

## On the Determination of a Compensation Model for Rain Degraded Digital DTH Links over a Tropical Location

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**Abstract:** Ku-band satellite remains the most cost-effective distribution channel for digital television services in terms of global coverage and wide bandwidth availability. However, signal attenuation due to rain remains the bane of the reception quality and the continuous availability. In the clear-sky, the minimum signal loss between a Ku-satellite and an earth station is about 205 dB. The amount of rain rate and the site's latitude further compound this minimum signal attenuation. Existing reported research works are mainly limited to modelling of rain-induced attenuation without porting research findings into compensation product in terms of appropriate mitigation technique. This study is aimed at developing a robust compensation model for the rain-induced digital satellite television services for an improved quality and availability of service in Nigeria, with a specific objective of determining the optimal dish size for compensating the signal attenuation on the digital satellite TV downlink. The methodology employed involves rain data collection from the International Telecommunication Union-Radiocommunication (ITU-R) worst rain zone in Nigeria. The determination of appropriate dish sizes for different parts of Nigeria was carried out. A compensation model was derived for the rain degraded DTH link; and practical dish size of 1.5 m, for 48 dBW satellite footprint, was found to be adequate for compensating Ku satellite signal attenuation, regardless of rainstorm in Nigeria.

**Keywords:** Rain Attenuation, Compensation model, Rain rate, DTH links, Ku Band.

### I. Introduction

The digital satellite television (TV) is the high-quality TV signal received via a Direct-to-Home (DTH) link with a communication satellite. The satellite in this scenario serves as the space repeater station for the distribution of the high definition TV content across the globe. Seemingly, this application has gained global acceptance even with the ongoing digitization of the conventional Analogue Television (ATV). However, it stands as one of the several communication applications placing increasing demand on the radio spectrum. The availability of larger bandwidths and higher data rates in the

Ku-band is considered favorable for the deployment of the digital TV via satellite. Interestingly, the migration of digital satellite TV from the C-band to the Ku-band has successfully isolated its transmission from interference from the various terrestrial microwave applications. It also provides a substantial bandwidth, which sufficiently accommodates the digital TV content delivery for DTH services and to a wide range of terrestrial TV broadcasts ranging from the cable TV, mobile TV to the new Smart TV services. A typical distribution of the digital television content is shown in Figure 1.

However, at such high frequencies, the water content in the atmosphere naturally appears as an obstacle on communication links. According to [1], water can appear in the atmosphere in the liquid state as rain, fog or clouds; in the solid state as snowflakes or ice crystals and can also appear as water vapour in its gaseous state.

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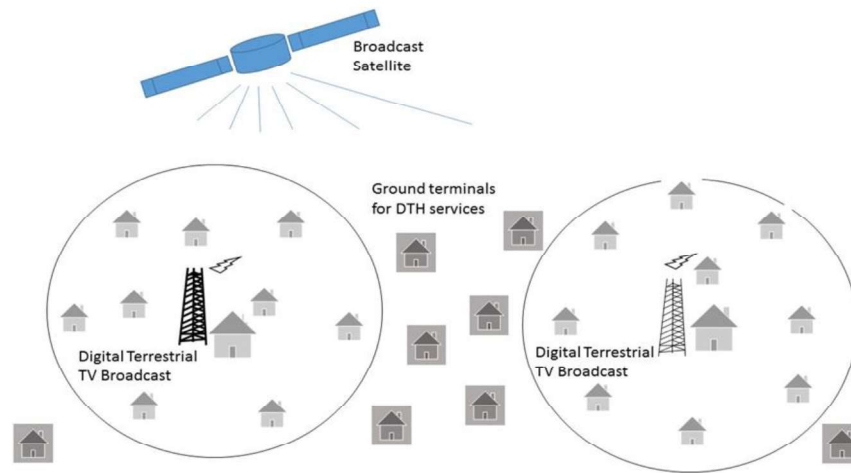


Figure 1. Typical Distribution Network for Digital Satellite Television

Water in any of these forms exists as a natural atmospheric phenomena which tends to present some form of impairment on communication systems [2]. In most cases, system availability as well as the quality of the service delivered is compromised. Water in the form of rain is actually considered as a predominant phenomenon and its effect is quite distinct and considered not negligible, causing severe damage to the digital DTH signal at reception. Moreover, its effect is particularly more pronounced in tropical climates, which is described in [3] as “a climate characterized with high rainfall intensity, high frequency of rain occurrence and the increased presence of large raindrops as compared to temperate climates.”

