Measurement of Wet Offset Parabolic Antenna at Ka-band with Different Elevation Angles

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Abstract—Ka-band frequencies are most susceptible to rain attenuation compared to lower band such as Ku and C-band. This problem is more serious in tropical regions including Malaysia because of their high rainfall intensity. Other than the rain attenuation, the wetness of the antenna system can cause additional signal degradation due to rain. Therefore, wet antenna experiment was conducted to observe the effect of water on the feeder and reflector of the parabolic antenna at Ka-band. Measurement was performed at 39.6 GHz for the worst case condition of the Ka-band using a downconverter. The Ka-band signal received by a parabolic antenna will be downconverted by the downconverter to UHF frequencies and transmitted to the spectrum analyzer through a coaxial cable for power measurement. The experiment is conducted to observe wet antenna attenuation for wet reflector and wet feeder separately at three different angles; 30°, 60° and 78°. Finally, the total wet antenna attenuation is obtained by adding the contribution from both the wet feeder and reflector. The highest attenuation of 6.50 dB is observed at the maximum rain rate of 210 mm/hour.

Keywords: Ka-band, UHF, Rain fade, Wet Antenna Attenuation, Down-converter

1. INTRODUCTION

The effect of rain water build-up and run-off on the parabolic antenna surfaces is significant at higher frequencies such as Ka-band frequencies. Due to its unique dielectric properties, water is considered to be the most common attenuator for the microwave signals. Water drops and water films formed on the antenna surfaces during rain event can cause both scattering and absorbing of microwave signals which could attenuate the signal. It depends on the factors such as the antenna size, elevation angle, rain rate, and so forth [1].

Wet antenna losses are required to be subtracted from the measured rain attenuation in order to get the propagation losses accurately [2]. An estimation by researcher indicates that antenna attenuation due to wet surface could reach 10 dB at Ka-band [1].

Majority of wet antennas studies were conducted by researchers at a lower Ku-band frequency such as those conducted by Mostafa *et al.* [2]. Their experiments of wet antenna measurements at 11.5 GHz and 12.4 GHz was carried out using simulated rain on the 0.6 m parabolic antenna as a receiver. The rain rate was measured using the rain gauge. At 54° elevation angle, the wet antenna attenuation at 270 mm/hour was 2.83 dB at 11.5 GHz and 1.83 dB at 12.4 GHz, respectively [3].

Rahim *et al.* [4] discusses the measurement of wet antenna attenuation on 26 GHz terrestrial microwave link in Malaysia. The researchers carried out a wet radome experiment on enclosing 2-feet parabolic dish using water spray to create four types of testing; splashing, sheeting, rivulet and droplet. The wet antenna losses obtained from the experiment were 0.4 dB (droplet test) to 3 dB (splashing tests) at 0.01% of time, or 52.5 minutes/year of the rain attenuation was exceeded. In this study, the wet antenna was created using water spray which did not simulate real rain situation. Assumption of water thickness of 0.25-0.3 mm was predicted using Gibble's formulation [4, 5]. The water thickness assumed to be located randomly all over the radome even though they were using water spray in which that will not represent the real rain. In the real situation, the water layer thickness is unknown and varies across the dish, thus, it is more practical to relate the water thickness with the rain rate.

Islam *et al.* [6] derived an analytical approach to obtain wet antenna losses for 37.06 GHz. Calculated result shows that the wet antenna loss is almost constant for medium rainfall intensity (50 mm/hour - 120 mm/hour) and changes sharply at low and heavy rainfall rates. Practically, the measurement of wet antenna increases gradually with the rain rate at the Ka-band, thus the proposed approach is not so accurate in comparison with actual measurement.

