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Design of a Broadband Microstrip Patch Antenna Operating between 1.5 Ghz - 4.5 Ghz

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

A printed circuit board-fabricated antenna is known as a microstrip patch antenna (MSA). It consists of a dielectric substrate that is encased in a ground plane on one side and a radiating patch on the other. A MSA's adaptability is enhanced by its small size, light weight, affordable production costs, simplicity of installation, etc. It can be examined using many antenna parameters, including the voltage standing wave ratio (VSWR), reciprocity, field areas, and S parameter. The Roger 3003 material (lossy) was used as the substrate in this work to create a rectangular broadband MSA with a bandwidth of 1.5 GHz to 4.5 GHz. A copper conductor with a thickness of 0.003 mm was used as the inset feed, and a gap of 1.00 mm existed between the patch and the

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inset feed. CST studio suite software was used to simulate this MSA and the results obtained were a reference impedance of 50 Ω; an S-Parameter of -10.75 dB and a farfield radiation pattern with a directivity of 2.34 dBi, -17.7 dBi and -37.7 dBi along the X, Y and Z axes respectively.

Keywords: Microstrip patch antenna (MSA); ground plane; minute size; narrowband; printed circuit board; radiating patch. substrate.

1. INTRODUCTION

A MSA is a type of antenna that operates at microwave frequencies. It consists of a metallic patch that is printed or etched onto a dielectric substrate, which is commonly made of materials like fiberglass or ceramics (Balanis, 1992). The patch is typically fed using a coaxial cable or a microstrip transmission line, and it radiates electromagnetic waves into free space (Bhunia, 2014). Figs. 1, 2 and 3 show its simple structure, side and top views respectively. The top view shows that MSA radiates only from the width side (Bhunia, 2014). The design of microstrip patch antennas has several advantages. They are relatively low-cost to produce, lightweight, and can be fabricated using standard printed circuit board (PCB) processes. Their planar structure makes them compatible with integrated circuits, allowing for easy integration into electronic systems (Parasuraman et al., 2020). The performance of MSA depends on several factors. These include the dimensions of the patch, the shape, and size of the ground plane, the substrate properties, and the feeding technique (Bhunia, 2014). By varying these parameters, the antenna's characteristics such as frequency of operation, impedance matching, and radiation pattern can be tuned to specific requirements (Rashmitha et al., 2020).

