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Design of Compact Multiband Rectangular Microstrip Patch Antenna for IEEE 802.11 Standards

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Abstract: A multi-band compact rectangular microstrip patch antenna is proposed for IEEE 802.11 standards. Proposed antenna covers all five distinct frequency ranges 2.4 Ghz (IEEE 802.11 b/g/n), 3.65 GHz (IEEE 802.11 y), 4.9 Ghz (IEEE 802.11 j), 5 GHz (IEEE 802.11 a/h/j/n/ac) and 5.9 GHz (IEEE 802.11 p) bands. The design frequency is 2.42 GHz applicable for WLAN, UMTS and Wi-MAX application. The three resonance frequencies are observed to be 2.58, 3.74 and 5.12 Ghz. The return loss of proposed antenna is -16.41 dB at 2.42 GHz and -33.28, -15.6 and -19.02 dB at respective resonance frequencies. The simulated fractional -10 dB bandwidth of lower, middle and upper resonance frequencies are 42.25% (1.829-2.809 GHz), 10.9% (3.487 -3.889 GHz) and 20.89 % (4.844-5.974 GHz), respectively. The maximum gain, directivity, antenna efficiency and radiation efficiency of proposed antenna are 6.05 and 6.6 dBi, 94.91 and 98.56%, respectively. The experimental fractional -10 dB bandwidth are 52.42% (2.28-3.9 GHz) and 11.01% (5.15-5.75 GHz) with 2.85 and 5.43 GHz resonance frequency respectively. Both simulated and experimental results of proposed antenna cover all five frequency ranges issued by IEEE 802.11 WLAN standards which show good agreement. The analysis of rectangular patch antenna is performed with strip line feed by using IE3D mentor graphics simulation software.

Key words: Multi band, compact antenna, IEEE 802.11 standards, resonance frequency, return loss, bandwidth

INTRODUCTION

Low profile, ease of fabrication, comfortable to all planar and nonplanar surfaces, multi structured, inexpensive to manufacture and simple are the advantageous properties of microstrip patch antenna (Balanis, 1997). However, it has some limitations in terms of bandwidth and efficiency which are affected by the dielectric substrate material. The bandwidth of antenna is enhanced by using slot (Jia-Yi and Wong, 2000). By loading slot and notch on rectangular patch different shape has been form like H, U, E with the help of which the bandwidth of antenna has been enhanced (Ang and Chung, 2007; Ansari and Ram, 2008). A dual and multiband rectangular microstrip patch antenna is proposed by using the combination of a pair of slots and notch (Kunwar *et al*., 2017; Yadav *et al*., 2016; Wong and Sze, 1998; Ansari *et al*., 2008). Microstrip patch antennas are used in all mobile, missiles, spacecraft, satellite and wireless communication applications where size, weight, performance, aerodynamic profile, cost and ease of installation are essential requirements.

In this study a slot loaded and notch loaded rectangular microstrip patch antenna for multi band frequency operation is simulated and tested. The effect of variation in length and width of the notch and slot on the resonance frequency and bandwidth are presented. The simulation is done with the help of IE3D mentor graphics simulation software tool.

Design considerations: The first step of design consideration is choosing a suitable dielectric substrate material of appropriate thickness and loss tangent. Next step of design consideration is determination of width and length that is dimensions of the patch for design resonant frequency. The patch length or patch width can be used to determine the resonant frequency. Patch length is generally used to determine the resonant frequency where as patch width has minor effect on the resonant frequency. An accurate value of the width and length affects the performance factor of antenna and can be calculated using equations as (Balanis, 1997):

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$$W = \frac{\lambda_0}{\sqrt[2]{0.5(\varepsilon_r+1)}}$$

Where:

λ_0 = The free space wavelength
W = The patch Width
ε_r = The substrate dielectric constant

$$L = \frac{\lambda}{2}$$

where, λ is the wavelength in the dielectric (substrate), i.e., $\lambda = \lambda_0/\sqrt{\varepsilon_r}$, L is patch Length. Due to the fringing effects, the actual length of the patch is electrically smaller than the length of the patch. An extension in dimensions of the patch along its length have been occurred on each end by a distance ΔL which is a function of the width-to-height ratio (W/h) and the effective dielectric constant $\varepsilon_{r\varepsilon}$. The equation of effective dielectric constant $\varepsilon_{r\varepsilon}$ is given as:

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

The extension length ΔL is calculated as (Balanis, 1997):

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

With the help of the above equations, the actual length of the patch can be calculated using equation as given below:

$$L = \frac{u_0}{2f_r\sqrt{\varepsilon_{r\varepsilon}}} - 2\Delta L$$

Where:

u_0 = The velocity of light in free space
f_r = The design resonant frequency

MATERIALS AND METHODS

Design specifications: The design of rectangular patch for proposed antenna without slot and notch is shown in Fig. 1. The proposed antenna is designed for 2.42 GHz frequency and using glass epoxy material substrate with dielectric constant 4.4. With the help of above equations the calculated patch dimension that is patch width and patch length are 37.80 and 29.20 mm, respectively. The length and width of the ground plane are taken 39.20 and 47.80 mm, respectively. Height of the dielectric substrate is 1.6 mm and loss tangent tan δ is 0.01 (Garg *et al*., 2001). Antenna is fed through 50 Ω microstrip line feed.

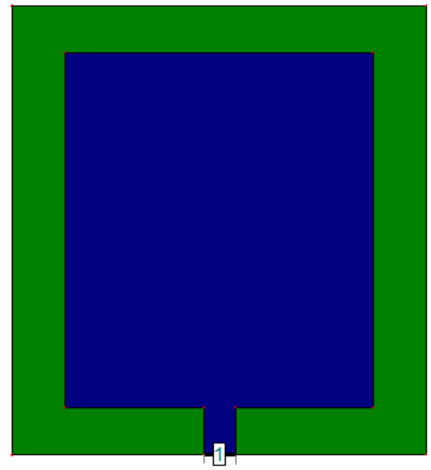

Fig. 1: Rectangular patch antenna

Table 1: Design specifications for proposed antenna

Parameters	Values
Design frequency (f_r)	2.42 GHz
Height of substrate (h)	1.6 mm
Dielectric constant (ε_r)	4.4
Loss tangent	0.01
Patch Width (Wp)	37.80 mm
Patch Length (Lp)	29.20 mm
Ground plane Length (Lg)	39.20 mm
Ground plane Width (Wg)	47.80 mm
Width of Strip line (S1)	5 mm
Length of Strip line (S2)	3 mm
D1	10.75 mm
D2	21.2 mm
D3	19.9 mm
D4	2.5 mm
D5	4.4 mm
D6	4.35 mm

IE3D mentor graphics simulation software tool has been used for simulation work. Table 1 shows the specifications for proposed microstrip patch antenna.

Antenna design procedure: For making the proposed microstrip patch antenna, the antenna is loaded with inverted T slit, inverted U slit and a pair of rectangular slot. The different steps for getting structure of proposed antenna are shown in Fig. 2-4 shows the inverted U-shape structure of proposed antenna. By combining the structure shown in Fig. 3 and 4, the structure of proposed antenna has been achieved. Figure 5 shows the geometry of proposed antenna. The microstrip line feed of 50 Ω is placed at centre of lower length patch through a strip of length 3 mm and width 5 mm to achieve impedance matching. The return loss vs. frequency graph for different structures are shown in Fig. 6 and 7. From the graph it is observed that by loading slot and notch on rectangular patch antenna the resonance frequency, return loss and bandwidth of the antenna varies. Other parameters like gain, directivity, antenna efficiency, radiation efficiency and radiation pattern also varies by loading slot and notch on rectangular patch antenna.