The abovementioned wet antenna measurements were conducted at Ku-band frequencies while an analytical approach was used to calculate the attenuation at 37 GHz. In this work, the actual measurements were carried out in order to observe the wet antenna effect at the highest frequency in the Ka-band frequencies at 39.6 GHz. At the highest Ka-band frequency, the experiment is more difficult to be conducted due to high propagation loss along the transmission path. To observe for the degradation of the signal, the spectrum analyser need to be used and should be located at a place which is secure from water droplet. The weak 39.6 GHz signal received on the antenna feeder will not reach the spectrum analyser since the coaxial cable will give high attenuation.

Considering high losses at Ka-band, the down converter need to be used to down convert the weak Ka-band signal to UHF frequencies for transmission over the coaxial cable to the spectrum analyzer. The comparison of the measured down converted signal power during dry condition and wet condition of the surface and feeder of the parabolic antenna can be observed.

2. METHODOLOGY

The block diagram of the Ka-band Down Converter is shown in Figure 1 consists of the off-the-shelf low noise amplifier (LNA), frequency mixer, frequency multiplier, local oscillator (LO) and band pass filter (BPF). The 9.5 GHz adjustable YIG oscillator was used as a microwave source before multiplied to 38 GHz to operate as a local oscillator. The 39 GHz signal received from antenna will be amplified by the LNA and mixed with 38 GHz LO signal to produce a 984 MHz intermediate frequency (IF) signal. The IF signal will be filtered, amplified and transmitted over the coaxial cable to the spectrum analyzer.

Figure 2 shows a complete system of a down-converter in a water-proof box with the dimension of $(15 \times 9 \times 6)$ cm. The measurement were carried out at the School of Electrical and Electronic Engineering, Engineering Campus, Universiti Sains Malaysia located at 5.17° N 100.4° E.

Figure 3 shows the Ka-band reflector which has the dimension of 85 cm × 54 cm. The parabolic antenna will reflect the electromagnetic waves to the feeder located at the focal point, $f/D = 0.71$.

The experiment setup of wet antenna measurement is shown in Figure 4. The transmitter and receiver antenna were placed at 5.3 m relative distance from each other. The transmitter located on a rooftop of the first level building of the School of Electrical and Electronic Engineering, USM Engineering Campus while the smooth reflector surface of the antenna receiver is placed on the ground level at three different elevation angles. The downconverter is located at a receiver parabolic antenna feeder to translate the Ka-band frequency to UHF frequency to mitigate the losses of the received Ka-band signal.

The experiment was performed on clear days when there was no occurrence of rain and both

