

Design and Analysis of Rectangular Printed Loop Microstrip Patch Antenna for Wireless Communication at 2.4 GHz.

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Abstract— A rectangular microstrip loop patch antenna for wireless communication system at 2.4 GHz operating frequency is proposed and analyzed. The objectives of this project are to design and analyze both simulation and measurement results for the proposed antenna to make comparison. The design is fabricated on FR4 substrate of dielectric constant, ϵ_r equal to 5.0 and tangent loss 0.025. A combination of several equations and technique are used to get the initial geometrical parameters. The antenna can operate at 2.4 GHz within the desired specification by adjusting the dimensions. The antenna has return loss of -14.781 at 2.401 GHz for simulation and -13.692 t 2.513 GHz for measurement. The voltage standing wave ratio, VSWR is 1.443 for simulation and 1.521 for measurement. The antenna has an omni-directional characteristic. The design and simulation are done using Computer Simulation Technology CST Microwave Studio software and the measurement using Vector Network Analyzer (VNA). The design procedure, simulated and measured has been discussed in this paper.

Keywords – microstrip loop patch antenna, quarter wave impedance matching, Computer Simulation Technology, Vector Network Analyzer.

I. INTRODUCTION

The demand for antennas that are capable to be embedded in portable devices such as cell phones and became a main component in wireless communication has increased due to the evolution of modern wireless communications systems [2]. Microstrip patch antenna, also known as printed antennas is an antenna that fulfils the requirement of modern antenna such as lightweight, low cost, and easy to be integrated into accompanying electronics [1]. These characteristics give it advantages compare to other type of antennas when it comes to application in wireless communication.

In designing microstrip antennas, there are many kind of shapes that can be apply such as square, rectangular, circular and elliptical, but any continuous shape is possible. For fabrication of microstrip antenna only a few materials are needed so it is inexpensive, easy to manufacture and light

weight. Determining the right size of microstrip antenna is crucial as the size of microstrip antenna is contrary to the frequency. This means that the smaller the size of the antenna, the higher the frequency that it can detect but the bigger size of the antenna, the lower frequency it can detect. These are the reasons why the microstrip antenna design is use widely for ultra-high frequency signals.

In this paper, a microstrip loop antenna is as proposed in Fig. 4. The antenna was designed, optimized and analyzed at 2.4 GHz operating frequency. The basic design uses conventional rectangular microstrip patch antenna as shown in Fig. 1 as reference before upgrading it into a rectangular loop microstrip patch antenna. The loop structure of this type of antenna provides good matching for inputs such as coaxial cable and transmission line.

