DESIGN AND SIMULATE A RECTANGULAR PATCH MICROSTRIP ANTENNA FOR BLUETOOTH SYSTEM

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Abstract - The main purpose of this project is to design, simulate, fabricate and measure a single rectangular patch antenna at microwave frequency range. This project used computer aided design (CAD) package for designing and simulation before the fabrication process of the designed antenna is being made. The antenna was designed and simulated using CST Studio Suite 2006. CST Microwave Studio is a fully featured software package for electromagnetic analysis and design in the high frequency range. After the fabrication process, the antenna is measured using Vector Network Analyzer (VNA). The results obtained will be compared with the simulation results. The antenna is designed to operate at Bluetooth system operating frequency of 2.4-2.484GHz.

Keywords: Rectangular Microstrip Patch, Return Loss

1.0 INTRODUCTION

The demand for Bluetooth support of mobile devices has experienced tremendous growth in recent years. Bluetooth technology supports short distance, low data rate wireless communications. The antennas used for Bluetooth applications include planar monopole antennas and conventional patch antennas. Bluetooth technology may be implemented in a small integrated circuit, but the available Bluetooth antenna designs still require a relatively large space.

In recent years, the current trend in commercial and government communication systems has been to develop low cost, minimal weight, low profile antennas that are capable of maintaining high performance over a large spectrum of frequencies. This technological trend has focused much effort into the design of microstrip (patch) antennas. With a simple geometry, patch antennas offer many advantages not commonly exhibited in other antenna configurations [1].

Microstrip antenna is becoming popular and important these days. This is due to their versatility in terms of possible shape that makes them applicable for many different application and situations. Basically, microstrip antenna covers the application from 1 to 40GHz ranges where small circuit, suitable to be included in active device and capable of handling up to several watts of power is readily achievable [2]

1.1 Microstrip Antenna Theory

Microstrip antennas are popular for low-profile applications at frequencies above 100 MHz and also referred to as patch antennas. These antennas are low-profile radiators that are typically lightweight, small in size and conformable to planar and non-planar surfaces. Since patch elements are fabricated using printed-circuit technology, they can be manufactured in large quantities to reduce cost and are compatible with monolithic microwave integrated circuit (MMIC) designs. These antennas are well suited to applications where an aerodynamic profile and reliable performance are significant constrains. As a result, patch antennas have found numerous applications in aircraft, spacecraft, missiles and satellites [3].

The radiating patch of a microstrip antenna can be shaped in a variety of configurations including rectangular, circular, elliptical and triangular. Basically, the microstrip antenna structure consists of three parts. Firstly, a thin strip of metallic plate, dielectric or known as substrate and grounded plate that being attach to the substrate. . The ground plane is specified by an electric boundary condition. Figure 1.1 below depicts the geometry of a rectangular microstrip patch antenna [3].

