Research Article

Study of the Effect of Simulated Rain on the Offset Parabolic Antenna at Ku-Band with Different Elevation Angles

H. Mostafa, S. I. S. Hassan, J. S. Mandeep, M. F. Ain, and H. A. Khedher

Received 16 November 2006; Revised 20 March 2007; Accepted 24 April 2007

Recommended by Joshua Le-Wei Li

Effect of rain on the receiver antenna is a major factor to degrade the system performance in a frequency above 10 GHz. This paper deals with the wet antenna attenuation at Ku-band with three different frequencies at different rain rates. During the Ku-band propagation experiment, it was discovered that rain water on the antenna caused a significant attenuation. It is necessary to estimate the losses caused by water on the antenna in order to separate these losses from the atmospheric propagation losses. The experiment was done at USM Engineering Campus to study the attenuation for these physical parameters. A Ku-band RF signal was generated by a signal generator and transmitted via horn antenna. The signal was received using a smooth offset antenna of 60 cm by 54 cm (Astro dish) and measured using spectrum analyzer. In order to simulate a rain, pipes with bores of a same distance were implemented. Three cases were considered: in the first case one pipe was used to simulate low rain rate, the second case two pipes were used to simulate medium rain rate, and the third case three pipes were used to simulate heavy rain rate. In addition, the tap was used to control the flow of water in order to get more values of rain rate. The total attenuation of RF signals due to water layer on the feed and on the reflector feed was found to be 3.1 dB at worst case. On the other hand, the attenuation of RF signal due to the feed only was 2.83 dB, so the major attenuation occur was due to feed.

Copyright © 2007 H. Mostafa et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

1. INTRODUCTION

Effect of rain on the parabolic reflector and on the feed window is considerable at higher frequencies. It depends on antenna size, elevation angle, rain rate, and so forth [1]. Wet antenna losses are required to be subtracted from the measured attenuation in order to get the propagation losses accurately. The effect of water on the surface of reflector and radome of feed window is of growing interest in satellite communications. Experimenters speculate that the effect could be responsible for more than 3 dB of attenuation at Ka-band; however few experiments have been conducted. The ACTS propagation experiment has conducted several of these wet antenna experiments using various methods.

Acosta 1997 defined four regions at which a water cell can cause signal degradation. Using the ACTS satellite, Acosta measured the effect of a spherical water cell with a diameter of 0.35 m placed at each of these locations. The volume of the water cell was 1.56 in³. The antenna used in the experiment was a parabolic reflector with an offset feed and $F/D = 0.6$, the results at four regions were as follows: region 1 represents the region only affected by path losses; the losses were 0.25 dB. Region 2 represents a water cell located on the antenna dish. A water cell at this location causes the dish to re-

flect in a nonsymmetrical fashion, causing an overall degradation in the systems performance; the losses were 0.44 dB. Region 3 represents a water cell falling between the feed horn and the dish of the antenna; the results were 1.13 dB. Finally, region 4 represents a water cell on the feed horn itself. Water on the feed horn causes attenuation of all parts of the signal being directed to the feed from the dish; the results were 9.5 dB, thus, a water cell at region 4 is expected to cause more attenuation than the water cells located at region 2 and region 3 [2].

The simple experiment of spraying water first on the ACTS propagation terminal (APT) antenna reflector and later on the feed window was conducted in the fall of 1993 after satellite transmissions were acquired but before the official start of the ACTS propagation experiment [3].

The result was generally less than 0.3 dB of attenuation due to water droplets on the feed, and the attenuation due to water droplets on the reflector was 1.9 dB at 27.5 GHz and 1.0 dB at 20.2 GHz. According to Hendrix et al. [4], they have studied the water on the surface of a radome due to rain flows down in three different forms: as a laminar sheet, as rivulets, and as droplets. The form of the water flow on a spherical radome is dominated by the hydrophobic properties of the radome [4].

FIGURE 1: Experiment system setup.

The longer water stays as droplets as the rain intensity increases. The attenuation of droplets is smaller than the attenuation caused by a continuous film or by rivulets due to the fact that the attenuation mechanism of droplets is relatively weak scattering compared to the absorption and reflections caused by a continuous film [5].

A campaign to examine experimentally the magnitude of the wet antenna problem was undertaken at several ACTS propagation experiment sites. Bringi and Beaver [6, 7] reported attenuation values in excess of 9 dB produced by spraying water on the APT antenna. Similar sprayer measurements were made at the ACTS experiment sites in British Columbia [8].

