DESIGN AND ANALYSIS OF COMPACT PRINTED TRIPLE BAND ANTENNA FOR WI-MAX, WLAN AND WIRELESS SYSTEMS

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Abstract

In this paper, we design a compact single antenna which is used for different bands. The term compact here means that the size of the antenna is very small to the tune of just 24×30mm². This antenna is fabricated on roger RTduroid 5880 with thickness 0.79 mm, and is designed using partial ground plane. The antenna is equipped with two inverted L shaped stub and a stub of combination of inverted L shape and T shape; and it resonates at three frequencies, 2.57GHz, 3.52GHz, and 5.51GHz. As the operating range of antenna covers these frequencies, its main use is in Wi-MAX (wide interoperability for microwave access) and WLAN (wireless local area network). All the parameters and details are elaborated by the ensuing parts of this paper.

Keywords:

Compact Size Antenna, Single Antenna, RTduroid, Inverted L and T Shape

1. INTRODUCTION

There is high demand for small-sized equipment in the electronics and wireless equipment market, because the small-sized components occupy less space giving the scope for the inclusion many latest features, and for effective heat sinking. Reducing the size of the antenna used in a wireless system is of key importance from the perspective reducing the size of the entire system itself. The antenna discussed in this study is mainly designed for use in Wi-MAX and WLAN systems.

For providing a perfect antenna for this requirement we studied numerous published papers to get the knowledge of design and measurements of antenna. A number of multiband antennas have been reported by researchers having good efficiency, CPW-fed stub loaded slot antenna is design in reference 1with dimension of $0.245\lambda_o \times 0.53\lambda_o \times 0.013\lambda_o$; a symmetrical U shaped antenna is designed in reference 2 with dimension of $0.166\lambda_o \times 0.32\lambda_o \times 0.006\lambda_o$, reference 3 represents the F shape stub antenna with dimension of $0.187\lambda_o \times 0.294\lambda_o \times 0.008\lambda_o$, so many more references are given from which we are taking help to design our proposed antenna.

In our work we are only mentioning the main references [1]-[12]. All the researchers of these papers have already created multiband antenna using different dimensions and material, so we are taking the best features from their antenna to create an optimized proposed antenna. In our article, we design a compact printed antenna. It consists three inverted L stub with different height (vertical) but with same thickness on Roger RTduroid 5880 dielectric substrate and the middle inverted L stub connected with a T stub (90 degree rotated T stub). Due to the varied heights of the inverted L stub (and T stub) they resonate at different frequencies. This feature is very useful for us to use a single antenna for different frequency bands.