Rain attenuation therefore remains a major loss factor for planning both the satellite and terrestrial links, especially for transmissions in the microwave and millimeter-wave bands. There are two basic approaches for determining this major loss factor. The first method is based on direct measurement of the rain induced attenuation from experimental radio links, where the rain rate statistics and the fade margin required for designing radio links are provided. The other method depends mainly on the

estimation of rain attenuation from the knowledge of the point rainfall rate, drop size distribution (DSD) or any other relevant parameter along the radio paths [4]. The latter is an indirect method and is based on the use of propagation models.

In Nigeria, however, planning is predominantly based on prediction and this is due to the dearth of experimental propagation measurement campaigns in Nigeria. Such predictions are based on a set of procedures defined by models developed from measurements conducted in other locations. Conversely, most of these models were developed from measurements conducted in specific locations and climates.

Table 1. Fade Mitigation Techniques for Satellite Communication Systems

Categories	Types
EIRP Control Techniques	Up-Link Power Control (ULPC)
	End-to-End Power Control (EEPC)
	Down-Link Power Control (DLPC)
	On-Board Beam Shaping (OBBS)
Adaptive Transmission Techniques	Adaptive Coding (AC)
	Adaptive Modulation (AM)
	Data Rate Reduction (DRR)
Diversity Protection Schemes	Site Diversity (SD)
	Satellite Diversity (SatD)
	Frequency Diversity (FD)

Due to the complex and random nature of rain, it is quite challenging to find a model which is simple and at the same time sufficiently precise to predict the behavior of radio waves propagating through rain [4, 5]. Hence, the universality of these models is therefore questionable and this has been probed in several investigations in the tropical [6-8], sub-tropical [9, 10] and equatorial climates [11, 12].

The satellite in the Ku band remains the most cost-effective distribution channel for digital television, the internet, and other digital services in terms of global coverage and wide bandwidth availability. However, signal attenuation as a result of weather inclement, particularly rain, remains the bane of reception quality and continuous availability. For instance, even for a clear sky reception, devoid of weather inclement, the minimum signal loss between a Ku satellite and an earth station is about 205 dB. This outrageous heavy signal degradation is further worsened by the level of rain at the earth station's dish; and its relative location to the equator and the satellite. The heavier the rainfall and the longer the relative location's distance, the higher the signal attenuation.

Existing reported research works are mainly limited to the modeling of rain-induced attenuations without porting their research findings into products in terms of the determination of the appropriate satellite dish size to compensate for the rain-induced signal attenuation. This study is aimed at determining the compensation model for optimal reception of digital television within the worst rain zone in Nigeria.

## II. Related Works

Rain rate data remain undoubtedly very useful for microwave and millimeter wave propagation

studies. The increase in the number of direct in-situ measurements across Nigeria is further enhancing qualitative research with increasing rain rate data for more in-depth investigations and optimal planning of systems operating on either the terrestrial or satellite links. For example, useful rainfall statistics were presented in [13] [14] and several other studies [15-18] have also presented similar records over the years.

Reports for other tropical locations have also been very useful. Such is the work of [19] which investigates the propagation characteristics induced by rain as observed from the long-term data archived between 2004 and 2010 over the tropical Kolkata. The effect of rainfall was also investigated in [20] under tropical raining conditions on path loss at the millimeter wave band for a small cell size of about 200 m. Time series of rain rate predicted were used for estimating the rain induced attenuation over terrestrial paths.

