Optimization of the Dual Band Microstrip Patch AntennaVia Perturbation and L-network Matching for WLAN Application

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***Abstract*-Microstrip patch antennas (MPA) have become more popular in portable wireless communication systems. These antennas are light in weight, low profile, and support wideband and low in the cost of fabrication. Wireless communication deals with antenna performances, which has led to several researches on dual band and wideband antennas in which these antennas are embedded into an RF printed circuit board, so they cannot be seen from the device point of view.The L-network method was used for impedance matchingby introducing a separate network that can match the desired resistance known as the characteristic impedance and by perturbing the rectangular patch increases current path length giving rise to second order mode. The Electromagnetic full wave simulator software Antenna Design System (ADS) is used to simulate the patch antenna with parameters to be observed such as the return loss and voltage standing wave ratio (VSWR).**

***Keywords*-Microstrip patch antenna, Return loss, VSWR, Dual band, ADS software.**

I. INTRODUCTION

In the Microstrip antennas became very popular in 1970s and by the beginning of 1980s microstrip antennas were fully in operation for antenna design and modeling (Shera and Ashish, et al. 2016). In the last few decades microstrip antennas or printed antennas have been extensively used because of their characteristic advantages like low profile, light weight, low cost and ease of fabrication. A microstrip antenna consists of a conducting or radiating patch on one side of the substrate and ground plane on the other side, these patches are made up of conducting materials like copper or gold. They are photo etched on the dielectric substrate (Aishwarya and Prabhu, 2017). These printed antennas radiate because of fringing field effect between the patch edge and ground plane.

Likewise, the microstrip patch antennas suffer from several drawbacks which had led to numerous research works on the planar type to achieve a better presentation. These antennas suffer from narrow bandwidth of which different methods have been employed to better performances such as applying slot cuts or increasing the substrate thickness to achieve a wide band and by increasing the dielectric material it become quite difficult incorporating the antennas in small portable devices. Also attaining the exact feed point to achieve impedance matching is also a difficulty faced by these antenna types hence causing spurious radiation, low gains and low efficiency (Balanis, 2005).

Though, narrow bandwidth has always been a problem encountered with these antenna types. Narrow frequency bandwidths are not entirely appreciated for several applications where high quality is required because they support a lower rate transmission. However, the narrow bandwidths are still relevant for the purpose of relative shot distance two way communication devices such as walkie talkie. They are also useful for security systems that require minimal detection, such as the government security systems. With these limitations the need for research to investigate and overcome this issue is of high demand. Numerous techniques have been applied to enhance the performance of the microstrip antennas such as increasing the substrate thickness or modifying the shape of the patch (Balanis, 2005).

In this research, An E shaped microstrip patch antenna is designed and simulated via the ADS software to receive Wi-Fi signals that can operate in 2.4 GHz and 5.8 GHz with a bandwidth for both resonating point of frequencies at approximately at 0.38 GHZ.The microstrip patch antenna basically is an "E" slot antenna cut into a "hole" and lies on a piece of RF conductor with a certain thickness as shown in Fig 1.1.

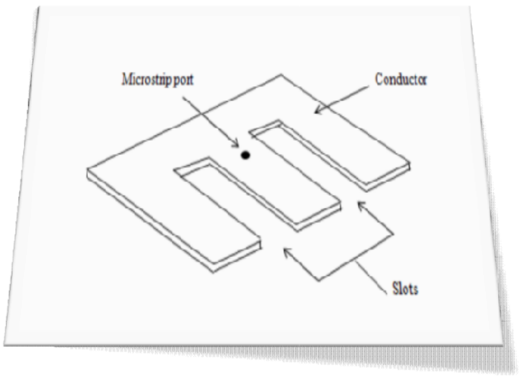

Fig 1.1: Sample of the slotted E- patch Antenna

a) Research Aim & Objective

The need for research to improve the technology for next generation Wireless Local Area Network (WLAN) following the Wireless Fidelity (Wi-Fi) standard that introduced Multiple-input and Multiple-output (MIMO) technique has emerged. The IEEE 802.11n was realized to help overcome overcrowding or interference issue and since then the need for antennas that can support higher data rate applications have been work in progress.