Table.1. Proposed work with reference antennas

No. of bands in antenna	Dimensions of antenna	Bandwidth (GHz) $|S_{11}|\leq$10dB	Realized gain
Triple band [1]	30×65×1.6 ($0.245\lambda_o \times 0.53\lambda_o \times 0.013\lambda_o$)	2.375-2.525 3.075-3.8 5.0-6.9	1.1-1.5 4.6-5.6 2.0-3.6
Triple band [2]	20×38.5×0.8 ($0.166\lambda_o \times 0.32\lambda_o \times 0.006\lambda_o$)	2.10-2.49 3.22-4.30 4.89-6.12	2.7-3.2 3.1-3.5 2.8-3.3
Triple band [3]	23×36×1 ($0.187\lambda_o \times 0.294\lambda_o \times 0.008\lambda_o$)	2.35-2.59 3.31-3.93 5.07-6.35	2.67-3.19 2.05-2.24 2.66-3.48
Triple band [4]	28×32×1 ($0.23\lambda_o \times 0.266\lambda_o \times 0.008\lambda_o$)	2.29-2.88 3.26-3.88 4.17-6.07	3.8-4.4 4-4.65 1.9-3.5
Triple band [5]	33×50.9×0.8 ($0.319\lambda_o \times 0.492\lambda_o \times 0.007\lambda_o$)	2.8-3.0 3.3-3.5 3.8-8	2.32 1.21 -6
Triple band [6]	26×30×0.8 ($0.212\lambda_o \times 0.25\lambda_o \times 0.006\lambda_o$)	2.33-2.55 3.0-3.88 5.15-5.9	1.08-1.39 2.35-3.49 2.46-3.28
Triple band [7]	23×38×1.6 ($0.184\lambda_o \times 0.304\lambda_o \times 0.013\lambda_o$)	2.28-2.56 3.29-4.21 5.05-5.91	1.48-1.96 2.1-3.22 2.63-3.56
Triple band [8]	40×40×0.8 ($0.325\lambda_o \times 0.325\lambda_o \times 0.007\lambda_o$)	2.35-2.58 3.25-4 4.95-5.9	-0.3 0.9 3.8
Triple band [9]	40×45×1.6 ($0.28\lambda_o \times 0.31\lambda_o \times 0.011\lambda_o$)	2.02-2.14 4.26-4.28 5.45-5.56	1.87 2.90 4.13
Triple band [10]	37×40×1.58 ($0.302\lambda_o \times 0.327\lambda_o \times 0.013\lambda_o$)	2.30-2.75 3.19-3.18 5.06-6.15	2.5 0.824 2.02
Triple band [11] - target antenna	24×30×0.79 ($0.2\lambda_o \times 0.25\lambda_o \times 0.006\lambda_o$)	2.43-2.67 3.37-3.58 5.1-5.65	0.5-1.75 1.3-1.9 1.7-1.9

It is a triple layer antenna with partial ground plane which means the bottom layer does not cover the whole dielectric substrate. In this antenna design we are capable of changing the resonating frequency by changing the thickness (horizontal) of stub. We fabricate and design the antenna for the purpose of validation. This compact printed multiband antenna works for Wi-MAX at 2.5GHz, 3.5GHz, 5.5GHz and also 5.2GHz and 5.5GHz for WLAN system. This compact printed multiband antenna works for Wi-MAX at 2.5GHz, 3.5GHz, 5.5GHz and also 5.2GHz and 5.5GHz for WLAN system.

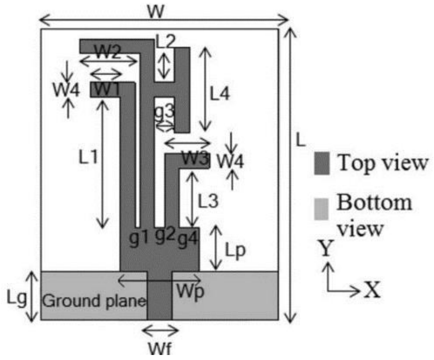


Fig.1 Geometry of proposed compact printed multiband antenna

2. CONFIGURATION AND ANALYSIS OF ANTENNA

Above Fig.1 represents the geometric view of the proposed antenna in *xy* plane. First we have to design the software version of the antenna in CST. All the dimension of the antenna is provided in the Table.2.

Table.2. Parameter of proposed antenna

Parameters	L	W	L_p	L_g	W_f	W_p	L_1	L_2	L_3
Values (mm)	30	24	4.5	5	2.44	8	13.5	3	6.15
Parameters	L_4	W_1	W_2	W_3	W_4	g_1	g_2	g_3	g_4
Values (mm)	9.1	3	6	4.5	1.5	0.5	1	2	2

The antenna is designed on low loss dielectric Roger RTduroid 5880 substrate with partial ground plane. Thickness of dielectric substrate is 0.79mm and value of dielectric constant is 2.2 and loss tangent is 0.0009.

