A Space-Diversity Technique for Mitigating Signal Fading in Radio Transmission

Ijemaru Gerald Kelechi
Federal University Oye-Ekiti
Department of Electrical
& Electronics Engineering
+2348035523341
gerald.ijemaru@fuoye.edu.ng

Akinsanmi Olaitan
Federal University Oye-Ekiti
Department of Electrical
& Electronics Engineering
+2348068108694
olaitan.akinsanmi@fuoye.edu.ng

Obikoya Gbenga Daniel
Federal University Oye-Ekiti
Department of Electrical
& Electronics Engineering
+2348060722200
gbenga.obikoya@fuoye.edu.ng

ABSTRACT
Despite over seventy years of broadcasting, Radio Nigeria (FRCN) network signals still have poor reception and sometimes total failure. Apart from the problems of attenuation, fading, distortion, interference and noise, which are age-long problems militating against the performance of a digital communication system, radio communications engineers also face some new challenges arising from bandwidth limitation, equipment complexity, power limitation, noise limitation and cost. These problems are often encountered in the design of any communication systems and arose due to the imperfect nature of the communication channel. Each attempt to solve the problems creates additional cost, resulting from increased complexity in the design or increased radio frequency (RF) power requirement. The diversity technique presented in this paper is aimed at solving the problem of signal fading and poor reception of radio signals. The results of the previous studies have presented space diversity technique as a good tool for combating signal fading in a radio broadcasting station, whose studio and transmitting stations are located at different geographical locations, by connecting multiple antennas at both the transmit and the receiver ends. Simulation was conducted using MATLAB to verify the relationship between antenna heights and coverage distance in the line-of-sight transmission. The results are in total compliance with the attenuation square law, which states that signal strength is inversely proportional to distance.

CCS Concepts
• Hardware →Integrated circuit →Interconnect →Radio frequency and wireless interconnect

Keywords
Space-Diversity Technique, Signal Fading, Antennas, Simulation, MATLAB, Attenuation, Interference, Noise.

1. INTRODUCTION
Radio broadcasting was introduced into Nigeria in 1933 by the then colonial government to relay the overseas service of the BBC. The service was called Radio Diffusion System, RDS [1, 35]. From the RDS emerged the Nigeria Broadcasting Service, NBS, in April 1950. In April 1957 through an Act of Parliament No. 39 of 1956, the Nigerian Broadcasting Corporation, NBC was born [1, 2, 35]. NBC had MW/SW stations at Lagos, Ibadan, Enugu and Kaduna. In 1978, NBC was reorganized to become the Federal Radio Corporation of Nigeria, FRCN otherwise known as Radio Nigeria.

In the early days of Federal Radio Corporation of Nigeria (FRCN), her network programmes (signals) were originated from Ikoyi studios and transmitted by 300KW short wave transmitters located at Ikorodu, Lagos state. Other zonal stations on receiving the signal through an AM Yaesu receiver then retransmitted simultaneously for her zonal listeners. Poor reception and inherent noise associated with AM transmission caused the organization to acquire NITEL dedicated telephone lines that linked the studios of the zonal stations to that of the network studio. Although, signal quality improved greatly, NITEL microwave link failure and dead lines occasioned by weather (rainfall) still made FRCN network signal to be unstable. Recently the organization acquired a channel in the NTA satellite earth station located at Victoria Island Lagos to ensure that the sources of her network programmes were decentralized and reception crystal clear around the world. This acquisition led to TVRO system used by FRCN Zonal and FM stations to relay her network programmes. After all these transformations, FRCN network programmes still suffer intermittent break (fast fading) and sometimes total failure (slow fading).

The block diagram of Fig. 1 can symbolically represent any communication system. The information or message from the source is fed to the transmitter for modulation and amplification, after which the modulated signal is transmitted to the receiver through a channel or path. At the receiver, the information is decoded or demodulated and the message signal is reproduced.

The central section of the communication system is the channel, which electrically connects the transmitter and the receiver. A channel may be a pair of wire, a coaxial cable, free space, power line carrier (PLC), a radio wave or even a laser beam. Regardless of the type of medium used, the output of the channel is usually a smeared or distorted version of the input. This deterioration is as a result of the non-ideal nature of the communication channel. This causes certain unwanted and undesirable effects, which invariably corrupt the information-bearing signal [1]. As a result, errors are introduced in the information being transmitted. Factors that degrade system performance are attenuation, which is a progressive decrease in signal power with increasing distance, distortion and interference [1]. The problem of interference is very common in broadcasting where a radio receiver may pick up two or more signals at the same time.

