

MINIMIZATION OF ATTENUATION ON KU-BAND SIGNAL DUE TO WET PARABOLIC ANTENNA OPERATING ON SATELLITE DOWNLINK USING HYDROPHOBIC COATING

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ABSTRACT

Northern Nigeria experiences a long period of rainfall annually. Parabolic dish antennas operating on the KU-band suffer significant signal degradation due to the accumulation of water on the surfaces during rain. The thin layer of water that is retained on the surface of the dish creates a dielectric interface medium which results in signal scattering and consequently reduces the antenna gain, therefore, losses are experienced. In this work, simulated rain experiment was carried out to verify the capacity of hydrophobic coatings to reduce signal fading due to wet parabolic dish antenna. It was carried out in isolation of other known major contributors to signal fading during rain. Downlink signal from Intelsat 7/10 satellite operating on KU-band on orbital slot 68^oE broadcasting TV services to West Africa was used as the signal source. The extent of reduction in signal attenuation resulting from applying hydrophobic coating was evaluated. The work became necessary in order to increase broadcast availability and reliability during rain. The preliminary results obtained from the experiment using two hydrophobic coatings indicated about 0.5 dB and 0.8 dB reductions in the attenuation during rain by the satellite receiving systems. Application of hydrophobic coating is recommended for enhancement of signal reception.

Keywords: Attenuation, Hydrophobic Coating, KU-band, Wet Antenna, Satellite

1 INTRODUCTION

Commercial and private KU-band TV viewers usually experience considerable signal failure periods on their satellite receiving systems during the rainy season. These failures result from signal attenuation due to some well-known and established factors. Some common factors causing Ku-band signal attenuation during rain include; propagation path attenuation resulting from raindrop absorption, signal scattering due to raindrop, scintillation resulting from turbulent wind conditions during rain, and refraction. Other factors mostly common in temperate zones include; snow, hail, and fog. Rainwater also causes changes in satellite signal polarization by converting energy from one polarization to another, thereby causing interference between channels that depend on orthogonal polarization for frequency re-use. It was established [1] that the treatment of radomes covered with hydrophobic coating results in appreciable improvement of the wet antenna attenuation effect. Hydrophobic materials are substances that are water resistant and insoluble in water. It was also recommended in [2] that rain-related effects and losses on signals operating on the C and KU bands must be taken into account, especially in dual-polarized systems. Similar areas of application of hydrophobic and anti-soiling materials to reduce particle adherence to irradiance collecting surfaces are the use on the surface of Photovoltaic (PV) solar panels [3]. This is to reduce the soiling of the surface by dust or other wet particles to improve power output. The hydrophobic properties of some materials are used to advantage in this application. This is very similar to their applications in parabolic antenna systems. To compensate for differences between the beacon or pilot carrier and the uplink carrier, the transmit power can be modified. An incorporated carrier monitor refines power adjustments for loopback carriers. Figure 1 demonstrates downlink carriers visible at the uplink Earth station. New link

adaptation techniques involve adapting modulation schemes and coding based on radio link quality. The accuracy of a special Adaptive Modulation and Coding (AMC) scheme depends on precise channel condition prediction. Fade duration data within an established link can provide insights into the behavior of a wireless channel in tropical regions [4].

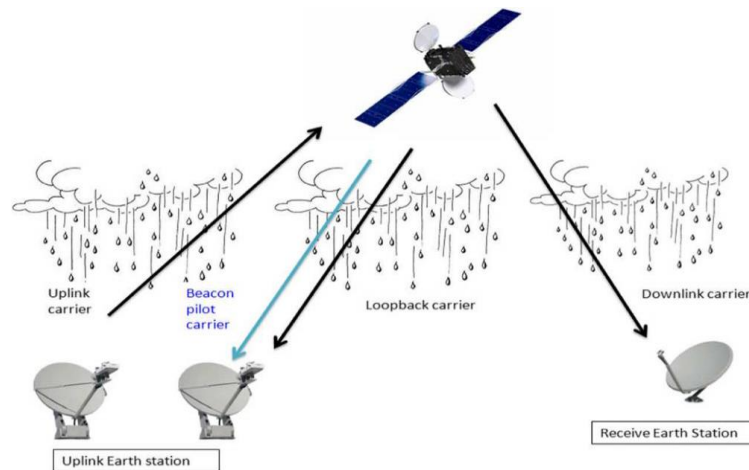


Figure 1. Schematic of a satellite uplink power control [4]