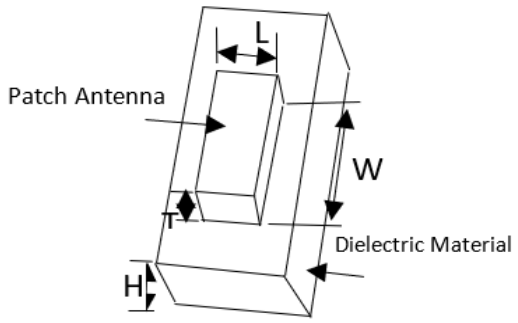

Fig. 1. H is the height of the dielectric material

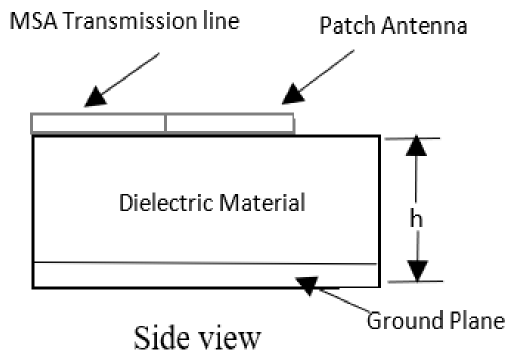

Fig. 2. W is the width of the patch antenna

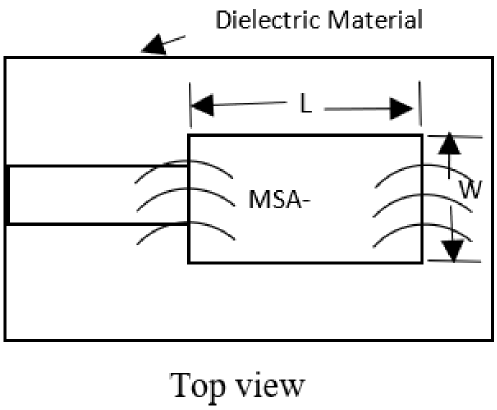

Fig. 3. L is the length of the patch antenna

There are various patch shapes used in microstrip patch antennas, such as rectangular, circular, triangular, and elliptical. The patch dimensions determine the resonant frequency and the shape of the patch affects the radiation pattern. Each shape has different radiation characteristics, and the choice depends on the desired radiation pattern and application requirements (Bhunia, 2014). The ground plane beneath the patch acts as a reflector and helps achieve the desired radiation characteristics. It is typically larger than the patch and acts as a ground reference for the antenna (Balanis, 1992). The ground plane's design impacts the antenna's radiation efficiency, gain, and bandwidth. The dielectric substrate is crucial to the functioning of the antenna since it supports the patch mechanically and has an impact on the bandwidth, radiation efficiency, and impedance matching. The antenna's electrical characteristics are affected by the dielectric constants and loss tangents of the various substrates (Rashmitha et al., 2020).

1.1 Problem Statement

The industry and education industries in Nigeria are eager to have an operational MSA that might be integrated into a smartphone. To that end, this research initiative was developed in the University of Calabar's Physics Department in the Nigerian state of Cross River. We decided to work together to complete this study for my Engineering Physics master's thesis (Archibong, 2020).

Universities in Nigeria encounter difficulties in manufacturing microstrip patch antennas, an essential part of contemporary wireless communication systems, despite improvements in engineering education and technology. This problem is caused by several things, such as out-of-date curricula, subpar lab spaces, restricted access to specialist software and equipment, and a dearth of certified teachers with knowledge of microwave engineering and antenna design (Odia & Omofonmwan, 2007). As a result, graduates are ill-equipped to design, manufacture, and test microstrip patch antennas, which limits Nigeria's capacity to make a meaningful contribution to the quickly developing field of wireless communication technology. Nigerian universities must address these issues, improve their engineering curricula if they hope to provide their students with the tools they need to make significant contributions to the creation of cutting-edge communication systems both domestically and internationally (Archibong, 2020). A M.Sc. thesis from the University of Calabar's Physics Department in Calabar, Nigeria, was motivated by the desire to question the current quo.

2 MATERIALS AND METHODS

2.1 Materials

A CST studio Suite software was used

2.2 Methods

Feeding techniques play a crucial role in determining the performance of a microstrip patch antenna (Balanis, 1992). The feeding technique refers to the method used to excite the electromagnetic waves on the patch, which enables it to radiate and receive signals effectively. It is crucial for efficient power transfer to the patch. There are a few common feeding techniques used in MSA, including: microstrip line feed, coaxial feed, aperture coupled feed, proximity coupled feed and proximity coupled microstrip line feed. The choice of feeding method depends on factors such as impedance matching, ease of fabrication, and desired radiation characteristics (Balanis, 1992).

The microstrip line feed, often known as the inset feed, was employed in this work. This technique involves using a microstrip transmission line to feed the patch antenna. A strip of conductive material is connected to the edge of the patch and is extended down towards the feeding point. The advantage of this technique is its simplicity and wide bandwidth (Bhunia, 2014).

Before commencing the simulation, the following steps were taken in the design:

(1) Choose the operating frequency, which in this case is 1.5 GHz to 4.5 GHz.
(2) Select a dielectric material as a substrate for the MSA. For proper mechanical support, enhanced electrical performance of the MSA circuit and transmission line, the Roger 3003 with a dielectric constant of 4.3 F/M was chosen.
(3) The height of the dielectric material, denoted by H_S, was chosen such that it will increase the MSA bandwidth, and to add more volume to the fringing effect of the radiation. This value was 1.50 mm.
(4) The thickness of the copper annealed material used as both patch antenna and the ground plane was chosen to be 0.035 mm. This is the industry standard for any copper annealed material used in MSA (Balanis, 1992).