CoRI'16, Sept 7–9, 2016, Ibadan, Nigeria.

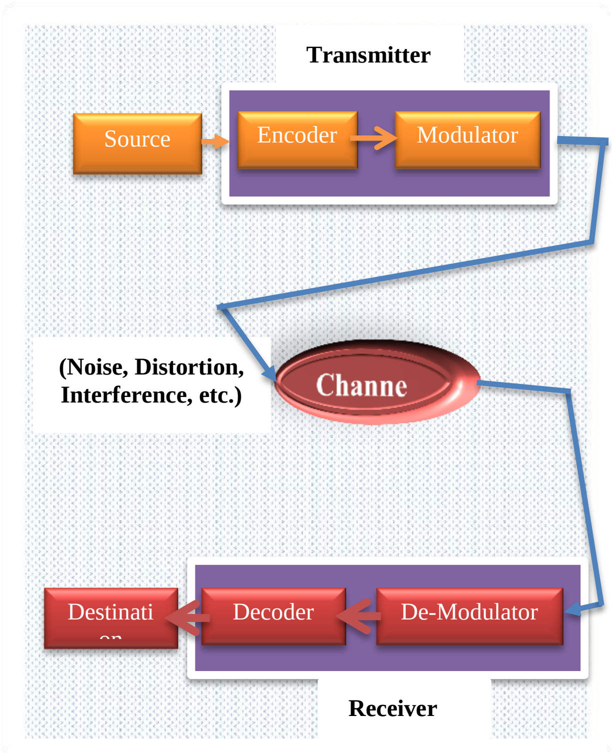

Fig. 1: Block Diagram of a General Communication System

Radio network programmes in Nigeria are often associated with intermittent breaks (fast fading) and sometimes degenerate into static noise and total failure (slow fading). This can be traced to daily incidents of high rise of buildings and towers occasioned by the topography of the country with hills, trees and valleys [2]. Again, atmospheric conditions during most part of the year, like rainfall, always pose a great challenge. For instance, during rainy season, most of the newly established FM stations in Nigeria shut down at a slight sign of the rain because of the accompanying lightning, which on many occasions have damaged the power modules of their transmitters and the analogue output cards of their digital console.

The purpose of this work is to explore the applications of MIMO systems with focus on a Space-Diversity Technique for combating signal fading, so that broadcasting media in Nigeria can tap from its gains to improve on the reception quality of their signals with an increased coverage area. Again, the study also aims at analyzing the relationship between antenna heights and maximum coverage distances in line-of-sight propagation and signal strength of the received signal using simulation.

This study – "A Space-Diversity Technique for Mitigating Signal Fading in Radio Transmission" will focus mainly on radio broadcasting network signals in Nigeria. However, the result of the study will still be applicable to other communication systems.

This paper work is organized into eight sections. The introductory part in section 1 deals with the general perspectives and objectives of the work. Section 2 reviews relevant work in MIMO systems, while section 3 presents the various types of diversity schemes, combating signal fading with a space-diversity technique and exploitation of diversity techniques in multi-path propagation. Section 4 gives a detailed step-by-step approach in carrying out the study, which includes research methodology, data collection and presentation. The relationship between antenna heights/distances and electric field strength simulated using MATLAB is presented in section 5. Also included in this section is the analysis of signal strength when the number of receiving antennas connected in the circuit is varied. This is followed by an acknowledgement in section 6, while section 7 presents the conclusion and recommendations. Finally, section 8 looks at the future work to be carried out.

2. REVIEW OF RELEVANT WORKS IN MIMO SYSTEMS

Since the invention of the radio telegraph by Marconi in 1895, wireless communication has attracted great interest and is now one of the most rapidly developing technologies [3]. From narrow-band voice communications to broadband multimedia communications, the data rate of the wireless communications has been increased dramatically, from kilobits per second to megabits per second [4]. According to the authors in [3], the last two decades witnessed an explosion in the advancements of wireless systems and hence future wireless networks face challenges of supporting data rates higher than one gigabit per second.

