

## Path Clearance Effect On Microwave Radio Link Within 11km Path Length and 2GHz-20GHz Signal Frequency

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### **Abstract**

*Path clearance has significant effect on communication links utilizing Microwave frequencies that exhibit Line-of-Sight (LOS) mode of propagation. Ideally, microwave signals in UHF, SHF and EHF bands propagate wireless signals in a straight-line path known as LOS using directional antennas. This paper presents the effect of path clearance on 2GHz to 20GHz range of signal frequencies in steps of 2GHz, 5GHz, 10GHz, 15GHz and 20GHz along a signal path length of 11km from Bayero University Old Campus to Langel Village, Kano-Nigeria. The two radio sites (A and B) are located at Old Campus Bayero University, Kano  $N11^{\circ}58'40.0''$   $E8^{\circ}28'35.0''$  489m (a.s.l) and Langel Village  $N11^{\circ}58.30.0'$   $E008^{\circ}22.20'$  476 (a.s.l) Kano Northern-Nigeria. Path length and coordinates were measured using Germin eTrex20 GPS system with WGS-84 standard. Furthermore, the microwave signal degradation due to path clearance effect at different signal frequencies was considered. The simulation results obtained are presented in terms of received signal level, obstruction loss, fade margin, free space loss and Netpath Loss. The observed degradation due to obstruction and other losses along the signal path were calculated using ITU-R Rec. models. It was found that; for clear LOS link from Bayero University Old Campus to Langel village an antenna height of 35m suffices on both sites for normal atmosphere and minimum transmission requirements with 0dB obstruction loss. These tower heights are sufficient for the transmission at any given signal frequency and obstacle (trees, mountains and buildings) heights of up to 12-meters. The Netpath loss and free space loss increase with increase in signal frequency, which leads to decrease in the received power level above the threshold of -70dB level. The link satisfied the clearance criteria with 0dB obstruction loss and more than 0.6F1 clearance with addition of up to 6m-to-7m obstructions. The clearance increase in as the frequency increases.*

**Keywords:** Microwave, Signal, Fading, Frequency, obstruction, loss, Line-of-Sight

## **1. Introduction**

The design of transmission performance of terrestrial line-of-sight (LOS) microwave (MW) radio communication links is significantly influenced by propagation phenomena of obstruction (path clearance) loss and multipath fading. These effects may be due to abnormalities of environmental parameter changes such as; terrain (mountains, water, topography) and atmospheric (temperature, humidity, fog, rain) changes. An ideal MW LOS radio link can be defined as a communication link that propagate signals in ultrahigh frequency UHF (0.3-3GHz), super high frequency SHF (3-30GHz) and extremely high frequency EHF (30-300GHz) bands wirelessly using directional antennas from transmitter (Tx) to Receiver (Rx) in a straight line-of-sight with no obstructions or obstacles along the signal path [1, 2]. These frequency bands require that; Tx and Rx have almost perfect sight of each other via free space using EMW radiation [3, 4]. Electromagnetic waves (EMW) signals propagating via free space may encounter problems such as reflection, refraction, diffraction, scattering and absorption due to terrain and variabilities in environmental physical parameters [5,6]. These may lead to signal fading (destructive interference) or boost (constructive interference) that in turn decreases or increases the received signal power level at the receiver end [7].

Obstruction fading (loss) may be due to temporary or permanent changes of the terrain, which blocked the transmission path. In multipath fading; a multiple transmission paths are created which may cause destructive or constructive interference of the multiple waves at the receiving site antenna. Multipath and obstruction losses can be mitigated by different methods. Sufficient antenna heights for transmitting or receiving or both can reduce or completely mitigate the occurrence of obstruction loss (fading) to an acceptable value. Diversity protection methods such as frequency or space diversity can be used to mitigate or completely eliminate transmission impairments due to multipath fading [8].

In conventional LOS links; the link path length is a function of antenna height and signal frequency. The coverage area may be bounded and affected by other things such as; the earth curvature, physical obstructions and obstacles such as mountain, hills, tall buildings, tree branches, weather (rain, snow, wind, fog, temperature, humidity, smog) [9, 10].

In fixed terrestrial microwave communication systems, the Tx antenna and Rx antenna should be in a clear LOS (no physical obstruction or obstacle) along the signal path [11,12]. An optical or clear LOS exists if an imaginary straight line can be drawn connecting the Tx and Rx antennas. This is required to propagate signals with a clearance of first (1<sup>st</sup>) Fresnel Zone ( $F_1$ ), which is normally bounded by specific system with high frequency or short wavelength [13, 14].

## **2 METHODOLOGY**

Microwave LOS radio link planning and design method were used in this research. Step-by-step procedures from planning, physical site survey, design and simulation of link based on ITU-R Rec. and models were conducted [15, 16]. Planning, design and simulation of microwave LOS radio link can be divided into three (3) major steps namely: Network or link planning, link design and link simulation using HERALD software[17, 18].

Garmin eTrex 20 Global Positioning System (GPS), Personal Computer (PC) running windows operating system (OS), Licensed HERALD Software; Trip (Distance) calculator were used to carry out field survey for this research.

