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ANALYSIS EFFECT OF WATER ON A KA-BAND ANTENNA

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Abstract—Wet antenna attenuation during rain events is examined through carrying out simulated rain experiments. These were conducted on the receiving antenna located at Penang, Malaysia. The findings from these experiments are used to estimate rain attenuation data for that path by adjusting the collected data for wet antenna attenuation. This was done for the 1-year period of March 2007 to February 2008 and includes average and worst month cumulative distribution functions. The results of the measurement indicated that the wet antenna effect is a significant attenuator, and should be included in a link budget. The measured attenuation values were 4 dB for the wet feed window and total reflector plus feed window attenuation value of 6.3 dB at 20.2 GHz, at a rain rate of 100 mm/h.

1. INTRODUCTION

The performance of millimeter-wave and centimeter-wave antennas is degraded during wet weather. In particular, if radomes are used to protect the antenna system, layers of liquid form and modify the wave-fronts through absorption, reflection, refraction, and scattering. Similarly, liquid on a perfect reflector produces undesirable effects, but a given thickness of liquid is not nearly as serious on a reflector as on a radome [1]. The receiving antennas of the advanced communications technology satellite (ACTS) propagation experiment have been shown to introduce attenuation of their own when their surfaces become wet [2, 3]. This attenuation is in addition to the rain-induced attenuation along the propagation paths. The magnitude and nature

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of the wet-antenna attenuation has been the subject of numerous investigations [3–5]. The main findings of these investigations are the antenna attenuation due to surface wetting could reach values of 10 dB at Ka-band and the antenna attenuation during rain at any instant of time is essentially related to the amount of water accumulated on the antenna surfaces at that instant. It is, however, largely independent of the instantaneous rain rate. In general, wet radome surfaces result in much higher attenuation than that due to wet reflectors.

In general these results showed that feed wetness are the main contributor to the system losses, with reflector wetness being a lesser factor. The water in the feed aperture distorts the electric field's distribution of the feed creating a high perturbation on the feed standing wave ratio (SWR). The reflector losses can be explained by additional scattering losses due to rain drop's size at the surface of the reflector. This creates a distorted reflector surface that reduces the antenna gain by several dB's in the worst case. Frequency scaling may not seem to hold when the antenna is saturated with water, a factor that need's to be considered in a system design that employs fade compensation and frequency scaling [6].

It may not be possible to extract the true instantaneous path attenuation data from the measured data, but it would be useful to have reasonable estimates of the path attenuation, estimates that could be used with a measure of confidence in system design and in modeling and frequency scaling [7]. The key to separating path and antenna attenuation lies in estimating the latter through simulated-rain experiments. Using the information obtained from these experiments, suitable models can be developed for estimating attenuation along the path. These experiments were conducted on the Ka-Band receiving antenna at Universiti Sains Malaysia (USM), under conditions similar to those prevalent during rain events. The preliminary analyses of these measured data, together with the corresponding predicted rain attenuation, are discussed. The results strongly suggest that water on the radome has a significant consequence on the received signal level.

2. METHODOLOGY

The main station for the experiment was located at University Sains Malaysia (USM) (Lat.: 5.17°N and Long.: 100.4°E) in Nibong Tebal, Penang and is about 7 km from the sea and about 57 m above mean-sea-level. The transmitted EIRP of the antenna is 17.0 dBW with a Right Handed Circular Polarization and a modulation of PCM that uses a horn type of antenna. The antenna is a 1.2 m parabolic dish with off-axis feed horn. With the elevation angle of 60°, both dish and feed horn face upwards. The experiments were performed on clear days when there was no rain activity along the propagation path. The experimental setup consisted of a system of 7 elevated sprinklers, which resulted in high rain rates above 100 mm/h (2 m above the antenna), adjustable to produce sprays of a wide range of drop size and intensity, ranging from heavy showers to mist-like precipitation. The sprays from the sprinklers were directed upwards. A pump in the water line feeding the sprinklers forced sprays to rise in the air more than 2 m further before falling on the antenna in a simulated rain fashion. Figures 1

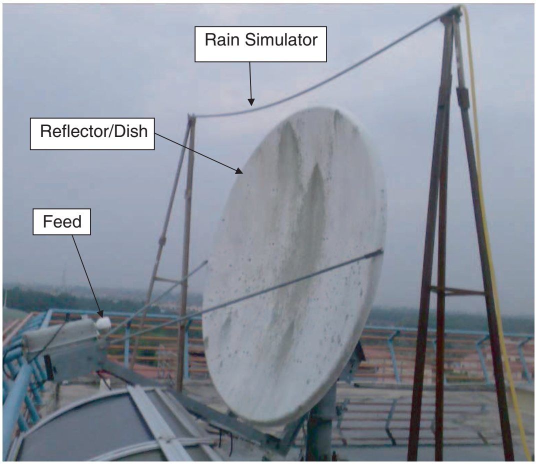

Figure 1. Experimental setup.