Among numerous factors that limit the data rate of wireless communications, multipath propagation plays an important role [5], [16-18]. In wireless communications, the radio signals may arrive at the receiver through multiple paths because of reflection, diffraction, and scattering. This phenomenon is called multipath propagation, which causes constructive and destructive effects due to signal phase shifting. Channels with multipath fading fluctuate randomly, resulting in significant degradation of signal quality. When the bandwidth of the signal is greater than the coherence bandwidth of the fading channel, different frequency components of the signals experience different fading. This frequency-selective fading may further limit the data rate of wireless communications.

In order to mitigate multipath fading, Code Division Multiple Access (CDMA) and Orthogonal Frequency-Division Multiplexing (OFDM) were developed [4], [19] – [20]. While CDMA mitigates multipath fading by transmitting signals which occupy a wider bandwidth, OFDMA splits the channel into many small bandwidth carriers, each of which occupies a narrowband channel [4]. Though a small percentage of this wideband channel may undergo deep fading, the overall channel could still be in good shape. The lost signals could be recovered with the help of a Rake receiver and/or maximum-ratio combining [6]. Although these two schemes are effective in mitigating multipath fading, they have the limitation of providing a higher data rate compared to other techniques [4].

The last decade witnessed the deployment of multi-antenna systems, which are also referred to as multiple-input multiple-output (MIMO) systems. These technologies are undoubtedly the most promising to achieve higher data rates. MIMO is a method of transmitting multiple data beams on multiple transmitters to multiple receivers [7], [21-23].

The benefits of these arise from the use of extra spatial dimension, which involves the use of multiple antennas at the transmitter and/or receiver ends. With this technique, the rich scattering channel is exploited to create a multiplicity of parallel links over the same radio band, thus providing MIMO with several advantages such as array gain, spatial diversity gain, and spatial multiplexing gain [8].

The authors in [9], [24], and [28] present some of the performance improvements and potential applications of MIMO technology to include:

- Array Gain – improves system robustness to the noise thereby increasing coverage and quality of service (QoS)
- Diversity Gain – MIMO achieves spatial diversity by providing the receiver with multiple identical copies of the transmitted signal to mitigate multipath fading, increase coverage and to improve the quality and reliability of the reception. Diversity is maximized to mitigate channel fading and decrease the bit error rate (BER)
- Multiplexing Gain – is achieved by transmitting independent data signals from different antennas to increase throughput and spectral efficiency.
- Co-channel interference mitigation – increases cellular capacity.

For MIMO to be effective, the paths need to be de-correlated. That is, the signals travelling need to behave differently from each other, so that if any one part experiences fading, there is a high probability that the other parts will not undergo fading and hence the signal can still get through [7], [25-27]. This can be possible with proper exploitation of techniques such as spatial separation (space-diversity) of the antennas or separation of the transmitted waveforms via time separation, polarization separation, frequency separation, etc.

RF signal transmission between two antennas commonly suffers from power loss in the space. This power loss between transmitter and receiver is as a result of three different phenomena: **distance-dependent decrease in power density** called path loss or free space attenuation, **absorption due to the molecules in the atmosphere of the earth** and **signal fading** caused by terrain and weather conditions in the propagation path [2], [29] – [30]. Path loss is the attenuation which occurs under free-line-of-sight conditions and which increases with the distance between base station and mobile. Fading is an attenuation that varies in an irregular way. Signals move through areas with obstacles of various sizes, surrounded by mountains, buildings and tunnels. Occasionally, these obstacles will shadow or completely cut off the signal. Although the consequences of such shadowing effect depend on the size of an obstacle and the distance to it, the received signal strength inevitably varies. This type of fading is referred to as shadow fading [26], [28]. Multi-path fading is a completely different kind of fading involving irregular signal strength variations as a result of several signals at the receiver. The performance degradation can be solved by increasing the transmitted power and resizing the antenna. However, this solution is not economically attractive, hence the need for special reception techniques such as the space-diversity technique (multiple receiver combining technique) [3-4], [28-29].

In telecommunication, a diversity technique refers to a method for improving the reliability of a message signal by utilizing two or more communication channels with different characteristics. Diversity is important especially in mitigating fading and co-channel interference [2], [28-30]. It is based on the fact that individual channels experience different levels of fading and interference.

3. TYPES OF DIVERSITY SCHEMES

This section presents the various methods of reducing signal fading and the types of diversity combiner.

