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SCHOLARLY ARTICLE

Design and Simulation of Antennas Towards a Local Content Mobile Network Base Station Application

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ABSTRACT

All mobile base stations are characterized by antennas which are mostly dipole antenna based. Nigeria is one of the big market in mobile communication industry but unfortunately all major infrastructure required in this industry are imported from other countries of the world. This paper presents dipole-based antenna design and simulation for LTE Nigerian networks. This is a step towards the production of a Nigerian-made mobile base station antenna. A single dipole as well as 4 and 8 dipole arrays were simulated and results show a maximum gain of 2.1dBi, 9.1dBi and 12.3dBi respectively. A microstrip patch antenna as well as 2 and 4 patch arrays were also simulated and results show a directional radiation pattern with maximum gain of 10.1dBi for a single patch antenna and 11.4dBi and 13.4dBi for 2 and 4 patch arrays respectively. In both cases, antennas resonated at the designed frequency of 2.6GHz with a return loss of less than -14dB for dipole and -23dB for microstrip which are below the required benchmark of -10dB. All simulations were carried out and optimized in MATLAB. Results have shown that these antennas are suitable for small cell mobile base station applications and with good beam-steering mechanism, can also be deployed to other applications like localizations systems.

Keywords: *Antenna Design; Base Station (BS); Dipole Antennas; Micro-strip Patch Antennas; MATLABZ*

Introduction

Mobile communication in Nigeria just like other parts of the world like UK, USA, China, India etc. has experienced an explosive growth in the last two decades. It has grown from 2G popularly known as GSM to 3G (UMT), 4G (LTE) and then to the recently launched 5G. This shows that Nigeria's development in mobile communication has been following the global trend of growth in this sector. This growth is characterized by expansion in coverage and capacity leading to cell densification. The more the number of network cells in a particular location, the more the number of base stations of different sizes.

A mobile communication base station is a transmission and reception station in a fixed location, consisting of one or more receive/transmit antennas, microwave dish, and electronic circuitry that are used to handle cellular traffic. One main feature of any base station is antenna system. Base station antennas for mobile communication systems have tremendously increased in numbers in both rural and urban areas. Typically, these antennas are 1 to 2 meters long comprising of antenna arrays with gains between 15 and 21dBi placed in towers between 25 and 75 meters above ground. These antennas are characterized by high efficiency and can handle power of up to 500W or more. Antennas currently used in cellular base stations are either Omni-directional antennas or directional antennas. Omni-directional antennas are antennas that exhibit a circular radiation pattern and operate in virtually all directions while directional (or sector) antennas are those that operate in a specific direction, most commonly covering an arc of 120 degrees or less, depending on capacity requirements.

According to data released by Nigerian Communication Commission, NCC (Venture, 2017) , no major equipment required in a mobile network BS is produced in Nigeria. This has motivated this research paper to design and simulate antennas towards a made-in-Nigeria mobile base station antennas.

Review of BS Antennas

Antennas can be categorised into six types; electrically small antennas like short wire dipole antennas, resonant antennas like half-wave dipole, microstrip patch and Yagi antennas. Others are broadband Antennas, aperture antennas, fan-beam antennas and array antennas (Paine, 2017). Base station antennas (BSAs) are the key components of cellular phone networks. A general overview of the design of base station antennas for mobile communications explaining underlying theoretical and practical implementation aspects in mobile communication networks of today and the future was presented in (Beckman & Lindmark, 2007). There has been extensive research dedicated to the design and development of base station antennas over the past two decades. Dipole-like structures are preferred for ease of construction, low-profile form, and low intermodulation distortion. However, it is very difficult to achieve high fractional bandwidth (FBW) with these structures and yet maintain gain and other design specifications for the whole frequency band. Depending on the operational requirements, it is usually intricate to achieve the gain, half-power beam width (HPBW) and isolation requirements over a large frequency band. On the other hand, a systematic approach to design, fabrication and testing of a micro strip antenna with the justification of low profile, ease of fabrication, low cost and conformability was presented in (Al-Naiemy et al., 2012). For a base station antenna, low profile antenna is not really a major requirement because space is not always an issue.