The antenna is designed using a 50Ω micro strip feed line with partial ground plane and two inverted L shaped stub and a mix inverted L and T stub. The overall size of the antenna is 24×30mm². The optimized antenna's dimensions are given in Table.2. In the designing process of this antenna, we are using four prototypes antenna as step by step design. First, we have to design a rectangular patch dimension $L_p \times W_p$ and excited through feed line (50Ω) of width W_f. This rectangular patch resonates at higher frequencies. For reducing resonance frequency, we added different stubs in it. An inverted L-stub is added to the left upper side of the rectangular patch and we call it Resonator 1. Now, it provides resonance at 3.56GHz, whereas our purpose is to design the antenna to be used at 2.5/3.5/5.5GHz for Wi-MAX and 5.2/5.5GHz for WLAN.

Again we are added a bigger inverted L-stub to the rectangular patch at a gap of g_1 from previous stub. It is called Resonator 2. Now the antenna is found to resonate at 2.57GHz and 3.5GHz. We, then, added a horizontal T-stub to the largest inverted L-stub. It is called Resonator 3. Due to T-stub, the lower frequency reduces and second resonance remains same. Both Resonator 2 and Resonator 3 are called dual band antenna because they are resonating at two different frequencies.

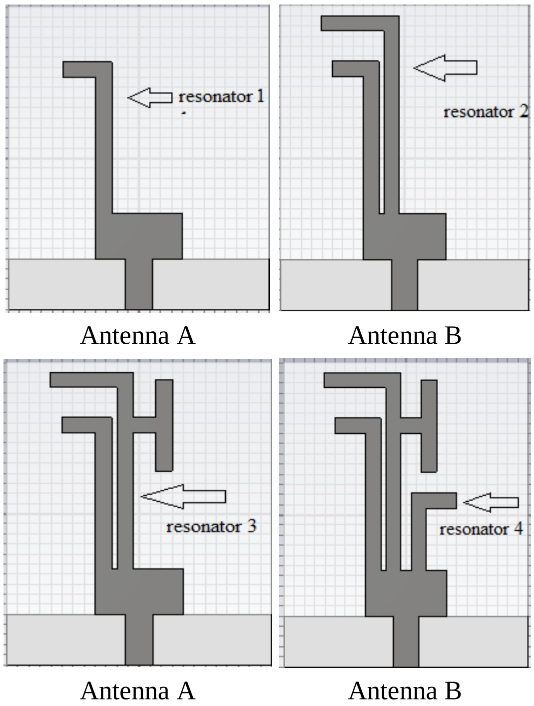


Fig.2. Step by step procedure of design of compact printed multiband antenna

Now we add the smallest inverted L-stub to the rectangular patch at a gap of g_2 from the largest inverted L-stub. It is called Resonator 4 and this whole setup is our final antenna. For getting the further result, we have to simulate the antenna. After simulation we plot a graph comparison between real impedance and imaginary impedance as seen in Fig.2. As displayed in Fig.4, we conclude that the three encircled regions define the three resonance mode in the proposed antenna, namely 2.57, 3.52 and 5.51GHz.