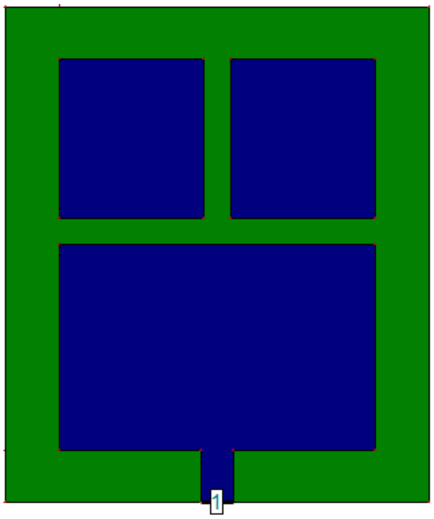

Fig. 2: Step 1 for proposed antenna

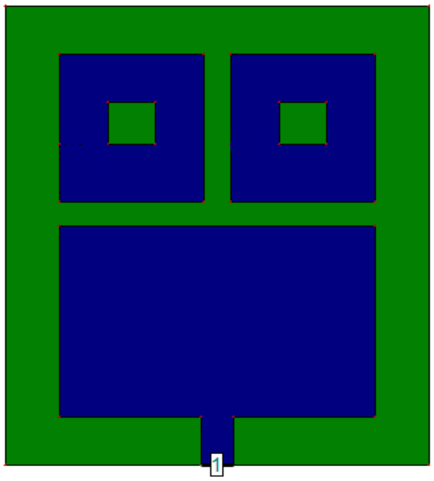

Fig. 3: Step 2 for proposed antenna

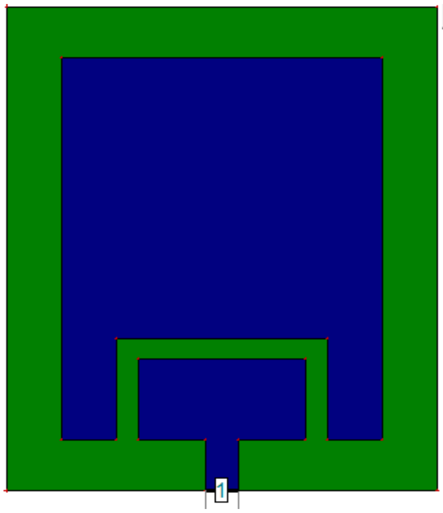

Fig. 4: Inverted U-shape for proposed antenna

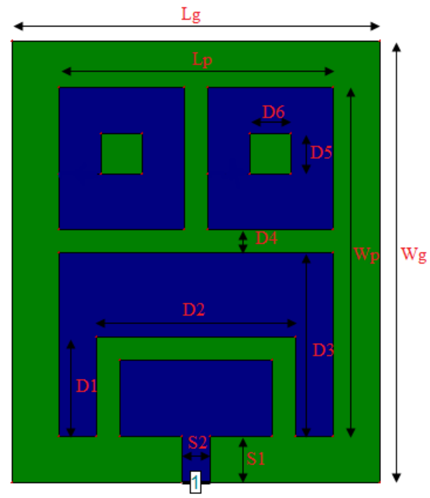

Fig. 5: Geometry of proposed antenna

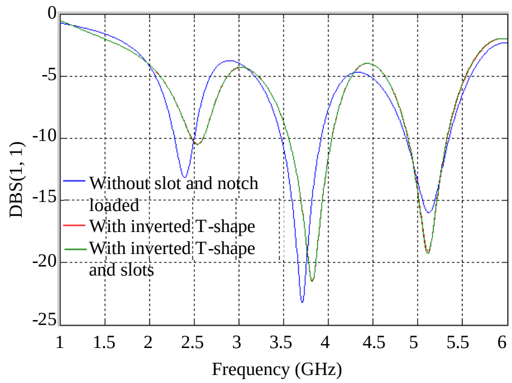

Fig. 6: Return loss vs. frequency display of Fig. 1-3 S-parameters display

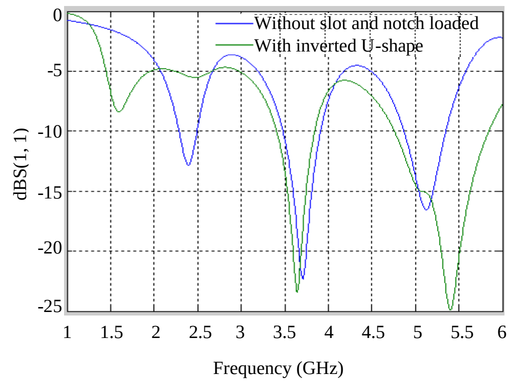

Fig. 7: Return loss vs. frequency display of Fig. 1-4 S-parameters display

RESULTS AND DISCUSSION

IE3D mentor graphics simulation software tool has been used to simulate the proposed antenna structure.

The structure of normal rectangular patch is shown in Fig. 1. After simulation it is observed that the normal rectangular patch antenna without slot and notch loaded have three bands between frequency 1-6 GHz. The resonance frequencies of these bands are 2.396, 3.707 and 5.124 GHz and -10 dB bandwidth is found to be 9.2, 12.17 and 9.61% for lower, middle and upper resonance frequency. The lower resonance frequency of rectangular patch antenna is near to the design frequency. For enhancing the bandwidth and return loss more negative, the antenna is loaded with slot and notch and forms a structure of proposed antenna. In first step the rectangular patch is loaded an inverted T-shape structure which is combination of notches shown in Fig. 2. Due to this the -10 dB bandwidth of middle band is enhanced up to 12.92% but rest two bands bandwidth degraded. The resonance peak of lower and middle band is moved towards the higher frequency region but resonance frequency of upper band is moved towards