International Journal of Information Sciences and Engineering | *ISSN 1694-4496*
Published by AIR JOURNALS | *https://airjournal.org/ijise*
16/18 Avenue des Longaniers, Quatre Bornes, Mauritius
airjournals@gmail.com; enquiry@airjournal.org

SCHOLARLY ARTICLE

Design and Development of Microstrip Patch Antenna for Wireless Communications

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Accepted: September 24th, 2022	Published: September 30th, 2022

Citations - APA

Onuigbo, C. M., Egwuagu, O. M., & Eze, M. N. (2022). Design and Development of Microstrip Patch Antenna for Wireless Communications. *International Journal of Information Sciences and Engineering, 6(2), 46-59.*

ABSTRACT

The growing utilization of wireless communication devices demands antennas with enhanced broad-bandwidth and better capacity for future generation wirelesses network. This places a demand on antenna with wideband, low profile and small in dimension. Microstrip antenna having all these features can easily be incorporated into wireless communication devices. This work geared at optimizing the system low bandwidth capacity and also to meet the miniaturization requirement using a compact ultra-wideband smart microstrip antenna. In other to achieve this, Bakelite was chosen as a suitable substrate for the microstrip because of its excellent property as a dielectric material. For a good reception, the parameters relevant for the antenna design were determined. To get rid of any unwanted deposits, the substrate was Photo-etched by fabricating the radiating element and feed lines on the substrate. Relevant equations for the design of different parts of the antenna were derived. For free network, a model for coaxial cable to microstrip transition was developed. The performance of the system was measured and results show a design of Microstrip patch antenna (MSPA) with Return loss of-39.009dB, bandwidth of 2.2% at - 10dB, Maximum Radiated Power Value of 8.58 dBi, Minimum Radiated Power Value of -45.3 dBi and more than 89% of the fed power was absorbed by the antenna operating at a frequency of 2.4 GHz.

Keywords: *Microstrip; Substrate; Ultra-wideband; Patch Antenna; Etching*

Introduction

A microstrip is a type of transmission line that comprises of a conductor fabricated on dielectric substrate with a grounded plane. It is easily contracted and integrated with microwave devices making it a popular choice of transmission line. They can also be referred to as signals that are externally routed on a PCB. Their calculation model is based on the thickness and width of the trace, the thickness of the substrate, and the dielectric type and thickness (Lee et al, 2017). Microstrip lines are used to transmit microwave-frequency signals. In telecommunication, a microstrip antenna (also known as a printed antenna), typically refers to an antenna fabricated, using photolithographic techniques, on a printed circuit board (PCB). According to (Lee et al, 2017), by making use of foil microstrip transmission lines, the antenna is usually connected to the transmitter or receiver. In this presentation, the design specifications and development of microstrip patch antenna for wireless communication is at 2.4GHz frequency band. Despite the occurrence of interference between devices operating at this frequency band, the 802.11 standard provides several distinct radio frequency bands, divided into 14 channels of WLAN and Wi-Fi channels. This WLAN/Wi-Fi technology makes use of the frequency band from 2401 to 2484 MHz, spaced 5 MHz apart, with the exception of the last two channels which are spaced 12 MHz apart in various wireless communication protocols.

Mutiara et al (2011) did a rectangular microstrip patch antenna design for wireless communication application at 2.4 GHz with gain of 11 dB for outdoor use. Abdullah et al, (2017) designed, characterized and produced microstrip antenna slot double bowties 5 array using Co Planner Waveguide (CPW) as trigger with middle frequency of 5.8 GHz on a range of 4 – 8 GHz for 2.4 GHz wireless communication.

Colaco and Lohana (2021) designed, compared and analyzed the performance of Microstrip Patch Antenna at Millimeter Wave Band by using various geometrical shapes. Kumar et al (2021) designed and simulated microstrip fractal patch antenna which operated at the frequency of 7.23 GHz using a FR4 substrate with a gain of 10 dBi and return loss of-19.8 dB was equivalent to 90%radiated input power. Arvind et al, (2021) designed and analyzed Dolphin shaped patch antenna with edge and coaxial feeds at Wi-Fi frequency of 2.4 GHz. The gain of the triple ground variation was 6.4 dBi while the gain of the ground structure was 5.25 dBi.