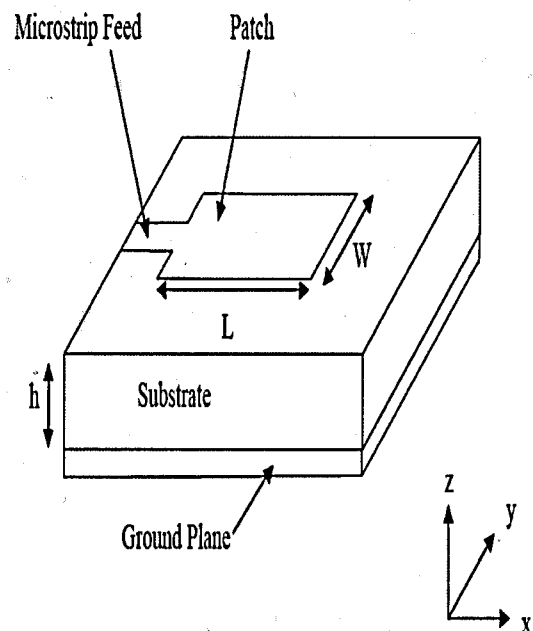


Fig. 1. Microstrip patch antenna

II. METHODOLOGY

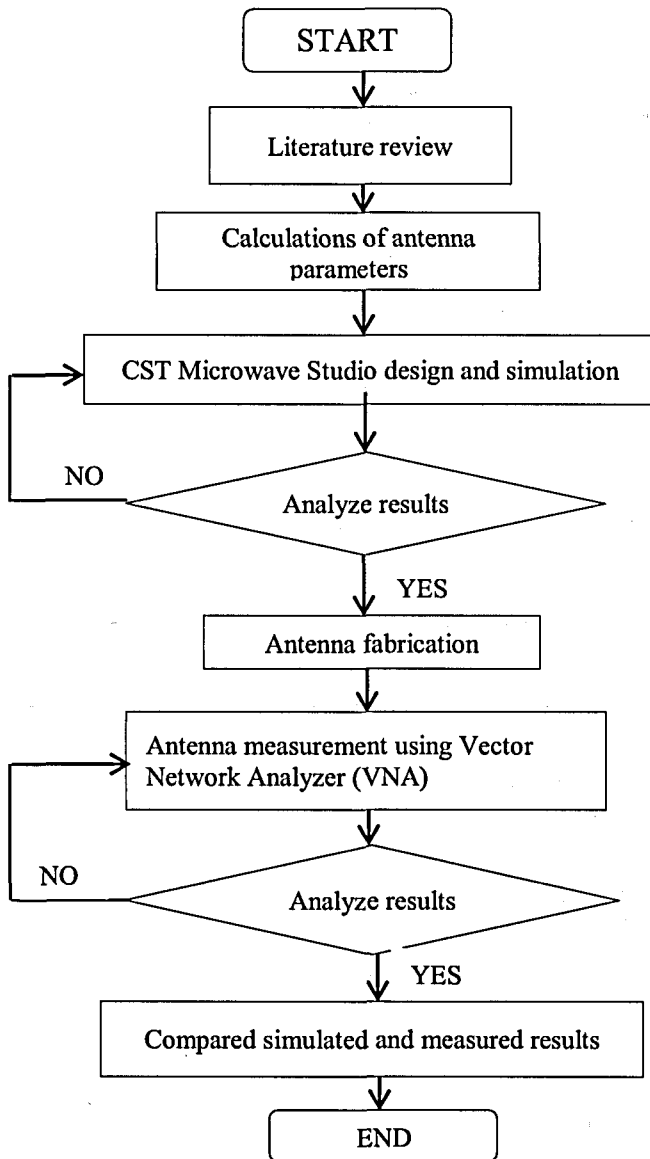


Fig. 2. Flow chart of project

Fig. II above shows the flow chart of the project. To realize this project, literature review was carried out through reading past works and journals on the required area.

A. Literature Review

Many designs have been investigated in the past on microstrip patch antenna for wireless communication system [1], [5], [7], [8], [9] and [10]. Microstrip patch antenna suffers from some advantages such as: 1. Narrow bandwidth 2. Low gain 3. Large ohmic loss in large feed network 4. Radiation from feeds contributes to the radiation pattern 5. Excitation of surface waves 6. Low polarization purity. [7].

A planar monopole antenna for 2.4GHz WLAN was proposed by [9]. It was successfully designed and operated at 2.4GHz (2.256-2.687 GHz) frequency. The antenna design achieved good return loss S_{11} and the bandwidth of proposed antenna is 431 MHz [9]. The antenna gain, directivity and radiation pattern are suitable for WLAN application.

Printed monopole antenna structure is shown in Fig. 3 and it was considered as an evolution of the conventional microstrip antenna with ground plane eliminated [10]. In [8], microstrip patch antennas for broadband indoor wireless system are proposed. For this project, the parasitic ring element scheme had been implemented to two broadband antennas. The first antenna was made from a narrowband rectangular patch antenna designed to resonate at 2.45 GHz, hence four parasitic rectangular patches were added resulting in a bandwidth of 180 MHz using a VSWR of 1.6:1 and 214 MHz using VSWR of 2.0:1[8]. The production of the second antenna was motivated by the key ideas of bandwidth improvement, reduced real estate and input impedance enhancement [8].