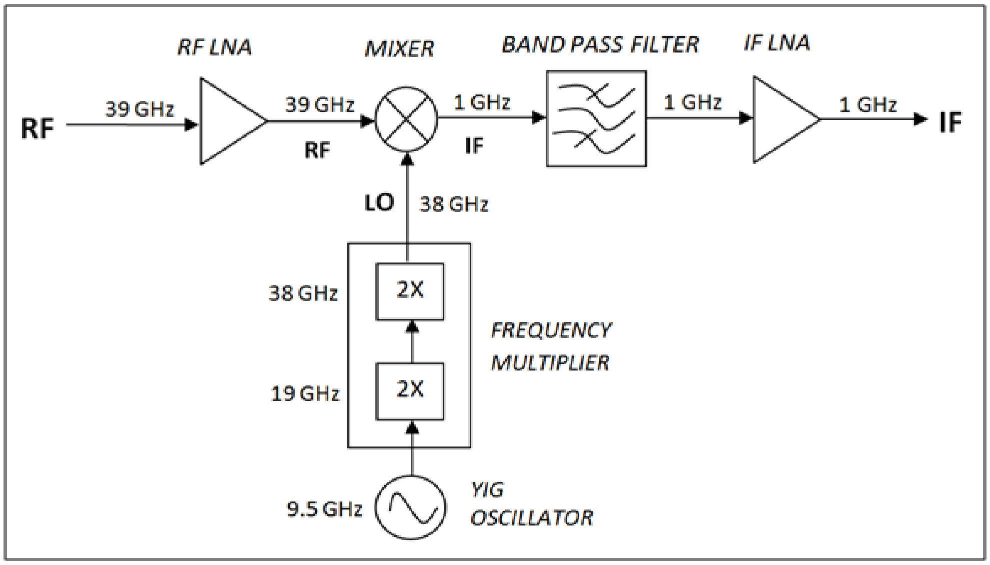

Figure 1: Down converter block diagram

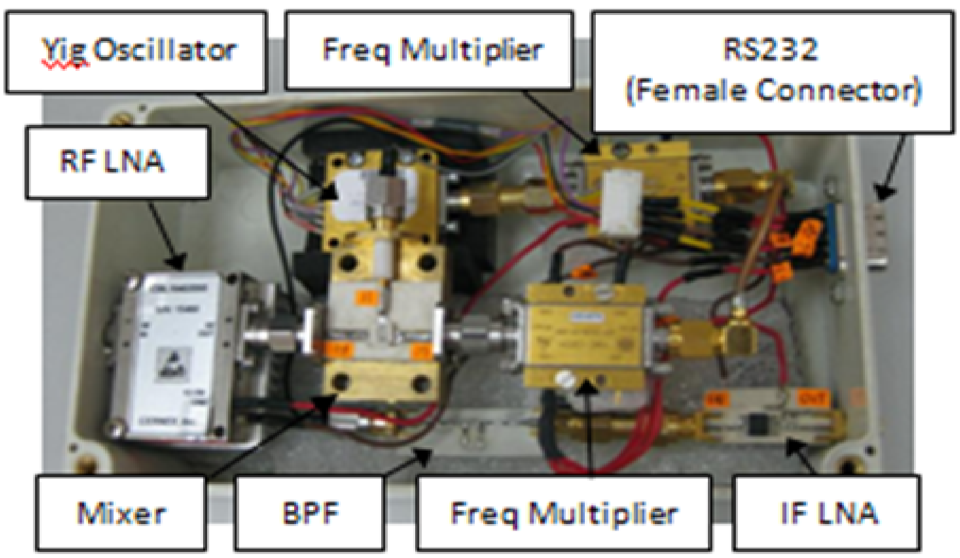

Figure 2: A complete system of downconverter in water-proof box

dish and feeder of antenna receiver were dry. Initially, a 20 dBm signal induced from the Signal Generator was transmitted using the horn antenna at 39.6 GHz frequency. The signal was received using an offset parabolic antenna and measured on the spectrum analyzer where the span frequency of the equipment was fixed to 500 MHz while the center frequency was 984 MHz to observe the level of IF power generated by the downconverter.

The wet antenna experiment was conducted to find specific attenuation contributed by the wet antenna in two conditions:

i. Water Stream Result (with Rain Rate)
ii. Water Droplet Result (without Rain Rate)