The latter experiment included rain gauge measurements to determine the rain rate produced by the sprayer. In each case, the experiments were made on clear sky days and the reported attenuation was due only to the water sprayed on the antenna. In one of the experiments, the reflector had been sprayed with a hydrophobic coating in an attempt to eliminate the water layer but with no success. Acosta [9] reported results of a comparison between observations made using two closely spaced antennas, one shielded from rain and the other exposed to the rain. He observed more than 4 dB of attenuation attributable to water on the exposed antenna at rain rates up to 40 mm/h [10].

The flow rate was controlled so that repeatable experiments could be made at the same effective rain rate. The measured attenuation values were 2 dB for the wet feed window at 20.2 GHz and 27.5 GHz and the total reflector plus feed window attenuation values of 3.9 and 6.3 dB at 20.2 and 27.5 GHz, respectively, at a rain rate of 40 mm/h. A mythology for system design has developed from the earlier work: radomes may produce unacceptable increases in attenuation when exposed to rain, but a wet reflector causes little additional attenuation. However, in remote sensing at millimeter wavelengths, the additional attenuation due to water on a metallic reflector surface has been noted as a source of measurement error [11].

In an earlier study of the wet antenna problem for very small aperture antenna satellite communication sys-

tem (VSAT) applications, Cheah [12] calculated the expected attenuation produced by a uniform thin water film on a smooth metallic reflector and on a thin dielectric radome window for the feed. Using his calculations, the predicted attenuation for a water layer on the feed surface would be about 2 dB for the APT antenna and the attenuation, due to a water layer on the reflector, would be negligible. The experimental observations were significantly different from these predictions. The problem lay in the design of the APT antenna reflector.

All the previous work studied the wet antenna attenuation at high frequency more than 14 GHz, so in this paper, the wet antenna attenuation at frequency less than 14 GHz on ASTRO antenna has been studied.

2. METHODOLOGY

The simulated rain experiments were carried out on the receiving antenna of offset antenna smooth reflector surface. The experiments were performed on clear days when there was no rain event along the propagation path. The experimental system comprises a compact receiver and a transmitter. The transmitter for RF links here was formed by locating the transmitter apparatus 14.2 m above ground level of the building of electrical and electronic engineering. The distance between transmitter and receiver was $R = 17$ m. the measurements were taken at two different elevation angles 51° and 24° degrees. The smooth reflector surface (offset dish) was used as receiver antenna. Figure 1 presents the experiment system.

The experiment was located in USM engineering campus. Figure 2 shows the experiment setup. It shows the locations of offset antenna dish, the PVC pipes, and rain gauge. The pipes were changed to three cases. The water source value was controlled in order to have several rain rate values. The received RF signals (CW) of 11.5, 12, and 12.4 GHz were recorded manually for several minutes successive at each rain rate in order to get a stable reading. The rain rate data was collected using a tipping bucket rain gauge (Casella Rainfall Logging System). The antenna wetting losses are defined as the difference between the dry antenna and the wet antenna.

The estimated rain rate is derived from measurements of the rain accumulation made with a rain gauge. Since the rain rate is defined as the time derivative of the accumulation, we estimated the rain rate from the slope of a running linear least-square-error fit of the accumulation data.

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 data logger's clock was regularly synchronized with that of the computer and the lag in time observed was 4 seconds 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.

FIGURE 2: The outdoor experiment setup.

The average rain rate was calculated using the time elapsed between successive tips.

In the beginning of the experiment, continuous wave (CW) of frequency 12.4 GHz was first selected from the signal generator, and RF signal was transmitted to receiving antenna by using horn antenna. From the spectrum analyzer (used as receiver), the center frequency of 12.4 GHz and span frequency of 20 MHz were selected. RF signal was received from receiving antenna to spectrum analyzer through QUICKFORM cable five meters. The direction of the antenna was changed in order to get the best signal. The received power was read for dry antenna (without simulated-rain). The rain gauge was placed near the antenna to record the rain rate automatically.

The water source was opened to get the simulated rain referring to wet antenna, and the receiving power was read and recorded after the rain between 3 to 10 minutes. The wet antenna attenuation was defined as the difference between the receiving power before the raining and after the raining. The formula is written as

$$\begin{aligned} \text{Wet antenna attenuation} \\ &= \text{power received for dry antenna} \\ &\quad - \text{power received for wet antenna.} \end{aligned} \quad (1)$$

The average attenuation was taken during the same rain and the same frequency. The rain rate was varied by varying the pipes construction. The above steps were repeated for the other frequencies.