Hence, the goal of this research is to design a wide band microstrip patch antenna that is operable in a 2.4 GHz and 5.8 GHz microwave frequency range. This is realized by suppressing harmonics of an unwanted frequency band, to reduce interference for the intended multi band to achieve a more robust connection. Having a wider band for IEEE.802.11n infers having a bandwidth that supports multiple 20 MHz channels at the 2.4 GHz, multiple 40 MHz and 80 MHz channels at 5.8 GHz frequencies suitable for quadruple play services.

b) Research Scope

The scope of this research focuses mainly on designing a microstrip patch antenna that exhibits a wide band feature. This is to realize a dual band reception with operating frequencies that resonates at 2.4 GHz and 5.8 GHz, useful for high performance communication with less noise interference. Since the antenna parameters are the key measurement in determining the success of the design, the scope then also covers looking into several antenna theories. These theories could be applied during the design to attaining a better bandwidth and achieve a general antenna performance enhancement.

The microstrip antenna designs exhibits reduction in bandwidth and gains due to the influence of the substrate thickness or thinness. Methods to overcome this can be applied but by increasing the thickness of the substrate produces surface waves or refraction index making impedance matching difficult. To overcome this drawback a thin substrate with moderate permittivity dielectric constant can be used to achieve a better performance.

II. LITERATURE REVIEW

This chapter presents the review of theory and also the related works for the patch antenna. This is of high relevance to the research before proceeding to the design and practical works. Several antenna parameters such as the VSWR, impedance, gain, radiation pattern and S-parameter will be discussed briefly.

Furthermore, this chapter will also review previous papers published. Papers published below 2010 may not be reviewed as the technologies proposed may be obsolete or unable to be applied in this research work. It is crucial to review those papers because it aids in understanding the design steps of the antenna as well as modifications made by other researchers to improve the antenna performance.

1. Review of Theory

a). Antenna Gain

The gain of an antenna is defined as effective radiated output power in comparison with the input power. The effective radiated power is the actual power that would have to be radiated by a reference antenna to produce the same signal strength at the receiver as the actual antenna produces. Antenna gain usually is expressed in dB (Constantine, 2005).

b). Antenna Impedance

The impedance of an antenna is important to determine the maximum power transferred or received. Antenna impedance usually depends on the structure design and frequency. In practice, the impedance of an antenna should be kept as close to 50 Ω as possible. This is crucial because the antenna impedance has to match the impedance of coaxial cable where the signal is injected from the source to the antenna. If the antenna impedance is matched to the line impedance, the injected signal will not experience losses, but accepting these input signals at the terminal (Sonia Sharma, 2017).

c). VSWR (Voltage Standing Wave Ratio)

The VSWR of an antenna is vital in measuring how efficiently a radio frequency power can be transmitted from a power source, through a transmission line and into a load. Very often a transmission line terminated at the antenna is usually not equal to the characteristic impedance. When a transmission line is mismatched to the antenna, the antenna impedance is unable to absorb the entire power incident upon it and so some of this power is reflected back towards the sending end of the line. If the sending end terminals are matched to the source impedance, all of the reflected energy will be absorbed by the source impedance and there will be no further reflections. On the other hand, if the sending end of the line is also mismatched, some of the energy will be reflected by the antenna impedance and further reflected at the sending end terminals and thus will be sent back towards the load again (Thomas A. Milligan, 2005).

d). S-parameters

S parameters are important to determine the impedance matching and maximum power flow to the antenna. There are four types of S parameters:

S_{11} - Input reflection coefficient

S_{12} - Reverse transmission coefficient

S_{21} - Forward transmission coefficient

S_{22} - Output transmission coefficient

For antenna measurement, the values of S_{11} and S_{22} can be used to determine the antenna coefficient. But the S_{11} is the best choice to be used as it can measure how much signal will be reflected back fromthe antenna to the input coefficient. For the concept of the S-parameter, let's imagine a signal flowing from left to right with an arrow pointing to the right. This arrow indicates the flow of the power to the transducer and if the impedance is matched, a maximum power transfer will occur. If the impedance of the transducer is different with the transmission line, the signal will be reflected back (Yi Huang, 2008).