3.1 Frequency Diversity

This involves sending of the same information using two or more different frequencies of transmission or different transmitters set to different frequencies. The arrangement is such that the transmitter (s) selects the frequency with better signal and uses that as its preferred signal [10, 31]. This is however difficult to implement as the task of generating severally transmitted signals and combining signals received at different frequencies is quite enormous. Again, the scheme requires commercial FM and TV stations to obtain as many licenses as the number of frequencies they intend to use. This factor alone makes it unattractive to broadcast stations, coupled with the fact that it also demands a large space to site the receiver and their antennas.

3.2 Time Diversity

This involves the transmission of multiple versions of the same signal at different time intervals. Essentially, a redundant forward error-correction code is added and the message is spread in time by means of bit-interleaving before it is transmitted. This is predicated on the perception that the obstacles blocking signal paths are not stationary, hence the essence of transmitting the same information at different time intervals [11, 28, & 32]. However, time is wasted while the receiver evaluates the received signals to determine the best to use. Moreover, while the scheme may be better in data transmission, it is out of need in a radio and TV transmission where a live broadcast may be required. Also, in the event where the obstacles are permanent, transmitting the same information even a couple of times will not yield any better reception.

3.3 Rake Receiver

A rake receiver is a radio receiver designed to counter the effects of multipath fading [12], [27, and 33]. This is achieved by utilizing several sub-receivers called fingers. Each finger independently decodes a single multi-path component, which is later combined to make the most use of the different transmission characteristics of each transmission path. Rake receivers are common in a wide variety of CDMA radio devices such as mobile phones and wireless LAN equipment [12].

3.4 Space Diversity

This is also known as antenna diversity. It is one of the diversity schemes that utilize two or more antennas to improve the quality and reliability of a wireless link. In urban and indoor environments, there is usually no clear line-of-sight between the transmitter and the receiver; rather the signal is reflected along multiple paths before finally being received. Each of the bounces can introduce phase shifts, time delays, attenuations, and even distortions that can destructively interfere with one another at the apertures of the receiving antenna [2, 24, 30-32]. Space diversity is effective at mitigating these multipath situations, because multiple antennas afford a receiver several copies of the same signal. Each antenna experiences different interference environment. Thus, if one is experiencing a deep fade, it is likely that another has a sufficient signal. Signals received from the various antennas are then fed to a diversity combiner, which either selects the antenna with the best signal strength or adds the signals coherently.

Application of space diversity to combat signal fading is not new to mobile and fixed wireless telecommunication providers. In this research work where the scheme will be helpful in radio broadcasting was explored. Radio Nigeria, like some older radio and television stations whose studios and transmitting stations are located at afar distance, could make use of this scheme. A microwave transmitter and receiver called studio-transmitter link (STL) is used to couple the studio output to the main transmitter through the line-of-sight propagation. The signal suffers a lot of degradation before reaching the microwave receiver at the main transmitting station.

The usability of this scheme was tested at Federal Radio Corporation of Nigeria (FRCN) transmitting station Shogunle Lagos state, and it was found that multiple antennas spaced out provided increased signal strength. The space diversity scheme tested in this research work is reception diversity.

3.4.1 Advantages of Space Diversity

The following are some of the advantages of space diversity technique as outlined by the authors in [13, 26, 32, & 34]:

- Improvement in uplink performance for reception of both mobiles and portables
- It is flexible as it can be applied either at the transmitting station (transmit diversity) or at the receiver end (diversity reception).
- It is very simple and can be used independently unlike pattern and polarization diversity schemes.
- It is cheaper than frequency diversity that requires several transmitters to generate the required frequencies.

The disadvantage of space diversity is that it requires large structures and thereby occupies space.

3.4.2 Diversity Combiner

This is an electronic device used to combine the multiple received signals of diversity reception device into a single improved signal. Several diversity combining methods as shown in [14] include:

- Switching – the signal from one antenna is fed to the receiver for as long as the quality of that signal remains above some prescribed threshold. As soon as the signal degrades, another antenna is switched in. Of the antenna diversity processing techniques, switching is the easiest and the least power consuming.
- Selection – selection combining presents only one antenna signal to the receiver at any given time. The antenna selected is the one with the best signal-to-noise ratio (SNR) among the received signals.
- Combining – here, all antennas maintain established connections at all times. The signals are then combined and presented to the receiver.