The foregoing show how apt the use of microstrip patch antenna has been in various shapes and design in the modern-day wireless communication technology. The present work is an input into what earlier researchers have achieved in this regard for the improvement of the wireless communication industry. Frequency range of 2.4 GHz to 2.5 GHz is anticipated in this work which is in line with the requirements for Wireless Fidelity (Wi-Fi) enabled devices such as smart phones, personal computers, laptops, video game console and digital audio players. All these can conveniently connect to the internet provided they are within wireless network range of reception. With the development of microwave integrated circuit (MIC) and Monolithic MIC (MMIC), a microstrip patch antenna can operate at microwave frequencies of 300 MHz to 300 GHz. Thus, the design is intended for use in wireless communication network to enable the operation of the aforementioned devices and similar ones.

Literature Review
Geometric Appearance

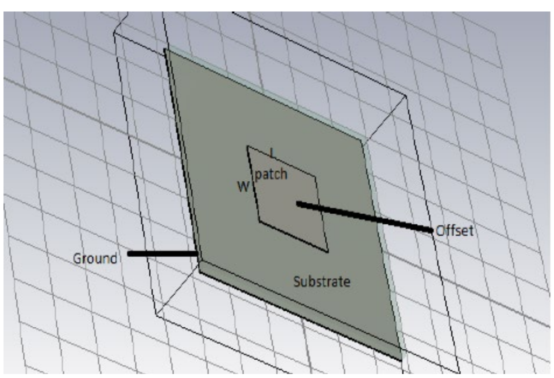


Figure 1: Geometric Appearance in 3D

The antenna has the geometric appearance shown in Figure 1. The figure provides the 3D physical appearance with three sections namely, the patch, the substrate and the ground or base element. The patch and base elements are made of conducting materials while the substrate is a non-conducting, dielectric material. The patch and ground or base element are typically made of good electric conductors like copper and aluminium. The substrate, being a non-conducting material such as foam, air or similar components, forms a kind of capacitor junction thereby creating electromagnetic field intensity by generating magnetic field. This results to electromagnetic wave generated between the patch and the base material and this is referred to as radiation unit in Antenna parlance.

Reviews of Relevant Literatures

Kumar and Jadaun (2012) presented a rectangular microstrip patch antenna (RMPA) with a defective ground structure (DGS) concept that is small in size and easy to manufacture. The proposed antenna was operated in what the authors referred to as S-band and X-band with three resonant frequencies. Two resonant frequencies reside in the X-band for use in Satellite communications, Weather mapping and detecting, long-range tracking radar for air traffic control and missile application while the third is operated in the S-band at 4.98GHz frequency for Wi-Fi of 13.5Mbps with a bandwidth of 10MHz and using the QPSK modulation technique. Simulation in the frequency band of 2 GHz to 14 GHz was used to arrive at the three resonant bands with directivity of the order of 6-8dBi with S11 of the order of ≤-10dB.

Ochoa and Wodeamanuel (2017) presented a computer simulated microstrip patch antennas designs for 2.4 GHz applications with a horizontal radiation pattern. Since Modern communication systems and instruments such as Wireless Local Area Networks (WLAN), mobile handsets and local positioning systems (LPS) require lightweight, small size and low-cost antennas, the choice of Microstrip Patch antenna technology was made to satisfy these needs. In order to achieve the best possible performance, the radiation characteristics of these designs with respect to various geometrical parameters such as the dimensions of the reflector and directors, and spacing between these elements were studied. The choice of Duroid 5870/5880 was made for the dielectric. Different designs were presented. The results showed that the third design presents the best radiation characteristics in the horizontal direction with a gain of 3.847 dBi and input impedance of 56.77 ohms.