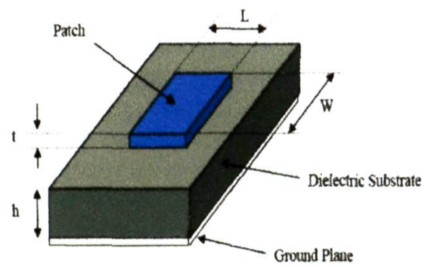


Figure 1.1: Structure of a Microstrip Patch Antenna

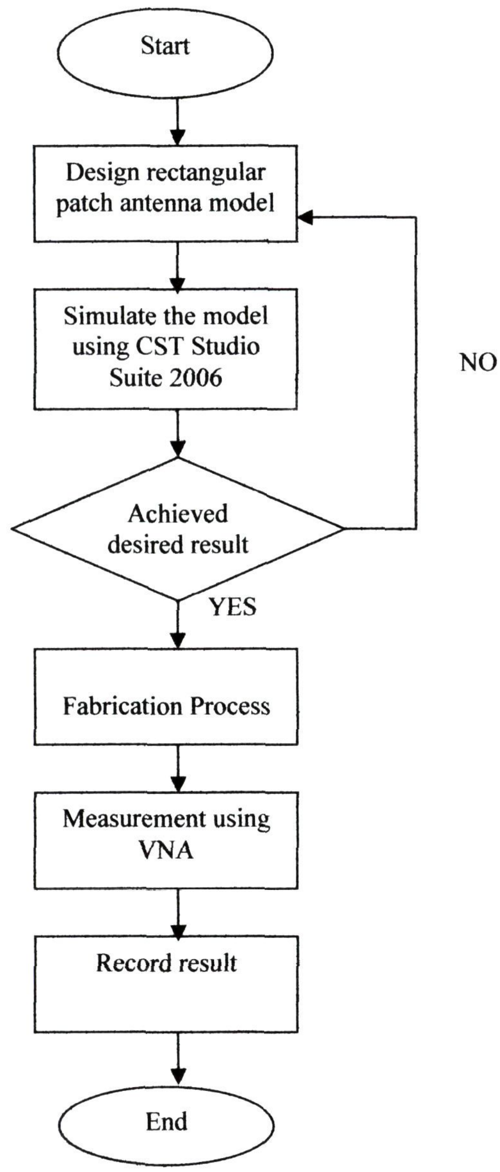
It is seen that a microstrip antenna is made up of a metallic patch and feed line that are offset from a ground plane by a dielectric substrate material. In order to eliminate the occurrence of surface waves, the thickness of the dielectric substrate is usually kept to a small fraction of wavelength ($0.003\lambda_0 \leq h \leq 0.05\lambda_0$). Surface waves degrade the performance of a microstrip antenna in two ways. First, they reduce the total power that available for direct radiation, which reduces the efficiency of the antenna. Second, surface waves adversely affect the pattern and polarization characteristics of the antenna since they are scattered at surface discontinuities, namely at the edges of the substrate and ground plane [3].

The dielectric constant of the substrate usually falls in the range of $2.2 \leq \varepsilon_r \leq 12$. This is indicative of the trade-off that exists between antenna efficiency and element size. Substrate materials with lower dielectric constants are typically low loss, which results in higher antenna efficiency. Substrates with higher dielectric constants allow size reduction of the element at the expense of antenna efficiency (due to increased loses) [3].

Photo etching is commonly used to deposit the patch and feed line on the substrate, so thickness of the metallization is very small ($t << \lambda_0$ where λ_0 is a wavelength in free space). The length of the metallic patch, L, is selected so that the antenna resonates at a particular operating frequency ($\lambda_0/3 \leq L \leq \lambda_0/2$). The length of the metallic patch needs to be tuned to account for the fringing fields at the edges of the patch. Finally, the width, W, is used to adjust the input impedance of the antenna [3].

2.0 METHODOLOGY

The objective of the project is to design, simulate, fabricate and measure a single patch rectangular antenna. Therefore, the simulation using CST Studio Suite 2006 is very important as this will predict the outcome of the designed antenna. But, due to some limitation of the CST Studio Suite 2006, Genesys has to be used. Genesys is used only to obtain the layout of the designed antenna for fabrication purposes. After the fabrication is complete the antenna is measured using Vector Network Analyzer (VNA) to check whether it can operate as desired.



3.0 DESIGN AND SIMULATION

3.1 CST Microwave Studio

CST Microwave Studio is a fast and accurate 3D EM simulation of high frequency problems. The module embeds a variety of different solvers operating in time and frequency domains. It offers three powerful solver modules and also provides "QuickStart Guide" that will assists us during the process of designing a particular design. This small window can be opened by choosing "Help → QuickStart" from the main menu. It will guide us through all the necessary steps of the simulation [4].

The most flexible tool is the transient solver, which can obtain the entire broadband frequency behavior of the simulated device from only one calculation run. This solver is remarkably efficient for most kinds of high frequency applications such as antennas, connectors, filters and many more. Before using the CST Microwave Studio for simulation purposes the parameter of the antenna must first be determined. For the simulation purposes of the rectangular patch antenna, this software is used [4].