(5) The gap between the patch and the inset fed, given as G_Pf, is usually 1.00 mm.
(6) The input impedance was 50 Ω. This is the internationally accepted value.
(7) Select the velocity of light to be $3x10^8$ m/s.
(8) Select the width of the window on the simulation software, given as SW, to be 50 mm.
(9) Select the length of the window on the simulation software given as SL, to be 50 mm.
Calculate the width of the patch antenna using this formula:

$$W = \frac{c}{2F_r} \cdot \frac{1}{\sqrt{\frac{\mathcal{E}+1}{2}}}$$

Where W is the width of the patch antenna to be designed; C is the velocity of light; F is

the operating frequency of the patch antenna to be designed, Ɛ = 4.3 F/M

$$W = \frac{c}{2F_r} \cdot \frac{1}{\sqrt{\frac{\mathcal{E}+1}{2}}} = 20.48 \text{ mm}$$

And the length L given as

$$L = [14.2H_s \text{ x } (\mathcal{E}_{reff} + 1.1758)] / \mathcal{E}_{reff} - 0.258 = 26.5 \text{ mm}$$

where: H_s = The height of the dielectric substrate

$\mathcal{E}_{reff}$ = The dielectric constant of the dielectric substrate (Balanis, 1992).

Next to be calculated was the length of the feedline, abbreviated as InL using

this equation. $InL = \frac{6h}{2}$

$$InL = \frac{6 \text{ x } 1.5}{2} = 4.5 \text{ mm}$$

Table 1 summarizes the parameters for the antenna simulation

Table 1. Parameters for microstrip patch antenna

Parameters	Value (Millimetre)
PW	20.48
PL	26.5
InL	5.10
InW	1.00
SW	50
SL	50
SH	1.50
Mt	0.035
K	7.07

where K represents the port extension coefficient and it has no unit.

2.3 Simulation of the Msa Using Cst Studio Suite

The Macros Bar' was selected from the CST Studio Suite's top horizontal bars, and a drop-down menu with a number of alternatives appeared. 'Calculate Analytical Line Impedance' was selected after selecting the 'Calculate' option. In order to determine the width of the feed line at which the impedance is 50, this was done. This is the impedance that all MSA must have.

It was then necessary to turn off the Working Plane and turn on the Local Work Coordinate Systems (WCS) by selecting the View and Modelling buttons, respectively, on the horizontal bar. The substrate and a portion of the ground plane were designed and made in accordance with specifications in order. The substrate was 80mm in both length (SL) and width (SW). 0.035mm was the height of the ground. The industry standard for the thickness of any copper used as a ground on a MSA is 0.035 mm. While the latter required a long list of processes, the former could be completed by selecting Brick under Modelling Option. The angle of rotation of U was altered to -90° by clicking the Align WCS and the Transform WCS one after the other. The pencil pointer from the "Pick a Point" option was then used to transfer the Local WCS to the substrate's bottom in order to build the ground plane. 16.3 mm from the feeding edge was the length of the partial ground.

The angle of rotation was altered to 90° and the Local WCS was repositioned at the top of the work. This was a requirement before designing and building the feedline. Here, the partial ground plane was made using the same procedure as above. The feedline's length, as specified by ML, was 15 mm from the feeding edge. The next element that needed to be designed was the patch. To achieve this, the Local WCS was transferred to the side of the feedline opposite to the feeding edge and the angle of rotation of U was changed to -90°. With this done, the patch was drawn and designed to specifications. The length (PL) and the width (PW) of the patch were 26.5 mm and 20.48 mm respectively.

Making the two insets, inset 1 and Inset 2, one after the other, was the following phase. The Modelling Session of the tool bar's Picks option was chosen, and the lower portion of the feedline was picked with a cursor after zooming in on the intersection point between the feedline and the patch. Making the two insets, inset 1 and Inset 2, one after the other, was the following phase. The Modelling Session of the tool bar's Picks option was chosen, and the lower portion of the feedline was picked with a cursor after zooming in on the intersection point between the feedline and the patch.

Before starting the simulation, the port needed to be set up and the feedline needed to be connected to the patch. The Plus option was chosen from the Boolean option on the Modelling session, and the Patch and the Feedline were highlighted on the Navigation Tree. The patch and the feedline were combined when the Plus option was selected in the Boolean option. The feeding edge was then magnified, and the feedline's edge was clicked on and selected to complete the Port's configuration. Then, after selecting the Home session on the Tool bar, the Macros option, the Solver choice from the drop-down menu, the Ports option from the following menu, and finally, the Calculate Port Extension Coefficient option from the last dropped-down menu, were all selected.