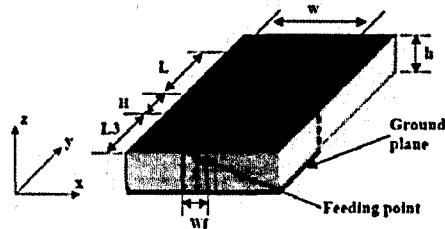


Fig. 3. Rectangular printed monopole antenna

B. Antenna Design

The basic calculations are used to design a basic rectangular microstrip patch antenna as shown below. After that, the antenna is turned into rectangular loop microstrip patch antenna and optimized to get the best performance. The resonant frequency of this antenna is 2.4 GHz with return loss < -10 dB. The antenna is built using FR4 Printed Circuit Board with copper plated on the two sides of the substrate and dielectric constant ϵ_r equal to 5.0. It is also designed with half ground due to the omni-directional characteristic that makes sure the patch loop radiate in both sides same as dipole antenna. With this type of design, the radiation pattern will come out as donut shape. The design specification of this antenna is shown in TABLE I.

TABLE I ANTENNA DESIGN SPECIFICATION

Resonant frequency (f_0)	2.4 GHz
Input impedance, Z_0	50 Ω
Return loss, S_{11}	< -10 dB
Voltage wave standing ratio, VSWR	< 2
Bandwidth, BW	< 500 MHz

There are three essential parameters that are crucial in designing microstrip patch antenna: 1. Operating frequency (f_0): choose the right resonant frequency according to application. 2. Dielectric constant of substrate: a substrate with high dielectric constant is suitable since it reduces the dimensions of the antenna. 3. Height of dielectric substrate: height of the dielectric substrate is important because a bulky microstrip patch antenna is not suitable to use [3].

So essential parameters for the design are:

- f_0 : 2.4 GHz
- ϵ_r : 5.0
- h : 1.6 mm

The transmission line model is used in this design. Below are the formulas and calculations used to design this antenna:

- Wavelength (λ);

$$\lambda = c / f_0 \quad (1)$$

$$c = 3 \times 10^8 \text{ and } f_0 = 2.4 \text{ GHz}$$

- Patch width (W);

$$W = \frac{c}{2f_0 \sqrt{\frac{(\epsilon_r + 1)}{2}}} \quad (2)$$

The design used FR4 as substrate so, $\epsilon_r = 5.0$. Using this equation, the width of the patch is calculated.

- Effective dielectric constant (ϵ_{eff});

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{w} \right]^{-1} \quad (3)$$

Taking the values of h and w obtained from (2) above and put into the equation (3), the effective dielectric constant (ϵ_{eff}) was calculated.

- Effective length (L_{eff});

$$L_{eff} = \frac{c}{2f_0 \sqrt{\epsilon_{eff}}} \quad (4)$$

Taking the value of ϵ_{eff} from equation (3), the effective length (L_{eff}) is obtained.

- Length Extension (ΔL);

$$\Delta L = 0.412h \left[\frac{\left(\epsilon_{eff} + 0.3 \right) \left(\frac{w}{h} + 0.264 \right)}{\left(\epsilon_{eff} - 0.3 \right) \left(\frac{w}{h} + 0.8 \right)} \right] \quad (5)$$

By substituting ϵ_{eff} , w and h , the length extension (ΔL) is obtained.

- Actual patch length (L);

$$L = L_{eff} - 2\Delta L \quad (6)$$

This is used to obtain the actual length of patch for the design.

- Ground plane dimensions (L_g and W_g);

$$L_g = 6h + L \quad (7)$$

$$W_g = 6h + W \quad (8)$$

The ground plane dimensions were calculated using above equation. After this design is finished, only then the ground is change into half ground due to omnidirectional characteristic of this antenna.

- Feeder width calculation using Z_0 ;

$$Z_0 = \frac{87}{\sqrt{\epsilon_r + 1.41}} \ln \left[\frac{5.98h}{0.8w} \right] \quad (9)$$

Z_0 is equal to 50 Ω and there is another method to determine the feeder width using CST software that will automatically calculate the value by using `macros > calculate > calculate analytical line impedance > thin microstrip`

- Quarter wave impedance matching.