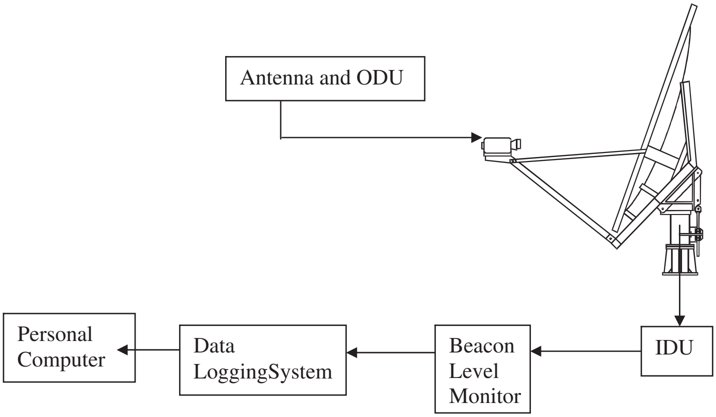

Figure 2. Beacon measurement setup.

and 2 shows the experimental and beacon measurement setup. The receiver setup for measurement is shown in Figure 2. It consists of an antenna, an outdoor unit (ODU), and indoor unit (IDU), a beacon level monitor, data logging system and a personal computer for user interface. The ODU houses the waveguide and low noise amplifier (LNA) and is mounted at the focal point of the parabolic dish. It downconverts the Ka-band beacon signal frequency to an intermediate frequency (IF) of 955 MHz. The ODU is connected to the IDU using a coaxial cable. The IDU which houses the power supply unit is also used for setting the data transmission mode, transmitting and receiving frequency, transmission output power and transmission rate. The beacon level monitor is connected to the IDU and placed indoor.

To account for any variation in the satellite signal strength due to orbital variations, the average clear day signal strengths on the day prior to and after the rainy day(s) were used in computing the rain attenuation. Calibration of equipments are done for every 6 months.

For average attenuation computation, the output signal of the receiver antenna, at the dish, was connected to a spectrum analyser, which was interfaced to a computer via a labVIEW-interfacing card. The labVIEW was programmed to record the peaks of sixty successive samples each of 1ms duration. The software then calculates the mean of these sixty peak values. These recordings were then repeated every 10 s giving six averaged peak values in a minute.

The rain rate was measured using a Casella tipping bucket arrangement of diameter 20 cm. The large diameter of the tipping bucket rain gauge was selected so that a more accurate measurement of the rain rate can be made. The rain gauge had its own programmable data logger. The clock of this was regularly synchronized with that of the computer and the lag in time observed was 4 s in one week. The rain rate was computed from the frequency of the tips of the tipping bucket rain gauge. The standard tipping bucket used had a calibration of 0.2 mm/tip. The tip times were recorded on the built in data logger of the rain gauge. The average rain rate was calculated using the time elapsed between successive tips.

The uncertainties in the beacon measurements, the uncertainty in the rain rate estimates and the variations due to wind are all considered to be independent zero mean random processes. Table 1 shows estimated upper bounds for the standard deviation in the attenuation due to each individual effect and the total standard deviation was calculated by adding the variances as follows [7],

$$\sigma_{total}^2 = \sigma_{beaconmeasurement}^2 + \sigma_{rainrate}^2 + \sigma_{wind}^2 \tag{1}$$

For the error budget in Table 1, the standard deviation which is the square root of the variance is used. The error budget shown in Table 1 was calculated for rain rates between 10 mm/h to 100 mm/h.

Table 1. Error budget (upper bound on the standard deviation).

Effect	20.2 GHz
Beacon measurement error	0.2 dB
Rain rate measurement error	0.3 dB
Wind error	0.3 dB
Total	0.5 dB

Table 2. Wind effect on rainfall rate at different levels.

Rainfall Rate mm/h exceeded at different percentage of time							
Level	1	0.3	0.1	0.03	0.01	0.003	0.001
Ground	13.9	30.3	51.5	89.1	129	170.8	212.4
50 m above Ground	13.5	29.5	50	87.3	126.1	167.5	208.5
% error	3	2.6	2.9	2.0	2.2	1.9	1.8

In order to see the differences in rainfall rate due to the effect of wind, one rain gauge should be placed at ground level and the other few meters above ground level. For this case, one rain gauge was placed at ground level in a pit and the other 50 m above ground level. Table 1 shows the difference of rainfall rate in terms of percentage error.

In this study, the wind-induced error was estimated from comparison measurements of elevated (50 m above ground) and ground level rain gauges. Table 2 shows that, a gauge exposed to wind typically caught by 1.8% to 3% less rain than a nearby gauge at ground level in a pit. This procedure was done to evaluate the integral wind-induced error of investigated rain gauges as a function of rainfall rate and to estimate the difference between the gauges.