For 3G networks covering a frequency range from 1710 MHz to 2170 MHz, an element gains of at least 8.5 dBi over the entire frequency band is required. A dipole based type of a base station antenna element with unique array formation to meet the design specifications was presented in (Isenlik et al., 2011). This work assumed a down tilt angle of the antenna to be fixed and can be set through the feed network of the antenna array. It is also possible to incorporate a mechanically controlled phase shift between the array elements for a tilt angle coverage from 0^o to 10^o. The antenna system can accommodate dual polarization in a single structure and a gain of 18 dBi was achieved. Impedance match is also a critical design parameter for BSA's. The voltage standing wave ratio (VSWR) must be less than 1.5 (min 14 dB Return Loss) across the frequency band.

To avoid multiple base station antennas installed on mobile communication mast and to avoid an increase of masts and payloads, there was need for multiband antennas (Jung & Eom, 2015). The multiband base-station antenna presented in this work provided a single/dual/triple or more multiple services using dual-polarization (45^olinear polarizations) according to the requirements of the service provider. This antenna was characterised by a shared aperture, having several array antennae sets for multiple services (Band 1: cellular service in 0.824~0.894GHz, Band

2: PCS, WCDMA, and Wi-Fi in 1.920~2.170GHz, Band 3: WiBro and WiMAX in 2.300~2.400GHz, and Band 4: WiMAX in 5.150~5.850GHz).

Another research on base station antenna carried out in Malaysia was dual polarized, fabricated using brass and achieved a voltage standing wave ratio (VSWR) below 1.4, a gain of 16dB and horizontal beam width of 105 degree (Asrokin et al., 2010).

It can be deduced that the following basic parameters form the bedrock of antenna design; the input impedance, reflection coefficient and return Loss, S-parameter, Bandwidth and Resonance, Radiation Pattern, Directivity, Gain and Radiation Efficiency, Aperture Efficiency and effective aperture, polarization of an EM Wave. It was also seen that most antennas designed for BS take their basis from a simple dipole design.

This research is based on an effort towards achieving a Nigerian made BS antenna using locally available materials and man power. A dipole-based BS antenna design for MTN LTE network is presented.

Half-Wave Dipole Antenna

A dipole antenna is the simplest practical antenna that exists. It is characterized by two conductive elements in the form of a rod or wire with the feeder at the center and radiating elements on either side as shown in Figure 1. Dipole antennas can be categorized as half-wave dipole, quarter-wave dipole, dual dipole or folded dipole. The most popular is the half-wave dipole which forms the basis for many other modern antennas like the L-shaped antenna, BTS antenna etc. A half-wave antenna has a total length of half the wavelength which is related to the frequency of operation. Dipole antennas are known to be omnidirectional radiating antenna with a donut-shaped radiation pattern on elevation. How well an antenna can radiate energy is dependent on the ability of the antenna to resonate at the same frequency as the radio signal applied from the transmitter and also on how well the feed point of the antenna is matched to the impedance of the attached transmitter energy source. The radius of half wave dipole does not affect its input impedance, because the length of this dipole is half wave and it is the first resonant length. An antenna works effectively at its resonant frequency, which occurs at its resonant length.

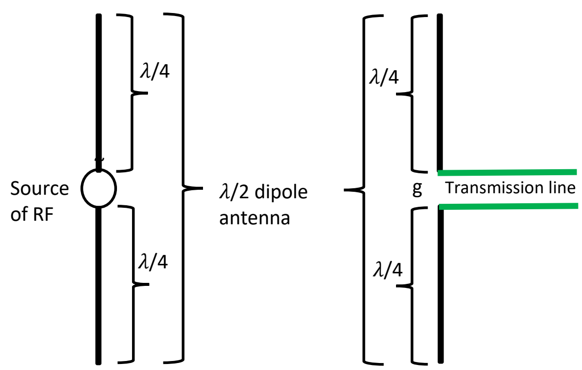


Figure 1: Half-wave Dipole Antenna

A half-wave dipole antenna was designed for LTE 2.6GHz which is the band supported by the most popular mobile network provider in Nigeria, MTN. The wavelength was calculated using $\lambda = {}^{c}/_{f}$ where c is the speed of light which is 3×10^8 and f is the frequency of operation to give $\lambda = 115.38mm$. The length of each arm of the dipole is ${}^{\lambda}/_{4} = 28.8mm$ giving a total dipole length, L of ${}^{\lambda}/_{2} = 57.6mm$. The feed gap, g is given by ${}^{L}/_{200}$ which results to 0.288mm while the radius of the antenna was given by 0.001λ (Mynuddin & Rahman, 2020) which gives 0.115mm.