the lower frequency range with more negative return loss. In next step inverted T shape structure is loaded with a pair of slots. Due to this slot loading the -10 dB bandwidth of lower band is enhanced up to 5.33% with shifting the resonance frequency to the lower frequency range. The bandwidth and resonance frequency of rest two middle and upper band is almost same with previous. The structure of this step is shown in Fig. 3. The simulated S-parameter display with frequency of Fig. 1-3 are shown in Fig. 6.

In next step inverted U-shape structure which is a combination of slot and notch is loaded on normal rectangular patch which is shown in Fig. 4. Due to this loading it is observe that the -10 dB bandwidth of middle and upper band enhanced up to 12.68 and 20.99%, respectively with shifting the resonance frequency lower frequency range but lower band disappear. The simulated S-parameter display with frequency of Fig. 1-4 are shown in Fig. 7.

So, for getting better result after loading inverted T-shape structure with a pair of slots, another inverted U-shape structure is loaded on normal rectangular patch antenna. The final design structure of proposed antenna is shown in Fig. 5. The hardware of proposed antenna for testing shown is shown in Fig. 8. Figure 9 shows both simulated and experimental S-parameter display with frequency of proposed antenna. The frequency ranges of multiband both simulated and experimental and their bandwidth are given in Table 2 and 3, respectively.

It is observed that the antenna resonate at three frequencies 2.582, 3.738 and 5.12 GHz and -10dB bandwidth is found to be 42.25, 10.9 and 20.82% for lower, middle and upper resonance frequency.