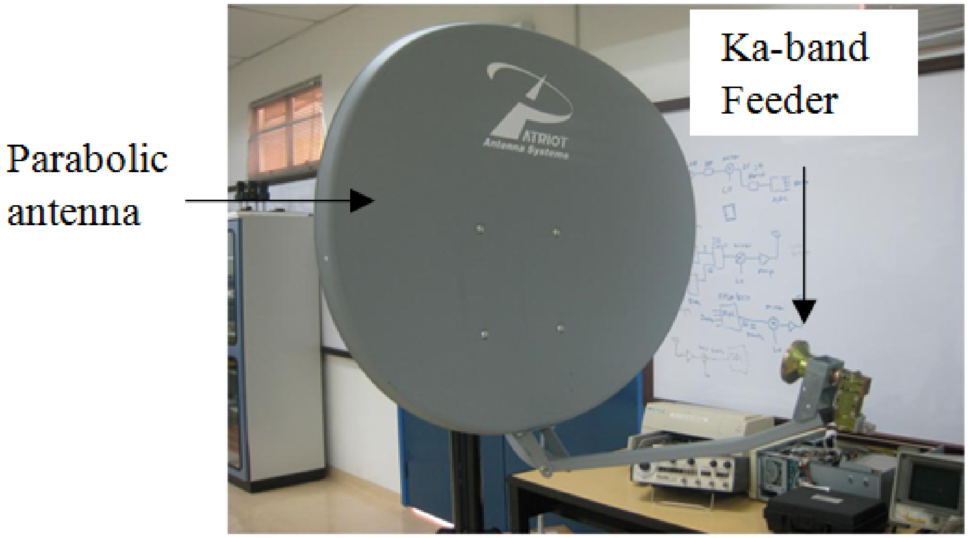

Figure 3: A Ka-band antenna for receiving 39.8 GHz signal

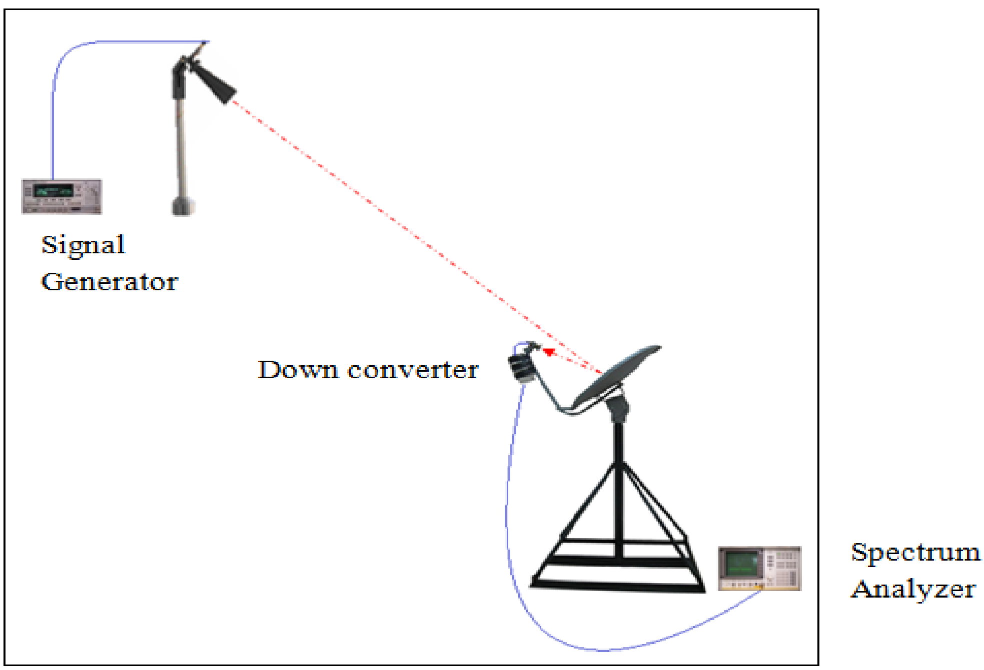

Figure 4: Wet Antenna Measurement Setup

Water stream result data was taken during the running of water on the antenna surface. The tap was used to control water flow and the rain rate was recorded by tipping the rain gauge bucket. At the same time, the received signal displayed on the spectrum analyzer was observed and recorded manually for every 3-4 minutes. When the tap was closed, the 984 MHz IF signal power was recorded when there were droplets of water accumulated on the dish. The wet antenna attenuation can be calculated using Equation 1.

$$\text{Wet antenna attenuation}_{(stream,droplet)} = Pr(dry) - Pr(wet)_{(stream,droplet)} \quad (1)$$

Where, Pr = power received

3. RESULTS AND DISCUSSION

3.1. Water Stream Result (with Rain Rate)

The simulated rain experiment was carried out on the receiving offset parabolic antenna at three different elevation angles i.e. 30°, 60° and 78°. As shown in Figure 5, at 60° elevation angle, the attenuation increases almost linearly proportional to the rain rates at about 0.5 dB in every step of mm/hour. The lowest effect of the wet reflector is at the position of 30°. At this position, water thickness on the antenna surface was very thin and less accumulation of water on the reflector in comparison to the higher angle. The highest attenuation was contributed by the highest elevation angle; in this experiment is 78° at a maximum rain rate of 210 mm/hour which is nearly 6 dB loss. The position of reflector for higher angle is facing upwards to the sky, causing more water to build up on the antenna surface before it is streamed down due to gravity.