3.2 Design Specifications

There are several essential parameters that must be considered in designing the rectangular patch antenna. These parameters are important in order to get the patch dimension. One of the parameters is the frequency of operation (f_o). The resonant frequency of the antenna must be selected properly. The Bluetooth system operates at the range frequency of 2.4-2.484 GHz. Hence, the antenna designed must be able to operate in this frequency range. The resonant frequency selected for the design is 2.46 GHz.

Another important parameter is the dielectric constant of the substrate (ε_r).The dielectric material selected for the design is Rogers RO4350 which has a dielectric constant of 3.48. The next parameter to be considered is height of dielectric substrate (h). The height of the dielectric substrate used in the designed is 1.524 mm.

The transmission line model will be used to design the antenna. Equations 1 to 10 are used to determine the dimensions and the feed position of the microstrip rectangular patch antenna. The most important parameters needed for the design of this antenna are the width and length of the patch antenna. An accurate value of the width and length affects the results very much [3].

i. Calculation of path width

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

ii. Calculation of effective dielectric constant

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

Where h is the substrate thickness and ε_{reff} is the effective dielectric constant, which arises due to the fact that in microstrip the rf signal is partly in air and partly in the substrate. The signal thus sees an effective dielectric constant, the value of which ranges between that of air to the substrate's [3].

iii. Determination of effective length

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}} \tag{3}$$

iv. Calculation of length extension

Although physically the patch dimension is of width W and length L, owing the fringing fields at the edges of the patch, the length is actually extended on each end by an amount of ΔL. therefore electrically the patch looks slightly bigger than the physical dimensions. The extra length ΔL is given by [3]

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{4}$$

v. Calculation of actual patch length

Since the patch is extended on each end by the amount ΔL, the actual length is thus

$$L = L_{eff} - 2\Delta L \tag{5}$$

vi. Ground plane extension L_g and W_g

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

$$W_g = 6h + W \quad (7)$$

Determination of feed point location:

To ensure maximum power transfer, the impedance of the feed needs to be matched to the path. Since the feed impedance is normally 50Ω, one therefore needs to determine the point on the patch where the input impedance is 50Ω at the resonant frequency. Normally the location of the feed is computed manually using numerical iterations or predicted using CAD [3].

Then, the position of the feeder can be determined from

$$\lambda_o = \frac{c}{f} \quad (8)$$

Since $W \le \lambda_o$,

$$G_r = \frac{1}{90}\left(\frac{W}{\lambda_o}\right)^2 \quad (9)$$

For input impedance $Rin = 50\Omega$

$$50 = \frac{1}{2G_r}\left[1 - \sin\left(2\left[\frac{\pi Y_o}{L}\right]\right)\right] \quad (10)$$

4.0 RESULTS

The results will be separated into two parts. The first part is the simulation results using CST Microwave Studio and Genesys. The second part is the measurement results after the fabrication process is completed. The antenna is measured using Vector Network Analyzer (VNA).

4.1 Simulation Result

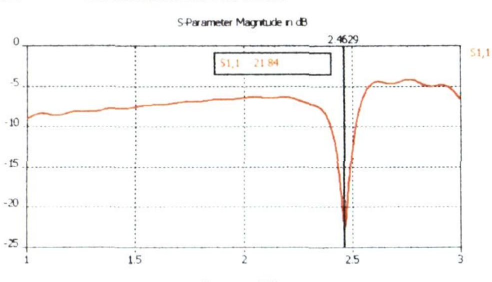


Figure 4.1: Return Loss (using CST Software)