The Port Extension Coefficient was displayed, and its value was obtained by clicking the calculate bar. K, the port extension coefficient, was assigned to be 7.07. It's important to remember that K has no unit. The port was then created by filling in the Waveguide Port box after selecting the Waveguide Option in the Simulation session of the Tool bar. The MSA was now prepared for simulation after the box had been filled and the port created.

A box labeled Time Domain Solver Parameters was displayed when the Setup Solver option in the Simulation session was selected before to beginning the simulation. The reference impedance on this box was set to 50, and the S Parameter Session's Normalize to Fixed Impedance and Adaptive Mesh Refinement options were used. After pressing the Start button, the simulation procedure began and ran for a few minutes. When the simulation was finished, the wideband microstrip antenna results were generated.

3. RESULTS

3.1 Reference Impedance

In the context of a MSA patch antenna, the term "reference impedance" refers to the characteristic impedance of the transmission line or feedline used to connect the antenna to the RF (radio frequency) circuitry (Kraus et al., 2007). In MSA, a microstrip transmission line is commonly employed to feed the antenna element. This transmission line consists of a thin strip of conductive material, such as copper, printed on a dielectric substrate (Johnson, 1992). The characteristic impedance of this transmission line determines the matching between the microstrip patch antenna and the feeding network (Sharma et al., 2017).

The reference impedance acts as a matching network that ensures efficient power transfer from the RF circuitry to the antenna element. It helps to reduce signal reflections at the point of connection, optimizing the performance and radiation characteristics of the antenna (Johnson, 1992). The typical reference impedance used in microstrip patch antennas is 50 ohms, which is the standard impedance used in most RF systems (Balanis, 1992). Fig. 4 has a reference impedance of 50 Hz.

However, other reference impedances can also be used depending on specific design requirements or system considerations (Balanis, 1992). Precisely controlling the reference impedance is crucial for achieving proper impedance matching, minimizing signal reflections, and maximizing the antenna's performance in terms of radiation and efficiency, bandwidth, and gain. Design techniques, such as adjusting the width length of the microstrip transmission line, can be employed to achieve the desired reference impedance and impedance matching (Bhunia, 2014).

3.2 S-parameter

The S-parameters, or scattering parameters, in the context of MSA, refer to the complex voltage reflection and transmission coefficients that characterize the behaviour of electromagnetic waves (EM) at different ports or junctions within the antenna system (Bhunia, 2014). Specifically, in MSA design, S-parameters are used to describe the relationship between the incident and reflected or transmitted waves at various points along the transmission line and antenna structure. They are crucial for analysing the performance of a MSA as they provide insights into its impedance matching, power transfer efficiency, and radiation characteristics (Balanis, 1992). These parameters are typically measured or simulated using network analysers or electromagnetic simulation tools.