As shown in Fig. 4, microstrip feed line mechanism is used. The length and width for the main feed line and quarter wave line can be calculated by inserting the value of width and length to match the required characteristic impedance to CST software. Fig. 5 shows the back structure of the antenna with half ground plane. The quarter wave impedance matching technique is used between main feed line and patch for impedance matching [4]. To determine the characteristic impedance of the quarter wave line, the following equation (10) is used:

$$Z_{\lambda/4} = \sqrt{Z_0 Z_1} \quad (10)$$

Z_0 = Characteristics impedance of main feed line.

Z_1 = impedance at patch edge

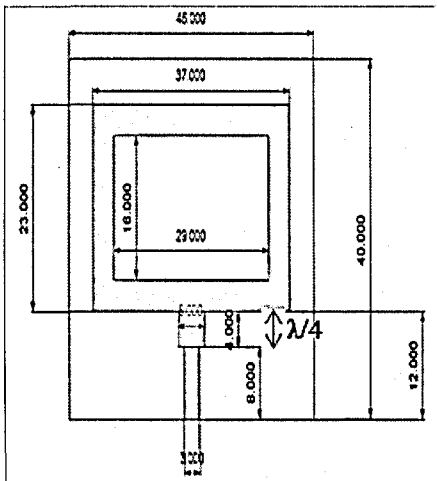


Fig. 4. Front structure of rectangular microstrip loop patch antenna (Unit in mm)

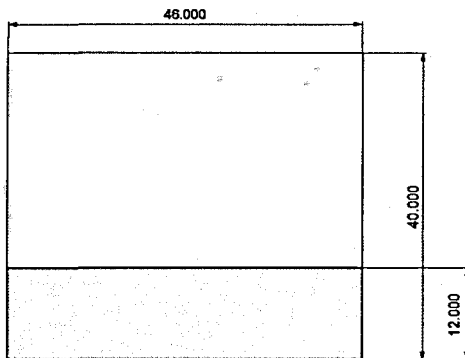


Fig. 5. Back structure of rectangular microstrip loop patch antenna (Unit in mm)

C. Simulation Setup

The software used to design and simulate the rectangular loop microstrip patch antenna is CST MICROWAVE STUDIO. This software can be used to design and simulate any type of microstrip antenna and other type of antenna. By using this software, the performance and antenna parameters of the designed antenna can be obtained. The design of the antenna is done step by step by first using the calculation shown earlier as a reference. Then the antenna was changed according to specifications or characteristics required. CST MICROWAVE STUDIO is software that can create, simulate and provides the designer with all necessary information for proper antenna analysis that includes features such as S parameters, input impedance, 3D and 2D pattern plot and far fields.

D. Optimization

Before the antenna design was completed as shown in Fig. 4, the antenna is then optimized to ensure the antenna operates at the required center frequency of 2.4 GHz and matching line impedance is 50Ω before been simulated. The impedance matching is crucial for a proper transfer of signal and energy from a source to a load.

TABLE II OPTIMIZATION OF FEEDER WIDTH FOR REQUIRED FREQUENCY

Feeder width (mm)	Resonant frequency (f_0)
2.0	2.387
3.0	2.401
3.5	2.41

III. RESULTS AND DISCUSSION

A. Line Impedance, Gain, and Directivity

The simulated result of line impedance, Z_0 of rectangular loop microstrip patch antenna is presented in Fig. 6. The required main feed line, Z_0 is of 50Ω characteristic impedance [4]. From the figure, Z_0 is equal to 50.03Ω which is an acceptable result since it was the closest value to $Z_0=50\Omega$ that was obtained after optimization.