4. RESEARCH PROCEDURES

Space diversity technique was applied at reception in radio broadcast station at FRCN Lagos operations main transmitting station using three antennas. The strength of the received signal was displayed on the STL receiver metering unit. After which, a second antenna was mounted on the mast with a space of 0.5m from the first one. Since there was unavailability of an electronic combiner, an RF multi-switch connector was used to parallel the outputs of the antennas. With the second antenna in circuit, a change in the signal strength reading was observed and noted. Finally, a third antenna was introduced and the new signal strength noted. The STL receiver metering unit served as the spectrum analyzer for measuring signal strengths.

Again, because of the important roles antenna heights play in bypassing obstacles that cause fading and other interference effects, MATLAB was used to verify its effects to maximum coverage distances in line-of-sight transmission and field strength of the received signal. Approximate value for the maximum distance between transmitter and receiver over a reasonably level terrain was calculated using:

$$d = \sqrt{(17ht + 17hr)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

Where d = maximum distance (km), ht = transmitting antenna height (m), and hr = receiving antenna height (m). The power density of the signal was calculated using the power density formula

$$P_D = \frac{p_t}{4\pi r^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

Where, P_D = Power Density of the signal, P_t = transmitted Power and r = maximum distance in meters.

The final calculation made in the simulation was to calculate the electric field strength (Signal Strength) using

$$\in = \sqrt{377P_D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(iii)}$$

4.1 Data Collection and Presentation

The applicability of space diversity technique was tested at radio Nigeria Metro FM station located in Lagos state. At the Ikoyi broadcasting house, the output of the studio was fed to a 250w, 450.15MHz STL transmitter located in the control room. The output of the studio transmission link (STL), through 50 ohms coaxial cable is terminated in an antenna mounted on a 120ft mast. At the Ikeja GRA, an STL receiver of the same frequency was installed. A receiving antenna mounted on 100ft mast through line of sight propagation receives signal of 450.15MHz frequency. Through a 50 ohms coaxial cable, the received signal is fed to the STL receiver. The output of the receiver passes through audio processors to a 20KW BE transmitter for terrestrial transmission.

With the original connection of one receiving antenna at the Ikeja GRA station, the received signal strength as displayed on the STL receiver metering unit was 8dB. When the second antenna was connected and the output paralleled, the STL receiver reading increased to 12dB. A third antenna was introduced and the received signal strength further increased to 15dB. These antennas were spaced at 0.5m apart and were mounted facing different positions.

Table 1: Signal Strengths for various Number of Antennas.

S/N	Number of Antennas	Signal Strength
1.	One	8dB
2.	Two	12dB
3.	Three	15dB

5. SIMULATION RESULTS AND ANALYSIS

To verify the relationship between antenna heights and signal strength, which is one of the objectives of this research, some conversions were made from feet to meters in S.I units and simulation was carried out.

Transmitting antenna height ht $= 120 \times 0.3048\text{m} = 36.576\text{m}$

Receiving antenna hr $= 100 \times 0.3048\text{m} = 30.480\text{m}$

In the simulated results shown, the transmitting antenna height ht was kept constant while the receiving antenna height hr was varied to take 15m, 20m, 30.48m, 35m, and 40m. The STL transmitter rated power Pt was maintained at 250w. Equations (i), (ii), and (iii) were used to evaluate the maximum coverage distances d, power density P_D and electric field strength $\in$ respectively. The following are the analysis of results from simulation:

5.1 Relationship between Distance and Antenna Heights

Fig 5.1 is a simulation result showing the effect of antenna heights to coverage distances. It is observed that the receiving antenna height is directly proportional to the maximum coverage distance in line of transmission. It was evident that the receiving antenna height hr increased equally with the maximum coverage distance d at which a signal transmitted through line-of-sight propagation.

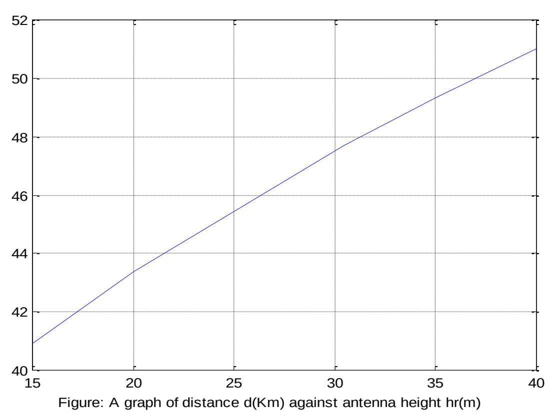

Fig 5.1: Graph of Maximum distance against Antenna height

5.2 Relationship between Power Density and Antenna Heights

Fig 5.2 shows that although the maximum coverage distance increases with increase in receiving antenna height, the power density of the received signal tends to decrease. This has placed a limit to the increase of antenna heights to achieve wider coverage. For instance, beyond 40m high, the power density of the signal tends to zero.