It is known that the more the antenna elements in an array, the higher the overall gain and the more the directivity of the radiation pattern. Antenna array system design and simulation was also explored starting with a 2-element dipole array system as shown on the schematic of Figure 2. A 4-element array and 8-element dipole array systems were also explored and discussed at the result section.

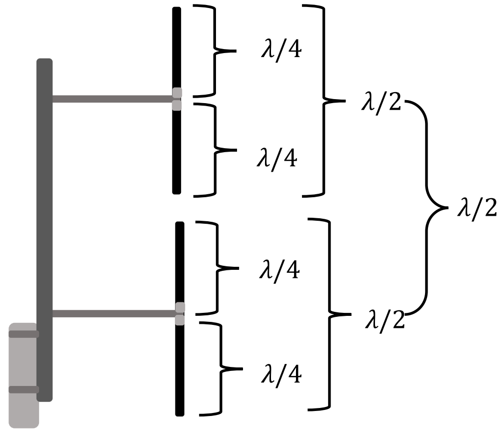


Figure 2: Two-Dipole Element Array

Microstrip Patch Antenna

A micro-strip antenna, also called a patch antenna or printed antenna, is an antenna which is primarily a two-dimensional flat structure. The general schematic of a micro-strip antenna is shown in Figure 3. It comprises of three main layers; the ground layer which is connected to the ground of the circuit, the substrate or dielectric which forms the middle layer and can be FR4, epoxy glass, RT droid etc. with a certain dielectric constant and lastly the patch layer which is the radiating element and appears on the top of the setup. The simplest form of a Micro-strip antenna is one whose conducting “patch” is one-half wavelength long, so that the metal surface acts as a resonator similarly to the half-wave dipole antenna. It is relatively easy to design and inexpensive to manufacture.

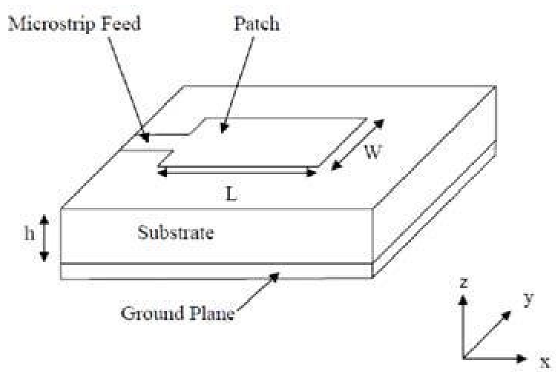


Figure 3: Micro-strip Patch Antenna

Material selection is a very important aspect of micro-strip antenna design because they all come with some advantages and disadvantages. For dielectric substrate; FR4 has high loss, low gain antenna but cheap and easily available, RT Duroid and PTFE are of low loss, low permittivity and produces high gain antennas, while Roger materials are considered for high performance, low weight, low permittivity, low loss, low distortion and for portable antenna design. The substrate used can enhance antenna's radiation capability because they improve electrical and mechanical stability of the antenna. The higher the permittivity of the dielectric substrate, the lower the size of antenna, it is also a good approach to reducing the antenna size. The radiating patch, the feedline and the ground can be of copper, silver or gold material. Silver is of better conductivity than copper or gold but copper is mostly used because it is highly reactive, harder and more affordable than silver and gold.
The dimensions of the micro-strip antenna can be calculated as follows;

The Width (W) of the patch is given by;

$$W = \frac{c}{2f_o\sqrt{\frac{\varepsilon_r + 1}{2}}}$$

Where; c is the Speed of light: 3 x 10^8, f_0 is the Resonance Frequency, ε_r is the relative Permittivity of the dielectric substrate.