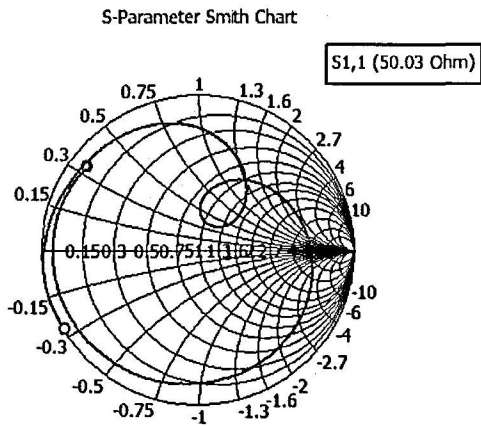


Fig. 6. Main feed line impedance from smith chart

Fig. 7 below shows the radiation pattern in 3D for the simulated antenna. This result is presented to show the gain of the antenna which is 3.388 dB.

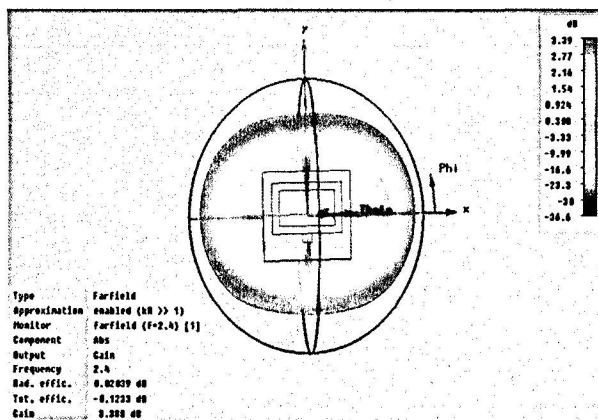


Fig. 7. Radiation pattern in 3D showing gain

Fig. 8 shows the radiation pattern in 3D for the directivity of the antenna. The antenna has a directivity of 3.368 dBi.

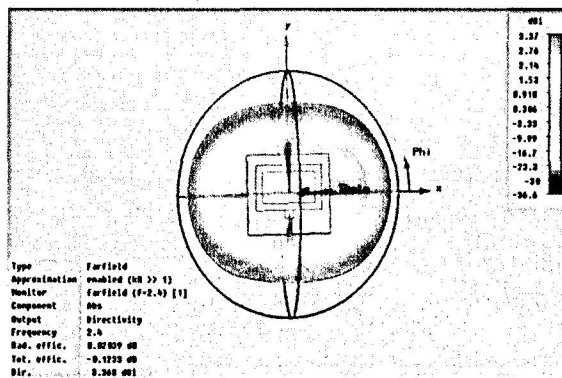


Fig. 8. Radiation pattern in 3D showing directivity

B. Radiation pattern.

The result of radiation pattern in polar plot for the simulated antenna is shown in Fig. 9 below. Radiation pattern shows the ratio of the maximum directivity of an antenna to its directivity in the opposite direction. From this plot, the front-to-back ratio is considered as zero because the front and back loop of the plot is almost symmetric. This characteristic is similar to that of a dipole antenna. The result indicates the omni-directional characteristic of the antenna.

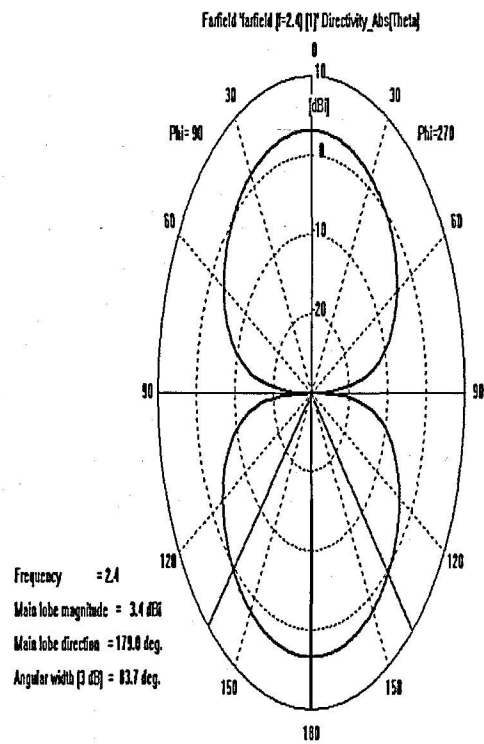


Fig. 9. Polar plot representing front and back loop

C. Return loss, S_{11}

The simulated and measured result for scattering parameter (return loss) of the designed antenna is presented in Fig. 10. The measurement of the antenna was done using vector network analyser (VNA). From the figure, the simulation result shows that the antenna operates at 2.401 GHz resonant frequency and it is acceptable considering it is the closest to required resonant frequency of 2.4 GHz.