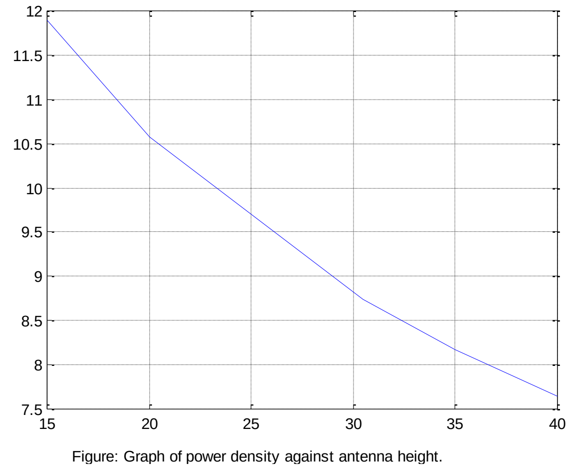

Fig 5.2: Graph of power density against Antenna height.

5.3 Relationship between Power Density and Maximum Distance

Fig 5.3 shows that power density decreases with increasing maximum coverage distance. At the distance d = 42km, the power density of the signal Pd = 11.25nW/m^2 approximately. As d increases to 50km, Pd dropped below 8nW/m^2, showing that maximum distance varies inversely with power density. To ensure that the signal level did not degenerate into a static noise, repeater or transceiver station can be sited at d = 46km.

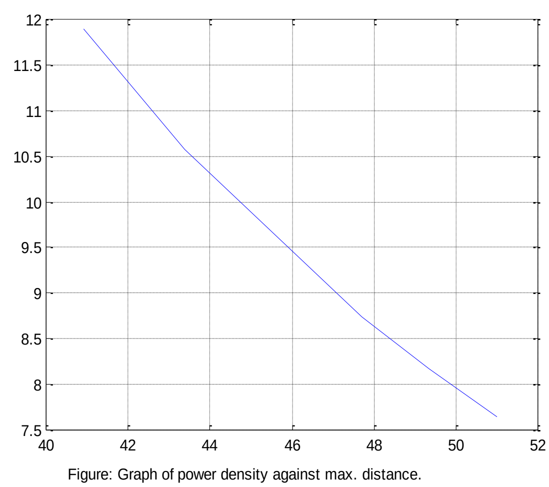

Fig 5.3: Graph of Power Density against Maximum Distance

5.4 Relationship between Electric Field intensity and Antenna Height

Fig 5.4 shows a graph of signal strength against receiving antenna height. The signal steadily decreased as the receiving antenna height was increased to obtain a new maximum distance. Between 30.48m and 35m, constant signal strength erroneously displayed as a result of approximations done on the close values of the field intensity using MATLAB programme. In general, it is observed that the receiving antenna height cannot be increased without limit to obtain an increased maximum distance, since the signal strength will deteriorate.

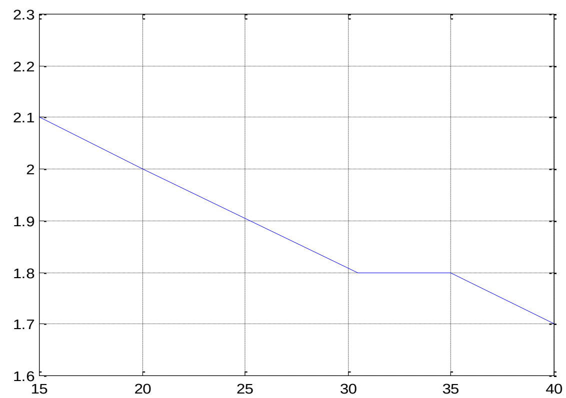

Figure: Graph of Electric field intensity against antenna height

5.5 Relationship between Field intensity and Maximum Distance

Fig. 5.5 shows a graph of electric field intensity against distance. From the graph, we observe that regardless of the approximation error of the field intensity around 48km maximum distance, signal strength is inversely proportional to the maximum distance of line-of-sight coverage.

These results are in total compliance with the attenuation law, which states that signal strength is inversely proportional to distance.