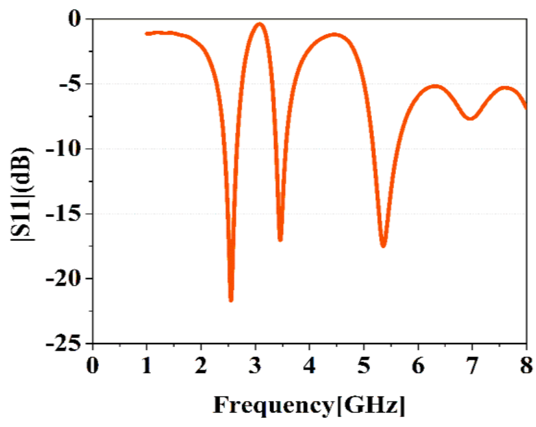


Fig.3. Reflection coefficient ($|S_{11}|$ dB) against frequency

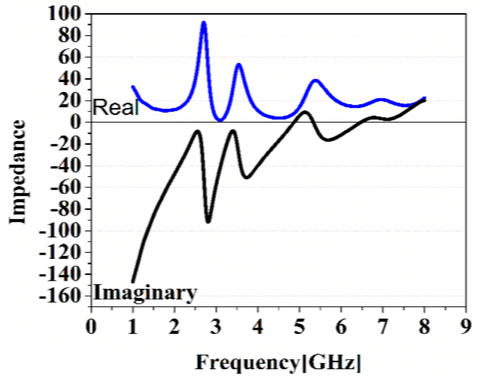


Fig.4. Input impedance against frequency

To understand the antenna's working and resonating phenomenon, we observed the current distribution of the antenna (given in Fig.7). We resonated the antenna at three frequencies which is 2.57, 3.52 and 5.51GHz and defined the role of each stub for their frequency resonance.

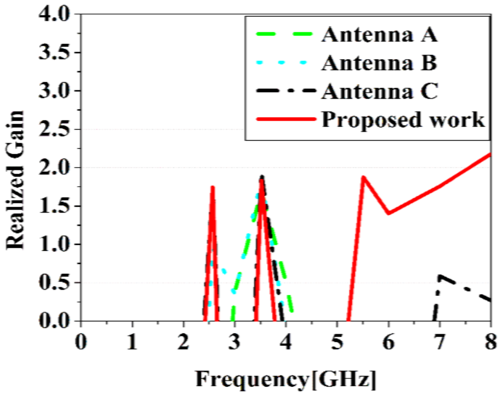


Fig.5. Realized gain against antenna configuration

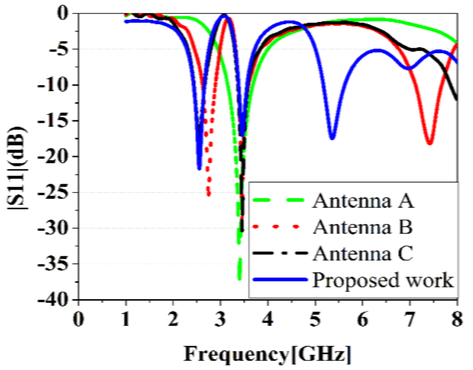


Fig.6. $|S_{11}|$ against frequency for above all antenna

First we resonated the proposed antenna at 2.57GHz and observed the surface current distribution is mainly in the Resonator-3, which is the combination of inverted L-stub and horizontal T-stub. So the resonance frequency 2.57GHz occurred due to the Resonator-3. It is shown in Fig.7(a).

Again we observed the surface current distribution in proposed antenna at second resonance frequency i.e. 3.52GHz. At this resonance frequency, most of surface current flowed in the left most inverted L-stub in the antenna. So, we conclude that the second resonating frequency (3.52GHz) occurred due to left most inverted L-stub as shown in Fig.7(b). Again we observed the surface current distribution in the proposed antenna at third resonance frequency i.e. 5.51GHz. At this frequency most of surface current flowed in the right most inverted L-stub. So, we concluded that the third resonating frequency occurred due to the right most inverted L-stub of the proposed antenna.

