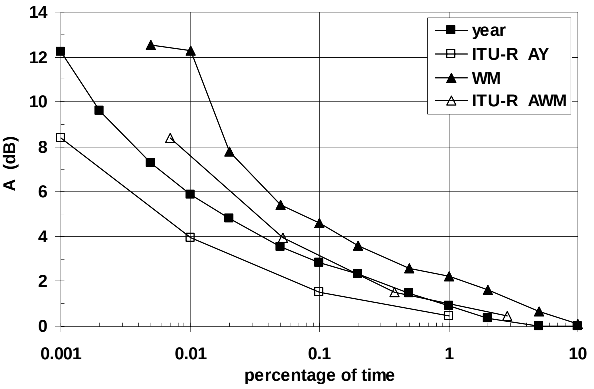

Fig. 8. Obtained cumulative distributions of attenuation due to rain for the whole year period and the worst month obtained at CSIRO.

3.3.2 TESTCOM, Praha

The measured cumulative distributions of rain intensity for the one-year period and the worst month over this one-year period are shown in Fig. 9. Obviously, the measured cumulative distributions of rain intensity are slightly lower than the calculated ones in accordance with [5], [9].

The measured cumulative distributions of attenuation for the one-year period and for the worst month over this one-year period are shown in Fig. 10. For comparison, the cumulative distributions of attenuation due to rain for the average year and for the average worst month calculated in accordance with [6], [9] for the one-year period of observation are also drawn in Fig. 10. Distributions were calculated for the average one-minute rain intensity measured at TESTCOM over the one-year year period of measurement ($(R(1)_{0.01} = 20.0$ mm/h), the average one-minute rain intensity calculated according to [5] ($(R(1)_{0.01} = 26.0$ mm/h), and the long-term average one-minute rain intensity measured at site with average meteorological condition in the Czech Republic ($(R(1)_{0.01} = 30.7$ mm/h) [10], [11].

4. Discussion

The measured rain intensities for calendar year 2004 are in good agreement with the calculated rain intensities obtained by applying the model outlined in [5] to Sydney and Praha respectively. The agreement is better than would be expected from only one-year of measured data as the ITU-R rain intensity model is statistical and based on long-term measurements. It was found [12] that the average root mean square error of rain intensity measured over 1-year period to the long-term rain intensity value is about 30% (root mean square values vary from about 7% for 1% of time to about 60% for 0.001% of time).

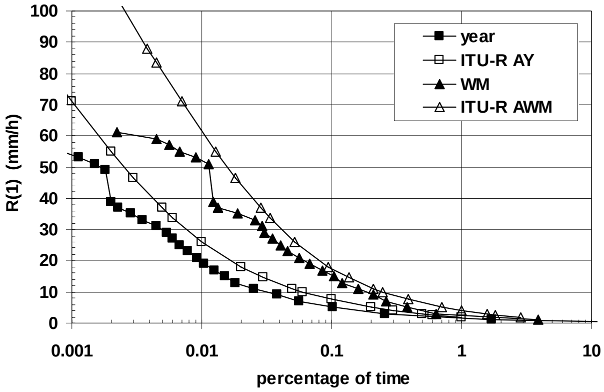

Fig. 9. Cumulative distributions of rain intensity for the whole year period and the worst month obtained at TESTCOM and calculated ones in accordance with ITU-R.

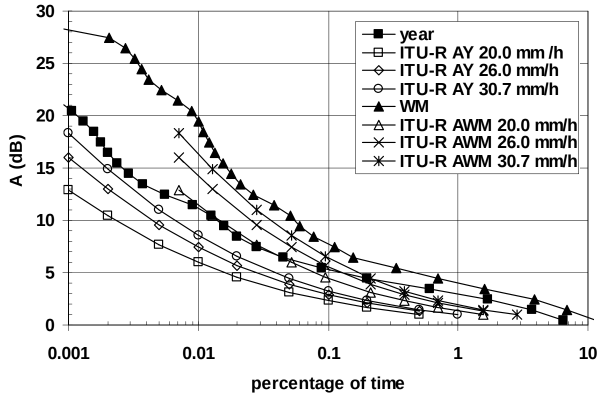

Fig. 10. Cumulative distributions of attenuation due to rain and the calculated ones for the whole year period and the worst month obtained at TESTCOM and calculated distributions in accordance with ITU-R.

The measured attenuation data at both sites and for all rain intensities is higher than that calculated using [6]. At a rain intensity of 20 mm/h the difference is approx. 5 dB/km at both sites, dropping to approximately 3 dB/km at rain intensity of 5 mm/h. It is possible that the higher measured attenuation is a result of wetting of the radomes at either end of the links. However, this is unlikely for two reasons:

(i) Rudimentary shades were used at each site to help prevent radome wetting; and

(ii) Despite the different path lengths (250 meters compared with 850 meters), both studies obtained a similar increase in measured attenuation when expressed in dB/km.

Other possible explanations for the higher measured attenuation are the spatial year-to-year variability of rainfall at the sites, and the fact that the ITU-R models have not been verified at frequencies over 40 GHz.

The results presented here are in broad agreement with previous studies [2], [4] that found measured attenuations were higher than those calculated using the ITU-R models for frequencies above 50 GHz and rain intensities below about 30 mm/hr. The major contrast with these earlier studies is that the measurements at CSIRO in Sydney also appear to show higher measured than calculated attenuation at rain intensities above 30 mm/hr. However, this high rain intensity data may not be representative as it was significantly influenced by unusually heavy storms in September and October 2004; it is hoped that further high rain intensity data will clarify this discrepancy.

5. Conclusions

Results from two propagation studies at frequencies near 60 GHz have been presented. The impact of rain on attenuation at 60 GHz has been investigated and the measured data were compared with the Recommendations of the ITU-R, which are based on measured data at lower frequencies.

The measured rain intensity data is in good agreement with the calculated rain intensities obtained by applying the model outlined in [5] to Sydney and Praha respectively. The agreement is better than would be expected from one-year of measured data as the ITU-R rain intensity model is based on long-term measurements.

The measured attenuation data at both sites is higher than that calculated using [6] for all rain intensities. At rain intensity of 20 mm/h the difference is approximately 5 dB/km at both sites, dropping to approximately 3 dB/km at rain intensity of 5 mm/h.

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