Durga and Ravindra (2017) designed and simulated micro strip slot patch antenna for multiband applications. The designed MPA is omnidirectional and provides stable radiation pattern, rectangular in shape and simulated using ANSOFT HFSS software. HFSS means High Frequency Structure simulator launched by the ANSOFT. The antenna frequency ranges are: 4.15-4.39 GHz, 10-11.6 GHz, 13.2-14.3 GHz, 16-17.1 GHz, 19.1-20 GHz, 4.4-4.5 GHz, 8.7-9.1 GHz, 11.54-12.85 GHz, 1.65 GHz, 2.24 GHz, 4.4-4.6 GHz, 5.6- 5.8 GHz, 7.45-8.15 GHz. It is mainly used for MIMO applications, WLAN, Wi-MAX and RADAR, UWB, mobile communications, satellite space communications and microwave frequencies. Four types of micro strip slot patch antennas were designed: three rectangular feed and one co-axial feed and the designed antennas would work in the area of MIMO applications.

Methodology

The methodology involved a design of the geometric appearance of a typical microstrip antenna array, choice and reason of substrate, etching method and instruments, development of its appropriate mathematical model and equations as well as final presentation of the resulting designed Microstrip Patch Antenna (MSPA).

The Substrate, Its Choice and Properties

A substrate is of the form of a dielectric and provides a separation between the patch which is the top of the antenna and its bottom or ground layer thus creating a three-layer antenna architecture as exemplified in Figure 1. Being of non-electrical conducting material, the choice of a good substrate material is critical in designing a good antenna with enduring radiating capabilities.

Choice

Bakelite was used as the substrate. It is a hard, infusible and chemically resistant plastic material. It is an organic compound of the hydrocarbon family got from a chemical combination of formaldehyde and phenol (phenol-formaldehyde resin). The compound was derived from coal tar and wood alcohol (methanol). Bakelite is a good insulator and used extensively in the manufacture of non-conducting parts of electronic and electric devices such as switches, wire insulation, sockets and of course, antennas as in the case of microstrip patch antenna.

Properties of the Substrate: Bakelite

The properties of Bakelite as a substrate in this research are outlined in table 1.

Table 1: Properties of Bakelite

Properties	**Range and Unit**
Mechanical Properties	
Tensile Strength	34.5 – 62.1 MPa
Yield Strength (Elastic Limit)	27.6 – 49.7 MPa
Compressive Strength	30.4 – 54.6 MPa
Thermal Properties	
Glass Temperature	167 – 267 °C
Max Service Temperature	200 – 230 °C
Thermal Conductivity	0.14–0.15 W/m.K
Thermal Conductor or Insulator	Good Insulator
Electrical Properties	
Electrical Conductor or Insulator	Good Insulator
Electrical Resistivity	$3.3 - 30\text{x}10^{18}$ µΩ·cm
Dielectric Constant	4 - 6
Dissipation Factor	0.005 – 0.01
Dielectric Strength	$9.84\text{-}15.7\text{x}10^{6}$ V/m

Etching of the Substrate

Traditionally, etching is the process of cutting into the surface of unprotected parts of a metallic surface in order to create an incised design in the metal. Acids or other mordants are used to create or engrave incision onto the base or ground material used in the fabrication of the microstrip patch antenna, in this case, copper, so as to introduce the Bakelite substrate as the dielectric. Considering the temperature of Bakelite, as shown in table 1 and the melting temperature of copper at 1084 °C, the substrate can deposit on metallic copper and subsequently coagulate onto it, forming a layer of dielectric substance as expected. Bakelite as a compound hydrocarbon does not really melt. It only softens and regains its stability by hardening again when its temperature falls. This makes it easy to be deposited onto an etched and corroded surface of copper. It remains there firmly to play the role of dielectric substrate in the microstrip patch antenna design process. When these are done, the antenna was then designed in the described procedure as follows.

Mathematical Equations for Antenna Design

The following mathematical equations were used in designing the microstrip patch antenna. The first step was calculating the effective length and width of the patch antenna.