### **2.1 Network Planning Procedure**

Network planning procedures include; environmental regulation consideration, identification of terminal radio sites, service and capacity requirements, performance objectives, frequency band selection, identification of suitable radio equipment and antennas and an estimate of maximum hop length [18,19].

### **2.2 Link Design**

Number of factors had influenced the design process of route and site selection among which include: maximum hop length, nature of terrain and environment, site-to-site terrain profile, availability of existing structures, new structures requirements, access roads, availability of electric power sources, and weather conditions. Final design was an iterative process of hop configuration; hop performance prediction, revision of route and site selection, revision of hop configuration and design.

In this paper HERALD program was configured with environmental and system parameters obtained from the site survey as in Tables 2, 3 and 4 and design process. These summarized the site and hops parameters for configuration.

Degrading factors of a microwave LOS link may include: atmospheric absorption loss, obstruction loss, Receiver (Rx) threshold degradation due to ground reflections, Rx threshold degradation due to interference. These can be predicted with consideration to suitable models to estimate impact on hop performance [16, 20].

**Table 1: Path Meteorological Data Sheet**

<b>Path Type</b>	Inland (Terrestrial)
<b>Climate Region</b>	Tropical
<b>Path Longitude</b>	Africa/Europe

**Table 2: Path Profile Data**

Site Name (Code)	Distance from SiteA BCP (km)	Elevation a.s.l (m)	Coordinates (WGS-84)
Biochemistry Car Park (BCP-01)	0	489	N 11 <sup>0</sup> 58.779' E 008 <sup>0</sup> 28.773'
Langel Village (LV_02)	11	476	N 11 <sup>0</sup> 58.30.0' E 008 <sup>0</sup> 22.20'

**Table 3: Site Data Sheet**

Description	Site A	Site B
Station Name	BCP_01	LV_02
RF Frequency Band (GHz)	2-20	
Path Length (Km)	11km	
Equipment Type	S0/6L/140/A	S0/6L/140/A
Equipment Capacity (Mbps)	34	34
Antenna type	GamX300-6L/D-Parabolic	GamX300-6L/D-Parabolic
Antenna Height (m)	35	35
Site Elevation a.s.l (m)	489	476
Polarization	D (V/H)	D (V/H)
Feeder Type	EEE-6000/bz	EEE-6000/bz
Feeder length (m)	35	35
Branching Loss (dB)	-1.10	-1.10
Antenna Gain (dB)	47	47
Tx Power (dBm)	24	24
Rx Threshold C <sub>min</sub> (dBm)	-70	-70
Feeder Kind	Waveguide	Waveguide
BER	1x10 <sup>-3</sup>	1x10 <sup>-3</sup>
Antenna Diameter (m)	2	2

### 2.3 Link Power Budget

ITU-R Rec. models used by the program to predict path clearance (losses and link clearance) were free space propagation and Fresnel zone clearance criteria models. The mathematical equations below are used for the link design.

#### Link Equation

$$P_r = P_t + G_t + G_r - FSL - L_f \quad (1)$$

#### Feeder Loss (dB):

$$L_f = \text{SpecificLoss} \left( \frac{\text{dB}}{\text{m}} \right) * \text{FeederLength}(\text{m}) = SL * FL \quad (2)$$

#### Antenna Gain (dB<sub>i</sub>):

$$G = 10 \log_{10} \eta \left( \frac{4\pi A_e}{\lambda^2} \right) = \eta D, \quad \text{Beamwidth (B)} = \frac{k}{fD} = \frac{k\lambda}{cD} \quad (3)$$

Where; G: is the Tx or Rx antenna gain (dB), A: the effective area of aperture (m<sup>2</sup>),  $\lambda$  is the wavelength (m) of the operating frequency  $f$ ,  $D$ : directivity and  $k$ : is a constant.

#### Power at Tx Antenna (dBm):

$$P_t = P_T - L_{bt} - L_{ft} \quad (4)$$

Where;  $P_T$ : is the total transmitter power, and  $L_b$ : is the Branching or connectors Loss

#### Free Space Loss (FSL in dB):

$$FSL = L_p = 32.45 + 20 \log_{10} d(\text{km}) + 20 \log_{10} f(\text{MHz}) \quad (5)$$

Where;  $d$ : is the path length (in km),  $f$ : is the operating frequency (in MHz)

#### Net Path Loss (NPL in dB):

$$NPL = L_N = \text{Losses} - \text{Gains} = FSL - G_t - G_r \quad (6)$$

Where;  $G_t$  and  $G_r$ : are the Tx and Rx antenna gains

#### Power at the Rx Antenna (dBm):

$$P_r = P_t - L_N \quad (7)$$

#### Rx Power (dBm):

$$P_R = P_r - L_{br} - L_{fr} \quad (8)$$

#### Fade Margin $F_m$ (dB):

$$G_s = P_t - C_{min} \geq F_m + L_p + TX_{Losses} + RX_{Losses} - G_t - G_r \quad (9)$$

Thus;

$$F_m \leq P_t - C_{min} - L_p - TX_{Losses} - RX_{Losses} + G_t + G_r \quad (10)$$