3. RESULTS AND DISCUSSION

Figure 3 presents the one-minute average attenuation measurements at 20.2 GHz on December 16, 2007. In this experiment, all seven sprinklers were active and the rain rate was between 80 mm/hr and 120 mm/hr. After the sprayer was turned off, the attenuation decreased

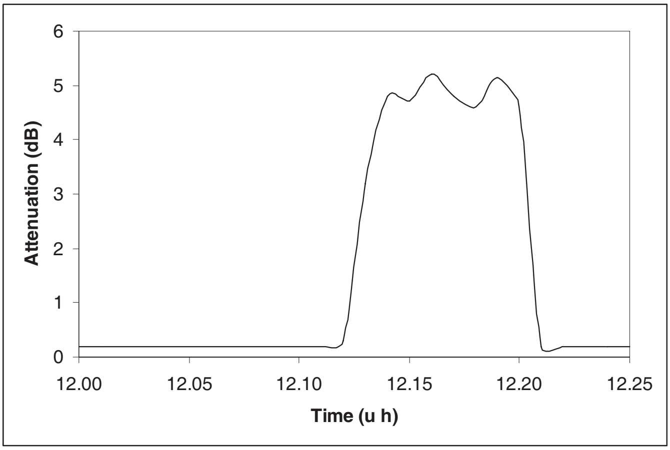

Figure 3. The sprayer of water onto the antenna on December 16, 2007.

rapidly. Most of the water ran off in less than a minute after the spray stopped. The variations in attenuation level during the experiment were attributed to the horizontal motion of the spray pattern caused by wind variations. The thickness distribution function will vary with the direction of the rainfall. In Figure 4, the mean thickness of the water layer for vertical rainfall is compared to rain at an angle of 60° with the vertical when the rainfall points toward the front of the dish. The water layer thickness were calculated by integrating numerically down the reflector surface from the top of the reflector to each coordinate used in the calculation of the reflected field [8].

Table 3 shows a comparison of the effects of water layers on radome

Table 3. Comparison of the effects of water layers on radome and reflector surface.

Thickness of water layer, d, inches	Radome transmission loss, dB	No radome transmission loss, dB
	20.2 GHz	20.2 GHz
5	6	0.05
10	9.2	0.22
15	11.2	1.1
20	13.1	2.8

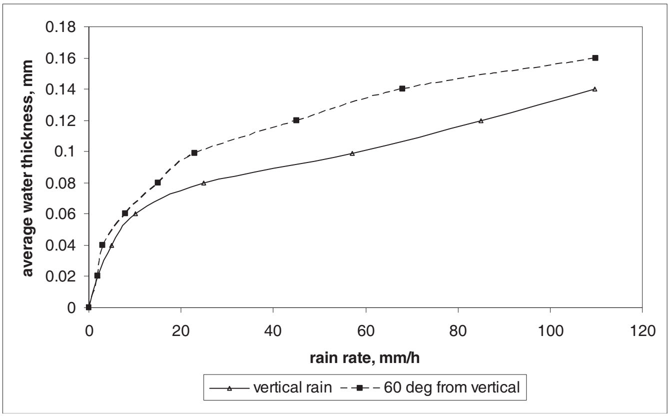

Figure 4. Vertical rainfalls compared with rain at 60° from vertical.

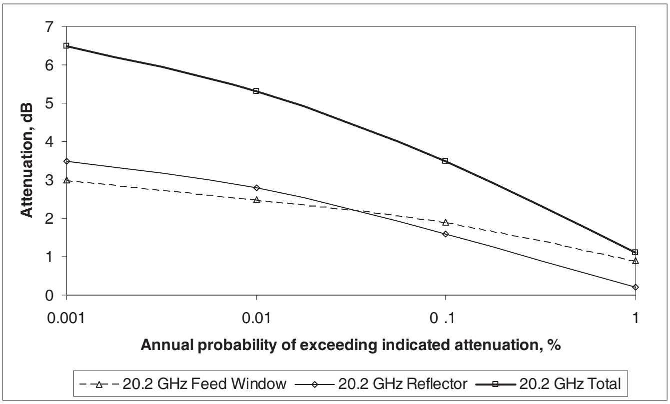

Figure 5. Rain incidents on the reflector, feed window and total of both at 20.2 GHz.

and reflector surfaces for given layer thicknesses If no radome is used, losses due to water layers formed on the reflector surface, although less predictable, are much smaller and will, in most cases, be negligible.

Figure 4 shows that wind blowing towards the front of the dish causes a considerably thicker water layer on the reflector than the case for no wind. Note that wind blowing towards the back of the dish theoretically will have the reverse effect and cause less water to accumulate on the reflector surface. The wet feed window (radome) attenuation was measured on several of the experiments by wiping the water off the feed immediately after shutting off the sprayer. The result was average attenuation values of 4 dB at 20.2 GHz. Figure 5, shows that total reflector plus feed window attenuation value of 6.3 dB at 20.2 GHz is achieved at 0.001 percent annual probability of exceeding indicated attenuation. In order to minimize the effect of wet reflectors the dielectric thickness of the reflector needs to be minimized to reduce the losses in the presence of a water layer.

4. CONCLUSION

The preliminary analyses suggest that the effects of water on the antenna radome may be an important mechanism in addition to rain attenuation along the path. The effects of water on the antenna radome is a possible cause of the higher attenuation measured. Tests were conducted to evaluate the effects of water on the antenna radome. The development of a procedure to estimate path attenuation from the measured attenuation data requires knowledge of the salient characteristics of the wet antenna attenuation.

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