Based on the formulas given in equations (1) and (2), the physical dimensions of the patch are designed.

$$L = \frac{C_0}{2f_r\sqrt{\varepsilon_{reff}}} \quad (1)$$

$$W = \frac{C_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (2)$$

Where;
L = effective length,
W = width,
f_r = frequency of the proposed antenna.
C_0 = the space speed of light and
ε_r = relative permittivity of the substrate.

Due to fringing, the antenna size is increased electrically by an amount of (ΔL). Thus, the effective increase in length (ΔL) of the patch was calculated using equation (3)

$$\frac{\Delta L}{h} = 0.412\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \quad (3)$$

Where 'h'= height of the substrate Thus, the length (L) of the patch was calculated using equation (4)

$$L = \frac{C_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (4)$$

Also, based on the formulas given in equations (5) and (6), the physical dimensions of the ground plane are calculated.

$L_g = 6_h + L$ (5)
$W_g = 6_h + W$. (6)

Where;
L_g = length of the ground plane,
W_g = width of the ground plane and
h = thickness of the substrate.

The effective dielectric constant was also calculated. Two conditions are considered in the calculation as seen in equations (7) and (8).

$$when \left(\frac{W}{H}\right) < 1$$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\left(1 + 12\left(\frac{H}{W}\right)\right)^{-1/2} + 0.04\left(1 - \left(\frac{W}{H}\right)\right)^2\right] \quad \textbf{(7)}$$

The next consideration in the calculation is given in equation (6).

$$when \left(\frac{W}{H}\right) \geq 1$$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\left(\frac{H}{W}\right)\right)^{-1/2} \quad (8)$$

Where H is the height of the substrate material

The definitions of the symbols and letters in the equations remain as earlier given.

Another parameter which is often left out but which is very important in microstrip patch antenna design is the Voltage Standing Wave Ratio (VSWR). The formula for this calculation is given in equation (7).

VSWR = $(Z_L+Z_O+Z_O-Z_L)/(Z_L+Z_O-Z_O+Z_L)$
= Z_O/Z_L (9)

Where;
Zo = no load impedance
Z_L = load impedance.

It is important to include this consideration in this design because a high VSWR in capable of reducing the delivered power to an antenna or any system for that matter significantly. The result of this effect can be reduced by range, heating of cables, damaged amplifiers, among others. Usually, this occurs when testing the designed device with very broadband, high-power, and poorly matched loads.

There is also need to calculate the effective dielectric constant ε_{eff} which is given in equation (8) as

$$\varepsilon_{eff} = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2}\left(1 + \frac{12h}{w}\right)^{-1/2} \quad (10)$$

In equation (8), earlier definitions of constants still hold.

The resonance frequency f_0 for the (1, 0) mode is given in equation (11) as:

$$f_0 = \frac{c}{2L_e\sqrt{\varepsilon_r}} \quad (11)$$

In equation (11), C is the speed of light. Other definitions stand.

From the canter of the patch position x_f, y_f was determined using the following expression

$$R_{in}(y = y_o) = R_{in}(y = 0)cos^2\frac{\pi}{L}x_f$$

$y_f = 0$

Where $R_{in}(y = y_o) = 50\Omega$ and $R_{in}(y = 0) = \frac{L}{2}$

The proposed antenna geometry is shown in Figure 1. The measured dimensions are taken in millimetres (mm).

Design Parameters

The parameters used in the design of the microstrip antenna as done in this work are shown in table 2.

