



Evaluation of C and Ku Bands Signal Degradation due to Rain Water Accumulation on Prime Focus Parabolic Antenna in the Tropical Region of Nigeria

Hassan Aliyu*, Buhari H. Mamman, Saeed M. Yarima, Ishaku T. Balami, Hassan S. Miya
Department of Electrical and Electronics Engineering,
Faculty of Engineering and Engineering Technology,
Abubakar Tafawa Balewa University, Bauchi, Nigeria.

ABSTRACT

Domestic satellite signal failure due to rainwater accumulation on the prime focus parabolic dish surface is a common phenomenon in the tropics. The problem is more pronounced with high-altitude satellites. This issue may result in a longer period of signal degradation or unavailability even after rain has long stopped. Rainwater collection issues on the surface of prime focus parabolic antenna have not been given adequate attention in the design of the dish systems supplied to the tropics from temperature zones. Most research works on signal attenuation due to rainwater in parabolic antennas are mostly associated with droplet effects in the atmosphere and wet antenna surface. However, the accumulation of water on the parabolic dish reflector surface causes it to exhibit some dielectric characteristics, thereby resulting in signal scattering which may reduce the gain of the antenna. An evaluation of the level of degradation of the satellite signals on C and KU bands due to rainwater accumulation of prime focus parabolic dish antenna during the rainy season is presented in this work. It involved the measurement of the signal degradation due to rainwater collected on the surface of the dish. The analysis was restricted only to end-of-rainfall conditions to isolate attenuations from other sources such as the atmosphere and wet antenna surface. The experimental results obtained indicated some significant levels of signal attenuation due to the accumulation of the rainwater on the dish surface. The attenuation results, however, indicated higher values on the KU-Band frequency. Modification of the dish surface at the region of the water accumulation was proposed to drain the water at the region of accumulation, thereby minimizing the signal losses during and after rain.

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INTRODUCTION

Domestic KU-band satellite system users in the tropics usually experience longer periods of received signal disturbances during and after normal rainfalls (Nitika & Kaur, 2018). A closer observation has shown that rain water accumulates on the surface of the prime focus parabolic dishes, especially when operating on a high altitude (high elevation angles) satellite

broadcast systems. When rain water accumulates on the dish reflector surface, it behaves as a dielectric boundary medium which causes signal scattering which may reduce the antenna gain and consequently resulting in some degree of signal attenuation or even complete signal loss (Apriono et al, 2023). This is in addition to the effect of increased weight of the dish when water accumulates on it which results

Corresponding author: Hassan Aliyu

hassancentauri@gmail.com

Department of Electrical and Electronics Engineering, Faculty of Engineering and Engineering Technology, ATBU, Bauchi.

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in slight deformation of the parabolic surface, thereby altering the focal point. This problem has not received much attention from manufacturers, most likely due to the fact that most enterprise satellite system operators use the offset type parabolic dishes, which do not have the problem of accumulating water during rain at all elevation angles. In such cases therefore, only the effects of rain droplets in the atmosphere and wet antenna surface issues are prominent.

A common rain-fading phenomenon experienced on KU-band parabolic receiving antennas that has received lots of attention is mostly the raindrop attenuation problem in the troposphere and this has undergone various forms of research over the years. This problem has been exhaustively investigated in many respects. Common problems of rainwater attenuation usually occur on this band at frequencies above 10 GHz.

In a similar investigation (Ojo et al, 2008), the researchers analyzed rain rate and rain attenuation for satellite communications in KU and Ka bands in Nigeria. Using the ITU-R model for rainfall data bank collected over 30 years. Contour maps were then developed for rain rate and rain attenuation for Nigeria. The exceedance for 0.001% of the year in northern Nigeria ranges between 12 dB to 15 dB and in the South between 16 dB and 19 dB on the KU-band. Also the Ka-band for 0.001% of the year shows attenuation of between 24 dB to 26 dB in the North and between 30 dB and 36 dB in the South. In another related development (Sarat et al, 2008), work was carried out on the prediction of KU-band rain attenuation using experimental data for the Hassan Master Control Facility in India. A result obtained on 11.544 GHz for four rain months for a probability of 0.01 of time was about 4 dB. Also, in Jatal, (2015), the effect of rain intensity on KU-Band signal in the Kurdistan region of Iraq was investigated and the result shows that some significant levels of attenuation were recorded with varying rain intensity in general but in this study, the attenuations experienced have shown some dependence on the signal polarization as well.