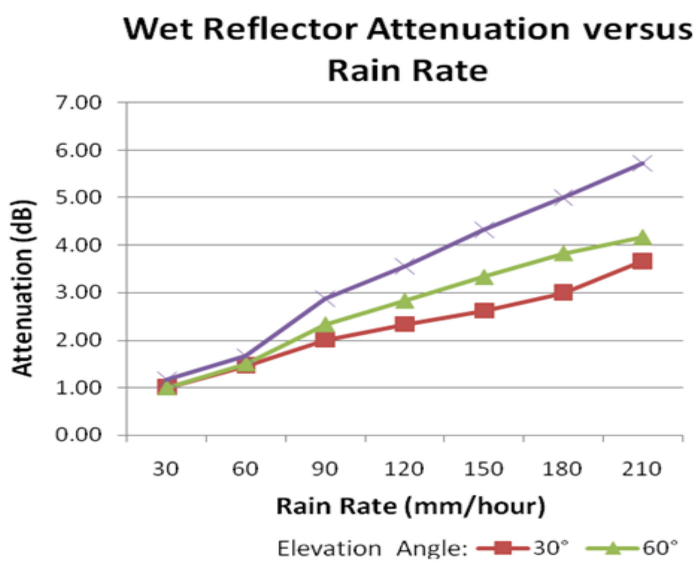

Figure 5: Wet Reflector Attenuation at different Elevation Angles vs. Rain Rate

Figure 6 shows the experiment result for the wet feeder at elevation angles of 30° and 60°. For elevation angle of 78°, the attenuation result is no longer valid because the feeder surface is less expose to the rain. The position of feeder at 78° elevation angle is practically facing downward, causing the feed window to completely dry although rain is pouring down as shown in Figure 7.

As shown in Figure 6, the wet feeder at the elevation angle of 30° exhibits significant attenuation difference compared to 60°. For the rain rate of 60 mm/hour to 210 mm/hour, the difference of attenuation between these two elevation angle is about 1.4 dB. At the lowest rain rate, both elevation angle experienced less attenuation because only a thin film of water is formed on the feed window. Subsequently, at 60° elevation angle, it is observed that only half of the feed window is wet during the experiment of rain simulation as illustrated in Figure 7. This contributes to less attenuation of wet feeder at 60° compared to 30°.