Table 2: Design Parameters and Values

Parameters	Parametric Values
Resonance Frequency (f_o)	2.4 GHz
Dielectric constant of the substrate (εr)	5
Height of the Substrate (h)	6mm
Length of patch (L)	75mm
Width of patch (W)	37.5mm
Length of ground plane (L_g)	150mm
Width of ground plane (W_g)	75mm
Feed position (X_f)	0.0187mm
Feed position (Y_f)	0

Coaxial Transition to Microstrip Model

To avoid low bandwidth and impedance mismatch in the design, there is need to design a microstrip patch antenna in such a way that impedance mismatch is avoided for a balanced reception. Thus, to ensure and achieve impedance matching, a Sub-Miniature version A (SMA) connector was used. It is a coaxial cable made of a semi-precision minimal connector interface using a screw-type coupling mechanism for coaxial cables. Also, to achieve this impedance matching, the centre conductor of SMA conductor was cut from the butt. Proper transit of coaxial to microstrip need to be done. Appropriate connector of microstrip substrate having both contact on the height and top, was employed. Also at the bottom, a ground contact was used. In transition of SMA connector to the microstrip, a design using conductor back Coplanar wave guide was used. The transition parameters chosen in other to obtain a characteristic impedance of 50Ω, minimize the reflection along the transition, avoid any sudden breakup and obtain peak bandwidth were;

Description

L_p = Length, W_p = Width, H_p = Height
l = Ground Plane Length,
w = Ground Plane Width, f = Feed Location

Properties

'Length' = Patch length along x-axis 75mm
'Width' = Patch width 37.5 mm
'Height' = Height of substrate 6mm
Ground plane length = 150mm
Ground plane width = 75mm

'Patch Center Offset' — Signed distance from center along length and width of ground plane [0 0] (default) | two-element vector in meters

'Feed Offset' — Signed distance from center along length and width of ground plane [–0.0187 0] (default) | two-element vector in meters

'Tilt' — Tilt angle of antenna 0 (default) | scalar in degrees
'Tilt Axis' — Tilt axis of antenna [1 0 0] (default) | three-element vector of Cartesian coordinates in meters as shown in figure 2.

Patch Microstrip Properties

Length: 75 mm
Width: 37.5 mm
Height: 6 mm
Ground Plane Length: 150 mm
Ground Plane Width: 75 mm
Patch Center Offset: [0 0]
Feed Offset: [-0.0187 0]
Tilt: 0
Tilt Axis: [1 0 0]

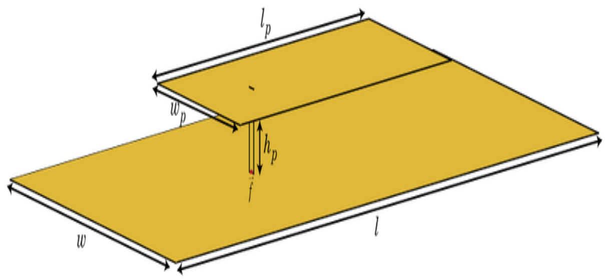


Fig 2: Configuration of coaxial transition to Microstrip Patch Antenna

Physical Measurement

Measurements done for the microstrip antenna are:

I. Measurement of the radiation power was obtained by measuring the gain and directivity of the antenna. The measurement was carried out using wave and antenna training system shown in fig 3. The log periodic antenna was used as the transmitting antenna, while the microstrip was the receiving antenna.

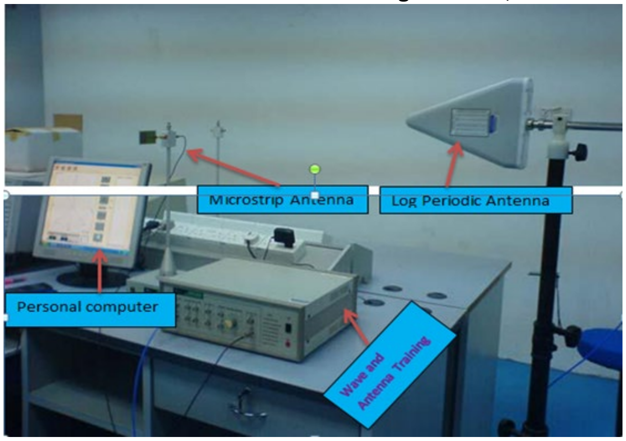


Fig 3: Radiation Pattern Measurement

II. Input reflection coefficient (S11). Under here, impedance and frequency of the antenna was taken. The antennas absorption of the fed power over the total power was measured. This measurement was carried out using network analyzer. To obtain the reading, microstrip patch antenna was attached to the network analyzer through the SMA connector as shown in fig 4.