All the findings in the preceding reviews were either predicted results using the ITU model or experimental results for the attenuation due to rainfall in the troposphere. However, in a research work conducted by Arslan et al (2018), a proposal for a new technique for satellite link attenuation measurements by estimating rainfall accumulation along the link path was given. Bit error ratio measurements technique was employed for the satellite link and this was used to identify periods of the rain during which the rainfall rate is estimated from signal attenuation measurements. The effective rain height used in converting the attenuation rate along the link path into the rainfall rate is estimated from polarimetric radar observations.

Another rain attenuation problem due to scintillation was analyzed in Animesh & Arpita, (2012) on the rain attenuation for KU-band in a tropical location of Kolkata in India. This problem was a result of fast fluctuations of turbulence in windy conditions during rain, especially when associated with heavy wind. It occurs simultaneously with rain attenuation. Wavelet analysis technique was used in the studies in this case. Rain attenuation was, however, found to be more dominant than scintillation.

The preceding studies, however, did not include attenuation due to water accumulation which is a common phenomenon on the prime focus parabolic antenna at high-altitude satellite angles mostly in the tropical regions. In a study conducted in Amuda et al, (2023), the effect of water run-off time from a parabolic antenna surface on a received signal was carried out using a rain simulator. KU-band frequency of 11.843 GHz on a vertically polarized signal was used in the experiment on a 0.6 m parabolic dish. The result showed some significant amount of attenuation variation from a water film thickness of 0.1 – 0.22 mm on the surface, with attenuation varying between 0.1 – 6 dB. Also, the attenuation in terms of water run-off times from the antenna surface showed values of between 0.1 – 6 dB for water run-off times of between 0.1 and 0.45 seconds.

Corresponding author: Hassan Aliyu

✉ hassancentauri@gmail.com

Department of Electrical and Electronics Engineering, Faculty of Engineering and Engineering Technology, ATBU, Bauchi.

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Despite the deployment of numerous fiber optic cable networks in Africa, satellite infrastructures remain crucial for providing communication access to rural and remote areas. Increasing telecommunications growth, bandwidth demand, and congestion in lower frequency bands has led to the use of higher frequency bands like C, Ka, KU, and V. Rain is a significant factor affecting signal propagation in these bands, particularly in tropical and subtropical regions like South Africa (Malinga et al, 2013). The paper estimated rain attenuation using the ITU-R model, analyzed link performance, and proposed appropriate fade margins for all provinces in South Africa.

Rain-induced signal degradation in satellite communications at frequencies of 10 GHz and above was studied in the tropical region. Rain attenuation at 38 GHz was measured over 20 months in Malaysia, considering seasonal and diurnal (Badron, et al, 2011). Results were compared with established prediction models and analyzed for signal loss and fading. The study identifies potential fade mitigation techniques, providing crucial groundwork for future communication link design.

In Alozie et al (2022), a thorough literature survey was conducted to address gaps and provide extensive discussions on rain attenuation modeling, analysis methods, and model validation techniques. The study identifies open research questions and applications, serving as a reference for rain attenuation design and analysis.

When designing communication links, the duration of rain fade events is an important consideration. Fading, which causes intermittent signal fluctuations, is prevalent in the tropical region due to frequent rainfall. However, there is a lack of fade duration data for equatorial and tropical regions in Africa. The study in Sanyaolu et al (2020) estimates the number of fade events exceeding different attenuation thresholds at Ka-band using the International Telecommunication Union (ITU-RP) model and Tropospheric Data Acquisition Network (TRODAN) data. Results show that fade duration decreases with increasing attenuation thresholds and latitude.

The equatorial region experiences the highest frequency of fade events, while the tropical zones have the lowest. Shorter fade durations are associated with heavy rains and higher attenuation. The number of fade events exceeding the 1 dB threshold is higher than other thresholds about fade duration.