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

FIGURE 3: Experiment spraying on the feed.

labVIEW-interfacing card. The labVIEW was programmed to record the peaks of sixty successive samples each of 1 ms duration. The software then calculates the mean of these sixty peak values. These recordings were then repeated every 10 seconds giving six averaged peak values in a minute.

The rain simulator experiments are used to distinguish the attenuation due to water on the reflector from attenuation due to water on the feed. The total attenuation due to the wet reflector and the wet feed is obtained by adding the two contributions. We assume vertical rain rate for the attenuation measurement since the wind is typically unknown.

The reflector and the feed were sprayed with water from a spray bottle in the spray bottle experiments. There is no rain rate in the spraying experiments and the thickness of the water layer is unknown. From the measurement, we found that the ratio the attenuation is significantly higher for water on the reflector than for the case with water on the feed. The attenuation was measured for both spraying the reflector and the feed separately.

For the spray bottle experiment, the reflector was sprayed first lightly and then more heavily. The attenuation measurements are sampled once per second. The feed was sprayed three times and wiped between sprayings. The first time the feed was sprayed lightly, the second time it was sprayed more heavily, and the third time it was sprayed even more heavily. The attenuation measurements are sampled once per second. Figure 3 shows the experiment spraying on the feed. The spikes in the attenuation are caused by the hand covering the feed during wiping.

3. RESULTS AND DISCUSSION

Wet antenna attenuation during rain events is examined through carrying out simulated rain experiments. These were conducted on the receiving antenna of the offset antenna (ASTRO dish). The findings from these experiments are used to estimate the attenuation data for the wetting by adjusting the collected data for wet antenna attenuation via two different angles.

FIGURE 4: The attenuation versus rain rate at elevation angle 24° via three frequencies.

The statistics of the attenuation data derived from the angles at three frequencies, nominally 11.5, 12, and 12.4 GHz. The wet antenna losses were measured at two different angles, 24° and 51°. All the measured data at the three frequencies, respectively, where the attenuation included the feed losses and reflector losses are plotted in graph form at the three different frequencies via two different angles at different rain rates.

The average attenuation at the three different frequencies (11.5 GHz, 12 GHz, and 12.4 GHz) via different rain rates at 24° and 51° elevation angles was calculated and plotted.

Figure 4 illustrates the attenuation at elevation angle 24° with three different frequencies, where the attenuation increases gradually with the increasing of rain rate. It is found that the increasing of attenuation at 11.5 GHz is less than other frequencies. The maximum attenuations at very high rain rate were 1.245, 2.75, and 2.97 dB at 11.5, 12, and 12.4 GHz, respectively. On the other hand, the attenuation at 12 GHz is almost equal to the attenuation at 12.4 GHz.

Figure 5 illustrates the attenuation at elevation angle 51° with the same frequencies in Figure 4, and the attenuation is similarly increases gradually with increasing rain rate, but in this case the attenuation was more than the previous case. The maximum attenuations at very high rain rate were 1.56, 2.88, and 3.1 dB at 11.5, 12, and 12.4 GHz, respectively. On the other hand, the attenuation at 12 GHz is almost equal to the attenuation at 12.4 GHz.

From the previous figures, the attenuation at low rain rate was the same for different angles, that means the reflector and the feed have approximately the same amount of water, which shows that the thickness of water was very thin for different angles.

In general, these results showed that feed wetness is 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

FIGURE 5: The attenuation versus rain rate at elevation angle 51° via three frequencies.

to raindrop's size at the surface of the reflector. This creates a distorted reflector surface that reduces the antenna gain by several dBs in the worst case.

4. CONCLUSION

In this experiment, the majority attenuation occurs due to the feed, so the result was taken only for 12.4 GHz as it will be similar at other frequencies. The average attenuation value resulting from measurement was 2.81 dB at very heavy rain rate. In general, these results showed that feed wetness is the main contributor to the system losses, with reflector wetness being a lesser factor. On the other hand, the attenuation due to water on the feed is much greater than attenuation due to water on the reflector. The attenuation occurred due to the water layer on the reflector dish was 0.2 dB at 12.4 GHz. This attenuation depends on the size of dish, roughness of reflector, and the thickness. Majority of the attenuation occurred due to the water on the feed. The result was 2.81 dB at 12.4 GHz. The worst case analysis in this experiment was 3.085 dB at 12.4 GHz and 51° elevation angle at heavy rain rate.