The most effective method for measuring rain attenuation is monitoring the received signal strength of a satellite beacon. Beacon signals are unmodulated signals sent from satellites to the ground station at a constant frequency and power, used for easy satellite tracking. KU-band frequencies are commonly chosen for beacon signals due to their higher resistance to rain attenuation. In [5], a comparison of rain attenuation in KU-band beacon signals using the ITU-838 model, based on rainfall rate observations at TURKSAT premises from 2012 to 2019 was carried out. The comparison involves calculations using both theoretical formulas and actual data. Among various frequency bands in satellite systems, KU-band is widely utilized in services like DVB, DAB, and the Internet. The ionosphere and rain directly impact satellite signals, leading to signal degradation. In [6], the focus was on studying the calculation of rain effects in the Iraqi Kurdistan region. It presents some results and offers solutions and recommendations to minimize rain-related signal degradation and enhance the received signal, aiming to benefit satellite system users in any location. The growing demand for accurate satellite link planning in the context of free-to-air satellite television deployment was addressed in [7]. It evaluates deterministic propagation models for analyzing signal quality at KU-band in Lagos state, Nigeria. The study compares measurements of channel-to-noise (C/N0) and bit error rate (BER) from six locations in Lagos with simulation results from the Institut Für Rundfunk Technik (IRT) and modified Irregular Terrain Models (ITM). The impact of the modulation scheme and error correction code on C/N0 and BER is considered. Results indicate a deviation of 0.732 dB and 0.285 dB from C/N0 measurements using the IRT and modified ITM models, respectively. Both models perform well overall, but the modified ITM model outperforms during heavy rainfall periods. Additionally, the paper highlights the rapid increase in BER when error correction code is not used and the limited impact of higher alternate modulation symbols on achievable data rates. In Southeast Asia, particularly in Indonesia, the primary satellite frequency bands used are KU-band and C-band. The quality of signal power reception in these frequency ranges is crucial for satellite communication. Due to the region's high rainfall, the propagation of satellite communication, especially above 3 GHz and particularly above 10 GHz, is significantly affected by rain attenuation [8]. To assess the impact of rain attenuation on satellite signal reception in real-time, the study developed an integrated measurement system in Pekanbaru City. The designed system successfully obtained satellite signal data in the C-band and KU-band channels, allowing for the rapid assessment of rainfall's influence on satellite communications within 10-second measurement duration. This provides real-time data to understand the impact of rain on satellite communications. Various forms of moisture in the atmosphere, such as fog, clouds, snow, and dust particles, can affect the propagation of electromagnetic waves, with the impact being frequency-dependent. When transmitting and receiving frequencies higher than 10 GHz in areas with heavy rainfall, significant degradation occurs. Understanding the statistics of rain attenuation in the vertical and horizontal polarized KU-band radio propagation through satellite earth-links in tropical regions is