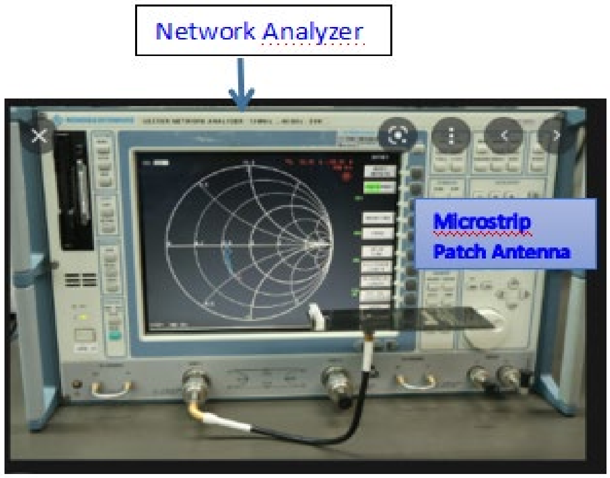


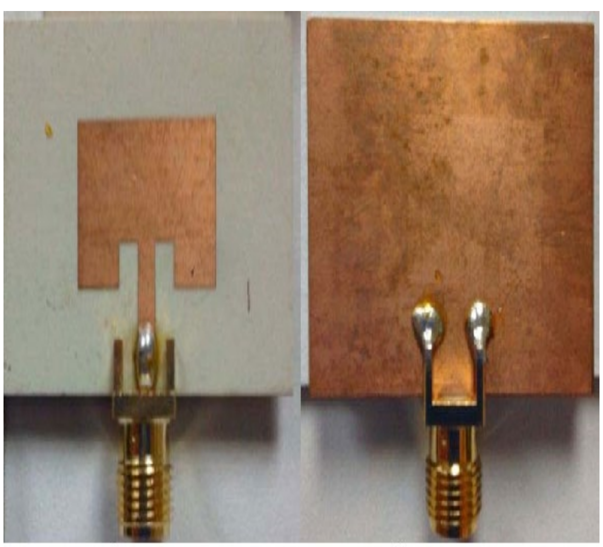
Fig 4: S11 measurement of microstrip patch antenna.

Results and Discussion

The results of the work carried out in this research are presented and discussed in this section**.**

Appearance and Shape

The geometry of the designed antenna after etching the substrate and development of coaxal to microstrip transition, the fabricated microstrip antenna is shown in Figure 5. The designed microstrip patch antenna is rectangular in shape. The figure in (a) shows the front view of the microstrip antenna designed, while the figure in (b) shows the back view.



a) b)

Figure 5: Micro script Patch Antenna

The azimuth position in a physical operation is shown in Figure 6. This shows the geographic polar position of the functional microstrip patch antenna.

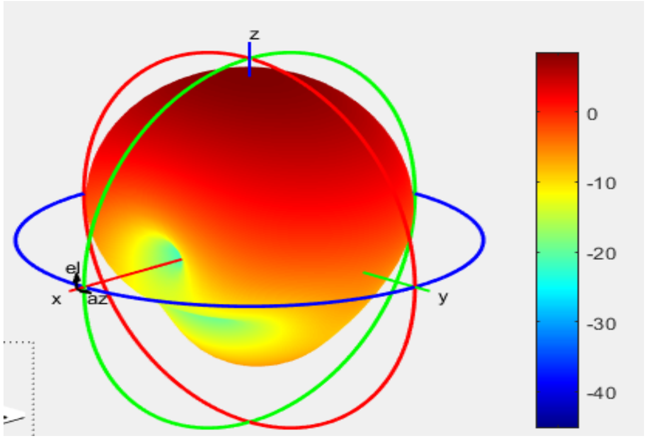


Figure 6: Antenna Azimuth Position.