As for the measured result, the antenna operates at 2.513 GHz with S11 of -13.692 where the graph was shifted to the right by 0.112 GHz and it is higher than the reference frequency. This can be explained due to the fact that in simulation, the antenna and ground plane are assumed infinite. The shifting of graph could also be caused by the different dimensions of the structure and the material parameters. The S11 of the simulated antenna is -14.871 dB at 2.401 GHz and the measured antenna is -13.692 dB at 2.513 GHz. Both the results produce good return loss value as it is required to be below -10 dB.

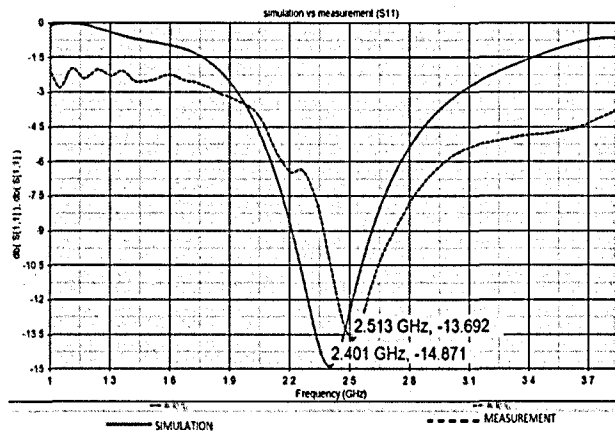


Fig. 10. Simulated and measured return loss, S_{11} of rectangular microstrip loop patch antenna

D. Voltage Standing Wave Ratio, VSWR

The simulated and measured VSWR of the antenna is presented in Fig. 11. VSWR is a measure of how well matched the antenna to the transmission line. The minimum value of VSWR is 1.0 dB where it indicates that there is no power reflected from the antenna. If the VSWR is smaller, it means that it is matched better to transmission line and more power is delivered to the antenna [6].

Higher values of VSWR indicate more mismatch loss. For the simulated result, the VSWR is at 1.443 dB and for measured result, the value is 1.521 dB. Both the results are considered acceptable since the value of good VSWR should be equal or greater than 1.0 dB and favourably less than 2.0 dB. However, there is a slight shift of about 0.112 GHz for the resonant frequency that effect the value of measured VSWR to increase about 0.078 dB. This effect could be due to the skin effects that may come from solder lead that was used for joining the transmission line and

connector. The effect of dielectric loss should also being considered as one of the factors. Choosing a substrate with high dielectric loss will worsen the measured VSWR.

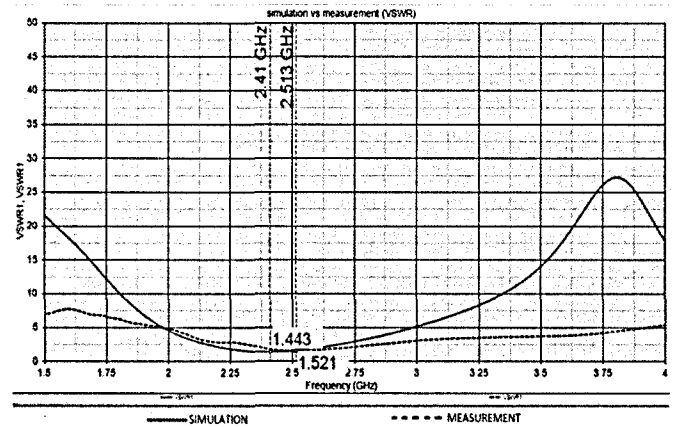


Fig. 11. Simulated and measured voltage standing wave ratio, VSWR of rectangular microstrip loop patch antenna