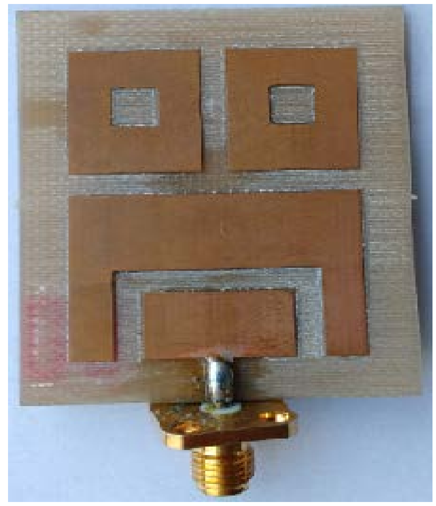

Fig. 8: Hardware of proposed antenna

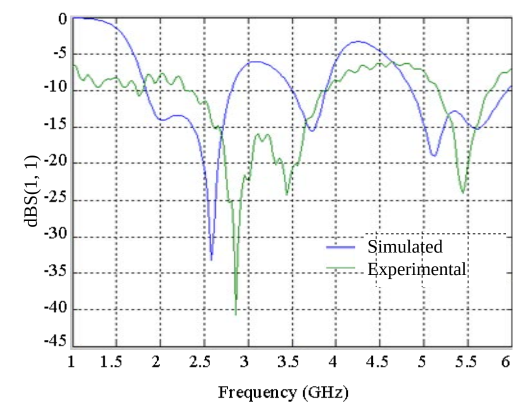

Fig. 9: Return loss vs. frequency display of proposed antenna S-parameters display

Table 2: Frequency ranges of bands (simulated)

Band/frequency	Lower (GHz)	Middle (GHz)	Upper (GHz)
F_l	1.829	3.487	4.844
F_r	2.582	3.738	5.120
F_h	2.809	3.889	5.974
Bandwidth (%)	42.250	10.900	20.890

Table 3: Frequency ranges of bands (experimental)

Band/frequency	First (GHz)	Second (GHz)
Fl	2.28	5.15
Fr	2.85	5.43
Fh	3.90	5.75
Bandwidth (%)	52.42	11.01

The return loss of proposed antenna is -16.41 dB at 2.42 GHz and -33.28, -15.6 and -19.02 dB at respective resonance frequencies. While transmitting the signals return loss with negative value reflect that antenna has not many losses. In Fig. 9, it is also observed that the simulated tri band of the antenna and experimental dual band of antenna, both cover all five distinct frequency

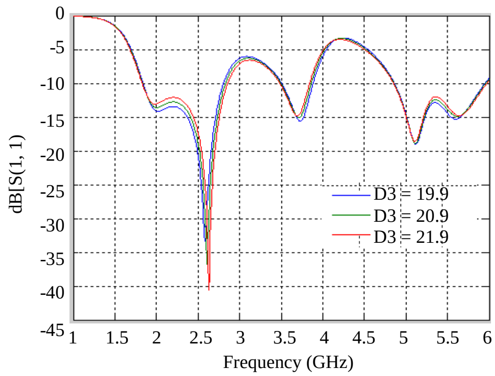

Fig. 10: Return loss of antenna S-parameters display

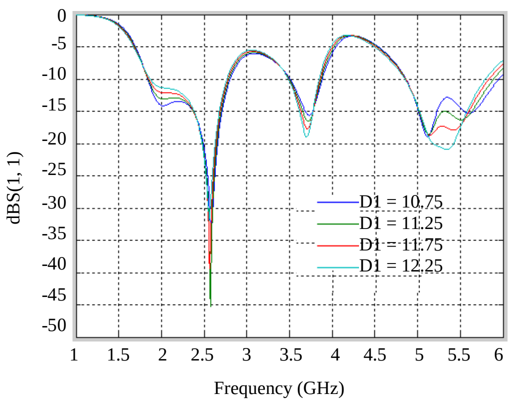

Fig. 11: Return loss of antenna S-parameters display

ranges 2.4 Ghz (IEEE 802.11 b/g/n) 3.65 Ghz (IEEE 802.11 y) 4.9 GHz (IEEE 802.11 j) 5 GHz (IEEE 802.11 a/h/j/n/ac) and 5.9 GHz (IEEE 802.11 p) bands. In Fig. 10, it is observed that the design band resonance frequency increases with increasing the distance of upper structure (inverted T) from the microstrip line feed side with lower structure (inverted U) distance remains constant. Due to this the bandwidth of design band increases. The bandwidth of design band is decreases with decreasing the distance of upper structure from the microstrip line feed side with lower structure remains constant.