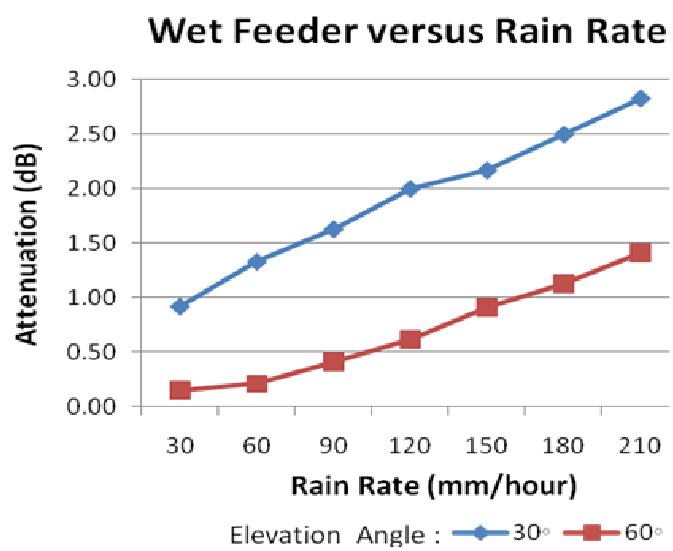

Figure 6: Wet feeder attenuation at a different elevation angle

Figure 7: Feeder facing downward at 78° Elevation Angle

The cumulative attenuation of wet feeder and reflector should be summed up in order to find the total attenuation of wet antenna. Figure 8 demonstrates the result obtained by adding the contribution from both the wet feeder and reflector. Based on Figure 8, the cumulative attenuation of wet feeder and reflector at the elevation angle of 30° has higher significant attenuation difference, compared to the attenuation at the angle of 60°. The attenuation at maximum rain rate of 210 mm/hour is 6.5 dB at elevation angle 30° while at 60°, the total attenuation is 5.5 dB. The difference is 1 dB of attenuation between these two angle at maximum rain rate.

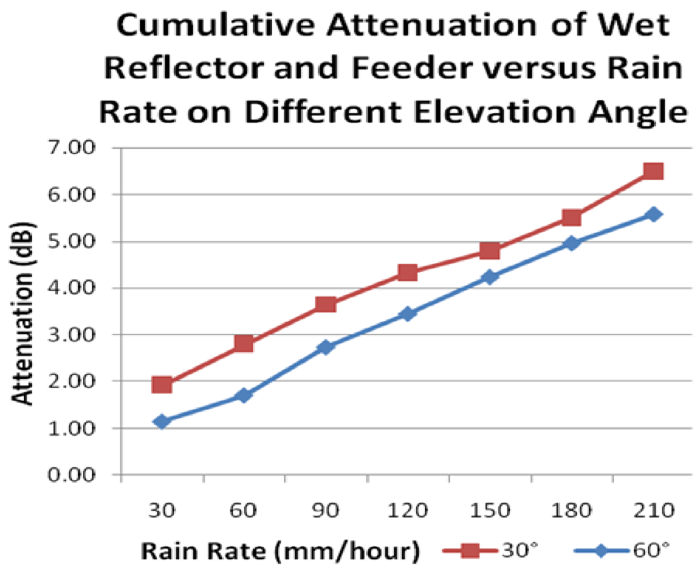

Figure 8: Cumulative attenuation of wet reflector and feeder at different elevation angle

3.2. Water Droplet Result (without Rain Rate)

Measurement was taken by observing for an average of 2 minutes after the tap was turned off. The result obtained is shown in Figure 9. The value of water droplet's losses is almost similar, which is about 2 dB between these three elevation angle of antenna; at 30°, 60° and 78°.

The attenuation is contributed by the uniformity of water dew on the antenna surface. After the rain has stopped, there are a water retention formed as a droplets on the antenna that caused all areas of the antenna surface to get wet, and this situation are applied to all angle and gives the same attenuation.

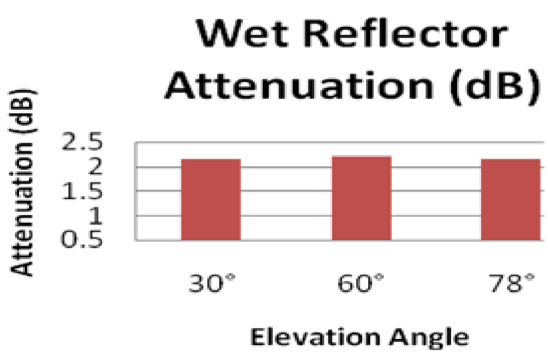

Figure 9: Water droplet attenuation on reflector

Figure 10 shows the formation of water droplets on the antenna at 60° elevation angle. When the microwave signal hit a droplet on the surface of the dish, scattering and absorption of the microwave energy will cause additional losses to the microwave transmission. The wavelength of 39.6 GHz is 7.576 mm is larger than the diameter of a raindrop in the range of 0.6 to 6.4 millimeters [7]. However, the water droplet might have possibility to collide with neighboring droplets on antenna surface hence the size will be enlarged. Therefore, the size of water droplet on

Figure 10: Water droplet on antenna

antenna surface become larger than the wavelength of transmission frequency causing the absorption of the microwave energy by water droplets. The illustration of this phenomenon is given in Figure 11 and Figure 12 respectively.