Output: Directivity
Frequency: 2.4 GHz
Maximum Radiated Power Value: 8.58 dBi
Minimum Radiated Power Value: -45.3 dBi
Azimuth: [-180°, 180°]
Elevation: [90°, 90°]

Impedance

Figure 7 shows a graphical presentation of the impedance versus the frequency. As shown in the figure, there is a known relationship between impedance and frequency. In the operation of a microstrip patch antenna as depicted in the graph of Figure 5, as the impedance of an inductor increases, its frequency also increases. Thus, impedance is directly proportional to the frequency in an inductor. When there is an increase in the signal frequency, the inductive reactance, X_L, also increases. At a particular frequency, resonance occurs and the reception of signals by an antenna gets to its peak.

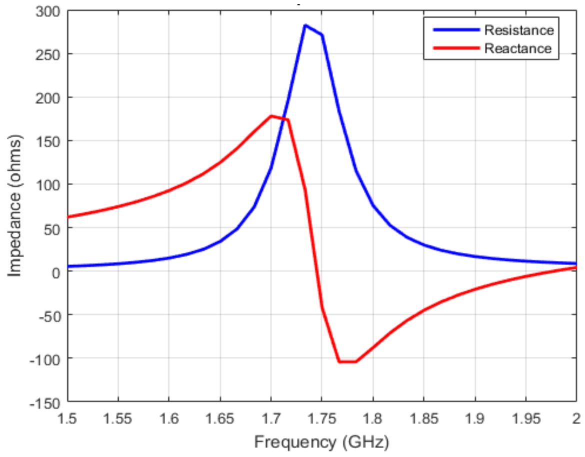


Figure 7: Impedance Relationship with Frequency

Return Loss

After measuring the reflected and forward power S_{11} (return loss) of the microstrip patch antenna with network analyzer, the result obtained is shown in table 3.

Table 3: Measured Results for the Proposed Antenna

Frequency	Return loss	Gain	Directivity
2.4GHz	-39.009dB	4.684dBi	6.286dBi

This result is shown in figure 8.

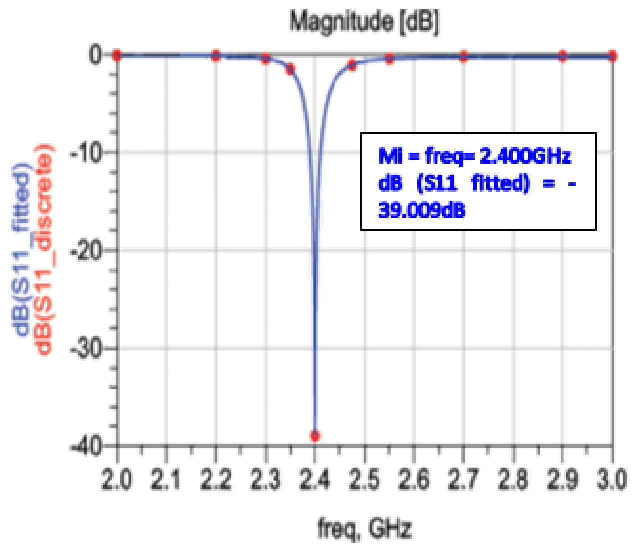


Figure 8: Return loss of Proposed Antenna

Return loss is the parameter that indicates the reflection of signal due to impedance mismatch.

From figure 6, it shows that at resonant frequency of 2.4GHz, the antenna displays a return loss of lowest dip of -39.009dB and the bandwidth of 2.2% at - 10dB. This shows that more than 89% of the fed power was absorbed by the antenna.

Established Bandwidth

The established bandwidth of the designed microstrip antenna is shown in figure 9.