Several other studies have been conducted on the suitability of rain attenuation propagation models over specific locations. The work of [21] assessed the performance of selected rain attenuation prediction models including the prominent ITU-R P.530-16, Silver Mello, Moupfouma and Abdulrahman models based on data sourced locally for typical impact over a terrestrial link. Results obtained also emphasizes the need for a domestic rain attenuation model specifically for designing microwave and millimeter wave links in the tropical regions. The performance of selected prediction models was also evaluated in [22], where the need for predicted models domesticated for short path-length on the 5G links was emphasized, especially for operations in the millimeter wave bands over tropical locations.

Interestingly the performance of prominent rain attenuation models is well reported over other locations across Nigeria [23-25]. These and other existing reported research works are mainly limited to estimating the rain induced attenuation, while others present efforts on the modelling of rain-induced attenuation, while efforts on the development of a compensation model has not been documented, especially for the optimal digital satellite TV reception across Nigeria.

Since atmospheric noise increases with frequency, designs at higher frequencies generally call for larger margins [26]. However, the latter is not technically or economically feasible, hence, it is more difficult for satellite operators to satisfy the recommended availability and QoS specifications [27]. In order to satisfy availability and QoS specifications, an appropriate fade mitigation technique (FMT) must be adopted. Interestingly, several FMTs have been proposed over the years [28], [29-31] and it is important to note that a number of them are already in use. However, the disgraceful effect of rainfall is still quite pronounced, perhaps in tropical climates which are of utmost interest in the present study. Table 1 shows the prominent FMT and their characteristics as detailed in [27] and [32].

According to [33], “the link margin for a given communication system can be improved by increasing the received power (i.e. by increasing transmit power or antenna gains), or by reducing the minimum threshold power (i.e. by improving the design of the receiver, changing the modulation method, or by other means). It is important to note that an increase in the link margin would usually involve corresponding increase in cost and complexity. Hence,

excessive increases in link margin are usually avoided.”

Ojo, et al. [34] opined that RF modifications (larger antennas or larger amplifiers) can be explored for compensating for the variation in the fade estimates deduced from predictions across the country. Mark [35] also suggested the use of larger antenna size for digital TV reception. In this case, the additional decibels of signal margin obtainable from the increased antenna aperture will allow the receiving system to continue to function during light to moderate rainstorms.

This work is mainly aimed at determining a cost effective method for providing high system availability for optimal reception of the high definition TV signal via the DTH link. The approach employed here is based mainly on the determination of the optimal antenna size, which guarantees that the QoS is maintained even during severe weather conditions.

### III. Methodology

The measurement campaign for rain induced attenuation on the digital television Ku satellite link is primarily made up of two experimental setups, which comprise of the precipitation measurement and the digital satellite signal measurement. These experiments are collocated and they run simultaneously. The measurement was conducted at the Federal University of Technology (FUT), Akure (7.17°N, 5.18°E). The block diagram of the measurement setup is shown in Figure 2.

Akure is the capital of Ondo State, and is situated in the southwestern part of Nigeria. The average annual rainfall recorded in Akure is 1485.57 mm