REFERENCES

- [1] T. Richard, R. Gedney, S. Ronald, and G. Frank, *The Advanced Communications Technology Satellite*, Scitech, Mendham, NJ, USA, 2000.
- [2] R. J. Acosta, R. Reinhart, D. Kifer, C. Emrich, and N. Goldshan, "Wet antenna studies on LeRC," in *Proceedings of the 21st NASA Propagation Experimenters (NAPEX XXI) Conference*, California Institute of Technology, El Segundo, Calif, USA, June 1997.
- [3] R. K. Crane, X. Wang, D. B. Westenhaver, and W. J. Vogel, "Acts propagation experiment: experiment design, calibration, and data preparation and archival," *Proceedings of the IEEE*, vol. 85, no. 6, pp. 863–877, 1997.
- [4] C. E. Hendrix, J. E. McNally, and R. A. Monzingo, "Depolarization and attenuation effects of radomes at 20 GHz," *IEEE*

- Transactions on Antennas and Propagation*, vol. 37, no. 3, pp. 320–328, 1989.
- [5] A. Manz, “Radome influence on weather radar systems: principles and calibration issues,” in *Proceedings of the AMS Workshop Radar Calibration*, pp. 1–8, Albuquerque, NM, USA, January 2001, http://www.gematronik.com/website/selex/pdf/pubs/2001_6.pdf.
 - [6] J. D. Beaver and V. N. Bringi, “The application of S-band polarimetric radar measurements to Ka-band attenuation prediction,” *Proceedings of the IEEE*, vol. 85, no. 6, pp. 893–909, 1997.
 - [7] V. N. Bringi and J. Beaver, “Ka-band propagation studies using the ACTS propagation terminal and the CSU-CHILL multi-parameter radar,” in *Proceedings of the 9th Advanced Communications Technology Satellite Propagation Studies Workshop (APSW IX)*, Herndon, Va, USA, November 1997.
 - [8] M. M. Kharadly, R. Ross, and B. Dow, “Analysis of ACTS-Vancouver path propagation data,” in *Proceedings of the 20th NASA Propagation Experimenters Meeting (NAPEX XX) and the Advanced Communications Technology Satellite (ACTS) Propagation Studies Miniworkshop*, Fairbanks, Alaska, June 1996.
 - [9] R. J. Acosta, “Wet antenna studies NASA LeRC,” in *Proceedings of the 11th Advanced Communications Technology Satellite Propagation Studies Workshop (APSW XI)*, Oklahoma City, Oklahoma, October 1998.
 - [10] D. Ramachandran, “Effect of water on antenna surface,” M.S. thesis, University of Oklahoma, Norman, Okla, USA, 1997.
 - [11] M. D. Jacobson, D. C. Hogg, and J. B. Snider, “Wet reflectors in millimeter-wave radiometry: experiment and theory,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 24, no. 5, pp. 784–791, 1986.
 - [12] J. Y. C. Cheah, “Wet antenna effect on VSAT rain margin,” *IEEE Transactions on Communications*, vol. 41, no. 8, pp. 1238–1244, 1993.

AUTHOR CONTACT INFORMATION

H. Mostafa: School of Electrical and Electronic Engineering, Engineering Campus, Universiti Sains Malaysia, Nibong Tebal 14300, Penang, Malaysia; mostafa.hussen.2005@yahoo.com

S. I. S. Hassan: School of Electrical and Electronic Engineering, Engineering Campus, Universiti Sains Malaysia, Nibong Tebal 14300, Penang, Malaysia; ssyed@eng.usm.my

J. S. Mandeep: School of Electrical and Electronic Engineering, Engineering Campus, Universiti Sains Malaysia, Nibong Tebal 14300, Penang, Malaysia; eemandeep@eng.usm.my

M. F. Ain: School of Electrical and Electronic Engineering, Engineering Campus, Universiti Sains Malaysia, Nibong Tebal 14300, Penang, Malaysia; mfadzil@eng.usm.my

H. A. Khedher: School of Electrical and Electronic Engineering, Engineering Campus, Universiti Sains Malaysia, Nibong Tebal 14300, Penang, Malaysia; khedher200@yahoo.com