From Fig. 11, it is also observed that the design band resonance frequency decreases with increasing the distance of lower structure (inverted U) from the microstrip line feed side with upper structure (inverted T) distance remains constant. Due to this the bandwidth of design band decreases. The bandwidth of design band is increases with decreasing the distance of lower structure from the microstrip line feed side with upper structure remains constant.

Variation of antenna gain with frequency is shown in Fig. 12. From Fig. 12, it is observed that antenna gain is maximum 6.05 dBi at 5.271 Ghz and 3.85, 4.03

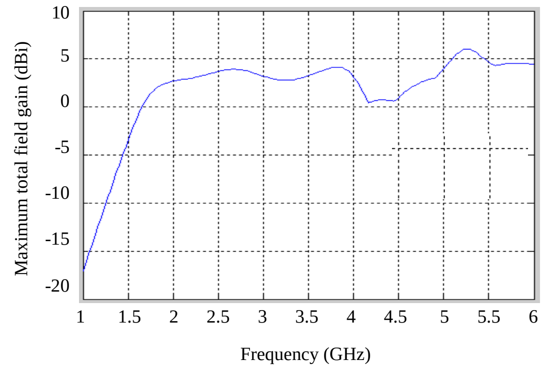

Fig. 12: Variation of gain with frequency total field gain vs. frequency display

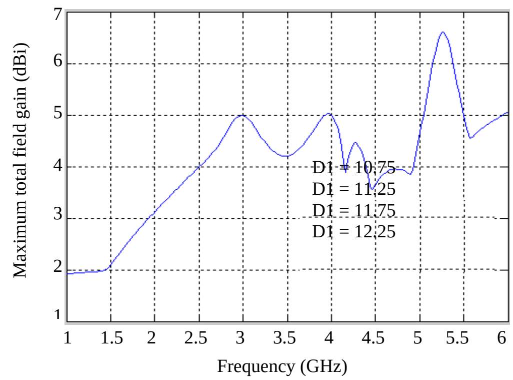

Fig. 13: Variation of directivity with frequency total field gain vs. frequency display

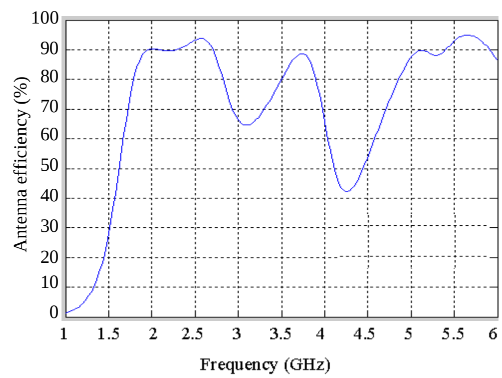

Fig. 14: Variation of antenna efficiency with frequency efficiency vs. frequency display

and 5.27 dBi for lower, middle and upper resonance frequency, respectively. Variation of antenna gain with frequency is shown in Fig. 13. From Fig. 13, it is observed that antenna directivity is maximum 6.6 dBi at 5.271 Ghz and 4.13, 4.55 and 5.73 dBi for lower, middle and upper resonance frequency respectively. From Fig. 14, it is observed that antenna efficiency is