2. *Reviews on Related Research Works*

This Sector illustrates other research reviews on slotted Microstrip patch antennas. The presented works were carried out by other researchers less than a decade ago, which shows proof that the slotted microstrip patch antenna does exhibit several relating properties to this research.

a). "U" Slot Microstrip Patch Antenna for WLAN APP.

In this paper, the Dual band and triple band slot Microstrip Patch Antenna for WLAN Applications was presented by (Garima, Amanpreet Kaur and Rajesh Khanna, 2013). The physical design of the antenna is shown in Figure 2.1.

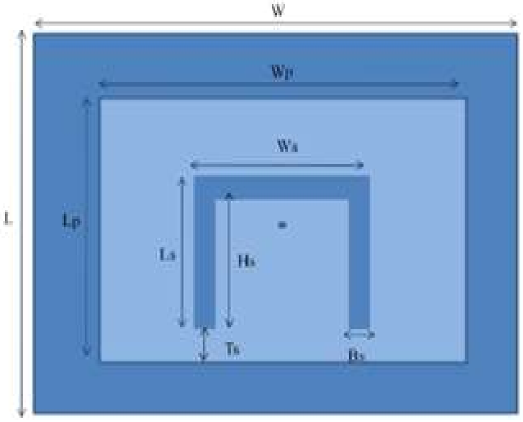

Fig 2.1: Slotted "U" microstrip patch antenna.

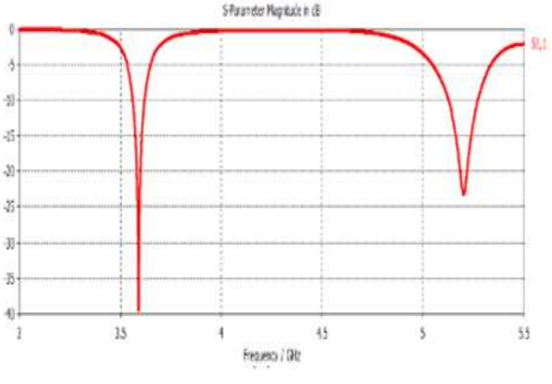

Fig 2.2: S_{11} results for the slotted "U"

The antenna lies on an FR-4 substrate which has a thickness of 1.57 mm and a relative permittivity of 4.4. The antenna was simulated from frequency of 3 GHz to 10 GHz which shows the S_{11} results as seen in Figure 2.2. Notice that, the antenna exhibits a dual band mode which occurs at 3.6 GHz and 5.2 GHz. The best S_{11} result is at 3.6 GHz which give -32 dB and -23 dB at 5.2 GHz of S_{11} magnitude (Garima, Amanpreet and Rajesh 2013).

b). Proximity Coupled Microstrip Patch Antenna wit X slot For Wireless Application

In This paper was presented by (Sastry and Sankar, 2014), and the proximity coupled and X slot patch antenna was designed to operate in a 2.45 GHz, using an FR4 material with substrate proximity coupled with microstrip feed line. The substrate material uses an FR4 (Glass epoxy) with a dielectric constant of (ε_r) = 4.4 and a thickness of 1.6 mm Figure 2.3.