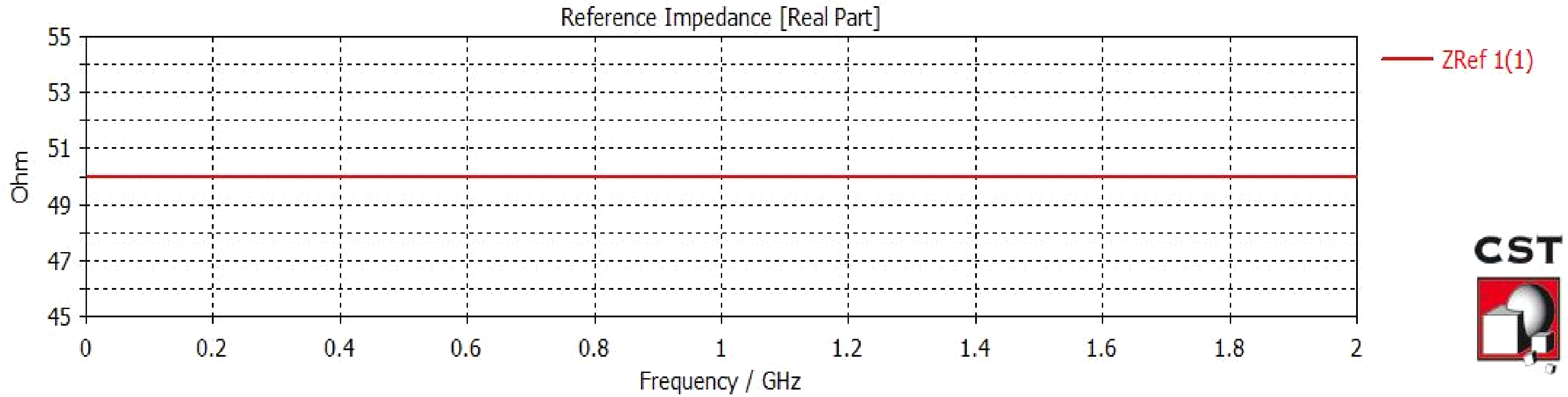

Fig. 4. Reference Impedance (Z_{Ref})

