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AN APPROACH TO DESIGN AND OPTIMIZATION OF WLAN PATCH ANTENNAS FOR WI-FI APPLICATIONS

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Abstract-Microstrip patch antennas have been widely used in a various useful applications, due to their low weight and low profile, conformability, easy and cheap realization. In this paper, an attempt has been made to investigate new microstrip antenna structure for wi-fi systems. The aim of this work is to obtain an efficient and economical patch antenna for indoor and outdoor uses. At present, dipole antenna is used indoor the portable devices such as laptops, mobiles, smart phones etc. and helix antenna is used as outdoor antenna for routers, modems, switches etc.
HFSS and MATLAB are used for the simulation and design calculations of the microstrip antennas. The return loss, VSWR, Directivity, gain, radiation pattern are evaluated. Using HFSS simulation software proposed antenna is designed/simulated and optimized. The effectiveness of the proposed designs is confirmed through proper simulation results. Further, after designing and optimization in simulation software, the proposed antenna is analyze for performance.
Keywords- VSWR, Directivity, microstrip antennas, HFSS, routers, Wi-Fi.

INTRODUCTION

With the ever-increasing need for portable computing devices and the emergence of many systems, it is important to design a portable and efficient antenna for communication [1]. The design of an efficient wide band small size antenna, for recent wireless applications, viz Wi-Fi, Bluetooth, ZigBee etc., is a major challenge [2]. Microstrip patch antennas have found extensive application in wireless communication system due to their advantages such as low profile, conformability, low-cost fabrication and ease of integration with feed networks. There are numerous and well-known methods to increase the bandwidth of antennas, including increase of the substrate thickness, the use of a low dielectric substrate, the use of various impedance matching and feeding techniques, the use of multiple resonators, and the use of slot antenna geometry. However, the bandwidth and the size of an antenna are generally mutually conflicting properties, i.e. improvement of one of the characteristics normally results in degradation of the other [3].

Recently, lot of commercially available antennas are used in wireless applications, for the outdoor application helix antenna are used and for the inbuilt integration antenna a simple microstrip dipole antenna is used for the Wi-Fi application[2]. For the outdoor application several other antennas are proposed by different people but their commercialization is a big issue because of their size as well as their structure.

This paper presents development of microstrip antenna at different frequency range. An antenna is a device used to transform an RF signal, traveling on a conductor, into an electromagnetic wave in free space. Antennas demonstrate a property known as reciprocity, it means that an antenna will maintain the same characteristics regardless if it is transmitting or receiving. Most of the antennas are resonant devices, which operate efficiently over a relatively narrow frequency band [5]. An antenna must be tuned to the same frequency band of the radio system to which it is connected; otherwise the reception and the transmission will be mismatched. When a signal is fed into an antenna, the antenna will emit radiation distributed in space in a certain way [2]. A graphical representation of the relative distribution of the radiated power in space is called a radiation pattern [4].

While optimizing the antenna parameter, using HFSS, the overlapping problem is most often encountered. Thus the best possible optimization is done with the redesigning and calibration of the antenna in the HFSS simulation tool. Also, the aim is to fabricate a microstrip patch antenna as a single unit with only one feed port.

Although the principal advantages of the present invention have been described above, a more thorough understanding of the antenna and its operation may be attained by referring to the drawings and description of the preferred embodiment which follow.

DESIGN AND ANALYSIS OF PROPOSED ANTENNA FOR WI-FI

The proposed antenna is the rectangular microstrip patch antenna and after theoretical calculation for the rectangular microstrip patch antenna the optimization technique is used for the desired output. To fulfill, our application, of the designing of the microstrip patch

antenna for the WLAN Wi-Fi application here two kind of rectangular microstrip antenna is proposed, these are:
a. Edge fed rectangular microstrip patch antenna
b. Inset fed rectangular microstrip patch antenn

EDGE FED RECTANGULAR MICROSTRIP PATCH ANTENNA

The rectangular patch antenna is approximately a one-half wavelength long section of rectangular microstrip transmission line. When air is the antenna substrate, the length of the rectangular microstrip antenna is approximately one-half of a free-space wavelength. As the antenna is loaded with a dielectric as its substrate, the length of the antenna decreases as the relative dielectric constant of the substrate increases [6]. The resonant length of the antenna is slightly shorter because of the extended electric "fringing fields" which increase the electrical length of the antenna slightly.