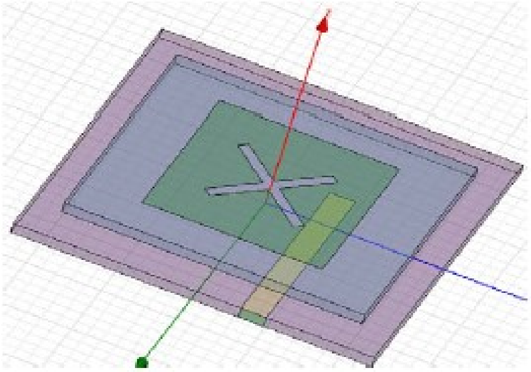

Fig 2.3: Slotted "X" patch antenna

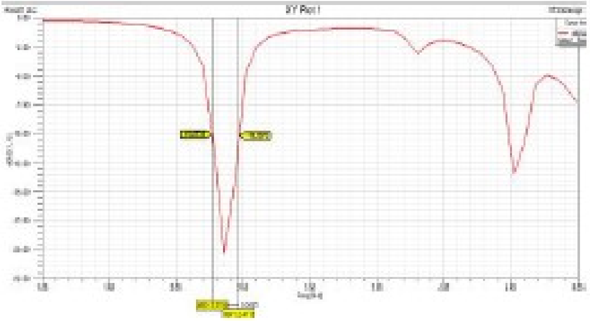

Fig 2.4: S_{11} result for the slotted "X" patch

Figure 2.4 shows the S_{11} result of the proximity coupled and X slot patch antenna resonates at 2.45 GHz with a return loss of -26 dB. A single band mode was achieved and the antenna can receive or transmit the signals at only that point of frequency.

c). Slotted "T" Microstrip Patch Antenna

Another dual band design of the microstrip patch antenna can be found in the paper presented by (Rajan Tiwari, Surya Paratap, Rahul Yadav, Parvesh Kumar and Virendra Kumar Rao, 2014). In this research, the antenna lies on an FR-4 substrate with a 1.6 mm thickness. Typical design is shown in Figure 2.5.

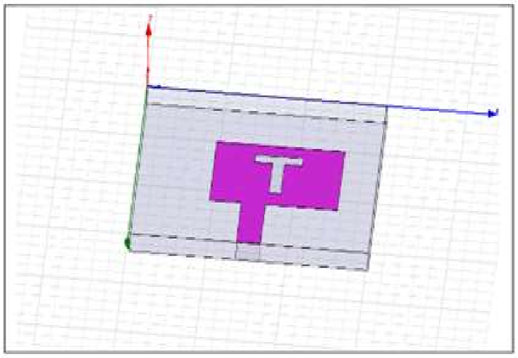

Fig 2.5: Slotted "T" microstrip patch antenna

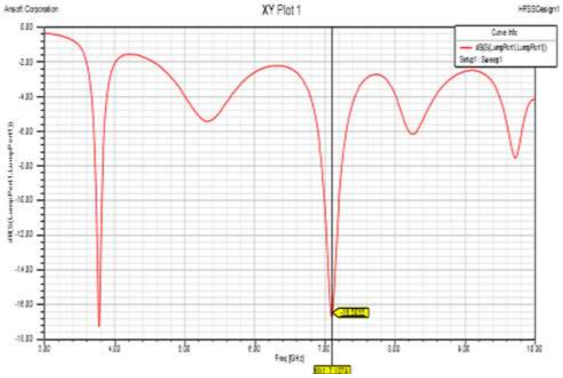

Fig 2.6: S_{11} result for the slotted "T" patch

The CST CAD software was used to run the simulation for the "T" slotted patch antenna and the result of S_{11} is shown in Figure 2.6. From the S_{11} results, it can be seen that there are two points of resonance with one at 3.8 GHz with a return loss of -17 dB and the other is at 7.2 GHz with a return loss of -16 dB, this exhibits dual band and the antenna can receive or transmit the signals at these two points of frequencies only (Rajan, Surya, Rahul, Parvesh and Virendra, 2014).

From the aforementioned data presented, it can be observed that there have been quite a number of research works done on the slotted patch antenna for various frequencies. Several of them use different techniques, shapes and dimensions. There are certain limitations to be considered; for instance the X patch is restricted to only single band frequencies and the T patch has a return loss below – 20 dB. No matter or whichever ways they operate, the most important criterion is to ensure the signal transmitted can be received at the receiving device.

III. METHODOLOGY

The issue of finding arbitrary parameter of patch antenna for specified characteristic differs from analysis problem of impedance matching and these difficulties have no distinctive solution. Designer has to design antenna using empirical formulas for the calculation steps.

a) Patch Antenna Arbitrary Design

This section will discuss about the E-patch antenna structure design and by following the calculations of the E-patch, the entire antenna diagram can be sketched into an ADS environment ready for simulation. The slot is formed by cutting the rectangular patch which is etched to aid in enhancing the performance of the antenna. To design rectangular MPA parameters such as resonant frequency, dielectric constant and height are considered for calculating the width and length of the patch (Balanis 2005).