Where;  $C_{min}$ : is the Rx Threshold (dBm) or min Receiver input for a given quality objective (e.g. BER),  $G_s$ : is system gain (dB)

$Tx_{Losses}$ : are the Tx feeder and branching losses ( $L_{bt} + L_{ft}$ )

$Rx_{Losses}$ : are the Rx feeder and branching losses ( $L_{br} + L_{fr}$ )

$F_m$ : is the Fade margin for a given reliability objective (e.g. BER)

Generally,

$$Hop\ Threshold = Equipment\ Threshold + Threshold\ Degradation$$

$$Fade\ Margin = Normal\ Rx\ Power - Hop\ Threshold$$

Equipment Threshold is the Rx Threshold, while Threshold Degradation is the losses due to reflection and interference. Nominal Rx Power is the power detector input ( $P_T$ )

$$F_m(dB) = P_R - C_{min}(Rx_{Threshold}) \quad (11a)$$

$$F_m(dB) = 30 \log_{10} d(km) + 10 \log_{10}(6ABf) - 10 \log_{10}(1 - R) - 70 \quad (11b)$$

Where;

**A**: Roughness factor (it is 4 over water or very smooth terrain, 1 over an average terrain and 0.25 over a very rough, mountainous terrain), **B**: Factor to convert a worst month probability to an annual probability (it is 0.5 for humid areas, 0.25 for average in land areas and 0.125 for very dry or mountainous areas), and **R**: Reliability (in decimal), **d**: path length (km), and **f**: frequency (GHz).

### Outage Prediction Model Equations

When signal distortion contribution to outage is not expected

$$OutageTime(\%) = Prob\{RxPower < HopThreshold\} = Prob\{P_R < C_{min}\} \quad (12)$$

When contribution to outage is expected from signal distortion

$$OutageTime(\%) = P\{P_R < C_{min}\} + P\{Outageduetodistortion/P_R > C_{min}\} \quad (13)$$

Where the second term of equation (12) on the right gives the contribution to outage **probability when the received signal severely distorted above the hop threshold**.  $P\{A/B\}$  means probability of event A, given that event B is true (occur).

These equations only help to clarify how the outage time is related to the Rx power level and to additional impairments in the received signal. They do not provide a practical means to predict outage time.

### 3. Results And Analysis

The results of the design and simulation of a direct link from Bayero University Kano Biochemistry Department Car Park Old Campus (BCP\_01) and LangelVilage (LV\_02) along Gwarzo road Kano-Nigeria are presented and discussed. Data was collected from site survey and in the software as shown in the Tables 1, 2 and 3.

Hop configuration report of the two sites under design gives the configured parameters of antennas, feeders and radio equipment as shown in Table 2 and 3.

Table 2 and 3 summarized the configurations of the link indicating the antenna types (code), gain, height, coordinates (latitude and longitude), radio equipment type (code), capacity, feeder type (code), specific loss, and elevation a.s.l. These configurations are the same for different frequencies used in the direct link. The path inclination ( $0.07^0$ ) and profile roughness (7m) were the same at all the frequencies considered.

**Table 4:Link Performance Summary**

Freq (GHz)	$P_T$ (dBm)	$P_t$ (dBm)	FSL (dB)	NPL (dB)	$P_r$ (dBm)	$P_R$ (dBm)	$F_m$ (dB)
2	24	19.4	119.5	25.5	-9.6	-44.2	25.8
5	24	19.4	127.5	33.5	-17.6	-52.2	17.8
10	24	19.4	133.5	39.5	-23.6	-58.2	11.8
15	24	19.4	137	43	-27.1	-61.7	8.3
20	24	19.4	139.5	45.5	-29.6	-64.2	5.8

Table 4 give the summary of link performance according to link power budget analysis equations (1)-to-(11) based on the configurations of Table 4. Feeder losses, free space loss (FSL), net path loss (NPL) taking into account FSL, and receiving/transmitting antennas gains were calculated. Powers at the transmitting antenna, receiving antenna, received at the detector input ( $C_{min}=-70$ dBm) and flat fade margin were also obtained and summarized in Table 4 for different frequencies. The software computed results were verified using link budget equations (1)-to- (11).

The results showed that; transmitted power ( $P_T= 24$ dBm) reduced to power at the Tx antenna ( $P_t = 17.9$ dBm) due to feeder and branching losses as observed from Table 4. Power received at the detector input ( $P_R$ ) is not the same as power at Rx antenna ( $P_r$ ).

Free space path loss (FSL) was observed to have effect on the net path loss (NPL), fade margin ( $F_m$ ) and the power at Rx antenna. Propagation losses due to obstruction and atmospheric absorption were zero since no obstruction losses along the path.

Table 4 summarized link performance at different frequencies for a direct link of 11.33km path length.

The FSL was observed to be decreasing negatively and increase positively from 119.5dB to 139.5dB with the increase in frequency from 2GHz to 30GHz while the NPL from 25.5dB to -45.5dB. These are true and were verified by design equations (5) and (6). When positive or absolute values are used, the losses will be increasing with increase in frequency but negative sign was used to indicate loss of signal instead of gain as shown in Table 4.