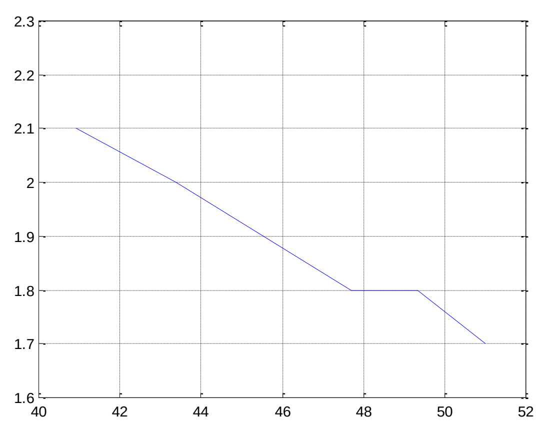

Figure: Graph of field intensity against max. distance.

Fig 5.5: Graph of Field Intensity against Maximum distance.

6. ACKNOWLEDGMENTS
Our thanks to Engr. Prof. O.O. Amu for his moral encouragement and charismatic leadership qualities.

7. CONCLUSIONS AND RECOMMENDATIONS

Based on the results obtained, we can conclude that Space – Diversity Technique can be utilized by broadcasting stations to improve their signal quality and invariably mitigate signal fading. The scheme would be much more helpful, if applied at reception and with a standard combiner. Besides, we also note that increasing the number of receiving antennas also increases the signal strength. Again, with multiple antennas spaced out, there will be improvement in signal quality while drop-outs or signal failure will be greatly minimized. Furthermore, it can be seen that although increasing the antenna heights also increases the maximum coverage distance in line-of-sight propagation, this cannot be increased indefinitely since there will be corresponding decrease in signal power resulting in fading.

We recommend that transmitters should not be sited far away from the information source (i.e. studio). But where it becomes inevitable, a repeater station or transceiver may be required to maintain the signal quality. Again, frequency allocation should be properly planned to prevent interference between RF channels. Besides, broadcasting houses should be properly earthed to prevent damage of equipment often caused by thunder and lightning and to guarantee longer life span of digital broadcasting equipment as well as safety of workers

8. FUTURE WORK

Future studies may focus more on developing an affordable and less power consuming combiner. This will help radio broadcasting stations and other small communication outfits to exploit the advantages of diversity schemes to improve the quality of their signals.

9. REFERENCES

[1] Onoh, G.N., Debray. 2005. Communications Systems. *Enugu: De-Adroit Innovation.*

[2] Ujam, U.N. 2002. *Determination of the effects of Metrological and Topographical conditions on UHF Signals.* Unpublished Master Thesis, Enugu State University of Science and Technology, Enugu Nigeria

[3] Ijemaru, G.K., Udunwa, A.I., Ngharamike, E.T., and Oleka, E.U. 2014. Evaluating the Challenging Issues in the Security of Wireless Communication Networks in Nigeria. *International Journal of Innovative Technology and Exploring Engineering (IJITEE), Vol 3 (12).*

[4] Schichuan, M. 2011. Exploration of Spatial Diversity in Multi-Antenna Wireless Communication Systems. *Dissertations and Student Research in Computer Electronics and Engineering, University of Nebraska-Lincoln.*

[5] Rapport, T.S. 2002. *Wireless Communications: Principles and Practice*. Prentice Hall

[6] Ziemer, R.E., Peterson, R.L., and Borth, D.E. 1995. *Introduction to Spread Spectrum Communications.*. Prentice Hall.

[7] Wi4 Fixed: The Motorola Point-to-Point Wireless Broadband Solution. 2007. *Multiple-Input Multiple-Output (MIMO) The key to Successful Deployment in a Dynamically Varying Non-line-of-sight Environment.*

[8] Paulraj, A., Nabar, R., and Gore, D. 2003. *Introduction to Space-Time Wireless Communications.* Cambridge UK: Cambridge University Press

[9] Kethulle, S. 2004. An Overview of MIMO Systems in Wireless Communications. *Lecture in Communication Theory For Wireless Channels*

[10] Singer, A. 1998. Space vs. Polarization Diversity

[11] Dietrich, C. 2000. Adaptive Arrays and Diversity Antenna Configurations for Handheld Wireless Communication

Terminals.

[12] Kyungwhoon, C. 1997. Performance of Direct-Sequence Spread-Spectrum Rake Receiver.