DESIGNING CALCULATION OF EDGE FED RECTANGULAR PATCH ANTENNA

There are several theories that can be used to analysis and design of rectangular microstrip patch antenna like transmission line model, cavity model etc. In the purposed antenna follow transmission line model design technique. According to this model a rectangular patch of length L and width W can be viewed as a very wide transmission line that is transversely resonating, with the electric field is varying sinusoidal under the patch along its resonant length L. The electric field is assumed to be invariant along the width W of the patch.

Furthermore, it is assumed that the antenna's radiation comes from the fields leaking out along out the width, or radiating edges of the antenna. Consider a Rectangular patch of Width W and Length L over grounded substrates with the thickness h and relative permittivity ε_r. For efficient radiator, a practical width that leads to good radiation efficiencies for fundamental TM_{10} mode is [4]

$$W = \frac{c}{2f\left[\frac{\varepsilon_r + 1}{2}\right]^{1/2}} \qquad (1)$$

Since some of the wave travel in the substrate and some in the air, an effective dielectric constant ε_{reff} is introduced to account for fringing and the wave propagation in the line and is given by [4]

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\left(1 + \frac{12h}{w}\right)^{\frac{-1}{2}}\right], \left(\frac{w}{h} \geq 1\right) \qquad (2)$$

Also it can be seen that the fields slightly overlap the edges of the patch making the electrical length of the patch slightly larger than its physical length. Thus a correction term ΔL also called Edge extension is introduced in account for the fringe capacitance. This edge extension ΔL is given by [4]

$$\Delta L = 0.412h\left[\left(\frac{\varepsilon_{reff} + 0.3}{\varepsilon_{reff} - 0.258}\right)\left(\frac{\frac{w}{h} + 0.264}{\frac{w}{h} + 0.813}\right)\right] \qquad (3)$$

Because of the fringing effect, the dimension of the patch along its length have been extended on each end by a distance L, so the effective length of the patch is given by [4]

$$L_{eff} = L + 2\Delta L \qquad (4)$$

In order to resonant, this effective length must be equal to half wavelength. In other words

$$L_{eff} = L + 2\Delta L = \frac{\lambda_g}{2} = \frac{\lambda_0}{2\sqrt{\varepsilon_{eff}}} \qquad (5)$$

Where, λ_g = Guide wavelength and λ_0 = free space Wavelength From equation

The resonant frequency is derived in terms of effective permittivity and effective length as given below

$$f_r = \frac{c}{2L_{eff}\sqrt{\varepsilon_{eff}}} \qquad (6)$$

For TM_{mn} mode, the f_r can be calculated for given length L, by following equation

$$f_r = \frac{c}{2\sqrt{\varepsilon_{eff}}}\left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2\right]^{\frac{1}{2}} \qquad (7)$$

After finding the actual length of the patch, the desired Rectangular Microstrip patch antenna is designed.

After calculation and optimization for the desired output the specification for the edge fed rectangular patch antenna is given in table 1.

Table 1- Specification for the Edge Fed Rectangular Patch Antenna

Parameters	**Units**
Operating Frequency	2.4835 GHz
Ground plane dimension (L × W)	16.67 cm × 8.1 cm
Patch Length	3.99 cm
Patch Width	4.77 cm
Dielectric Constant	2.2
Dielectric Material	Rogers RT/duroid 5870(tm)
Dielectric Substrate height	62 mil

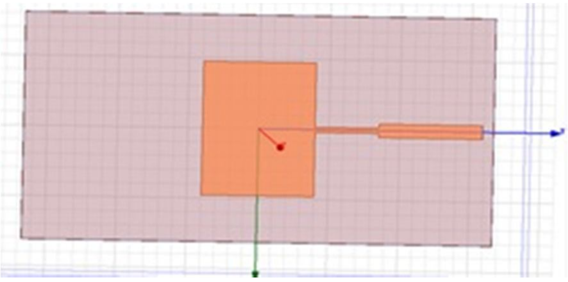
Table 2 shows the specification for the edge fed dimensions. The feed length for the edge fed and feed line as well as width is calculated by the TxLine calculator. After calculating the dimensions for the edge fed and feeding length and width, they are calculated for the 50Ω impedance matching, they are directly implemented in simulating software.