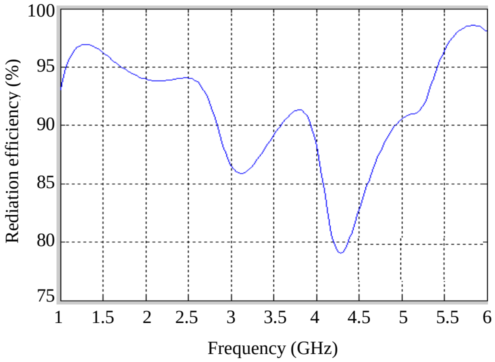

Fig. 15: Variation of radiation efficiency with frequency

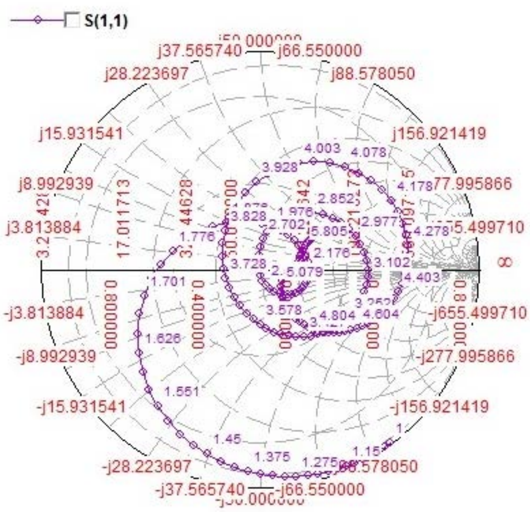

Fig. 16: Smith chart of proposed antenna

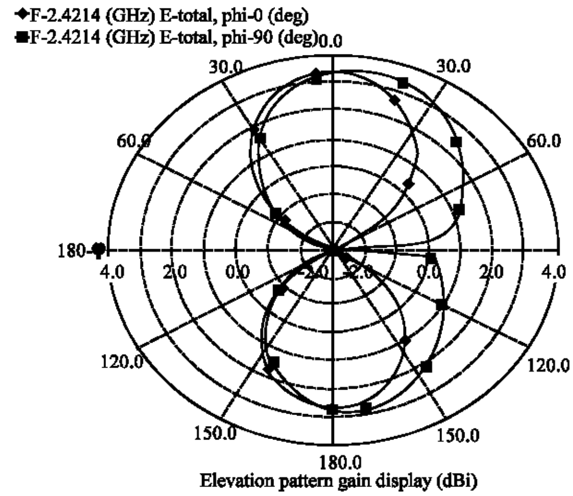

Fig. 17: Radiation pattern of proposed antenna

maximum 94.91% at 5.648 Ghz and 93.8, 88.7 and 89.8% for lower, middle and upper resonance frequency, respectively.

From Fig. 15, it is observed that radiation efficiency is maximum 98.56% at 5.824 GHz and 93.9, 91.2 and 90.9% for lower, middle and upper resonance frequency, respectively. The value of VSWR is 1.398 at 2.42 GHz and it is a measure of impedance mismatch. If the level of mismatch is not very high then it is considered as a good value. Thus, this value proves that the port of the antenna is properly matched. If the value of VSWR is high, it means that the port is not properly matched. In practically, there is always a slight mismatch that is no antenna port is perfectly matched.

Impedance matching can also be represented by smith chart which is shown in Fig. 16, for design frequency of 2.42 GHz. In smith chart the impedance locus should be lie as near as center of the chart for match an antenna and obtain a more negative return loss at resonant frequency. From Fig. 16, it can be observed that the impedance matching point for design frequency is very close to the centre of the smith chart. Figure 17 shows the radiation pattern of proposed antenna for $\Phi = 0°$ and $\Phi = 90°$. It can be observed that the nature of radiation pattern of proposed patch antenna is bidirectional.

CONCLUSION

A multiband rectangular microstrip patch antenna with slot and notch loaded has been successfully designed and fabricated. It is concluded that both simulated and experimental result of proposed antenna cover all five frequency ranges issued by IEEE 802.11 WLAN standards that is 2.4, 3.65, 4.9, 5 and 5.9 GHz bands which are useful in different applications like Wi-max, WLAN, UMTS and many more. From the analysis of proposed antenna it is also concluded that by varying the distance of slot and notch from the feed point the design band resonance frequency and bandwidth can be varies. This antenna has also improved maximum gain 4.33-6.05 dBi, improved directivity 6.01-6.6 dBi, improved maximum antenna efficiency 91.23-94.91% and improved maximum radiation efficiency 96.34-98.56% and simultaneously useful in wireless communication application.

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