crucial for budget link planning, especially for end-viewer television reception. Research work in [9] investigates the effect of rain on vertical and horizontal polarized KU-band signals to develop an appropriate link budget strategy when designing satellite networks and allocating higher power consumption to overcome rain fade loss. In a study in [10], 24 months signal strength data was collected at 12.245 GHz (KU-band) from EUTELSAT-W4 and concurrent rain intensity data in Nigeria. Measured fade durations are compared with the ITU-R P. 1623 and Cheffena-Amaya prediction models. The results indicate that the ITU-R model closely matches the measured data, while the Cheffena-Amaya model overestimates it. A modified ITU-R model is proposed based on the measured data, recommended for the Nigerian climate. These findings aid in planning and designing fade mitigation techniques for terrestrial-satellite microwave links in the KU-band, combating the effects of intense rain in tropical regions. The severity of rain impairments usually increases with signal frequency and also regional location [11]. It is a fact that rain fading becomes significant, most especially on microwave frequencies above 10 GHz. Hence, any transmission above this frequency has to deal with this problem, which could seriously reduce system availability. Rain water wets the surface of the parabolic dish antenna resulting in another significant attenuation factor. When a parabolic antenna surface is wet, the thin film of water on it could result in an unsymmetrical reflection of the signal in addition to signal absorption. Therefore, a good proportion of the signal will not concentrate on the principal focus as expected. In a research work conducted in [12], experiments were carried out using simulated rain by spraying water on the antenna surface. The results obtained showed attenuation of between 0.2 dB and 2.81 dB due to water droplets at 12.4GHz on the antenna reflector and feed respectively. An attenuation of about 9 dB was reported [13] in an experiment conducted by spraying water on the ACTS Propagation Terminal (APT) antenna. Depending on the hydrophobic properties of the material on the surface, radomes design technique, and rain rates, rainwater flows down the surface of the antenna as droplets, rivulets, or lamina sheets [14]. Generally, the amount of water that stays on the antenna surface and consequently causes signal fading depends on the rain intensity. At high rain rates, the water hardly stays on the surface as droplets, but as a thin film whose thickness shall depend on the rain intensity. This indicates a reduction in the hydrophobic properties of a surface as rain intensity increases. Tests conducted [15] on microwave landing system (MLS) antenna radomes have indicated significant degradation of system accuracy of about 2 dB in the presence of sprayed water on the radomes. Even, though, the effect is marginal because the system operates on the C-band, the effect on the system's accuracy cannot be underestimated. To minimize signal attenuation on the surface of radomes, the hydrophobic properties of the surface should promote the formation of water into beads rather than continuous film, because the attenuation is less when the water is in beads and also encourages rapid shedding of the water from the surface. Wind direction and speed also play important roles in these cases. The hydrophobicity of a surface depends on the free energy which could be evaluated by determining the contact angle of the bead/water droplets. This work aims to determine and analyze experimentally, the extent of the minimization of attenuation that could be achieved if the hydrophobic properties of the parabolic antenna (surface and feed) are improved on KU-band frequency. It is also to encourage the use of hydrophobic materials on domestic parabolic antenna systems during the rainy season in the tropics to improve the system's availability.

2 METHODOLOGY

This experiment was carried out in Bauchi, Nigeria located at the Abubakar Tafawa Balewa University, Yelwa Campus, Bauchi. The Campus is situated at Lat. 10.3° N and Long. 9.7°E. This zone experiences a considerable period of high rain fall each year. The experiment was setup using two same offset type parabolic dish antennas (dish 1 and dish 2) of 65cm major and 60cm minor diameters each. The two dishes were installed at the same height above ground looking at Intelsat 7/10 (orbital slot 68° E) and tuned to the frequency of 12.722GHz as shown in Figure 2. Two similar digital satellite receivers were used in this work. Each parabolic dish was connected to a receiver as shown and the outputs were connected to a spectrum analyzer to measure the signal strength received by each parabolic dish. Some convenient and common household hydrophobic materials have been selected and used in coating the surfaces of the parabolic dishes in this experiment. Vaseline petroleum jelly and olive oil were selected as hydrophob1 and hydrophob2 respectively. The signal power falling on each dish from the orbital satellite was then recorded on a clear sky day with no rain on the first instance. Thereafter, signal power from dish 1 and dish 2 was then monitored with the same surface conditions (no hydrophobic coatings)

at varying simulated rain rates. This result would subsequently be used as a control to ensure the accuracy of data collection and analysis; this is the standard procedure for this experiment. The surface of dish 2 was then thoroughly cleaned and hydrophob1 was coated on both the surface of the dish 1 and the feed radomes. The dish systems were then made to undergo the same varying simulated rain conditions while received signal power data were been recorded from dish 1 and dish 2 simultaneously.

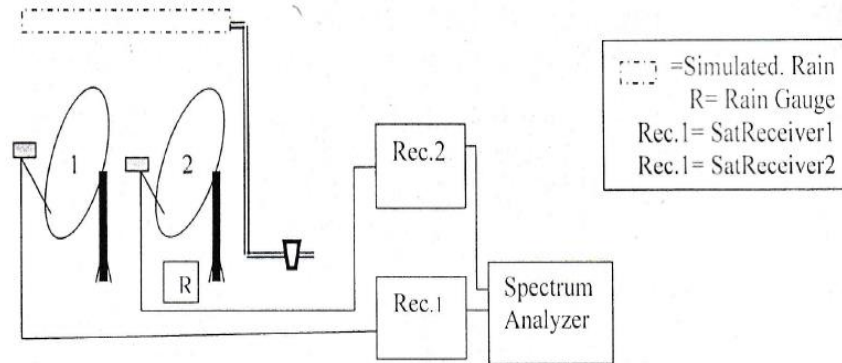


Figure 2. Experimental Setup

The surface of dish 2 was once again thoroughly cleaned and hydrophob2 was then applied to both the surface and feed radomes and then the same measurements were carried out on all dishes. Various rain rate conditions were obtained by adjusting the water flow rate using the tap control on the water feed pipes. It should be noted, however, that the antennas were subjected to the same atmospheric conditions in all cases. Hence, other known atmospheric losses remained constant on both dishes. The measured signal improvement achieved by using hydrophob1 and hydrophob2 could then be deduced from the collected data using equations 1 and 2 respectively as follows:

$$D2_{h1} - D1_{h0} = \text{Attenuation improvement using hydrophobic (hydrophob1) material} \\ \text{(Surface and LNB radomes)} \quad (1)$$

$$D2_{h2} - D1_{h0} = \text{Attenuation improvement using hydrophobic (hydrophob2) material} \\ \text{(Surface and LNB radomes)} \quad (2)$$

Where, $D1_{h0}$ = Dish 1 with no hydrophobic coating applied, $D2_{h1}$ = Dish 2 with hydrophob1 applied, $D2_{h2}$ = Dish 2 with hydrophob2 applied.

3 RESULTS AND DISCUSSION

The Results obtained from the measurements have shown that attenuation experienced on dish 1 represents the normal attenuation that the dish shall experience without any hydrophobic coating applied, and was obtained as 2 dB at a rain rate of about 100 mm/hr compared to clear sky conditions. When hydrophob1 was applied to the surface of dish 2, the difference in attenuation obtained concerning dish 1 represented the improvement obtainable by coating dish 2 surface and LNB radomes. Measurement taken has indicated an improvement of about 0.5 dB using hydrophob1 and 0.8 dB using hydrophob2 respectively at the same rain rate of about 100mm/hr using equations 1 and 2 as shown in Figure 3. At a higher rain rate of between 160mm/hr and about 250mm/hr, there wasn't much significant improvement using hydrophob1 or hydrophob2. This may not be unconnected with the fact that at this point rain beads were no longer forming due to the high rain rate striking the dish surface; rather the dish and radomes surfaces were covered with thin film of water. Therefore, the behavior of raindrops on dish 1 and dish2 surfaces was very similar in this instance. The results obtained and plotted for various rain rates and the corresponding attenuations are presented on the curves of Figure 3. These results show a similar trend to what was obtained in [12] on comparable elevation angle and frequency, even though different frequencies slightly higher were used, attenuation values at the same rain rates were quite similar under normal dish antenna surface with no hydrophobic material applied.

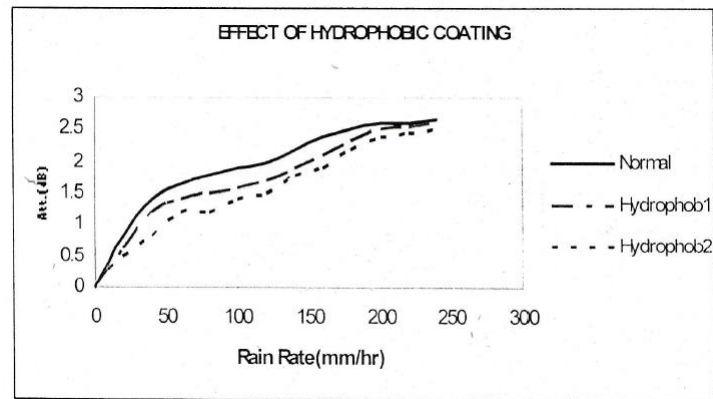


Figure 3. Results for using Hydrophob1, Hydrophob2 and without hydrophobic material

It could be deduced from Figure 2 that at low rain rates when raindrops were expected to form beads at the surface of the dish, there was improvement on the received signal. As a result of this, the attenuation due to the surface of the dish and feed radomes was consequently reduced. This is expected because the formation of beads on the dish surface reduces the attenuation due to rainwater.

4 CONCLUSIONS

Results obtained in this experiment have shown that applying hydrophobic coating on the surface of the dish antenna brought about improvement in the received signal quality under moderate rain rate conditions; thereby some level of improvements in the availability of received signal, depending on the hydrophobic properties of the coating could be achieved. Therefore, persistent moderate rain rate situations, which under normal circumstances could have resulted in signal freezes or total loss of signals, could be improved using hydrophobic coating. Therefore, dish antenna users could take advantage of this finding to improve their system's availability during the rainy season by applying common domestic hydrophobic material on the dish antenna surfaces periodically on their own.

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