The Effective Dielectric Constant (ε_{eff}) which is based on the height or thickness (h), dielectric constant (ε_r) of the dielectric material and the width (W) of the patch antenna of Equation (1) is given by;

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

The Effective length (L_{eff}) is given by;

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}}$$

The length extension ΔL which is the length increase due to the fringing effect (Endri et al., 2020) is given by;

$$\Delta L = 0.412h\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

The actual length (L) of the patch is therefore given by;

$$L = L_{eff} - 2\Delta L$$

The dimension of the ground plan is given by $6h + L$ for the long edge and $6h + W$ for the short edge. It has been shown that the antenna gain, VSWR, Return Loss and directivity are improved with increase in ground plane dimension (Pranathi et al., 2015).

Results and Discussion

Calculation of the micro-strip antenna dimensions was carried out using micro-strip patch antenna calculator (Mosin I Memon, 2013). FR4 material with dielectric constant, $\varepsilon_r = 4.55$ (Zaman et al., 2014) was seen to be popular but 'air' with $\varepsilon_r = 1$ was used as the substrate for sure of availability and possible local implementation in Nigeria. The calculated parameters are as follows; $W = 57.69231$ mm and $L = 55.55637$ mm for $h = 1.5$ mm.

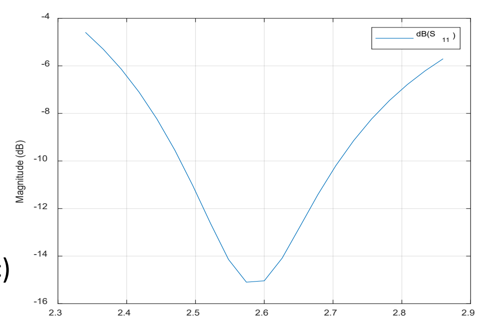
Simulation and Result

Simulations were carried out and optimized in MATLAB, first for a single dipole antenna element to obtain results of Figure 4.

(a)

(b)

(c)



(d)

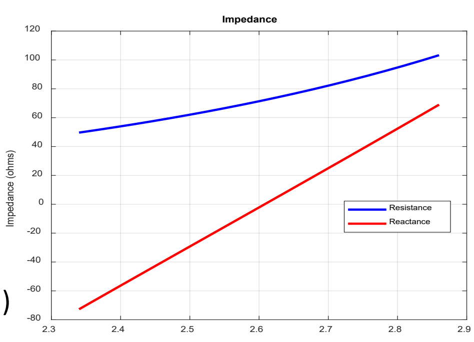


Figure 4: Simulation Results for Single Dipole

(a) 3D pattern, (b) elevation pattern (c) S11 parameter (d) Impedance

Secondly, array of 4-dipole as well as 8-dipole elements were simulated to obtain the results of Figure 5.

(a)

(b)

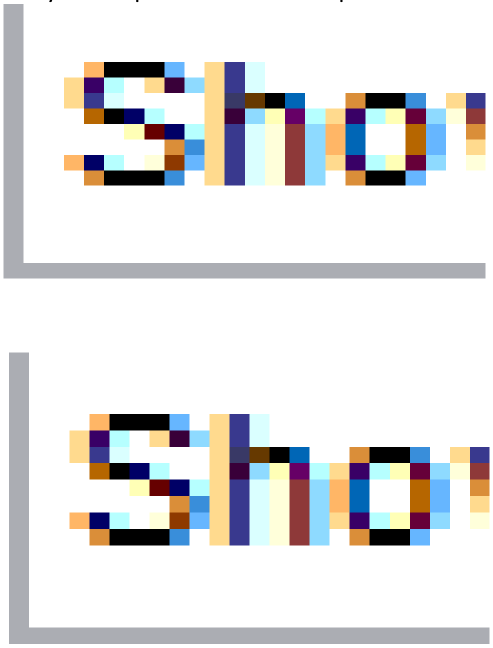


Figure 5: 3D Pattern of Dipole Array Simulation

(a) 4-dipole (b) 8-dipole elements

Dipole Simulation Result Analysis

Figure 4(a) is a 3D radiation pattern of the simulated dipole antenna showing omnidirectional radiation with a maximum gain of 2.1dBi and a minimum gain of -49.7dBi giving a doughnut shape visualized on the elevation diagram of Figure 4(b). This antenna radiated at the design frequency of 2.6 GHz with a return loss of less than -14dB as seen in Figure 4(c). Obtained result and shown in Figure 4(d) indicated that there is a good impedance matching between the feeder line and the antenna by showing a resistance of 70Ω and a reactance of 0Ω. Results of 4 and 8 dipole elements array simulations of Figure 5 (a) and (b) has shown that antenna gain has improved from 2.1dBi for a single antenna to 9.1dBi and 12.3dBi for 4 and 8 dipole arrays respectively. These antenna gains are suitable for small cell mobile network BS applications.