Rain has a significant impact on system performance above 10 GHz, particularly on the receiver antenna. In Mostafa et al (2007), the focus was on wet antenna attenuation at KU-band with varying rain rates. Experimental results show that water on the antenna causes significant attenuation, separate from atmospheric propagation losses. The attenuation was measured using a signal generator, horn antenna, and spectrum analyzer. Three cases with different rain rates were simulated using pipes, and the total attenuation due to water on the feed and reflector feed was found to be 3.1 dB in worst case. The feed alone accounted for the majority of the attenuation at 2.83 dB.

Signal degradation caused by hydrometeors, abnormal refraction, and selective fading can be predicted based on measurements. While older systems like microwave beams and ionospheric reflection are less important now, new techniques like fiber-optic links and wireless systems have gained significance. However, certain systems, such as digital television broadcasting via satellites, still play a significant role in communication. In Wilk-Jakubowski, (2018), results related to noise increase, rain attenuation, and overall signal degradation due to rain in the frequency range of 1 to 25 GHz were presented.

Northern Nigeria experiences about six months of wet season as stated earlier and with this characteristic of water accumulation on dish surfaces, TV signal reception from high-altitude satellites like the Nilesat101 may be intermittently disrupted for a long period whenever it rains. Reception may only be fully restored when the rain stops and the collected water on the surface naturally drains or dries out. This could, however, take some significant amount of time due to the high level of humidity in the atmosphere during the wet seasons.

Corresponding author: Hassan Aliyu

✉ hassancentauri@gmail.com

Department of Electrical and Electronics Engineering, Faculty of Engineering and Engineering Technology, ATBU, Bauchi.

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This work was carried out experimentally using a solid prime focus dish antenna to exclusively verify the amount of signal fading resulting from rainwater accumulation on the parabolic dish surface. This signal attenuation is an addition to those from other sources during the rainy season in the highlighted literature discussed.

PRIME FOCUS AND OFFSET FEEDS PARABOLIC ANTENNAS

The prime focus parabolic feed antenna is fabricated as a parabolic mathematical surface with the focal point at the

feed as shown in Figure 1(a). Hence, depending on the satellite look-angle, rainwater is bound to accumulate on the lower surface; the surface closest to the ground. The offset feed parabolic antenna is shown in Figure 1 (b). It is constructed as a cut-out upper portion of the complete prime focus feed antenna. The lower portion of the parabolic surface in the complete dish is missing. Consequently, the offset feed type antenna does not collect rain-water on its surface irrespective of the look-angle of the satellite signal source. However, each type has its advantages and disadvantages, as well as applications in the field.

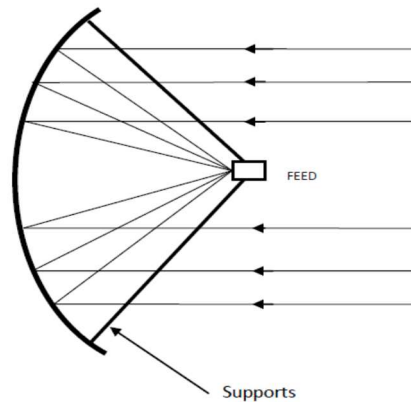


Figure 1(a): Prime Focus Feed Antenna

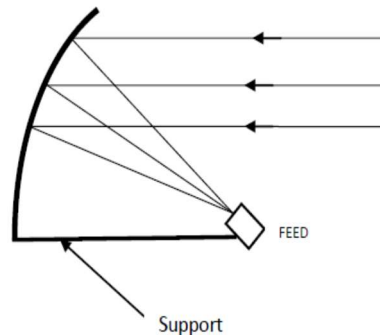


Figure 1(b): Offset Focus Feed Antenna

The prime focus parabolic antenna is popular for most Free-To-Air (FTA) TV satellite broadcast stations in Nigeria. The dish antenna is low-cost and serves a dual purpose for both C and KU band receptions. The offset-type antennas are mostly used for paid Direct-To-Home (DTH) digital satellite TV broadcasts and some corporate digital communications for uplink and downlink applications on the C-Band.