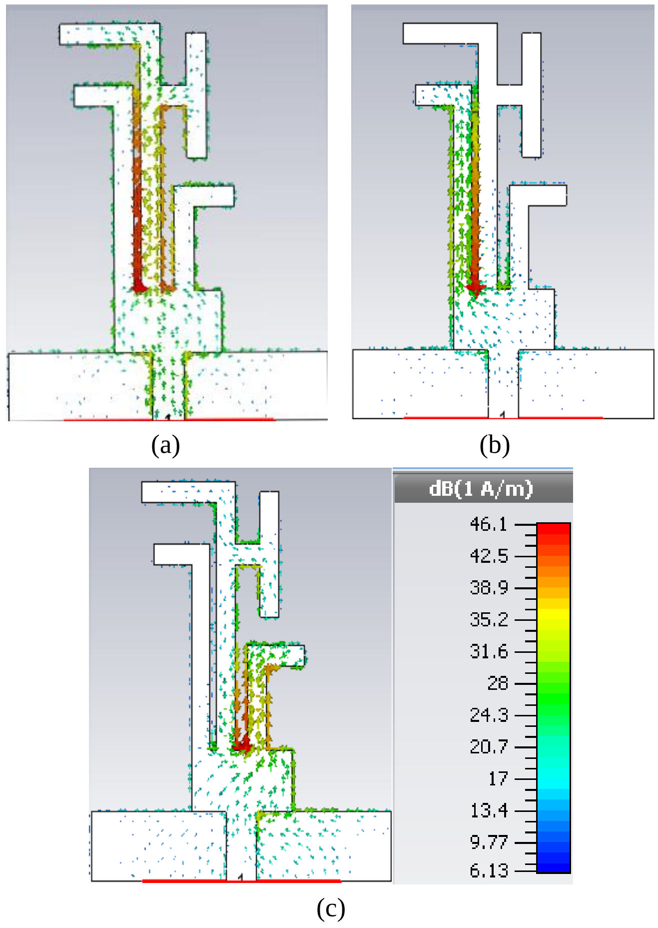


Fig.7. Surface current distributions at frequency (a) 2.57GHz (b) 3.52GHz (c) 5.51GHz

3. DESIGN PROCEDURE FOR PROPOSED ANTENNA

From the surface current distribution phenomenon discussed above, we understand that different resonance frequencies occurred due to different resonators present in the proposed antenna. For the design we need to know the f_{rn} (n^{th} resonance frequency) and ε_{eff} (effective dielectric constant), given as below:

$$f_{rn} = \frac{c}{4L_{sn}\sqrt{\varepsilon_{eff}}};n=1,2,3 \tag{1}$$

$$\varepsilon_{eff} \approx \frac{\varepsilon_r + 1}{2} \tag{2}$$

where ε_r = dielectric constant of substrate, ε_r = 2.2 (for Roger RT/duroid dielectric), L_{sn} = complete length of resonator which relate to f_{rn}, λ_g = guided wavelength.

As per the aforementioned discussion, we come to know that the first resonance frequency occurred due to resonator-3 which included inverted L-stub and horizontal T-stub. So, the complete length of resonator-3 is approximated as $W_2+g_3+L_1+L_2$. Length is always equal to one fourth of guided wavelength in medium given as,

$$L_{sn} = L_2+W_2+g_3+L_1 \approx \lambda_g/4 \quad (3)$$

All the values are already optimized and calculated in Table.1.

$$L_{sn} = 24.5\text{mm} \quad \varepsilon_{eff} = 1.6$$

From these values we calculate the first resonance with the help of equation 1 is f_{r1} = 2.42GHz. This is very close to the simulated resonance frequency 2.57GHz. Using the same procedure mentioned above, we calculated the second and third resonating frequencies. So, as the resonator 1 provided the second resonance frequency, the complete length of resonator 1 is given as $L_1 + W_1$.

$$Ls_2 = W_1 + L_1 \approx \lambda_g/4 \quad (4)$$

Applying these values from Table.1 into Eq.(1), we find that L_{s2} = 16.5mm and f_{r2} = 3.59GHz, which is very close to the simulated resonance frequency 3.52GHz. Now calculating these values or the third resonance frequency which occurred due to resonator-4, the complete length of the resonator-4 is calculated as L_3+W_3, given as below,

$$Ls_3 = W_3 + L_3 \approx \lambda_g/4 \quad (5)$$

All the values collected from Table.1 are applied to the aforementioned formulas to get, L_{s3} = 10.65mm and f_{r3} = 5.57GHz, which is closer to the simulated resonance frequency 5.51GHz. So, the antenna design justifies both the practical and theoretical approach.