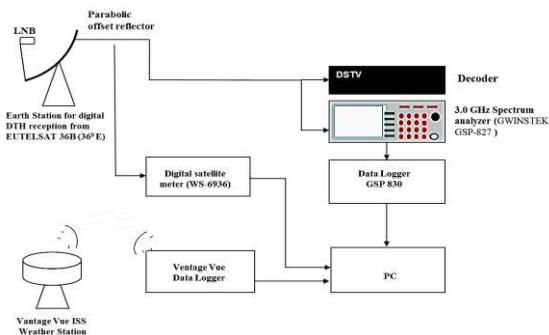


Figure 2. Block diagram of the experimental measurement setup

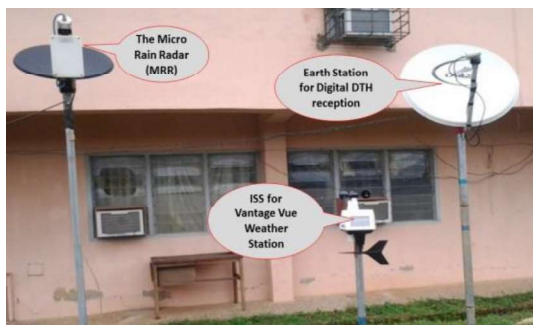


Figure 3. Outdoor unit for attenuation measurement on the DTH link at 12.245 GHz

Table 2. Characteristics of the satellite-earth link

Parameter	Description
Broadcast Satellite	EUTELESAT 36 B (on longitude 36° E)
Receive Station	FUT, Akure (7.17° N, 5.18° E), 358 m (ASL)
Path Length	36880.12 km
Height of receiving antenna above ground	1.5 m
Transponder frequency	12.245 GHz
Effective Isotropic Radiated Power (EIRP)	48 dBw
Symbol rate	27500 sps
Modulation	QPSK
Digital Satellite Television Standard	DVB-S
Forward Error Correction (FEC)	$\frac{3}{4}$
Receive antenna gain (0.9 m)	39.69 dB
Elevation angle at receiver station	53.2°
Total cabling and connection losses (22 dB per 100 m)	~2.2 dB
Gain of the (LNB)	65 dB
LNB input frequency	10.7 – 12.75 GHz
LNB output frequency	950 – 2150 MHz
L.O Frequency	9.75/10.6 GHz
Noise figure	0.3 dB
Free space loss	205.53 dB

as documented in [36]. The experiment for this study actually commenced in the month of July, 2012 and this experimental measurement is still in progress at the communications research laboratory of the Department of Physics, FUT, Akure. For observation over a period of two years – which spans from July, 2012 to June, 2014, the attenuation induced over the digital DTH link was estimated.

The precipitation experiment was conducted using the Davis 6250 Vantage Vue, which is an electronic weather station. Data collection for rainfall (mm) and the rain intensity (mm/h) was based on a self-emptying tipping spoon mechanism, with a resolution of 0.2 mm for each tip. The tipping spoon rain gauge is an essential part of the Integrated Sensor Suit (ISS), which basically represents the outdoor unit of this weather station. The rain gauge measures accurately with a precision of +1%, between 2 mm/h and 400 mm/h. The ISS is connected to the indoor console via the wireless medium, based on the frequency spread spectrum technique.

The interactive features of the Davis WeatherLink data logger were exploited for data storage and data transfer into an external memory device on the personal computer dedicated for the measurement. The outdoor unit for the precipitation measurement is shown in Figure 3. As part of the initial system configuration, the time on the weather station was synchronized with that on the personal computer, while the geographical coordinates, altitude, the preferred units of measurement and the integration time were clearly defined as earlier described in [24].

In order to monitor the digital satellite signal received concurrently at the pilot site, another

experiment was conducted and the installation was collocated with the precipitation measurement equipment. In this second experiment, an offset parabolic dish with a diameter of 0.9 m was installed to establish links with an active communication satellite distributing digital television DTH over Nigeria. EUTELSAT W4/W7 is the choice satellite for the experiment and is located at longitude 36° East. It was selected based on its prominence for the delivery of digital TV bouquets for Multichoice Africa. A Ku LNB was used and the Intermediate Frequency (IF) output was fed into the 3.0 GHz GWINSTEK GPS-827 spectrum analyzer and the WS-6936 digital satellite meter. The characteristics of the measurement setup is detailed in Table 2, while Figure 4 shows the indoor unit for the measurement.

#### IV. Results and Discussion

The detailed rain rate and the statistics of the received signal for the digital TV over the 12.245 GHz DTH link is presented. The clear-air statistics was estimated and used at every instance for deducing the corresponding rain attenuation. A typical time series for experimental observations between the month of July and December, 2012 is as presented in Figure 5. The corresponding effect of low, moderate and high rain rate was also evaluated while the squelching point for the digital TV signal was also determined.

In all, about 67 rainfall events were recorded and the drizzle rain rate accounts for 72% of the entire rain rate statistics, while widespread, showers and thunderstorm claims 10%, 13% and 5% respectively. The highest rainfall rate from the overall observation is 209.4 mm/h, which

was observed in the month of October. The effect of system availability is revealed in the duration of signal outage, which is about 115 minutes of outage over the 6-month rain attenuation measurement in the tropical Nigerian climate. It is apparent from the observation however, that the month of October is the worst month accounts for the highest rain rate value, a high percentage for thunderstorm rainfall type and most significantly, it recorded the highest duration for signal outage.