The FSL and NPL caused degradation that affected the performance of the link by reducing the Rx powers and fade margin. The power at the Rx antenna ( $P_r$ ) was observed to be decreasing negatively from -9.6dBm to -29.6dBm and Power at the detector input ( $P_R$ ) was decreased from -44.2dBm to -64.2dBm with decreasing fade margin ( $F_m$ ) from 25.8dB to 5.8dB at BER of  $1 \times 10^{-3}$  as indicated by Table 4. The receiver threshold ( $C_{min}$ ) was -70dBm at this BER. Therefore, increase frequency leads to loss in power by the system at the transmitter and receiver systems which were due to increase in free space loss along the path as signal frequency increases. The Rx powers and  $F_m$  were computed using equations (7), (8) and (10) respectively.

### **3.1 Path Profile and Clearance**

Table 2 give the Path profile data including distance from the first site and elevation a.s.l. that was derived from the contour map of the area. Height of obstacles above the ground level associated to profile point of 6km and 7km along the path are displayed in Figures 1, 2, 3, 4, 5 and 6 shown.

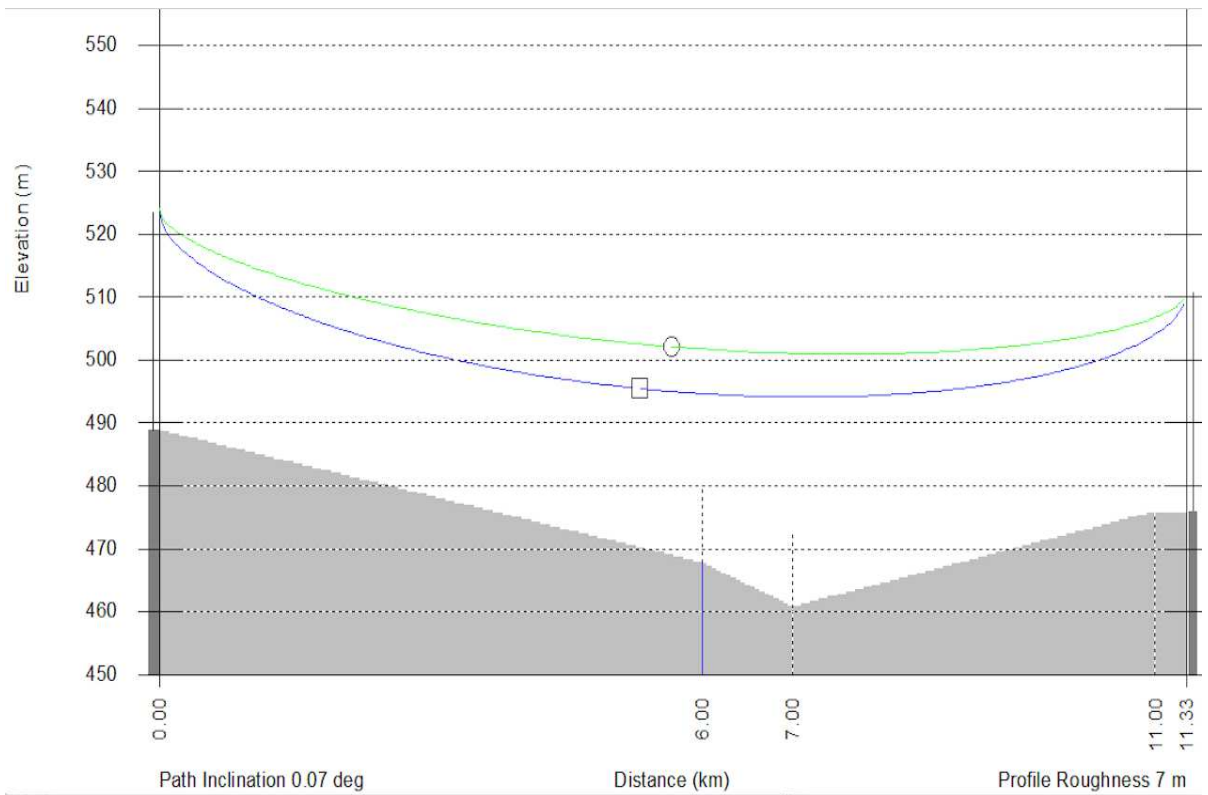


Fig: 1 Path Clearance at 2GHz

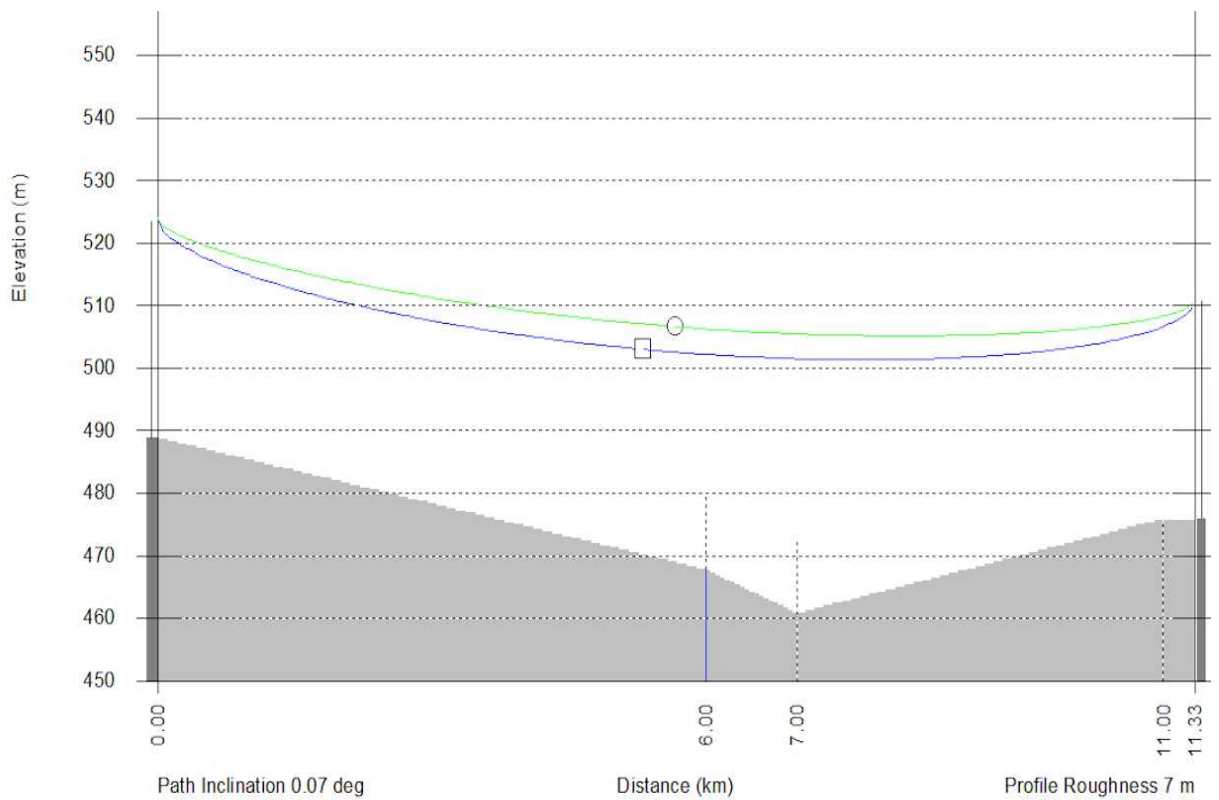


Fig: 2 Path Clearance at 5GHz

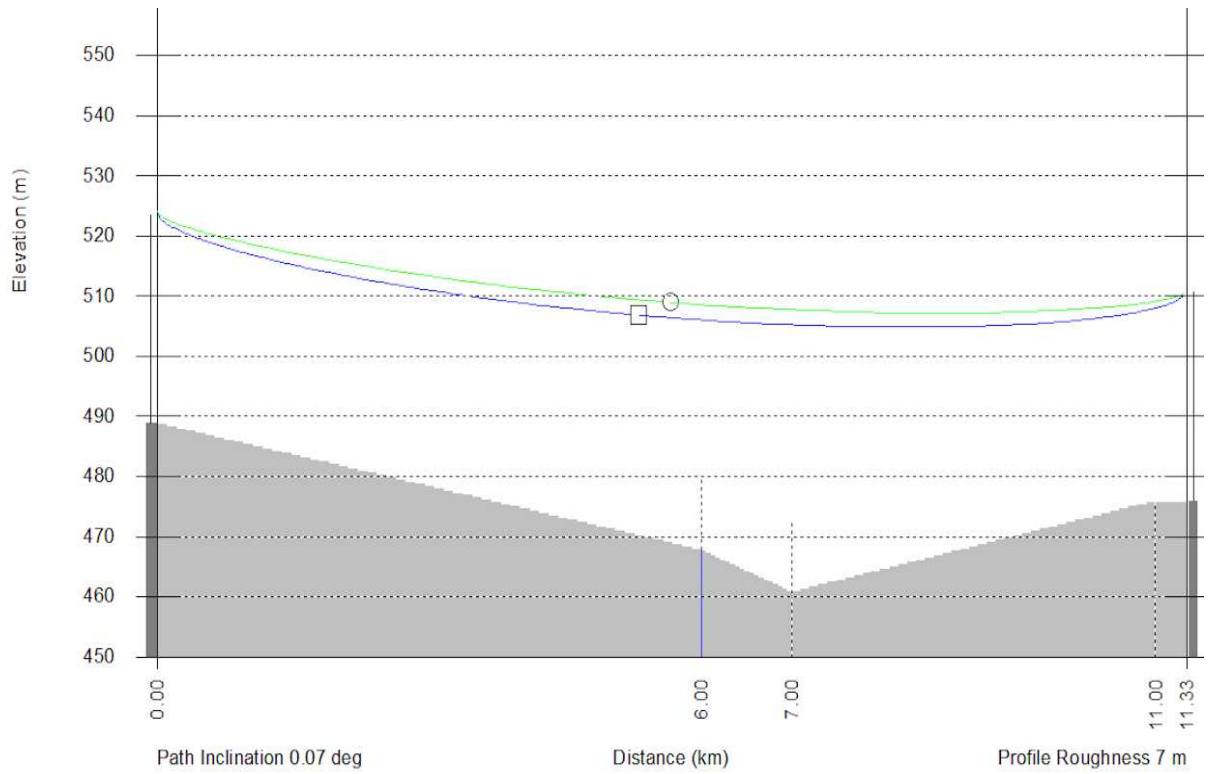


Fig: 3 Path Clearance at 10GHz

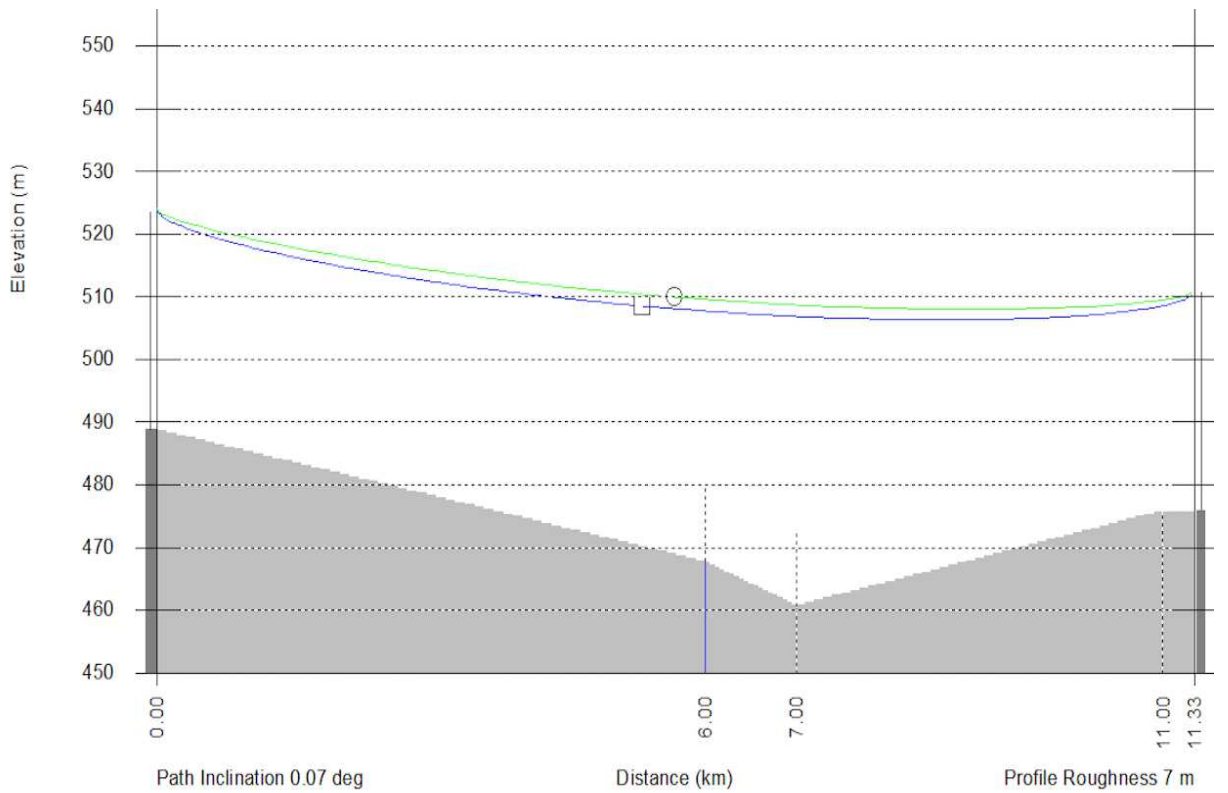


Fig: 4 Path Clearance at 15GHz

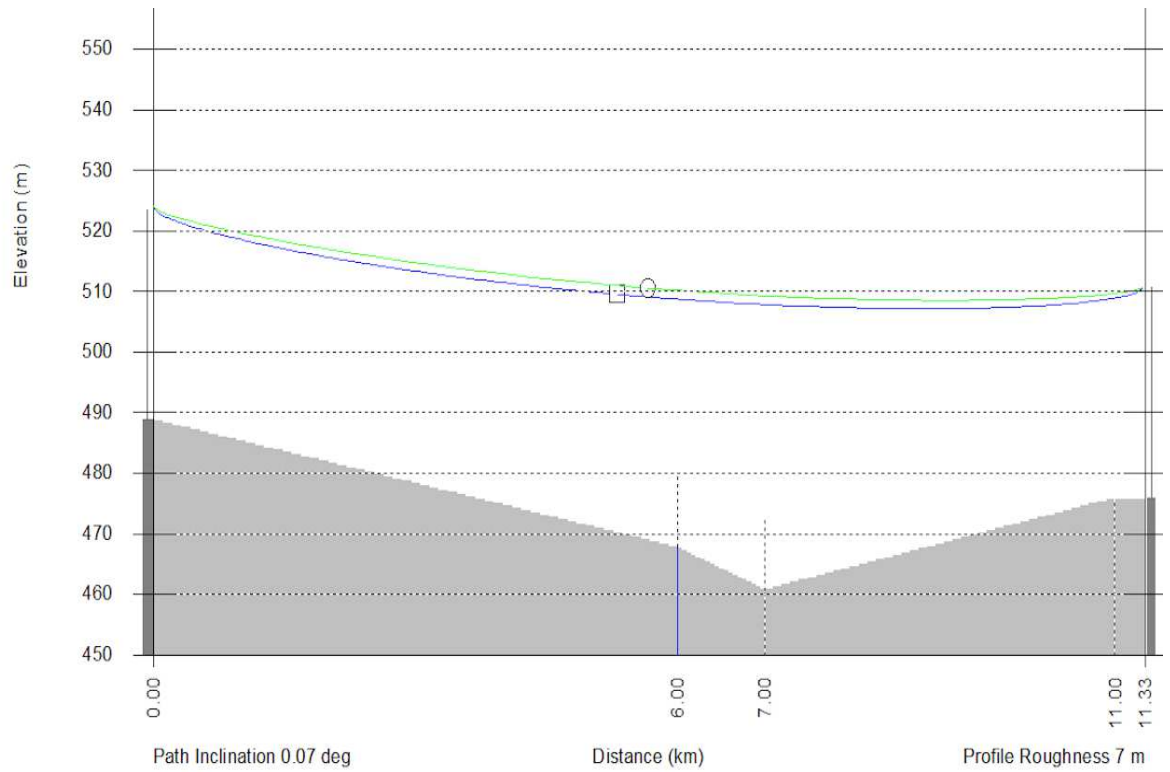


Fig: 5 Path Clearance at 20GHz

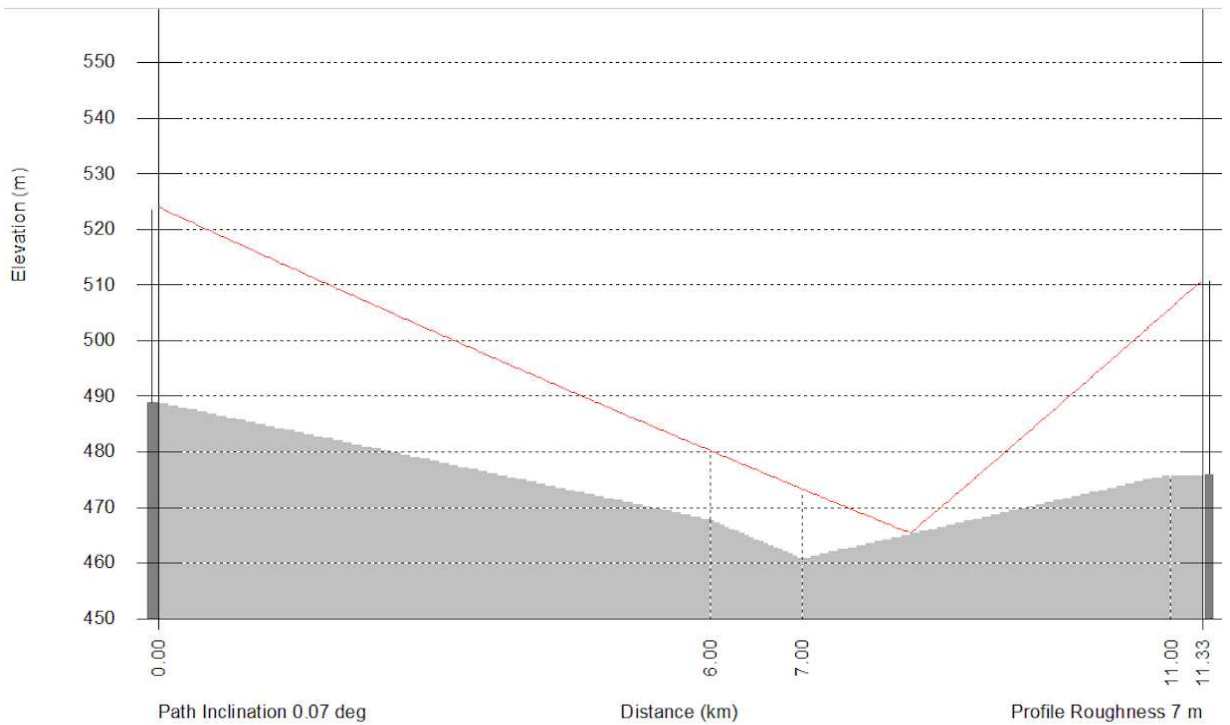


Fig: 6 Path Reflection Point

Terrain roughness of 7m and the path inclination of  $0.07^{\circ}$  were calculated from the path profile. The Path Profile clearance Figures below show a table of profile points (6.0km) with additional checkpoints (blue vertical line) where the terrain elevation of 469m a.s.l (end of vertical blue line at 6.0km) or 480m a.s.l (tip of the obstacle at 6.0km) is given, along with clearance and margin data, as a result of Clearance analysis. Margin (Marg) values (m) were computed as difference between the obstruction at 6.0km (blue vertical line) and K-factor (1.33 and 0.83) lines (green and blue) above the obstacle.