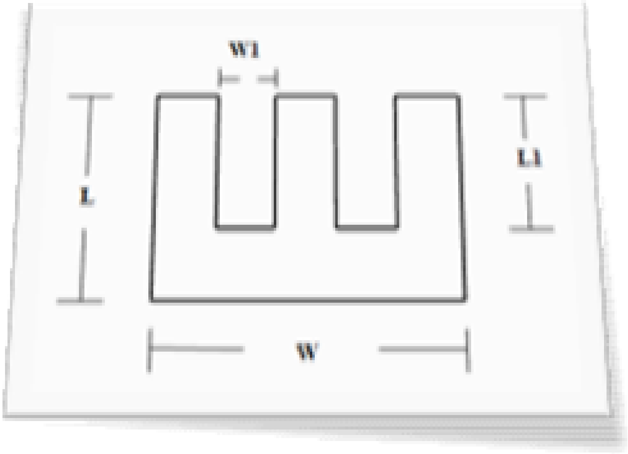

Fig 3.1 Layout of the E-patch

The design of the E-patch antenna uses an FR4 material which has the following technical specifications:

1. Thickness = 1.5 mm

2. Dielectric constant $\varepsilon_r = 4.4$

3. Operating frequency = 1 - 10 GHz

4. Substrate = Alumina

5. Double sided

Where

$c = 3 \times 10^8$ m/s (speed of light)
$\varepsilon_r = 4.4$ (FR4) relative permittivity
h = 1.5 mm (FR4) height of substrate
f_0 = operating frequency in GHz
L = length of the antenna in meter
L_{eff} = effective length in meter
ΔL = change of length
Useful Equations:

i) Wavelength

$$\lambda = \frac{c}{f_0} \qquad (1)$$

ii) Width

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{2}$$

iii) Effective dielectric constant

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12\frac{h}{W}}} \tag{3}$$

iv) Effective length

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{4}$$

v) The extended length

$$\Delta L = 0.421h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{5}$$

vi) Actual length

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

b) The L-network Impedance Matching Using Full Wave Model

The L-network is useful for impedance matching by introducing a separate network that can match the desired resistance known as the characteristic impedance. The method of analysis can then be employed such as transmission line and full wave modelwhich are used to fine tune the design and impedance matching. The transmission line model using a coaxial cable terminated with a thin substrate aid in suppression of surface wave. The load, impedance can be improved by method of etching on the patch to create perturbation and by etching slot introduce notches.

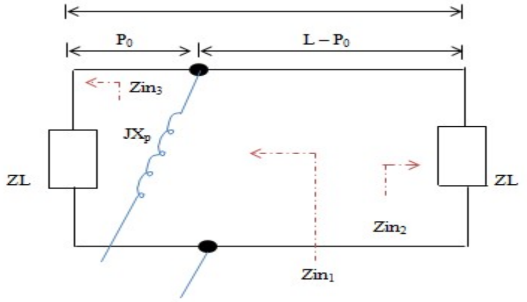

Fig 3.2: Equivalent Transmission line model with probe feed terminated with Load

From figure 3.2 the impedance Zin_3 is the input impedance from the left radiating slot of the patch from a distance of the probe position P_0.

$$Zin_3 = Z_0\left[\frac{ZL + JZ0\tan(BP0)}{Z0 + jZL\tan(BP0)}\right] \tag{3.1.1}$$

Input impedance represented by Zin_1 is the transformed input impedance Zin_3 at the feed point.

$$Zin_1 = Z_0\left[\frac{Zin3 + JZ0\,\mathrm{ta}\,(Bl)}{Z0 + jZin3\tan(Bl)}\right] \tag{3.1.2}$$

Also Zin_2 is the input impedance from the right radiating slot of the patch.