From the analysis presented, it is apparent that the digital satellite signal gets completely lost to the impairing rainfall effect, especially at high rainfall rates. This is typically described as signal

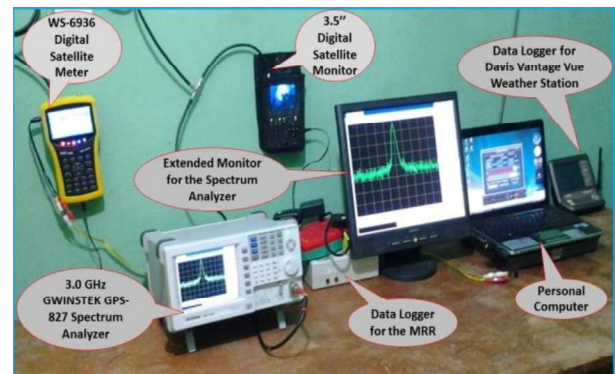


Figure 4. Indoor unit for rain attenuation measurement on the DTH link at 12.245 GHz

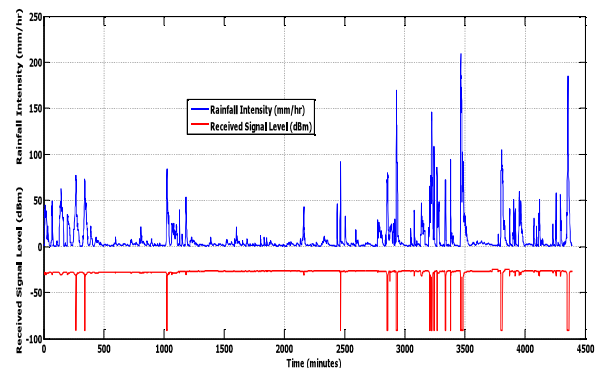


Figure 5. Time series for the rainfall rate and RSL for events between July and December, 2012

outage and it was experienced a number of times during the propagation measurement. The exact point where this occurrence was experienced is of interest in this analysis and it is referred to as the squelching point. The average of the received signal level (RSL) was then estimated for different rain rate values.

The power expected at the receiver under clear sky conditions was deduced along with the average RSL practically received from the propagation measurement during rainy conditions. Hence, the rain induced attenuation on the digital DTH link was determined by subtracting the power received during rainy condition from the power received during clear sky condition and it is expressed as:

$$A_{Rain} = RSL_{Clear-air} - RSL_{Rainy} \quad (1)$$

where  $RSL_{Clear-air}$  is the received signal level during clear air and  $RSL_{Rainy}$  is the received signal level during rainy conditions.

As observed from the results, it is apparent that the digital satellite meter and the spectrum analyzer could not monitor the signal level at heavy rain rates, particularly for rain rates  $\geq 65$  mm/h. At such instance, the noise level at the receiver increased abruptly, overwhelming the received signal and the digital television content (video and sound) was lost instantaneously. As reported in the study by Abdulrahman, et al. [37], “a huge margin is therefore required for link planning in this kind of climate, which is very difficult to obtain by using a spectrum analyzer.”

The rain attenuation estimates deduced from the propagation measurement along the 12.245 GHz digital DTH link were plotted against the corresponding rainfall intensity. This is as shown in Figure 6 and it clearly reveals the behavior of

the rainfall intensity during typical digital DTH reception and the response of the digital Integrated Receiver/Decoder (IRD) to the disgraceful rainfall effect. The relationship between the rainfall intensity and signal attenuation is shown in this Figure. For the rain attenuation estimate at 12.245 GHz, this relationship is linear and it indicates that the rain signal attenuation increases with rainfall intensity, as calculated based on the ITU-R P.618-10 recommendation. The other curve shows the rain attenuation on digital DTH reception at the same frequency.