Table 5: Path Clearance Summary

Freq (GHz)	K-Fact	%P	Xmin (Km)	C1/F1	Marg (m)	Obstruct Loss (dB)
2	1.33	100	6.0	1.71	14.7	0.0
	0.83	60	6.0	1.66	21.7	0.0
5	1.33	100	6.0	2.71	22.2	0.0
	0.83	60	6.0	2.62	26.3	0.0
10	1.33	100	6.0	3.83	26.0	0.0
	0.83	60	6.0	3.7	28.6	0.0
15	1.33	100	6.0	4.69	27.7	0.0
	0.83	60	6.0	4.54	29.6	0.0
20	1.33	100	6.0	5.41	28.7	0.0
	0.83	60	6.0	5.24	30.2	0.0

The path profile Figures 1, 2, 3, 4 and 5 were drawn using the specifications in Table 1, 2 and 3. Terrain heights at different path length were shown. The Tx antenna was positioned with 35m above the site elevation of 489m a.s.l at 0km path length. An antenna height of 35m above the site elevation of 476m a.s.l at 11.33km path length from Tx antenna was installed at Receiver (Rx) site.

The signal path was observed to be clear from all obstructions at all signal frequencies under design. Thus; obstruction loss was found to be 0.0dB at all signal frequencies observed.

The path inclination and profile roughness for direct link were observed to be 0.07-deg and 7m respectively (see Figures 1, 2, 3, 4, 5 and 6). The Tx and Rx antennas

were set at -0.1-deg and 0.0-deg arrival angle respectively. Path profile was displayed, together with the Fresnel ellipsoid sections for given k-factors (1.33 and 0.83) and radius percentages (100% and 60%). The earth curvature and tropospheric refraction were considered with k-factor =1.33 and 0.80; standard and minimum values respectively. These k-factor values have been used for normal atmospheric condition and sub-refraction condition. It was observed that margin from the ellipsoid section shown in the path clearance figures to the ground obstruction for  $K=0.83$  were greater than that of  $K= 1.33$  at all signal frequencies. The path clearance was also satisfied at all frequencies by setting the Fresnel zone of 60% ( $0.6F_1$ ) with  $F_1$  being the first Fresnel zone and there were no obstructions (mountain, tall buildings, trees etc) close enough to block the signal path with 0.0dB obstruction loss. The Tx and Rx antenna heights (35m) are sufficient for a clear LOS link in the case of direct link. Therefore, clearance criteria were satisfied by direct link from old campus BUK to langel village Kano State Nigeria as shown in Figures 1, 2, 3, 4 and 5.

The anticipated obstruction from tree growths and building structures of 12m along the signal path were added at 6km and 7km after a survey to the site of the proposed link. Direct link design and simulation satisfy the clearance criteria for LOS at all signal frequencies (2GHz, 5GHz, 10GHz, 15GHz and 20GHz) considered. Microwave radio communication from BUK to langel village was achieved using transmit and receive antenna heights of 35m with the 0dB obstruction loss and satisfactory path clearance.

Path visibility was checked by defined clearance criteria based on ITU-R Rec. 530-15 [16]. K-factor criteria of values 1.33 and 0.80 were defined as standard and minimum values respectively. Each k-factor value is associated to a percentage (100% and 60%) of the Fresnel ellipsoid radius as shown in Table 5. The clearance criteria are said to be satisfied when both k-factors (Fresnel ellipsoid) is free from obstacles for the given radius percentage (P%) and both margin values associated to these are positive (see Table 5). When one or both margin values are negative, then the visibility criteria are not satisfied. All margin values at signal frequencies considered by this paper were found to be positive as shown in Table 5.

Obstruction losses are estimated to be 0dB whenever the normalized clearance ( $C_1/F_1$ ) associated to k-factor value of 1.33 (standard atmosphere) is greater than 0.5 as shown in Table 5, the minimum value of  $C_1/F_1$  in this design was 1.66 at 2GHz signal frequency and 5.24 at 20GHz. From the results obtained; under standard atmosphere

the obstruction loss can be mitigated by increase in signal frequency. Obstruction loss corresponding to the minimum normalized clearance is computed with the assumption of three different obstacle shapes; *knife edge*, *smooth spherical earth* and *intermediate case*, as given in ITU-R Rec. 530 [16].

Reflection point along the signal path occurred at 8.16km from the first radio site (transmitting end) with 0dB signal attenuation at  $180^{\circ}$ -phase angle as shown in fig. 6

#### **4. CONCLUSION**

The paper has presented the path clearance effect on microwave radio link within 11km and 2GHz-20GHz signal frequencies with reference to ITU Rec models in [16,20].

The link satisfied the clearance criteria at all the signal frequencies used with 0dB obstruction loss. The link produced an effective, reliable, efficient and highly performed MW LOS link with more than 0.6F1 clearance by addition of up to 6m-to-7m obstructions in future with the increase in clearance as the frequency increases from 2GHz-20GHz. The results obtained showed no need for optimizing antenna heights or use of repeater(s) along the signal path.

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