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Analysis of Electromagnetic Radiation of Radio Waves Propagation in Okene, Kogi State, Nigeria

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ABSTRACT

The poor radio signals experienced in Okene and its environs have posed serious concern. This poor EM wave causes increased attenuation, which have resulted in distorted signals. This study considers two radio broadcast stations. The signal strengths of the two radio stations were compared and analysed. The signal strengths were measured using field strength meter. Sixteen locations were considered, while the wavelength and free space path-loss calculated. The approximate distances between the antennas were determined. The transmitting signal strength was 100.9dBμV (KA) and 102.2dBμV (KB). Receiving signal distances are 72.0km (KA) and 69.0km (KB). The free space path loss was 109.01dB (KA) and 109.39dB (KB). Though, transmitting signal strength of KA is lower with longer wavelength 3.21m and lower frequency 93.5MHz gives it an edge over KB which has higher frequency 109.5MHz and shorter wavelength 2.94m. It is however recommended that the FM stations should improve their network system for effective service delivery, mostly where low performances are experienced. Expectation is that at about 69km from transmitting antennas, booster stations will enhance signal effectively. This will lead to better signal quality and improved the satisfaction of the residents.

Keywords:
Radio waves,
Attenuation,
Impedance mismatch,
Path loss,
EM fields,
EM Spectrum,
Propagation pattern.

INTRODUCTION

Radio waves, a branch of electromagnetic waves consist of both electric and magnetic fields perpendicular one another and to their direction. This is propagated at the speed of light and mainly useful in communication (Kongban 2009). Radio waves has the refraction ability by the ionosphere. Meanwhile, at very high frequency (VHF), minimal refraction of radio waves is experienced (Daniel et al., 2016, Britannica 2022). Typically, process of modulation encourages transmission of audio frequencies via radio waves at specific angles (Commscope 2018). Modulation is the process of superimposing a low-frequency signal on a high-frequency carrier signal for transmission (Kongban, 2009). In the case of amplitude modulation (AM), the carrier wave amplitude is adjusted to match the low frequency audio signal. While the frequency is altered in frequency modulation (FM). At the receiving end, a radio receiver captures the radio wave and through demodulation extracts the information (Britannica 2022, Course Hero 2022). The radio frequency spectrum covers a large part of the electromagnetic spectrum and widely used in wireless broadcasting and communication. The likes of mobile radio communications, broadcasting, radar, and cell phones are products of radio frequency fields, or radio waves (Graf 2001). Radio propagation Is the behavior of radio waves as they travel from one point to another within the Earth's atmosphere (Ellingson 2016). Just like electromagnetic waves, radio signals also has characteristics such as reflection, refraction, diffraction, absorption, polarization, scattering, and interference. Saroj and Smruti (2011) noted that electromagnetic interference occurs when there is disruption in fields, resulting in distortions. When changing frequencies or channels in radios, this interference is ususally noticeable, which lead to noise. In television signals, due to signal distortion, it deteriorates the picture quality. One cannot predict radio propagation, and in transmission planning, probabilistic methods are used. Brain (2000) noted that various protocols have been established for radio wave propagation, the mode used depends on the distance between the transmitter and receiver. Obstacles and the propagation medium heavily influence the effectiveness of radio signal transmission, making signal strength crucial for the design and operation of radio systems (George and Theodore 1982, Amajama et al., 2023). In crucial communication areas, such as those where insecurity is on the rise, the measurement and analysis of radio signal strength is of high importance. In Nigeria, the escalation and manifestation of insecurity in armed banditry, kidnapping, and terrorism has led to ineffective communication systems due to poor radio signal reception from transmitting antennas (NSACC 2021). Government, individuals, and organizations aiming for long-term sustainability is critically concern with the security of lives and property, (Achumba et al., 2013, Hussein et al., 2004). (Hussein et al. (2004) emphasized that effective planning, management, and resource allocation for successful business operations is very essential in a secured environment. In acknowledging this, the Nigerian federal government invests a significant portion of its budget in security. However, shortcomings in communication system have hindered efforts in security. This paper aims to carry out a comparative analysis of the electromagnetic radiation (signal strength) using two FM stations in Okene, Kogi State, with the aim of recommending ways of improvements for enhanced signal quality and reception for better communication, especially for security matters in rural areas, to support sustainable development.