Table 2- Specification for the Feeding Element

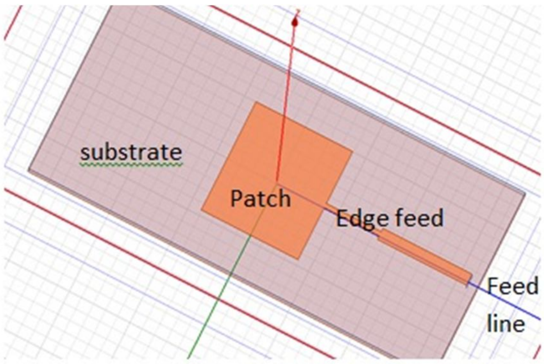
Parameters	**Unit**
Feed width	0.485 cm
Feed length	3.68cm
Edge Feed width	0.19 cm
Edge Feed length	2.267 cm

SIMULATION OF EDGE FEED RECTANGULAR PATCH ANTENNA

To simulate rectangular patch antenna, all above calculated parameters of the rectangular patch antenna is to be used for the designing in the HFSS simulation software. The design specifications are given in table 1 and table 2. Figure 1 shows the designed rectangular patch antenna structure within the HFSS simulation software. Figure 1 shows the purposed rectangular patch antenna structure.



(a)Top View



(b)Terminology

Fig.1-Microstrip rectangular patch antenna structure (a) Top View (b) Terminology

SIMULATION RESULT FOR EDGE FEED RECTANGULAR PATCH ANTENNA

The simulation of the purposed edge feed microstrip rectangular patch antenna design has been carried out by using HFSS software based on the method of moment. Figure 2 shows the variation of Return loss with frequency. Figure 3 shows the smith chart for the input impedance of the purposed edge feed rectangular patch antenna. Figure 4 shows the 2-D Radiation Pattern and Figure 5 shows the 3-D Radiation Pattern.