Table.3. Comparison of antenna factors

Name of antenna	Pattern of antenna	Bandwidth $\|S_{11}\|\leq 10$ GHz	Realized gain $\|S_{11}\|\leq 10$	No. of bands
Antenna 1	Left side inverted L-stub	3.1-3.72	0.55-1.67	Single
Antenna 2	Left and middle inverted L-stub	2.62-2.92 3.37-3.6	0.5-1 1.35-1.83	Double
Antenna 3	Antenna 2 with horizontal L-stub	2.42-2.68 3.35-3.6	0.2-1.7 0.1-2	Double
Desired antenna	Antenna 3 with right most Inverted L-stub	2.43-2.67 3.37-3.58 5.1-5.65	0.5-1.75 1.3-1.9 1.7-1.9	Triple

4. PARAMETER VARIATION STUDY ON DESIGNED ANTENNA

To learn the behavior of the designed antenna we had to change some of its dimensions. We know that our antenna provides three resonance frequencies and every resonance frequency occurred due to a particular resonator present in the antenna. So, we are going to change the horizontal length of resonators, while keeping the other parameters same as before.

We have seen that resonance frequency 2.57GHz is provided by resonator-3 and 3.52GHz is provided by resonator-1and 5.51GHz is provided by resonator-4. So, we are going to study the variation in W_1 of resonator-1, W_2 of resonator-3, W_3 of resonator-4. In this study of varied lengths, we increase and decrease the length by 2mm and get the result.

First we discuss the variation in W_1. W_1 for the proposed work is 3mm and now we study the behavior of antenna at W_1 = 1mm and W_1 = 5mm. For W_1 = 1mm and W_1 = 5mm, we got the reflection coefficient graph against frequency as shown in Fig.8. It is observed from the graph that the second resonance shifted toward right for decreased W_1 and shifted toward left for increased W_1.

Similarly, we discuss the variation in W_2 for resonator-3. W_2 for proposed work is 6mm, so we are going to study the variation at W_2 = 4mm and 8mm. when the length of resonator-3 decreased to 4mm then the first resonance shifted toward right or higher frequency and for increased W_2 (8mm) second resonance shifted toward left or lower frequency side (as shown in above Fig.9).

The same procedure was repeated for variation in W_3 for resonator-4. W_3 for proposed work is 4.5mm and we are going to study the variation at W_3 = 2.5mm and W_3 = 6.5mm. When the length of resonator-4 decreased to 2.5mm the third resonance shifted toward right side or higher frequency side whereas for increasing in length of W_3 to 6.5mm, the third resonance shifted toward left or lower frequency side (as shown in Fig.10). We also observed that W3 is most sensitive in comparison to W_1 and W_2.

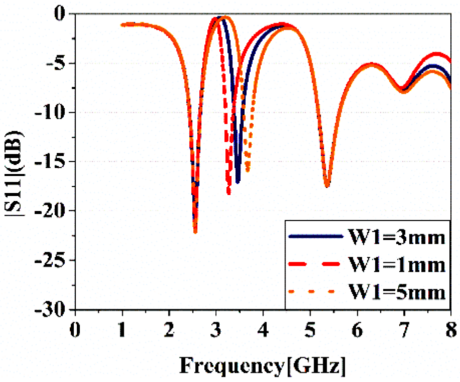


Fig.8. $|S_{11}|$ against frequency (with variation in W_1)

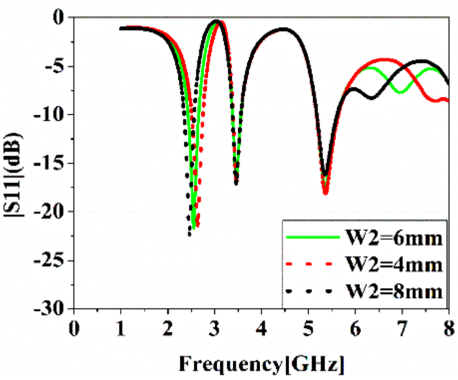


Fig.9. $|S_{11}|$ against frequency (with variation in W_2)