MATERIALS AND METHODS

Materials

The materials utilized for this study includes field strength meter; Spectral V5 RF power meter; 8VSB (ATSC) modulator meter; and a GPS device.

The Field Strength Meter

The field strength meter operates based on a straightforward passive (unpowered) circuit design In this design, the antenna intercepts radio frequency (RF) energy, which is then rectified to direct current (DC). The rectified DC is utilized to directly drive the meter, indicating the strength of the received RF signal. Its sensitivity is influenced by the following factors:

• Antenna Gain: How it intercepts RF signal; • Meter movement sensitivity; • Battery capacity.

Methods

Area of study

Okene, a strategically positioned town, is located at latitude 7.550° North and longitude 6.240° East, with an elevation of 384km above sea level. The town covers an area of 328km². According to the 2006 census, it has a population of 325,623. It is originally founded on a hill, it is now situated in the Valley of the Ubo River, a minor tributary of the Niger River. Okene operates on the West Africa Time (WAT) zone. The town's economy thrives on various businesses services and approximately 75% of the population engages in farming. Notable radio stations in Okene include Kogi Radio on 93.5 FM, situated on a hill in the Okene Bar area. It operates with a transmitter power of 10kW but broadcasts only 3kW for public consumption. Another radio station, TAO FM, operates on 100.9 FM and is located in Kuroko, Okehi. It has a combined transmitter power of 2kW that is fully broadcasted. Fig. 2 displays a map of Okene, indicating the locations of these two radio stations.

Method of determining signal strength

The field strength meter was activated and set to the radio frequency mode, specifically tuned to the FM mode to capture only frequencies within that range. With the antenna adjusted the scanning process commenced, and the screen readings were continuously monitored for approximately two minutes. As the readings fluctuated up and down, the peak value within this period was recorded. The distance between the location of the receiving antenna and the transmitting antenna of the radio channel was also noted. To minimize potential interference from external factors such as vegetation cover, trees, and buildings, the readings were taken in an open space. The data collection period spanned from August 19th to September 3rd, 2019, total sixteen days. During this period, rainy and cloudy days were avoided due to the equipment's sensitivity. At six specific locations in Okene town, labelled as points 02 to 07, the strengths of the two radio signals Kogi Radio (KA) and TAO FM (KB) were measured. These locations were selected randomly within Okene and environs.

The selected positions for measurement was based on sampling of the geographic area. The northern, eastern, and western parts of Okene town were put into consideration. This approach was aimed at ensuring that the coverage area was captured and represented. At each radio stations, the signal strengths of KA and KB were measured, labelled as 01A and 01B respectively. This was compared with the measurements at the other selected sixteen locations. Distances between the radio stations (transmitters) and the selected locations (receivers) were also recorded. Coordinates of each location were recorded with Global Positioning System (GPS) and codes assigned to them.

Method of calculating wavelength

The wavelength (λ) of the wave, which represents the linear displacement between two consecutive crests or troughs can be expressed as:

$$\lambda = c\, f \qquad (1)$$

Where: λ represents wavelength, v denotes velocity of the wave; given as $3 \times 10^{8} ms^{-1}$, and f represents the frequency of the wave. This is reflected in table 4