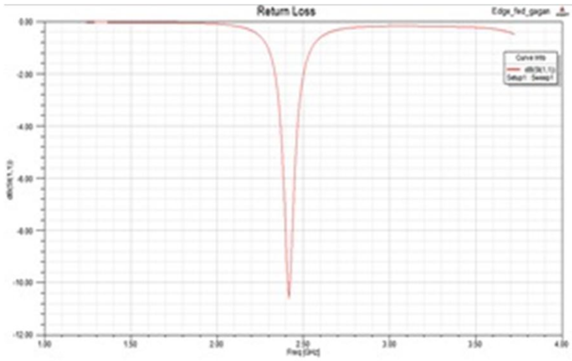


Fig.2- Variation of Return loss with frequency

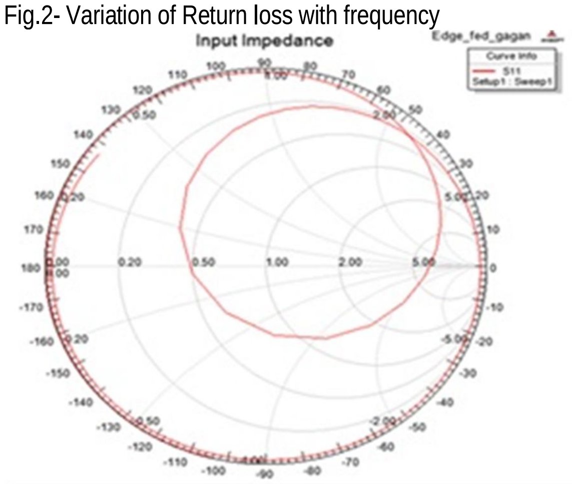


Fig.3-Input impedance (smith chart**)**

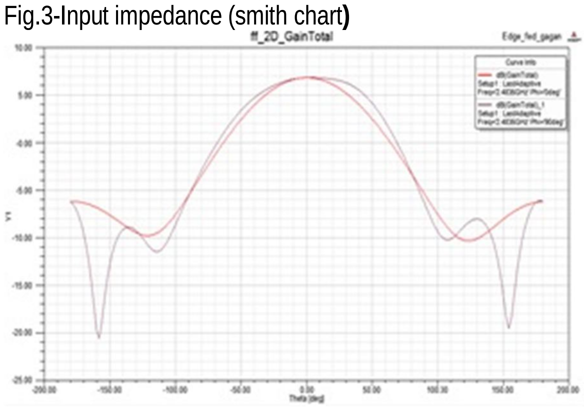
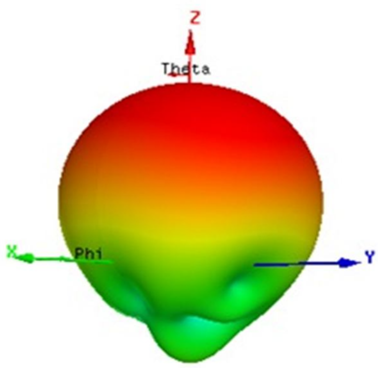
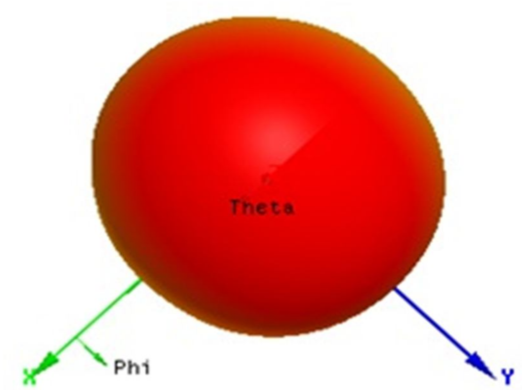


Fig.4-2-D Radiation Pattern



(a) Side view



(b) Top view

Fig.5--D Radiation Pattern (a) Side view (b) Top view

INSET FEED RECTANGULAR PATCH ANTENNA

A single element of rectangular patch antenna, as shown in Figure 6, can be designed for the 2.4835 GHz resonant frequency using transmission line model as previously discussed [6].

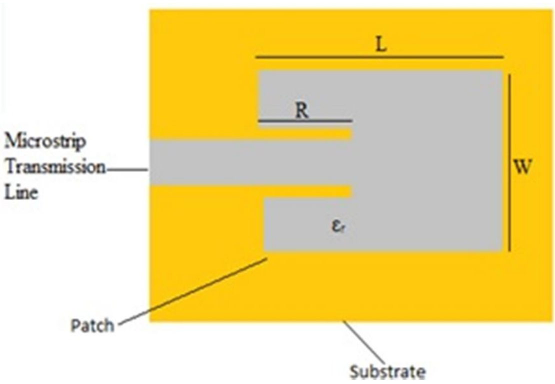


Fig.6-Basic structure of Inset feed Rectangular patch antenna

In the typical design procedure of the Microstrip patch antenna, the desired resonant frequency, thickness and dielectric constant of the substrate are known or selected initially. In this design of rectangular Microstrip antenna, a Rogers RT/duroid 5870(tm) dielectric material ($\varepsilon r = 2.2$) with dielectric loss tangent of 0.001 is selected as the substrate with 62 mil height [7]. Then, a patch antenna that operates at the specified operating frequency f_0 =2.4835 GHz can be designed by the following steps using transmission line model equations. The antenna is existed by the INSET feed away from the center of the patch.

DESIGNING CALCULATION OF INSET FEED RECTANGULAR PATCH ANTENNA

A similar process as the calculation of edge feed rectangular patch antenna is followed in this kind of antenna. The difference in this method is to insert a feed line in a patch so, calculation of inset length of patch is necessary. The inset length of patch is depending on the width of the patch as well as on the operating wavelength. Following is the procedure for the calculation of the dimensions of the inset feed rectangular patch antenna: [4]

To calculate the width "W" and length "L" of the patch antenna is given as:

$$W = \frac{\lambda_0}{2}\left(\frac{2}{\varepsilon_r + 1}\right)^{\frac{1}{2}} \qquad (8)$$

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_{eff}}\sqrt{\mu_0 \epsilon_0}} - 2\Delta L \qquad (9)$$

Where, the edge extension and effective permeability is given as [4]

$$\Delta L = 0.412\, h \frac{(\varepsilon_{eff} + 0.3)}{(\varepsilon_{eff} - 0.258)} \frac{(\frac{W}{h} + 0.264)}{(\frac{W}{h} + 0.813)} \qquad (10)$$

Where

$$\varepsilon_{\mathrm{eff}} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2}\left(1 + 12\frac{W}{h}\right)^{-1/2} \qquad (11)$$

With the help of dimension of the width of the patch the dimensions for inset length of the patch is to be calculated. For this, conductance is given by [4]