It is the output curve of the decoder amplifier and it shows the relationship between the rainfall intensity and the signal attenuation suffered as it relates with the amplifier of the digital TV

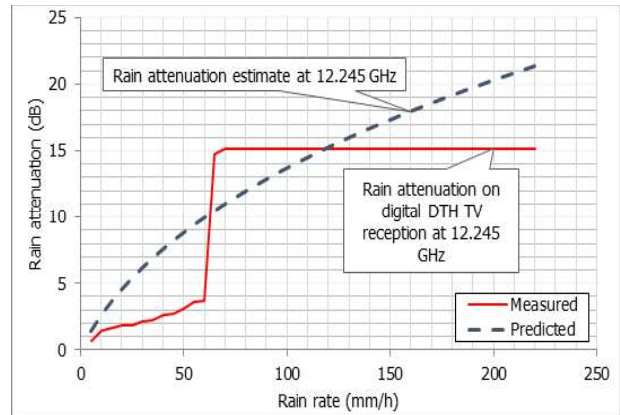


Figure 6. Relationship between the rainfall intensity and signal attenuation at 12.245 GHz

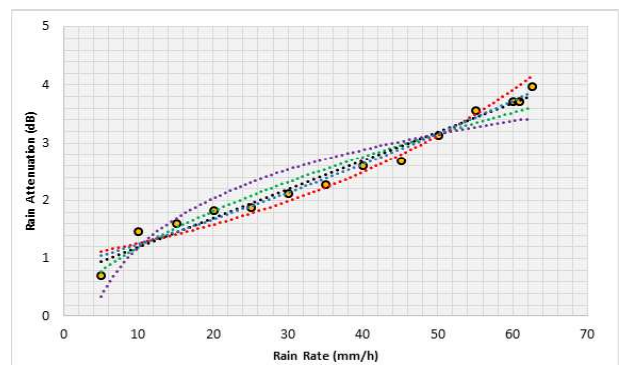


Figure 7. Rain attenuation measured at 12.245 GHz for  $(0 \text{ mm/h} < R < 65 \text{ mm/h})$

Table 3. Rain attenuation modeling for rain rates between 0 mm/h and 65 mm/h

Empirical expression	Empirical model	Regression Coefficient (R <sup>2</sup> )	RMS (%)
Exponential	$A=1.0085 \times e^{0.0226 \times R}$	0.8995	18.1
Logarithmic	$A = 1.2186 \times \ln(R) - 1.6132$	0.8738	20.1
Polynomial	$A = (0.0002 \times R^2) + (0.0373 \times R) + 0.8581$	0.9772	14.8
Power	$A = 0.2965 \times R^{0.6047}$	0.9594	9.16
Linear	$A = 0.0497 \times R + 0.7029$	0.9743	12.04

decoder. It was observed that the decoder performance remains satisfactory up to 3.71 dB, which corresponds to a rainfall intensity of 60 mm/h with an equivalent attenuation threshold of 4.63 dB, which is the highest the spectrum analyzer could practically measure before the signal is masked by noise. This is considered as the point at which the digital TV signal squelches. The amplifier enters saturation at this threshold and no signal is displayed on the analyzer at this instance, thus indicating complete signal outage and it lasts for the entire duration of the thunderstorm rainfall intensity. This is a clear disruption on the QoS and availability of services for satellite TV in the Ku band. It also depicts the inability of the spectrum analyzer and the digital satellite meter to measure signal levels at rainfall rates above 65 mm/h.

In order to obtain the empirical relationship between the rainfall rate and the attenuation induced on the 12.245 GHz digital DTH link by rain, the curve fitting technique was employed. The corresponding equation and regression coefficient for each of the models is as presented in Figure 7. It shows the rain attenuation plots for rainfall rates between 0 mm/h and 65 mm/h, which is between 0.72 dB and 3.97 dB. The regression coefficients (R<sup>2</sup>) are 0.8995, 0.8738, 0.9772, 0.9594 and 0.9743 respectively for the exponential, logarithmic, polynomial, power and linear fits. This is clearly presented in Table 3.

The root mean square (RMS) error margin was also deduced and employed for determining the empirical model which best fits the experimental data points. As shown in Table 3, the power law relationship recorded the least error, also presenting a regression coefficient of 0.9594. Since the regression coefficient is greater than 0.8, this implies that the power law model offers an acceptable level of accuracy. It is therefore considered as the empirical model for the rain attenuation on the digital DTH link, within the 0 mm/h - 65 mm/h and its as presented in Equation (2).