Table 1: Codes for the selected locations and their GPS Locations for Kogi Radio

Locations	Codes	GPS Locations
Kogi Radio Station	OK1A	Lat.N7^{0}33’3.52116” & Long.E6^{0}13’59.38392”
TAO FM Station	OK1B	Lat.N7^{0}33’7.78788” & Long.E6^{0}14’16.208”
Obehira/Okenwe Junction, Okene	OK2	Lat.N7^{0}32’54.69” & Long.E6^{0}12’13.81788”
Check Point, Okene	OK3	Lat.N7^{0}31’37.32168” & Long.E6^{0}15’18.03816”
FC/Lokoja Road, Okene	OK4	Lat.N7^{0}36’35.09568” & Long.E6^{0}15’41.24988”
Kabba/Obajana Junction, Lokoja	OK5	Lat.N7^{0}449’32.37852” & Long.E6^{0}34’57.9666”
Felele, Lokoja	OK6	Lat.N7^{0}50’43.2132” & Long.E6^{0}44’53.007”
Ganaja Village, Jimgbe, Lokoja	OK7	Lat.N7^{0}42’52.06428” & Long.E6^{0}44’25.3986”
CUSTEC Osara	OK8	Lat.N7^{0}40’33.5” & Long.E6^{0}24’47.1”
Magongo	OK9	Lat.N7^{0}28’60.02141” &Long.E6^{0}13’0.25124”
Ageva	OK10	Lat.N7.4710^{0}N & Long.E6.1633^0
Usunkwe, Kabba Road, Okehi	OK11	Lat.N7^{0}37’30.1908” & Long.E6^{0}12’45.16128”
Ogaminana Clinic	OK12	Lat N7^{0}35’ 50.93412” & Long E6^{0}13’50.8512”
Railway Station	OK13	Lat N7^{0}36’ 55.257” & Long E6^{0}15’45.268”
NIOMCO	OK14	Lat N7^{0}38’30.53508” & Long E6^{0}20’34.25856”
Central Park, Kabba	OK15	Lat 7.8342N & Long 6.0742E
Osara Gada	OK16	Lat N7^{0}40’ 46.68816” & Long E6^{0}25’18.7716”

Method of calculating free space path loss

The reduction in radio energy as it travels across distances between transmitting and receiving antennas is called free space path loss (FSPL). Assuming the antennas are isotropic and have no directivity. This means that the antennas are lossless, polarization of the antennas is the same, no multipath effects, and the radio wave path is sufficiently far away from obstructions that it acts as if it is in free space, then the FSPS can be expressed following Whitaker (2018) as follows:

$$FSPL = \{4\pi d\ \lambda\}^2 \quad (2)$$

Where, d is the distance between the antennas, λ is the calculated wavelength, and 4π is a constant. Here, d must be large enough that the antennas are in the far field of each other (d ≫ λ) (Mailloux et al., 1984). In terms of frequency, we can express FSPL as follows:

$$FSPL = \{4\pi df\ c\}^2 \quad (3)$$

Expressing it in decibel (dB) we have:

$$FSPL = 10\log10(\{4\pi df\ c\}^2) = 20\log10(4\pi df\ c) \quad (4)$$

$$FSPL = 20\log10(d) + 20\log10(f) + 20\log10(4\pi\ c) \quad (5)$$

$$FSPL = 20\log10(d) + 20\log10(f) - 147.55 \quad (6)$$

Where d is in meters, f is in hertz (s^{-1}), and c is in meters per second For typical radio applications, it is common to find d measured in kilometers and f in gigahertz, in which case the FSPL equation becomes:

$$FSPL = 20\log10(dkm) + 20\log10(fGHz) + 92.45 \quad (7)$$

RESULTS AND DISCUSSION

Signal Strength

Tables 2 and 3 is result of the signal strength measurements with the estimated distances from the radio channel, as recorded from each FM stations. However, it should be noted that at certain remote locations far from the transmitter, no signals were detected due to the attenuation of the signals. As the signals travel over long distances, they gradually weaken and experience attenuation. This phenomenon was predominantly observed when taking readings from the distant area in Lokoja. From the data in Table 2, the signal strength at location O1A is 100.9dBμV at distance of approximately 0.0m, indicating close proximity. Conversely, at location O15A and O16A there was no signal, which can be attributed to various factors such as signal attenuation due to the considerable distance (≈ 74km) and potential obstructions causing reflection, refraction, or Table 2. Signal strength with distance from KA Positions Signal Strengths (dBμV) Approximate distance btw the antennas x103 (m) Frequency of the signal.