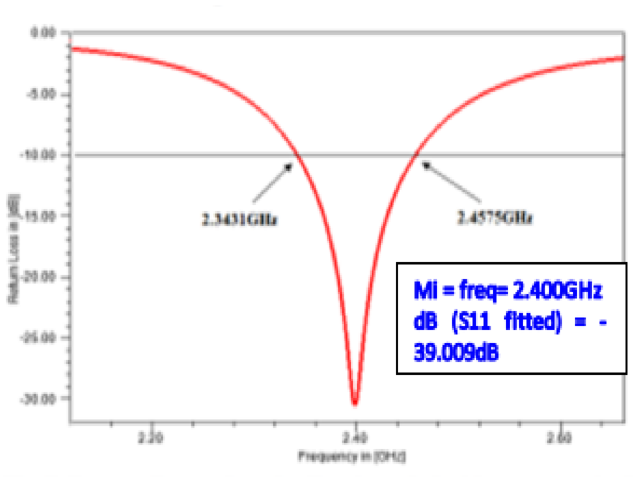


Figure 9: Established Bandwidth

From figure 9, it is noticed that the bandwidth of the microstrip resonator antenna has direct proportionality to the substrate thickness and to the square of the resonant frequency but maintains an inverse proportionality with the square root of the relative dielectric constant as earlier stated in equation (9). From figure 9, it can be seen that the higher cut off frequency is 2.48GHz and the lower cut off frequency is 2.3563GHz. The higher and lower cutoff frequencies have to be taken at the value of -10dB of return loss. The bandwidth is given by difference of higher cutoff frequency and lower cut off frequency. The resulted bandwidth of the patch at -10dB is approximately 123MHz. The patter radiation test is shown in figure 10.

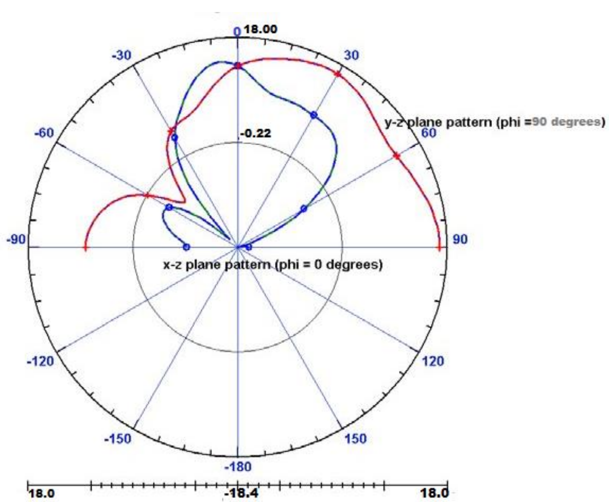


Figure 10: **Radiation Pattern of the Designed Microstrip Patch Antenna**

From figure 10, it was discovered that in the y-z plane at around 30 degrees, a maximum gain of 18dBi was achieved. Also, from the z-axis at the x-z plane, the gain pattern was consistent with a gain of around 12dBi.

Conclusion

Wireless communication infrastructure needs the radio frequency (RF) spectrum at all times. According to 802.11 standard, there are several distinct bands of frequency for use in Wi-Fi communication. These are 900 MHz, 2.4 GHz, 3.6 GHz, 4.9 GHz, 5 GHz, 5.9 GHz, 6 GHz and 60 GHz. Each frequency range has several channels into which it is divided. However, out of these frequency bands, the 2.4 GHz band is considered most ideal for use to connect devices which operate in low bandwidth activities such as internet browsing. Conversely, 2.4 GHz band provides the best choice for devices with high-bandwidth needs such as gaming and high-definition television (HDTV) streaming. The developed MSA performance in terms of return loss and radiation patterns conformed to requirement specifications. Due to the present-day peculiarity of the internet and its associated applications, the choice for the microstrip antenna design in this work could be seen to be apt and expedient. The designed microstrip patch antenna is generally of low cost, smaller in dimension, lighter in weight, low in profile, easy to fabricate and also satisfies the necessary conditions for receiving signals broadcast or transmitted from the 2.4 GHz frequency band. Its ease of fabrication and signal reception enhancement conformity stands it out.

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