The attenuation estimate is however different for rainfall rates greater than 65 mm/h. It was observed at such instance that the amplifier is no longer sensitive to the variation in the rainfall intensity, thus presenting a constant estimate of 15.185 dB. The amplifier is in saturation during such event and no signal is recorded by the spectrum analyzer and no image or sound is also displayed on the digital receiver. Hence, the relationship deduced for the rain induced attenuation on the digital DTH link is therefore based on the power law relationship. It is therefore given as;

$$A = 0.2965 \times R^{0.6047} \quad (2)$$

where  $A$  (dB) is the attenuation induced by rain and  $R$  (mm/h) is the rainfall intensity.



Having quantified the effect of rainfall on the digital TV signal for practical reception vis-a-vis the DTH link, there is the need to consider suitable methods of mitigating its effect on signal propagation in the Ku-band. Generally, the most prominent approach is mainly focused on the optimal use of available system resource (s) for the provision of additional margin in decibel (dB). This margin is described as the system gain, which maintains the necessary QoS against various transmission and other impairments. In order to compensate for the severe signal fading as a result of weather inclement experienced at frequencies above 10GHz, the fade margin must really be sufficient.

This approach is rather flexible and allows for compensation at specific sites. This is also considered suitable for locations with longer path distance due to their relative position to the equator and the satellite. For instance, Figure 8 shows the contour for the steerable beam for the Ku transponder on the EUTELSAT W4/W7 satellite. Locations falling at the edge of the beam with the EIRP of 48 dBW are likely to experience signal degradation.

It was observed that the recommended dish size for locations serviced by this beam is 0.7 m. The other beam for the same Ku transponder is as shown in Figure 9, for an EIRP level of 47 dBW. An antenna size of 0.75 m was recommended for typical receive-only earth stations over these locations.

The gain of the offset parabolic reflector (antenna) is given as [38]:

$$G = \frac{4\pi A}{\lambda^2} \quad (3)$$

where  $\lambda$  is the wavelength (m) and  $A$  is the effective aperture which is expressed as:

$$A = \frac{\eta\pi d^2}{4} \quad (4)$$

where  $d$  is the antenna diameter (m) and  $\eta$  is the aperture efficiency.

Substituting for  $A$  in (3),

$$G = \frac{4\pi}{\lambda^2} \times \frac{\eta\pi d^2}{4} \quad (5)$$

$$G = \frac{\eta\pi^2 d^2}{\lambda^2} \quad (6)$$

But  $\lambda = c/f$ , where  $c$  is the speed of light ( $3 \times 10^8$  m/s) and  $f$  is the transmitting frequency (Hz).

$$\therefore G = \frac{\eta\pi^2 f^2 d^2}{c^2} \quad (7)$$

The effective dish size in clear sky reception is given as:

$$d = \sqrt{\left(\frac{G \times c^2}{\eta\pi^2 f^2}\right)} \text{ [m]} \quad (8)$$

Given attenuation due to rain as  $A_R$  (dB), the absolute value is obtained as follows:

$$\beta = 10^{\left(\frac{A_R}{10}\right)} \quad (9)$$

where  $\beta$  is the rain attenuation compensation coefficient.

Therefore the compensated dish size model is given as;

$$d = \sqrt{\left(\frac{\beta \times G \times c^2}{\eta\pi^2 f^2}\right)} \text{ [m]} \quad (10)$$

However, for typical reception of the high definition TV on the TV receive-only platform, the 0.9 m dish is the common antenna size in use