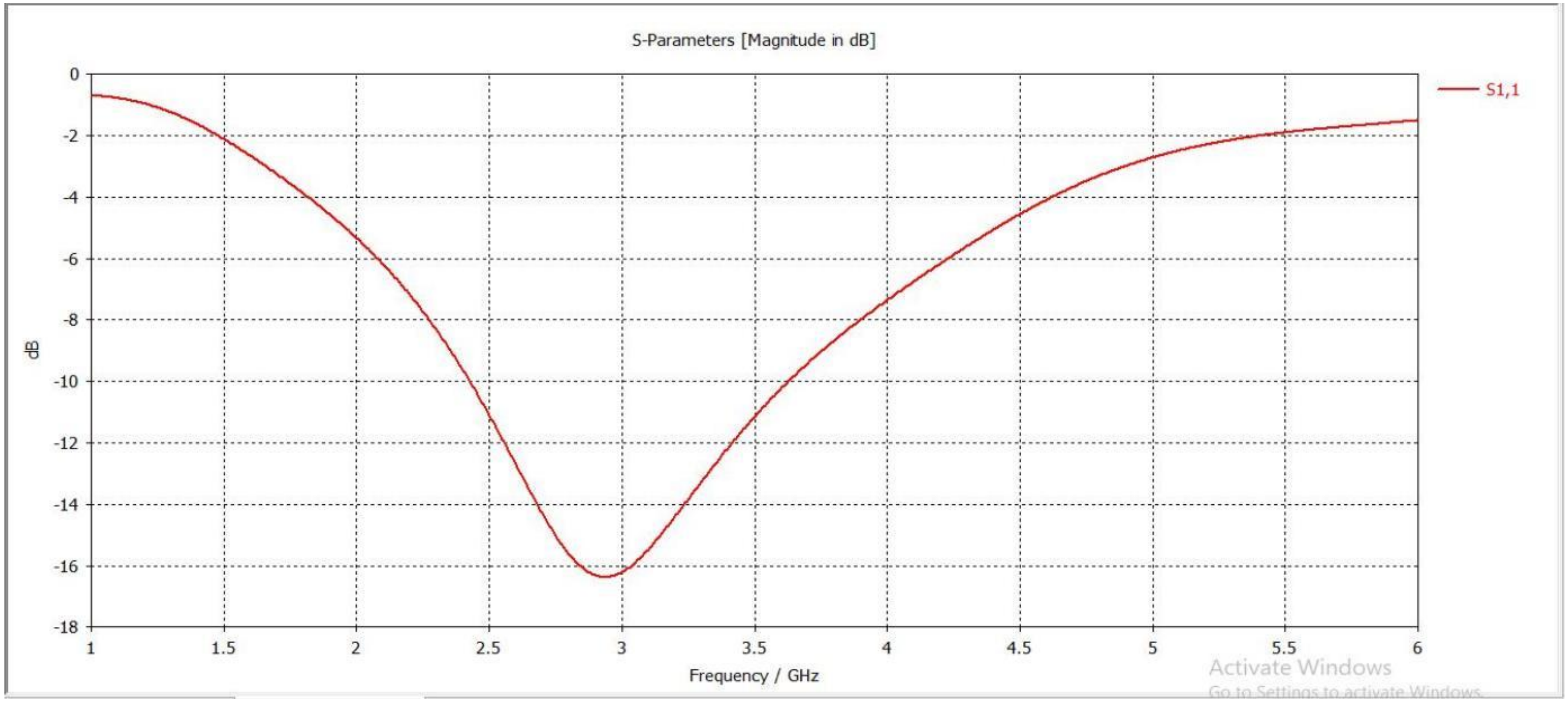

Fig. 5. S-Parameter

In the case of a MSA, the most commonly used S-parameters are S11 and S21 (Balanis, 1992). S11 represents the reflection coefficient when energy is incident on the antenna, whereas S21 represents the transmission coefficient from one port to another (Balanis, 1992). S11 is particularly important for evaluating the antenna's impedance matching, while S21 describes the amount of power transferred from the feed line to the radiating element (Sharma et al., 2017).

As shown in Fig. 5, the S11 Parameter utilized in this work is -10.75 dB for MSA. Because of this, if the antenna is given a power of -3 dB, or a 50% reduction in power, only 25% of the power (or -6 dB) will be reflected back toward the power source and the remaining 75% (or -0.75 dB) will reach and be radiated by the MSA, assuming a perfect impedance. Therefore, the MSA designed in this work has an efficiency of about 75%.

3.3 Far-field Radiation Pattern

The directional distribution of electromagnetic energy emitted by the antenna at a considerable distance from it is referred to as the far-field radiation pattern in an MSA (Balanis, 1992). This pattern indicates the strength and direction of the radiated power by describing how the radiation from the antenna is concentrated in various directions (Guha & Antar, 2011). Because of its small size, low profile, and simplicity of integration with contemporary electrical systems, MSA are widely used. Such an antenna's dimensions and structure affect its radiation pattern. It falls into one of two categories: directional or omnidirectional (Guha & Antar, 2011).

An omnidirectional radiation pattern, also known as isotropic, indicates equal radiation in all directions around the antenna (Guha & Antar, 2011). In practice, it is challenging to achieve a perfect isotropic pattern, but certain designs can provide relatively uniform radiation over a wide angular range (Balanis, 1992). On the other hand, a directional radiation pattern indicates that the energy is concentrated in specific directions, resulting in a higher gain at those angles. These patterns are desirable when the antenna needs to cover a specific area or establish communication with a targeted point (Guha & Antar, 2011).