Table 2: Signal strength from KA positions (dBμV)

Positions	Signal Strengths (dBμV)	Approximate distance btw the antennas x10^3 (m)	Frequency of the signal (MHz)
OK1A	100.9	0.0	93.5
OK2A	74.4	5.0	93.5
OK3A	59.1	5.5	93.5
OK4A	45.2	10.0	93.5
OK5A	30.3	71.0	93.5
OK6A	37.5	73.0	93.5
OK7A	Nil	75.0	93.5
OK8A	29.2	30.0	93.5
OK9A	25.1	27.0	93.5
OK10A	36.3	23.0	93.5
OK11A	41.2	18.0	93.5
OK12A	79.2	5.0	93.5
OK13A	62.5	7.5	93.5
OK14A	62.0	10.0	93.5
OK15A	Nil	73.0	93.5
OK16A	24.4	36.0	93.5

Table 3: signal strength from Position (dBμV)

Positions	Signal Strengths (dBμV)	Approximate distance btw the antennas x10^3 (m)	Frequency of the signal (MHz)
OK1B	102.2	0.0	101.9
OK2B	64.4	4.0	101.9
OK3B	42.9	5.0	101.9
OK4B	46.7	5.0	101.9
OK5B	36.4	69.0	101.9
OK6B	Nil	72.0	101.9
OK7B	Nil	73.0	101.9
OK8B	27.1	32.5	101.9
OK9B	23.4	23.0	101.9
OK10B	41.2	10.0	101.9
OK11B	21.3	23.0	101.9
OK12B	58.1	10.0	101.9
OK13B	54.4	12.0	101.9
OK14B	51.8	14.5	101.9
OK15B	Nil	75.5	101.9
OK16B	35.8	38.5	101.9

diffraction of the signals. Location O2A, at 5km, exhibits a signal strength 74.4dBμV. Though there is some variations in signal strength at different locations having same distance due to signal attenuation by obstructions like hills and valleys, overall, we can see that the signal strength is directly proportional to the distance. From Table 3, location O1B, corresponding to the radio FM station, registered a signal strength of 102.2dBμV at distance 0.0m, indicating close proximity. However, locations O14B, O15B and O16B did not detect any signals; and this could be attributed to fading, which occurs as signals traverse different media over longer distances, such as 72km and above in these respective locations. In addition to fading, the absence of signals could be attributed to other factors such as obstructions along the paths of signal propagation. 3.2 Wavelength From Tables 2 and 3, the wavelengths (λ) of the FM radio stations was determined using equation 1. The results of these calculations are presented in Table 4. In this context, it is important to note that both the frequency of the signal and the wavelength are directly related to the velocity of the electromagnetic wave, which is essentially a constant with an approximate value of 3x108m/s, representing the speed of light. From Table 4, it is clear that higher frequency signals characterized by smaller wavelengths, tend to experience faster attenuation compared to lower frequency signals with larger wavelengths. As a result, it can be inferred that KB, which operates at a higher frequency, is expected to attenuate more rapidly than KA when passing through different physical mediums such as brick walls and vegetation. 3.3 Free Space Path Loss From Tables 2, 3 and 4 the path loss of the FM signals for each selected locations were calculated using equation 6 and are presented in Tables 5 and 6. From Tables 5 and 6, it is clear that; in terms of path loss, the primary factor contributing to signal attenuation is the distance travelled by the signal through the atmosphere. As the signal propagates, it gradually gets attenuated below the sensitivity threshold of the receiving antenna.

Table 4: Calculated Values of the Wavelengths

Radio Stations	Frequency (MHz)	Velocity (ms^{-1})	Wavelength (m)
Kogi Radio	93.50	3.00×10^{8}	3.21
TAO FM	109.50	3.00×10^{8}	2.94

Consequently, the weak signal becomes difficult to be detected by the receiver. Figures. 3 and 4 further illustrate the relationship of distance, signal strength, and path loss for both KA and KB. It implies that as the distance increases, the path loss increases, while the signal strength decreases, even though not at same rate for the two stations but the trend is the same. However, KA outperforms KB as KB's network experience more attenuation as compared to KA at approximately same distance.