METHODOLOGY

This work was carried out to evaluate the extent of satellite system signal degradation due to attenuation associated with rainwater accumulation on the surface of the dish antenna during the rainy season in the tropical region. The phenomenon normally occurs when a prime-focus parabolic dish antenna is tuned to high-

altitude satellites. The experiment was carried out at the Abubakar Tafawa Balewa University, Yelwa Campus, Bauchi, Nigeria. The site is situated at Lat. 10.3°N and Long. 9.7°E. This zone experiences a considerable period of rainfall each year. The rainy season could last as long as six months or more in a year

Measurements for this experiment were done using a 1.8m prime focus-fed solid parabolic dish antenna as shown in Figure 2. This type of dish was used in the experiment due to its popularity with satellite FTA viewers and its characteristic of accumulating rainwater when looking at high-altitude satellites. The Focal point to Diameter (F/D) ratio of the dish is about 0.6; this determines the depth of the dish. Offset dishes are less susceptible to rainwater

Corresponding author: Hassan Aliyu

✉ hassancentauri@gmail.com

Department of Electrical and Electronics Engineering, Faculty of Engineering and Engineering Technology, ATBU, Bauchi.

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accumulation as only the upper part of the bigger

parabolic dish is used in its construction.

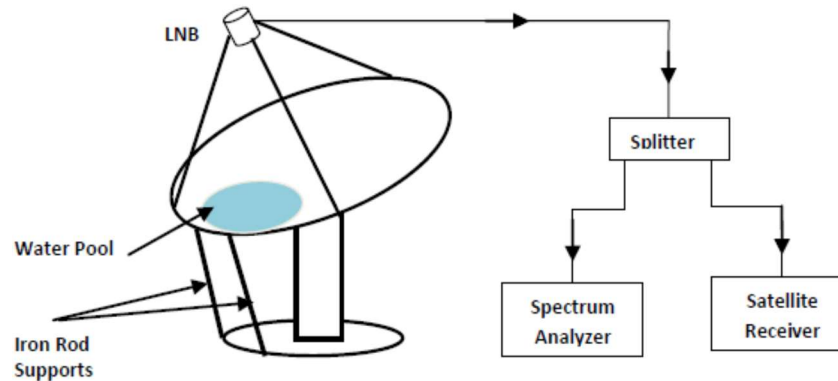


Figure 2: Experimental Setup

Measurements were carried out on clear days to minimize other forms of rain-based attenuations interfering with the data collected. The dish was tuned towards the Nilesat101 Satellite (Orbital slot 7° West) operating on KU-band. This satellite was specifically chosen because it has attracted lots of popularity among most satellite FTA viewers in Northern Nigeria. Tens of Thousands of the 1.8m dishes are brought into this part of Nigeria quite often. The dish has been generally accepted as a standard for Nilesat101 installations in Northern Nigeria, because of the low level of signal footprint in this area; making it a requirement to use a relatively large diameter dish (1.8m). The measurement setup was as shown in the figure. The dish was tuned to this satellite and monitored on the frequency of 11.823GHz as the amount of collected water was increased using a measuring cylinder. The dish was secured firmly using a solid support structure as shown in the figure to minimize the effects of bending moments on the stand and structural deformation of the dish's mathematical surface due to the weight of water at the accumulation point. The water was then introduced into the lower part of the dish at $0.2 \times 10^{-3} \text{m}^3$ at a time and signal strength was recorded until the maximum water collectible on

the surface had been attained; at this point any further increment results in runoff from the surface. The LNB was then replaced with that of a C-band and tuned to Atlantic Bird 3 service to West Africa (Orbital slot 5° West) on a frequency of 3.646GHz. The dish was also firmly secured as in the previous case. Water was then increased into the lower part of the dish at the same rate used for the KU-band. At each point, signal strength was also recorded to the maximum water collectible on the surface. It is also worthy of note that the maximum amount of water retainable on the surface depends on the angle of inclination of the dish; the smaller the angle of inclination, the more the volume of water collected and vice versa. The same final volume of water was used for attenuation measurements in both cases.

The signal strength results obtained for both cases were then converted to attenuation in dB and then a graph was plotted for the attenuation against the volume of water collected. The graph is presented in Figure 3.

RESULT AND DISCUSSIONS

This signal attenuation versus volume of water collected on the dish is shown in Figure 3.