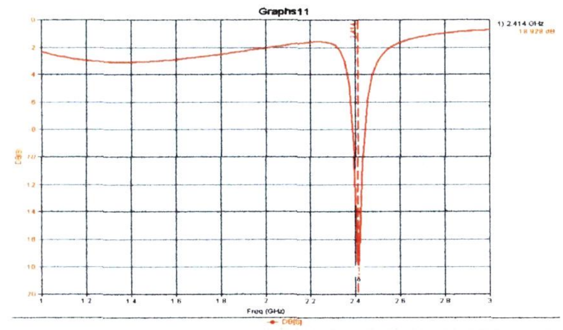


Figure 4.2: Return Loss (using Genesys Software)

Figure 4.1 and 4.2 shows the return loss for the patch antenna against frequency. From the both figure, it can be observed that the antenna resonate at 2.4 GHz. A negative value of the return loss indicates that the antenna did not have many losses while transmitting the signals.

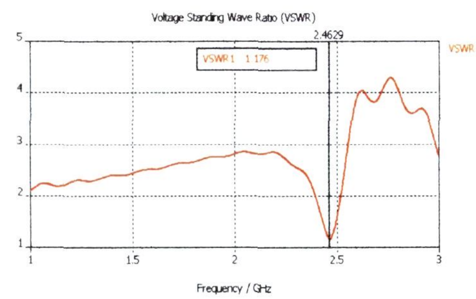


Figure 4.3: Voltage Standing Wave Ratio (VSWR) (using CST Software)

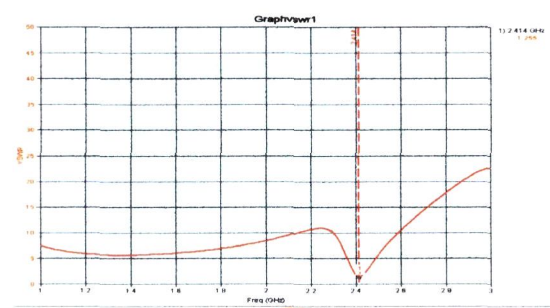


Figure 4.4: Voltage Standing Wave Ratio (VSWR) (using Genesys Software)

Figure 4.3 and 4.4 shows the voltage standing wave ratio (VSWR) for the antenna. A VSWR is a measure of impedance mismatch. As can be observed from the graph, the VSWR obtained is lower. This is considered a good value as the level of mismatch is not very high. A high VSWR means the port is not properly matched. Thus, this value proves that the port of the antenna is properly matched.

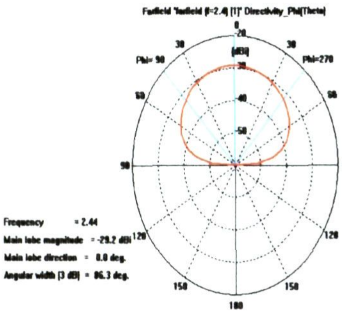


Figure 4.5 : Radiation Pattern

Figure 4.5 shows the radiation pattern of the antenna. The radiation pattern is represented in polar plot. Besides the polar plot, the radiation pattern is also represented in 3D plot as in Figure 4.6 and Figure 4.7 using CST Microwave Studio. From the 3D plot, it can be seen that the high radiation is indicated by red color [5].

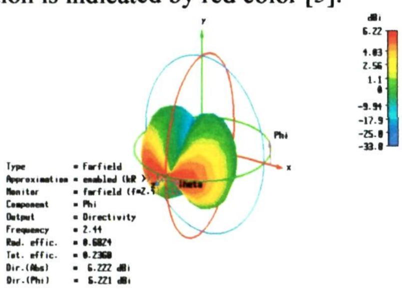


Figure 4.6 : 3D Radiation Pattern (Phi)

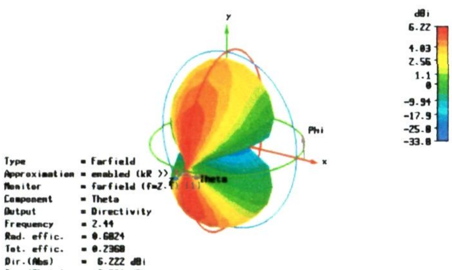


Figure 4.7: 3D Radiation Pattern (Theta)

4.2 Measurement Result

After the designed antenna is fabricated, it is then measured using Vector Network Analyzer (VNA) to check whether it can function as specified.