[13] Bolin, T., and Ying, Z. 2004. *Antenna Diversity Studies and Evaluation.* A Thesis Work at Sony Ericson Mobile Communications AB Site in Lund

[14] Brown, T.W.C. 2002. *Antenna Diversity for Mobile Terminals.* PhD Thesis, University of Surrey, Surrey UK

[15] Henten, A. 2009. Mobile and Wireless Communications: Technologies, Applications, Business Models and Diffusion. *Journal of Telematics and Informatics* 26, 223-226

[16] Arya, R., Nicholas, D., and Palash, K. 2010 Fading is Our Friend: A Performance Comparison of WiMAX-MIMO/MISO/SISO Communication Systems. *Scientific Research*, [Online] Available from <http://www.scirp.org/journal/eng/> [19th April 2016]

[17] Boutros, J., Viterbo, E. 1999. Signal Space Diversity: A Power and Bandwidth efficient Diversity Technique for the Rayleigh Fading Channel. *Ecole Nationale Superieure des Telecommunications Vol.* 46, Issue (13), pp. 1-17

[18] Bruno, E. 2001. The Problem of Interference in Wireless Communications. *The U.S. Regulatory "Solution" and the Property Rights Alternative*. Washington DC: Manhattan Institute for Policy Research

[19] Ceken, C., Yarkan, S., Arslan, H. 2010. Interference aware Vertical Handoff Decision Algorithm for Quality of Service support in Wireless Heterogeneous Networks. *Journal of Computer Networks, Vol.* 54, pp. 726-740

[20] Chandrasekaran, N. 2005. Diversity Techniques in Wireless Communications Systems. *Journal of Information Technologies, Vol.* 16, Issue (1), pp. 1-8

[21] Chiau, C.C. 2006. *Study of the Diversity Antenna Array for the MIMO Wireless Communication Systems*. Unpublished PhD Thesis, University of London

[22] Du, K., and Swamy, M.N.S. 2009. *Wireless Communication Systems: From RF Subsystems to 4G Enabling Technologies*. London: Cambridge University press

[23] Farrukh, R., and Athanassios, M. 2006. *Diversity Reception for OFDM Systems using Antenna Arrays.* London: Imperial College

[24] Foschini, G.J., and Michael G.J. 1998. On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas: Wireless Personal Communications. *Journal of Information Technology, Vol.* 6, (3), pp. 311-335

[25] Foschini, G.J. 1996. Layered Space-time Architecture for Wireless Communications in a Fading Environment when using Multi-element Antenna. *Bell Laboratories Technical Journal* 2, (1) 41-59

[26] Francis, C. 2007 Uses of the New Types of Wireless Technologies for Distribution and Substation Automation. Xanthus Publishing

[27] Fumiyuki, A., and Nobuo, N. 2000. Challenges of Wireless Communications IMT-2000 and Beyond. *Journal of IEICE TRANS Fundamentals E83-A,* (7) pp. 1300-1413

[28] Gajanana, K., Srinivas, K., Srikrishna, S., Bhashyam, B., and Koilpillai, D. 2008. Signal Space Diversity for Spatial Multiplexing. *Indian Institute of Technology-Madras* 6, (1) 1-5

[29] Hourani, H. 2005. An Overview of Diversity Techniques in Wireless Communications Systems. [Online] available from http://www.comlab.hut.fi/opetus/333/2004_2005_slides/Diversity_text.pdf

[30] Jardine, A., Thompson, J., McLaughlin, S., and Grant, P. 2006. MIMO Wireless and Mobile Communications: Dual antenna cooperative diversity techniques. *Journal of the Institute of Engineering and Technology* 153, (4) 556-564

[31] Jayaweera, S. 2009. ECE442: Wireless Communications. *Lecture 9: Cellular Systems*

[32] Johnson, G., and Scholes, K. 2002. 6th edn. *Exploring Corporate Strategy.* London: Prentice Hall

[33] Kauffman, R., and Techatassanasoontron, A. 2005. Is there Global Digital Divide for Digital Wireless Phone Technologies? University of Minnesota

[34] Kim, K., Floyd, J., and Mehta, H. 2004. Wireless Communication Using Integrated Antennas. *Silicon Microwave Integrated Circuits and System Research Group* (FL 32611) 34-79

[35] Federal Radio Corporation of Nigeria Frequency Guide, 2005. Abuja.