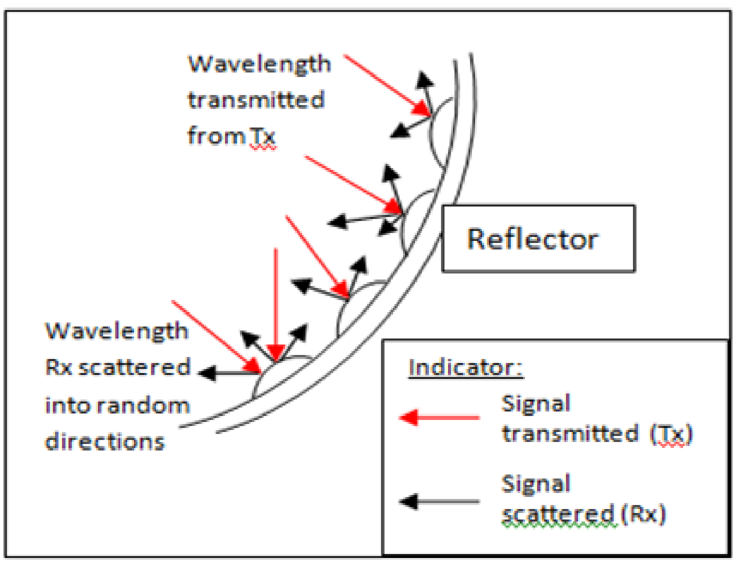

Figure 11: Illustration of scattering on rain droplet on antenna dish

4. CONCLUSION

As a conclusion, the main factor of wet antenna losses is due to the elevation angle. It is observed that, the higher the elevation angles, the longer the duration of water stays as droplets on the

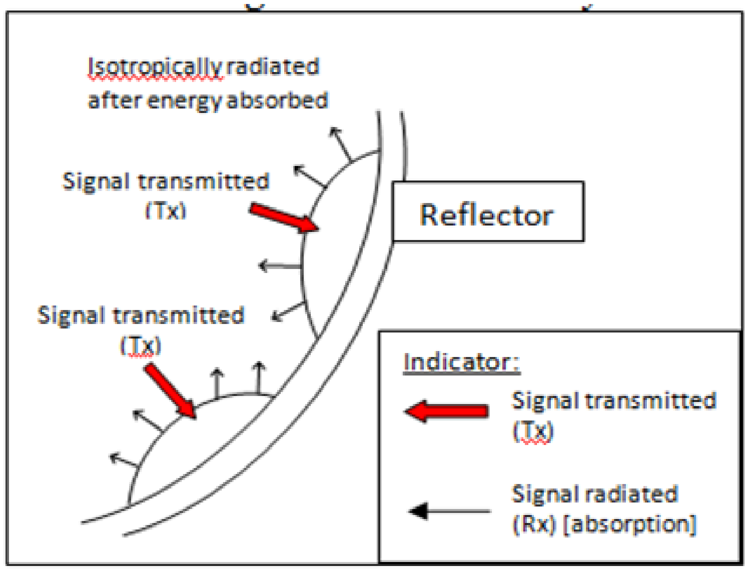

Figure 12: Illustration of energy absorption

antenna, thus the higher the attenuation. At higher elevation angle, the reflector of the parabolic antenna will be more exposed to the rainfall droplets. Water on the reflector surface acts as a dielectric interface medium which causes signal scattering and reduce antenna gain resulting in inevitable losses. In addition, water droplets accumulated on the feed window distort the electric field's distribution on the surface, causing attenuation of the signal traversing the window. The highest rain attenuation occurred is 6.5 dB with 78° elevation angle at maximum rain rate of 210 mm/hour.

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