$$Zin_2 = Z_0\left[\frac{ZL + JZ0\tan B(L - P0)}{Z0 + jZL\tan B(L - P0)}\right] \tag{3.1.3}$$

From this point the microstrip patch antenna impedance will be analyzed with the rectangular patch impedance represented by Z_p.

$$Z_p = \frac{1}{[G + BL + BC]} = \frac{1}{\frac{1}{R} + \frac{1}{j\omega L} + j\omega c} \tag{3.1.4}$$

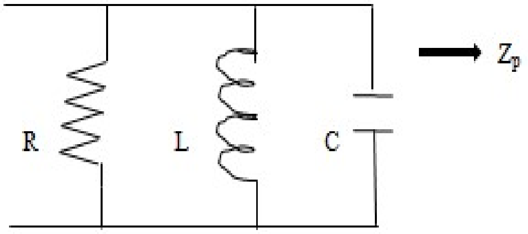

Fig 3.3 Equivalent Rectangular patch

By combining slots act as a complimentary of the dipole, the presence of grounding alternate the magnetic and electric field propagation of the slots. This means a horizontally placed slot will have an effect of propagating in the same direction of the patch antenna. Babinet principle (Thomas, 2005) define slot as:

$$Z_{cs}\,Z_s = \frac{\eta_0^2}{4} \tag{3.1.5}$$

Z_{cs} = Complimentary slot impedance,

Z_s = Slot impedance,

η_0 = Free space impedance.

From Fig 3.2 the patch layout has parallel loaded horizontal (Y direction) arbitrary slots symmetrically aligned and are proposed to help reduce cross polarization effects. By slot loading to the patch, multi band mode can be achieved.

Z_{SC} = Slot Combination impedance

Fig 3.5 Equivalent slot impedance

By creating slots enables perturbation on the patch redirecting the current path of the giving rise to an equivalent inductance and capacitance to the patch which gives rise to second order mode.

$L_2 = L_1 + \Delta L$ $\qquad$ $C_2 = \frac{C1\Delta C}{C1+\Delta C}$ $\qquad$ (3.1.6)

Z_N = Equivalent Notch

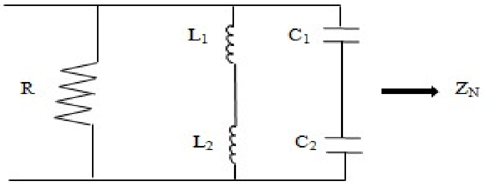

Fig 3.6 Equivalent Notch

Hence by effect of mutual coupling Z_N, Zsc and Z_p can be merged to form single Patch impedance. Z_L = Load impedance

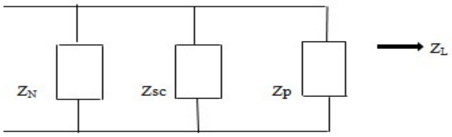

Fig 3.7 Equivalent Load impedance circuit

By introducing the probe connection to the load network will look like:

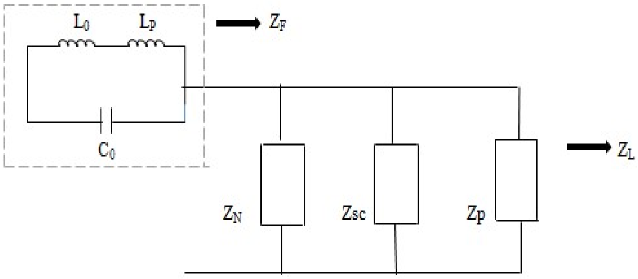

Fig 3.8 The L-network total equivalent input impedance of feed and slot loaded.

Z_F = Probe feed impedance, L_0 = Static inductor, C_0 = Static Capacitor, L_P = Series Probe inductance. Hence, Total input impedance:

$$Zin_{Total} = JX_P + \left[\frac{Zin1 \times Zin2}{Zin1+Zin2}\right] \qquad (3.1.7)$$

Where the reflection coefficient (Γ) of the antenna is:

$$\Gamma = \frac{Z_{antenna} - Z_0}{Z_{antenna} + Z_0} \qquad (3.1.8)$$

$Z_{antenna}$ = Load impedance

Z_0 = Characteristics impedance

The full wave model can now be used to fine tune the introduced microstrip patch antenna for optimum impedance matching.