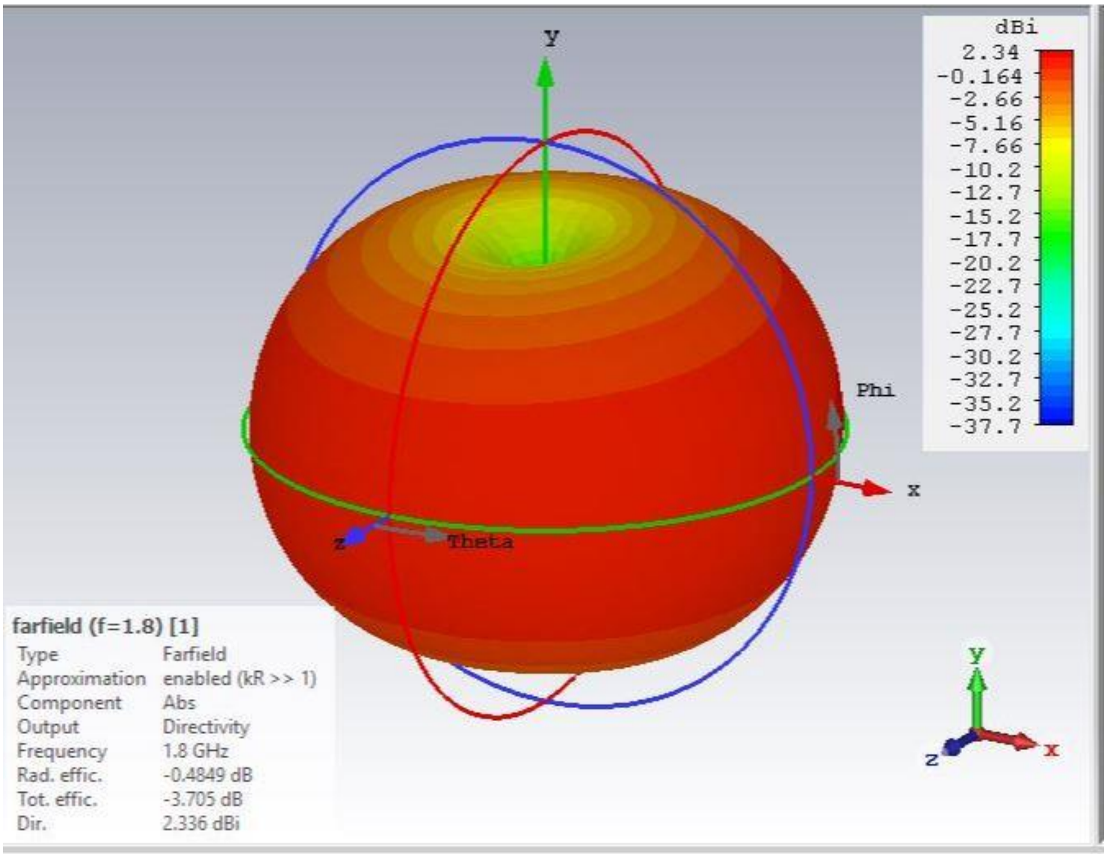

Fig. 6. 3-D Far field radiation pattern

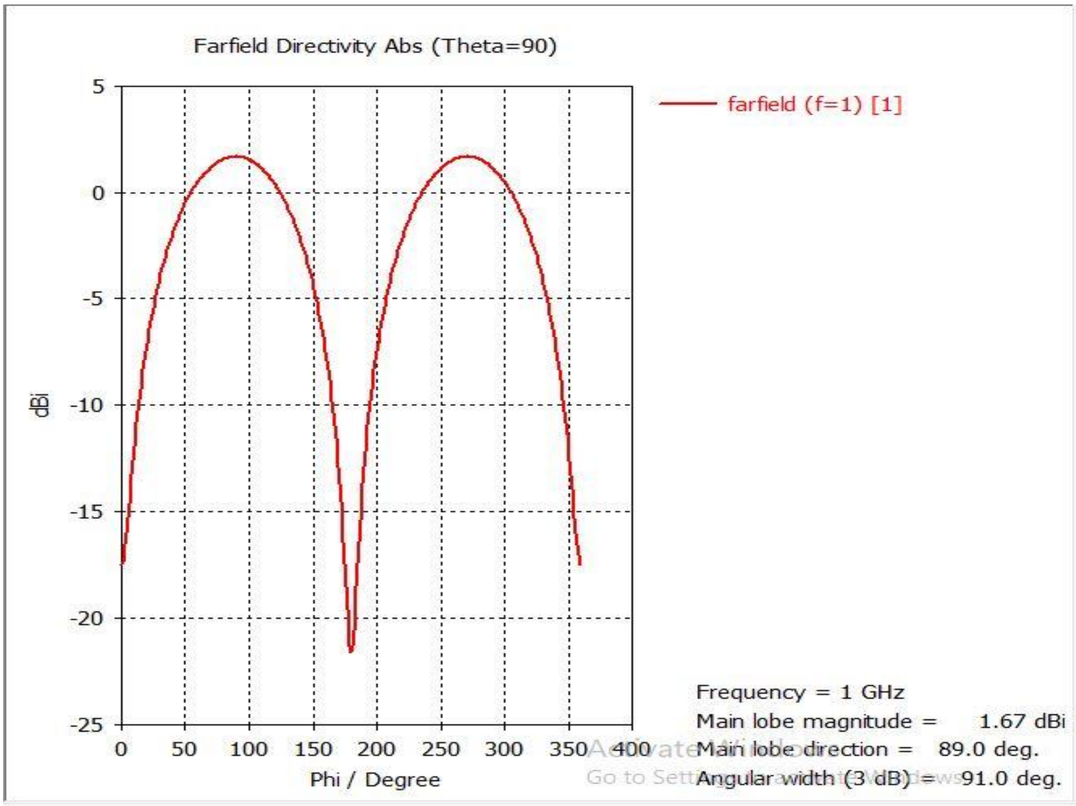

Fig. 7. 2-D Radiation Pattern of Broadband Microstrip Antenna

The far-field radiation pattern is typically represented graphically in either the polar or rectangular coordinate system. In the polar plot, the radiation pattern is shown as a function of the angle, while the rectangular plot displays the pattern as a function of azimuth and elevation angles (Balanis, 1992). Understanding the far-field radiation pattern of a MSA is crucial for applications such as wireless communication, radar systems, satellite communications, and other situations where precise control and knowledge of the antenna's coverage area are essential (Guha & Antar, 2011).

The radiation pattern depicted in Fig. 6 is the same in Fig. 7, which is illustrated. The elevation pattern in Fig. 7 is the radiation pattern that is plotted as a function of the angle measured off the z-axis (for a fixed azimuth angle). It is located on the left side of the image. The radiation pattern is shown in Fig. 6 to be minimum at 0 and 180 degrees and maximum broadside to the antenna (90 degrees off the z-axis) (Balanis, 1992).

To explain Fig. 6 critically, let us pick three values of the MSA directivity at 1.8GHz frequency and analysed:

A. -17.7 dBi in a farfield radiation pattern along Y axis

The term "dBi" stands for "decibels relative to isotropic", which is a unit used to measure antenna gain (Guha & Antar, 2011). In this case, -17.7 dBi indicates that the antenna's radiation pattern is directional and has a gain 17.7 dB lower than an isotropic radiator, which radiates equally in all directions. A negative value suggests that the antenna is not very efficient in that direction and is likely radiating less power compared to an isotropic antenna (Guha & Antar, 2011).

B 2.34 dBi in a farfield radiation pattern along Z axis

In the context of farfield radiation patterns, the term "dBi" refers to the gain of an antenna or the ratio of the power radiated in a particular direction compared to an isotropic radiator. An isotropic radiator radiates power uniformly in all directions (Balanis, 1992).