E. Fractional bandwidth

Bandwidth is another fundamental antenna parameter. It describes the frequency range over which the antenna can properly radiate or receive energy [6]. Fig. 12 and Fig. 13 shows the simulated and measured results for the S_{11} showing the required value of upper frequency, f_{upper} and lower frequency, f_{lower} for calculating the bandwidth of the antenna. The bandwidth of the antenna was calculated using equation (11) where the obtained -10 dB return loss bandwidth is about 339.1 MHz (2.2389~2.578 GHz) or 14.12% at 2.401 GHz frequency for the simulated result and the obtained -10 dB return loss bandwidth is about 271 MHz (2.393~2.664 GHz) or 10.8% at frequency of 2.513 GHz for the measured result.

Although there is a little decrease in the measured bandwidth compared to simulated result, both bandwidths are wide enough to cover the 2.4 GHz operating frequency.

$$\text{Fractional bandwidth, } BW = \frac{f_{upper} - f_{lower}}{f_c} \quad (11)$$

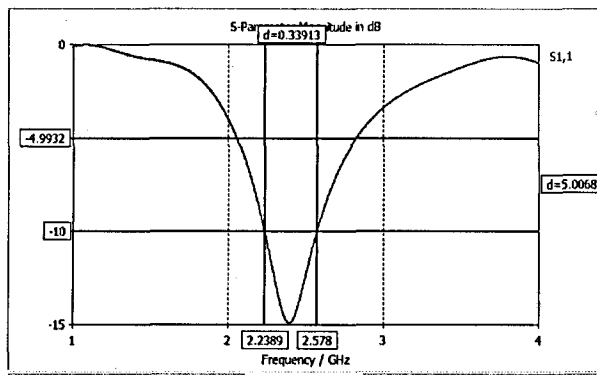


Fig. 12. Simulated bandwidth of rectangular microstrip loop patch antenna

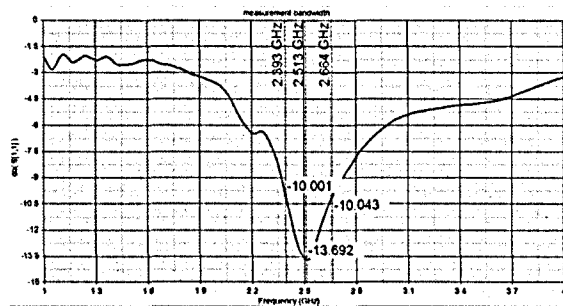


Fig. 13. Measured bandwidth of rectangular microstrip loop patch antenna

TABLE III COMPARISON OF SIMULATED AND MEASURED ANTENNA PARAMETERS.

Parameters	Simulation	Measurement
Resonant frequency, f_0	2.401 GHz	2.513 GHz
Return loss, S_{11}	-14.871 dB	-13.692 dB
Voltage standing wave ratio, VSWR	1.433	1.521
Bandwidth, BW	14.12%	10.8%

IV. CONCLUSION

The designing and fabricating of the proposed rectangular loop microstrip patch antenna has been successfully accomplished. The required specifications of the required antenna parameters have been met. The simulated antenna design achieved good return loss and VSWR of 2.401 GHz and 1.433 while the measured antenna gives the value of 2.513 GHz and 1.521. The simulated bandwidth in percentage was 14.12% and measured bandwidth was 10.8%. This gives the antenna a wider bandwidth that means the antenna can process more information at one time. For future works, the antenna can be made into a more compact size antenna and different shape of antenna can be try to improve the gain. Other feeding method that can also be used is coaxial feed. This antenna can perform well if this design is fully optimized.

ACKNOWLEDGEMENT

A whole lot of thanks to Prof Madya Norhayati binti Ahmad as supervisor of this project for her guidance and encouragement in doing this project. Special thanks to all the colleagues that have contributes their idea and comments regarding this project

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