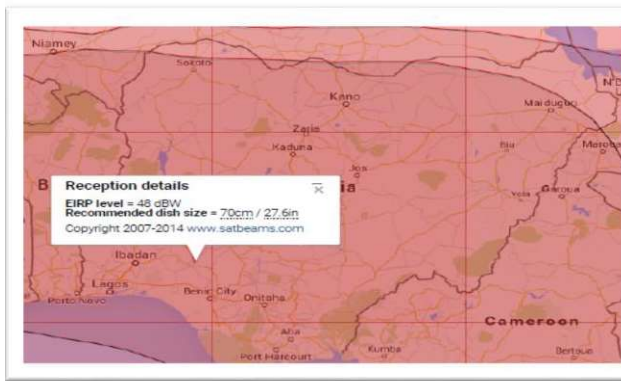


Figure 8. EUTELSAT W4/W7 (360 East) –Ku-band 48 dBW Beam over Nigeria

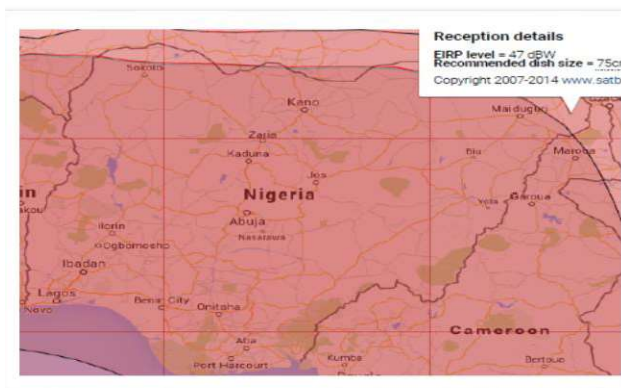


Figure 9. EUTELSAT W4/W7 (360 East) –Ku-band 47 dBW Beam over Nigeria

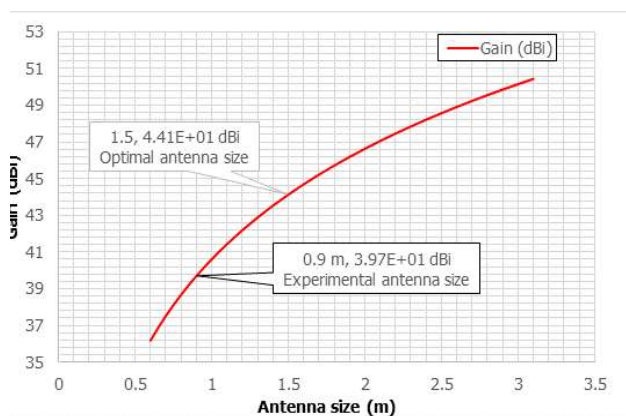


Figure 10. Determination of the optimal antenna size for compensation of digital satellite television reception

over Nigeria. The additional gain accruable from oversizing the receiver antenna is utilized so as to provide sufficient margin for the system to remain closed. Figure 9 shows the gain of the antenna 0.9 m offset parabolic reflector used for the propagation measurement described earlier in this study.

The equivalent gain was estimated based on an aperture efficiency of 70%. The attenuation estimated on the 12.245 GHz digital DTH link was used as reference for the determination of the practical antenna size for the rain degraded reception. Contrary to the recommended 0.7 m for typical reception by the satellite operators, a practical dish size of 1.5 m was deduced for optimal reception on the 48 dBW satellite footprint. It provides an additional gain of 4.4 dB and this was found to be adequate for compensating Ku satellite signal attenuation, regardless of rainstorm in Nigeria.

## V. Conclusion

Previous works were mainly limited to mere modelling of rain-induced attenuations without porting their research findings into products in terms of determination of appropriate satellite dish to compensate for the rain-induced signal attenuation. Based on the knowledge of the rain attenuation over the digital DTH link in the worst rain climate zone in Nigeria, the detailed rain rate and the statistics of the received signal for the digital TV over the 12.245 GHz DTH link was presented and the empirical model for the rain attenuation on the digital DTH link was deduced. The typical attenuation thresholds on the link was also deduced. The practical dish size for optimal reception of the HDTV was determined and a value of 1.5 m was derived for

the 48 dBW Ku beam for EUTELSAT W4/W7 broadcast satellite. This is considered adequate for compensating for the signal attenuation in the Ku-band, regardless of rainstorm in Nigeria. This work has also provided the practical dish size for sustaining the availability and quality of the digital satellite television in the Ku band.

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