If W >> λ_0,

$$G_1 = \frac{1}{120}\left(\frac{W}{\lambda_0}\right) \qquad (12)$$

If W << λ_0,

$$G_1 = \frac{1}{90}\left(\frac{W}{\lambda_0}\right)^2 \qquad (13)$$

Now, consider that the characteristic impedance of Microstrip line feeder is R_{in}. Thus, equate following equation to obtain matching between the input impedance of the patch and feeder (i.e. inset length, y_0) [4].

$$R_{in}(y = 0) = \frac{1}{2(G_1 \pm G_2)} \qquad (14)$$

And then

$$R_{in}(y = y_o) = \frac{1}{2(G_1 \pm G_2)} \cos^2\left(\frac{\pi}{L} y_o\right) \qquad (15)$$

Calculation result of Microstrip patch antenna shown in table 3 and table 4

Table 3- Specification for the Inset Feed Rectangular Patch Antenna

Parameters	**Units**
Operating Frequency	2.4835 GHz
Ground plane dimension (L × W)	11.92 cm × 8.1 cm
Patch Length	3.99 cm
Patch Width	4.77 cm
Dielectric Constant	2.2

Dielectric Material	Rogers RT/duroid 5870(tm)
Dielectric Substrate height	62 mil

Table 4- Specification for the Inset Length of Patch

Parameters	**Units**
Inset Distance	1.22 cm
Inset gap	0.243 cm
Feed Length	3.68 cm
Feed width	0.486 cm

SIMULATION OF INSET FEED RECTANGULAR PATCH ANTENNA

To simulate microstrip inset feed rectangular patch antenna, all above calculated parameters of the inset feed rectangular patch antenna is to be used for the designing in the HFSS simulation software. The design specifications are given in table 3 and table 4. Figure 7 shows the designed microstrip inset feed rectangular patch antenna structure within the HFSS simulation software.

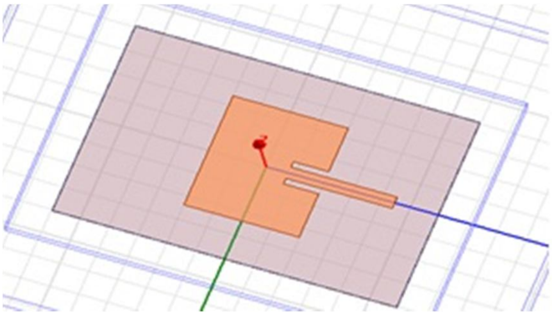


Fig.7-Microstrip inset feed rectangular patch antenna structure

SIMULATION RESULT FOR INSET FEED RECTANGULAR PATCH ANTENNA

The simulation of purposed inset feed rectangular patch antenna design has been carried out by using HFSS software based on the method of moment. Figure 8 shows the variation of Return loss with frequency. Figure 9 shows the smith chart for the input impedance of the simulated rectangular patch antenna. Figure 10 shows the 2-D Radiation Pattern and Figure 11 shows the 3-D Radiation Pattern.

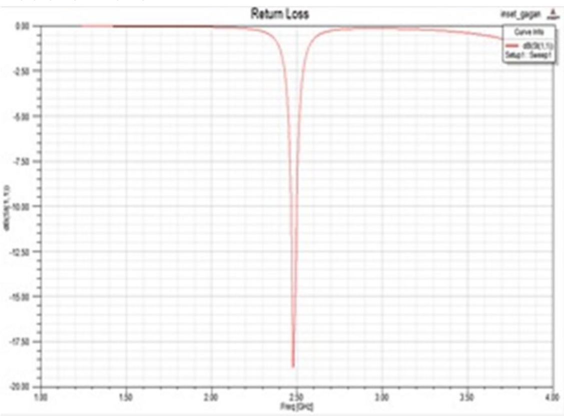


Fig. 8-Variation of Return loss with frequency

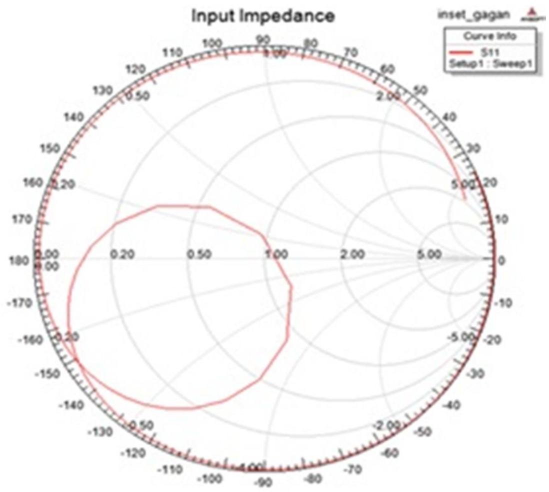


Fig. 9-Input impedance (smith chart)