Considering that microstrip antennas has been used for mobile base station antenna (Fernandes et al., 2013) design, a microstrip patch antenna was simulated to obtain are shown in Figure 6;

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(a)

(b)

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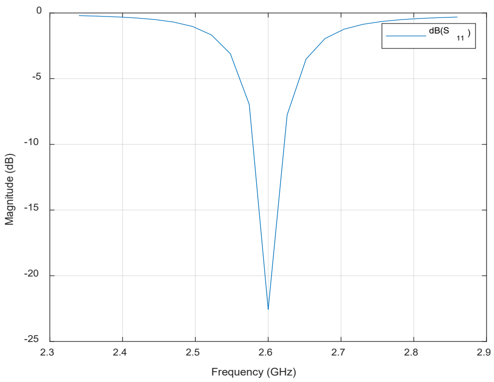
(c)



(d)

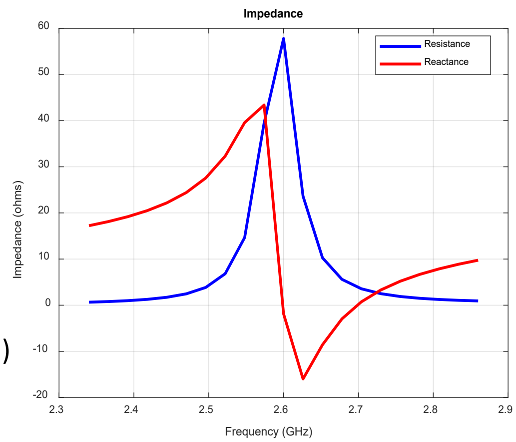


Figure 6: Patch Antenna Simulation Results

(a) 3D pattern, (b) elevation pattern (c) S11 parameter (d) Impedance

An array of 2 as well as 4 micro-strip antennas were also simulated in MATLAB to obtain results of Figure 7.

(a)

(b)

Figure 7: 3D Pattern of Micro-Strip Patch Array Simulation

(a) 2-elements (b) 4-elements

Patch Antenna Simulation Result Analysis

The 3D radiation pattern of Figure 6(a) a directional radiation pattern with a maximum gain of 10.1dBi and a minimum gain of -30.6dBi. The elevation diagram is shown in Figure 6(b). This antenna radiated at the design frequency of 2.6 GHz with a return loss of -23dB as seen in Figure 6(c) which is well below the required value of <-10dB. The impedance of Figure 6(d) has also shown a reactance of 0Ω at center frequency. Results Figure 7 (a) and (b) has shown that antenna gain has improved from 10.1dBi for a single patch antenna to 11.4dBi and 13.4dBi for 2 and 4 micro-strip arrays respectively. With suitable antenna steering mechanism, application of these simulated antennas can also be extended to a localization system like the one presented in (Abonyi, 2019).

Conclusion

A half-wave dipole antenna, dipole arrays of 2, 4 and 8 elements, micro-strip patch antenna, 2 and 4 elements patch arrays has been designed and simulated in MATLAB for MTN LTE network towards a Nigerian local content BS antenna. A maximum gain of 2.1dBi, 9.1dBi and 12.3dBi were obtained for a single dipole, 4 and 8 dipole arrays respectively. This shows that the more the number of elements, the higher the antenna gain. From the obtained radiation pattern, it was also shown that a directional pattern is obtained with dipole array as against a single dipole which exhibit omnidirectional pattern. A directional radiation pattern with maximum gain of 10.1dBi was obtained for a single patch antenna which increased to 11.4dBi and 13.4dBi for 2 and 4 micro-strip arrays respectively. In both simulated dipole and micro-strip, antennas resonated at the designed frequency of 2.6GHz with a return loss of less than -14dB for dipole and -23dB for micro-strip which are below the benchmark of -10dB as required. The results have shown that the simulated antennas are suitable for small cell BS deployment based on the obtained antenna gains and can also be extended to localization systems with good beam steering mechanism.

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