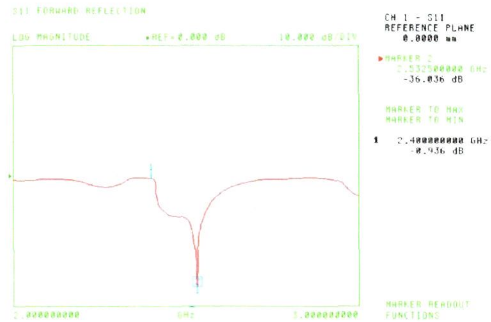


Figure 4.8 : Return Loss

Figure 4.8 shows the Return Loss of the microstrip antenna. From the figure it can be observed that the antenna resonate at 2.532GHz.

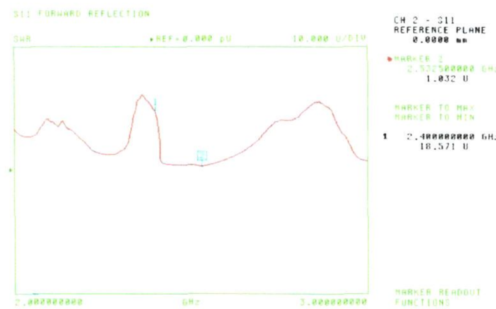


Figure 4.9: Voltage Standing Wave Ratio (VSWR)

Figure 4.9 shows the voltage standing wave ratio (VSWR) for the antenna. From the figure it can be observed that the antenna VSWR is 1.032.

5.0 DISCUSSION

Result from all the response can be considered acceptable, even though there are not as expected. The simulation result is not the same as the result from measurement. This is due to losses that occurred. As for the antenna the resonant frequency is not at resonant frequency. This is may be due to the error during the fabrication process. Besides that, the position of the screw on the plate that was placed near the patch is also contributes to loss. Another factor that contributes the loss is the position of the connector. It should be connected to the patch with the minimal length.

When designing the rectangular patch antenna, the width and length of the patch must be determined accurately. The patch width will affect the resonant frequency and radiation pattern of the antenna. A larger patch width will increased the power radiated and thus gives decreased resonant resistance. On the other hand, the patch length determined the resonant frequency. As a result, the single patch rectangular antenna's need to be adjusted so that the result will meet the desired specifications. Change in dimension will give impact to the designed. For example, change in width may increase or decrease the value of VSWR and input impedance. Hence, careful adjustment needs to be made in order to get the desired specification.

Another consideration that has to take into account when designing the antenna is substrate selection. The substrate dielectric constant must be considered properly. A low value of ε_r for the substrate will increased the fringing field of the patch. So, substrate with $\varepsilon_r \leq 2.5$ is preferred unless a small patch size is desired. A thicker substrate will increase the radiated power, reduces conductor loss and improve impedance bandwidth. But, it also will increase weight, dielectric loss, surface wave loss and extraneous radiation from the probe feed.

6.0 CONCLUSION

Upon completing this project, a single rectangular microstrip patch antenna has been designed at the frequency of 2.46 GHz. It can be concluded from the above results that, the dimension for the patch antenna must be determined properly because the dimension will affect the antenna performance later. Also choosing a proper position for terminating the feed line affects the overall performance of the antenna. Different types of feed methods affect the performance of the antenna.

6.1 Future Recommendation

Microstrip antenna is used not only as a single element but are very popular in array. The arrays are very versatile. This is because it can produce a required pattern that can not be achieved in single elements. The arrays are used to scan the beam of the antenna system and increased directivity. It also can be arranged in many ways. In future it is hoped that the array antenna can be analyze using CST Microwave Studio and then fabricated to test its performance.

7.0 ACKNOWLEDGEMENT

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