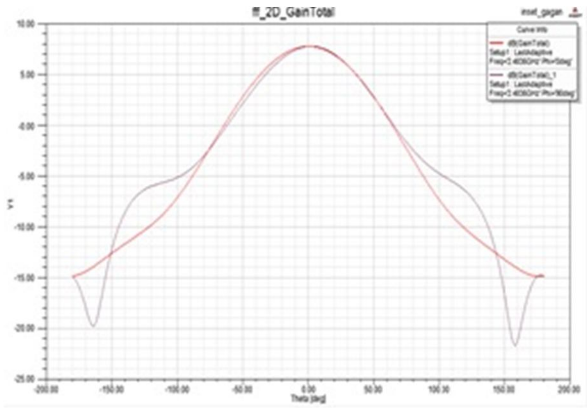
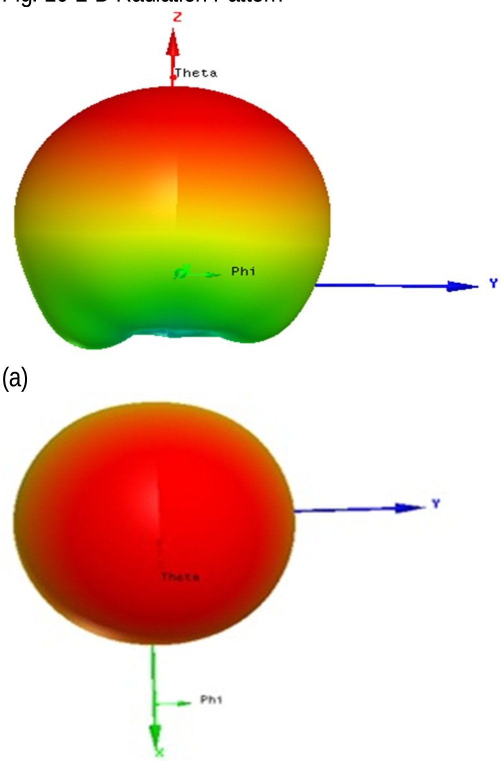


Fig. 10-2-D Radiation Pattern



(a)

(b)

Fig. 11-3-D Radiation Pattern (a) Side view (b) Top view

CONCLUSION

Two aspects of Microstrip antennas have been studied in this paper. The first aspect is the design of typical edge feed rectangular microstrip patch antenna and the second is the design inset feed rectangular microstrip patch antenna. A simple and efficient technique of inset method has been introduced for an impedance matching improvement of the antennas. Main concern of the paper is to design a new microstrip patch antenna for WLAN Wi-Fi application with different feeding technique. The purposed inset feed rectangular patch antenna is a more conventional approach for the implementation of a Wi-Fi application and it's a good choice to replace commercially available dipole antenna. Initially, edge feed rectangular microstrip patch antenna is designed to operate at frequency 2.4835 GHz. And then, the inset feed rectangular microstrip antenna is designed to resonate at frequency range 2.4835 GHz. The proposed antenna design optimization done with a standard electromagnetic simulator (HFSS). The accuracy, robustness and ease of fabrication of purposed antenna validate its potential application in Wi-Fi system over WLAN.

SUGGESIONS FOR FUTURE SCOPE

Based on gathered observations while completing this paper; topics were identified which would benefit for further investigation.

- Using the edge feed rectangular microstrip antenna as a basis, the circular dual frequency Microstrip antenna can be developed which cover Wi-Fi band as well as Bluetooth and Zigbee band. Same thing can be done with the inset feed rectangular microstrip patch antenna.
- Using the variation in edge feed length and inset feed length and by introducing the slot in this patch to develop the WLAN concept (5.2 GHz frequency) and also this patch can be used in satellite communication where the low frequency ratio patch is used.

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