When we say an antenna has a gain of 2.34 dBi in a specific direction, it means that the antenna radiates power in that direction with an intensity approximately 2.34 times higher compared to an isotropic radiator (Balanis, 1992). This measurement allows us to understand the directional properties of the antenna and its ability to focus or concentrate the radiated energy in a particular direction (Balanis, 1992).

C -37.7 dBi in a farfield radiation pattern along X axis

-37.7 dBi represents the power level, measured in decibels relative to an isotropic radiator (dBi), at a specific direction from a radiating source; which is along the X axis. A negative value, such as -37.7 dBi, indicates a radiation pattern with low power in the given direction relative to an isotropic radiator. An isotropic radiator emits radiation uniformly in all directions. Therefore, the negative value suggests that the power in that particular direction is significantly lower compared to an isotropic radiator (Guha & Antar, 2011; Bach & Vaughan, 2011; CISCO, n.d.; Mohammed et al., 2022).

4 CONCLUSION

The main goal of this study is to integrate an MSA with an operating frequency range of 1.5 GHz to 4.5 GHz into a locally manufactured smartphone in Nigeria. To that end, the design and simulation of the MSA are examined. Examining the simulated antenna closely reveals the following:

- The MSA's farfield radiation pattern indicates that its directivity is 2.34 dBi along the Z axis, -17.7 dBi along the Y axis, and -37-7 dBi along the X axis. Its reference impedance, which serves as an impedance matching network, is 50 Ω.
- The S Parameter, which is the complex voltage reflection and transmission coefficient that describes how EM waves interface at the various ports, is also present.
- A farfield radiation pattern demonstrating the MSA's directivity along the X, Y, and Z axes, which are 2.34 dBi, -17.7 dBi, and -37-7 dBi, respectively.
- It is important to remember that the MSA radiates poorly along the other axes and only effectively along the Z axis. This means that this designed and simulated antenna is omni-directional.
- Even though the farfield was measured at 1.8 GHz, the outcomes will be the same for any other frequency lying within the operational frequency spectrum of 1.5 GHz to 4.5 GHz.

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 this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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