Table 5: Calculated free space path loss for Radio Kogi

Location/ Measured Values	Signal Strengths (dBµV)	Approximate distance btw the antennas $\times10^{3}$ (m)	Wavelength (m)	Free Space Path Loss
OK1A	100.90	0.00	3.21	0.00
OK2A	74.40	5.00	3.21	85.83
OK3A	59.10	5.50	3.21	86.67
OK4A	45.20	10.00	3.21	91.85
OK5A	30.30	71.00	3.21	108.88
OK6A	37.50	73.00	3.21	109.12
OK7A	Nil	75.00	3.21	109.36
OK8A	24.40	30.00	3.21	101.40
OK9A	25.10	27.00	3.21	100.49
OK10A	36.30	23.00	3.21	99.09
OK11A	41.20	18.00	3.21	96.96
OK12A	79.20	5.00	3.21	85.83
OK13A	62.50	7.50	3.21	89.36
OK14A	62.00	10.00	3.21	91.85
OK15A	Nil	73.00	3.21	109.12
OK16A	24.40	36.00	3.21	102.99

Table 6: Calculated free space path loss for TAO FM

Location/ Measured Values	Signal Strengths (dBµV)	Approximate distance btw the antennas $\times10^{3}$ (m)	Wavelength (m)	Free Space Path Loss
OK1B	102.20	0.00	2.94	0.00
OK2B	64.40	4.00	2.94	84.65
OK3B	42.90	5.00	2.94	86.59
OK4B	46.70	5.00	2.94	86.59
OK5B	36.40	69.00	2.94	109.39
OK6B	Nil	72.00	2.94	109.75
OK7B	Nil	73.00	2.94	109.88
OK8B	27.10	32.50	2.94	102.86
OK9B	23.40	23.00	2.94	99.85
OK10B	41.20	10.00	2.94	92.60
OK11B	21.30	23.00	2.94	99.85
OK12B	58.10	10.00	2.94	92.60
OK13B	54.4	12.00	2.94	94.20
OK14B	51.80	14.50	2.94	95.83

OK15B	Nil	75.50	2.94	110.17
OK16B	35.80	38.50	2.94	104.31

Findings indicate an inverse relationship between the wavelength and frequency of the signal. Higher frequency channels exhibit shorter wavelengths. The path loss depends on the distance between transmitting and receiving antennas. However, it is minimal and approaches zero at the FM stations due to the short distances between the antennas. Distance directly affects path loss and inversely affects signal strength. Larger distances result in greater path loss. The strong radio signals at the stations are attributed to their proximity to the transmitters. Signal losses occur due to obstacles like vegetation, hills, mountains, trees, water bodies, bushes, and buildings that obstruct signal propagation. Refractions, diffractions, and reflections from such obstacles impact signal quality, as observed with KA, and KB. Previous studies by Meng, Lee, Ng (2010), Gökhan, Lavent (2000), and Aguirre et al. (2012) support these findings regarding signal loss and the influence of human bodies on transmitted signals. At close ranges, signal weakness is observed in densely populated areas due to human presence. Signal Strength (dBμV) Distance x 10^{-3}(m) Path Loss (dB) dosimetry evaluations. These losses are more significant in the abdomen region compared to the knee due to greater mass and liquid content. Comparing path loss with measured signal strengths reveals an inverse relationship. Higher signal strengths correspond to lower path loss, while lower signal strengths result in higher free space path loss. Findings from the study revealed that, even though KB operates at a higher transmitting signal strength 102.2dBμV compared to KA with 100.9dBμV, KB experienced higher free space path loss 109.39dB compared 109.01dB for KA. This was due to the fact that KB operates on shorter wavelength 2.94m at higher frequency 109.5MHz compared to KA with longer wavelength 3.21m and lower frequency 93.5MHz. Also, KA was received at 72km compared to 69km for KB. Therefore, KA network outperforms that of KB. The FM stations can improve their competitive advantage by investing in network infrastructure to boost their signal for better and quality service delivery.

CONCLUSION

In conclusion, despite the radio stations transmitting at a minimum of 2kW from elevated locations, limitations of their signal coverage have been identified. The results obtained clearly indicate the areas where optimal signal reception can be expected based on the measured signal strengths. It is evident that the quality of radio signals is greatly influenced by these factors. Moreover, the results demonstrate an inverse relationship between signal strengths and the calculated free space path loss at most locations. Higher path loss corresponds to lower signal strengths. To improve signal coverage, it is recommended for the radio stations to consider installing booster stations approximately 69km away from the main stations, considering the locations of their target audiences. Additionally, prospective radio stations can use these findings as a guide for selecting suitable locations to establish their own stations. DISCLAIMER (ARTIFICIAL INTELLIGENCE): Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts. COMPETING INTERESTS: Authors have declared that no competing interests exist.

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