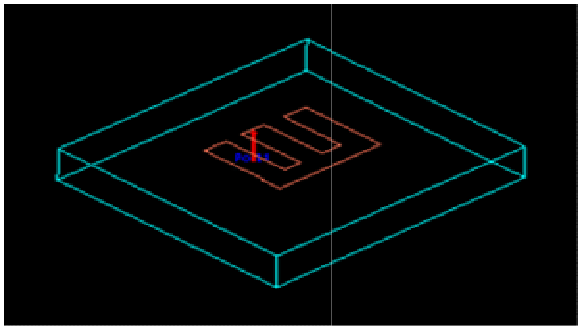

Fig 3.9 Design of the E-patch using ADS full wave model

IV. RESULT & DISCUSSION

The design of the E-patch Microstip antenna using the ADS software shows the simulation results are presented to estimate the performance of the antenna by using the antenna equations to determine the arbitrary dimensions and fine tune via full wave model. With design specification of the FR4 relative permittivity ε_r = 4.4 and thickness of the substrate at 1.5 mm. the criterion for determination of frequency band is value of return loss less than -10dB. Figure 4.1 shows the return loss plot and resonant frequencies at 2.4 GHz and 5.8 GHz. Figure 4.2 show the VSWR plot variation.

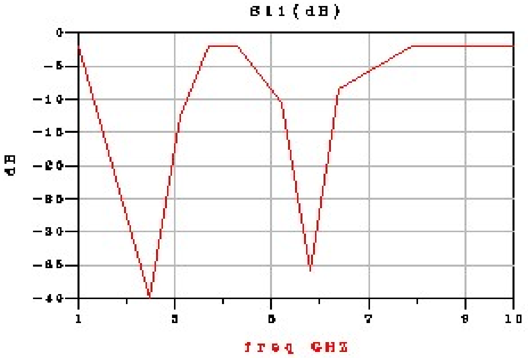

Fig 4.1 simulation results of S_{11} for E-patch

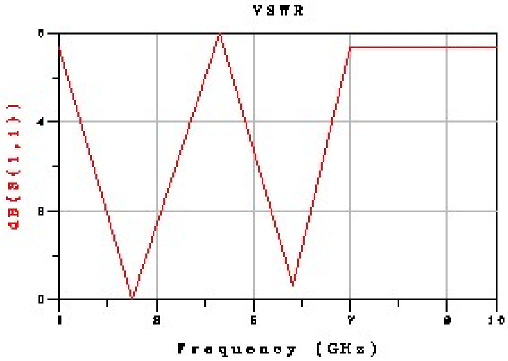

Fig 4.2 VSWR plot simulation result.

From the above S parameter variation plot, it is observed that the lower band resonates at 2.4 GHz with a return loss of –40 dB while the upper band resonance occurs at 5.8 GHz having a return loss of -35 dB with both resonating frequency relative bandwidth not less than 10 %, and having a gain of about 10 dBi. Similarly, the VSWR variation plot shows the value of 1.020 at 2.4 GHz and 1.036 at 5.8 GHz.

V. CONCLUSION

The E-patch microstrip antenna has been achieved through design by applying useful equations, slot cuts and technical parameters to enable a better performance. The E-patch antenna is designed to operate in a Wi-Fi range and the theory involves an FR4 material having a dielectric constant of $\varepsilon_r = 4.4$, with a substrate thickness of 1.5 mm. The Electromagnetic simulator software package used to fine tune the design for impedance matching for this simulation was the Advance Design System, and from the simulation results, it is eminent that the E-patch antenna has provided a useful design that operates in a dual band mode with resonant frequencies at 2.4 GHz and 5.8 GHz. Although at this frequencies, the resultant S_{11} magnitudes are less than -20 dB, this shows a good percentage value acceptance of the signal reflected. Also, an acceptable VSWR result of less than 2 was obtained which is a customary criterion that confirms a well-accepted matched antenna.

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