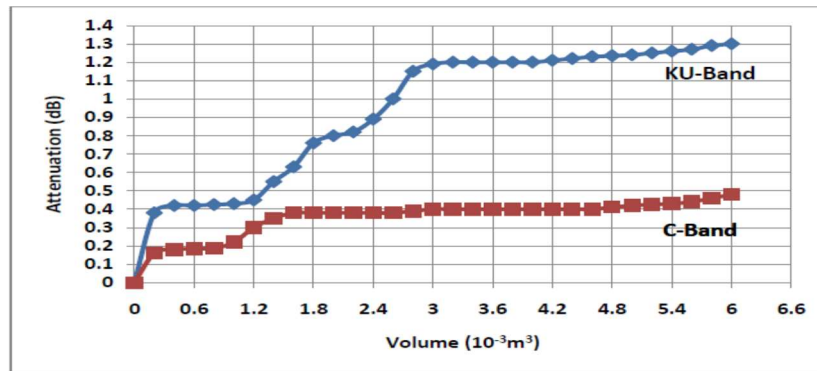


Figure 3: Attenuation versus Volume of Water

It could be observed from the results obtained in the figure that signal attenuation of up to 1.3 dB is possible, this, however, depends on the frequency and the volume of water accumulated on the dish surface alone.

The KU-band curve for 11.823GHz shows that as the water accumulates on the dish surface, the signal deteriorates up to a point where a total loss in the TV signal occurs. Signal attenuation of about 1.3 dB has been recorded on this frequency for high water accumulation.

On the other hand, the C-band curve for 3.646GHz shows that attenuation of up to 0.5 dB could occur as the water collects on the dish surface. This also led to TV signal deterioration. The signal deterioration levels may, however, depend on the frequency, signal strength from the source, and receiver sensitivity. The antenna size also plays a significant role in the level of deterioration of the signal as the gain of the

antenna increases with an increase in the dish diameter; the increase in diameter results in an increase in the overall signal capture area of the antenna.

The signal deterioration of the prime focus type antenna could, however, be minimized by providing a drain around the water accumulation region to enable speedy automatic evacuation of water from the pool region. This method may be most effective especially when the rain is simply drizzling so that continuous evacuation of the water is achieved. Under heavy rain, however, this method may not be very effective. To implement this method as a solution, perforations are made at the lower rib of the dish as shown in Figure 4. A few small holes of about 5mm will be drilled around the pool area from the center of the pool upwards toward the center of the dish.

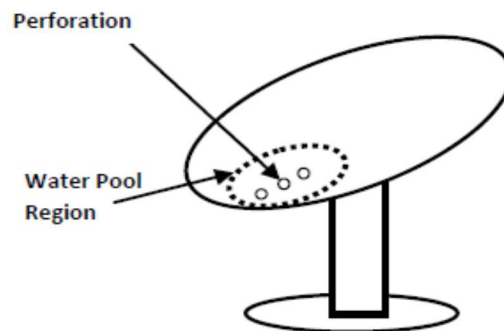


Figure 4: Modified Antenna Dish Surface

Corresponding author: Hassan Aliyu

✉ hassacentauri@gmail.com

Department of Electrical and Electronics Engineering, Faculty of Engineering and Engineering Technology, ATBU, Bauchi.

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CONCLUSION

The experiment showed that water collection on the prime focus parabolic dish antenna operating on the KU-band could result in significant attenuation that could lead to total loss in TV signals. During the experiment, the total loss in TV pictures was experienced on the KU-band. The unsymmetrical reflection of the signal by the collected water and absorption of the signal, by water, resulted in this signal deterioration. The attenuation on the C-band signal was, however, less severe compared to that of the KU-band, because the level of signal absorption and the unsymmetrical reflection of the signal by the water were less in this case.

As discussed earlier, under rainy conditions, water is bound to collect on a solid prime focus parabolic dish that is looking at high-altitude satellites. In this experiment, as a proposed solution, small holes of a few millimeters (5mm) in diameter were made at the bottom of the region of water accumulation on the dish. This, depending on the size of the hole reduces the accumulation rate and reduces time for signal restoration after rain. Evacuation of water through the holes resulted in full signal restoration in the experiments within a few minutes of the end-of-rain conditions.

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Corresponding author: Hassan Aliyu

✉ hassancentauri@gmail.com

Department of Electrical and Electronics Engineering, Faculty of Engineering and Engineering Technology, ATBU, Bauchi.

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Corresponding author: Hassan Aliyu

✉ hassacentauri@gmail.com

Department of Electrical and Electronics Engineering, Faculty of Engineering and Engineering Technology, ATBU, Bauchi.

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