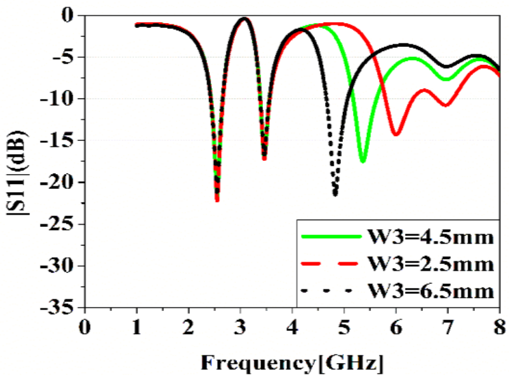


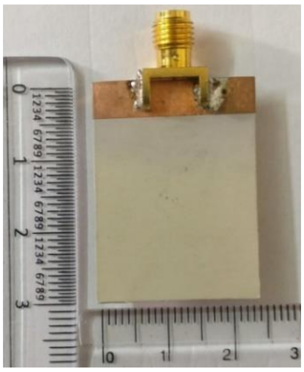
Fig.10. $|S_{11}|$ against frequency (with variation in W_3)

5. RESULTS

After designing and simulating the proposed antenna in CST microwave studio, we inferred the following results:

- The proposed antenna radiates at three frequencies (2.57GHz, 3.52GHz, and 5.5GHz). It is called as triple band antenna used for Wi-MAX and WLAN. It provides better realized gain at these resonance frequencies.
- In the simulation process of this antenna we got some important results i.e. $|S_{11}|$ against frequency, VSWR against frequency, radiation pattern against frequency, input impedance against frequency, realized gain. The antenna return loss (S_{11}) is measured on ENA series vector network analyzer, set up as shown in Fig.11(c).
- There are some variations in the measured and simulated (CST) result due to environment effects, soldering joints of SMA connector, proper material properties variation and other effects.

(a)



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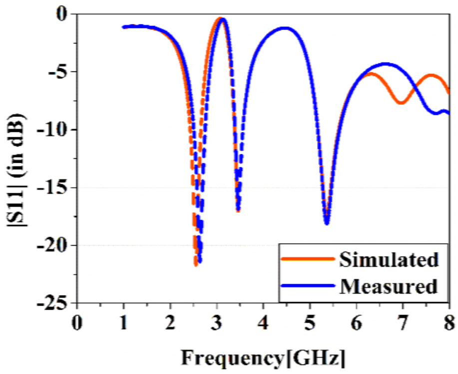
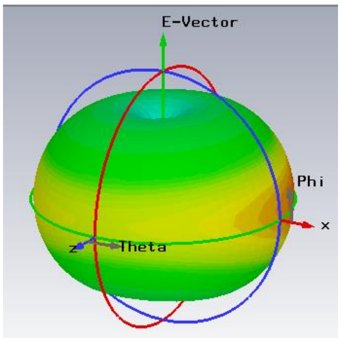
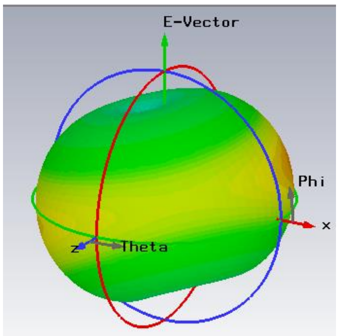


(c)

Fig.11. Proposed antenna images (a) Front view (b) Back view (c) S_{11} measured on VNA setup



(a)



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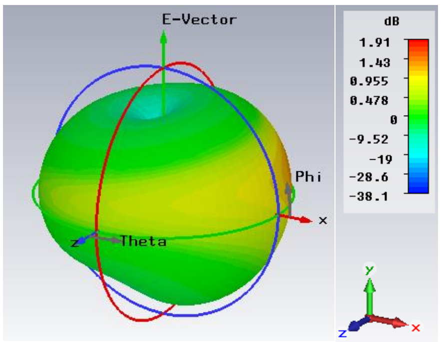

(c)

Fig.12. 3D-Radiation pattern of proposed antenna at resonance frequencies (a) 2.57GHz (b) 3.52GHz (c) 5.51GHz

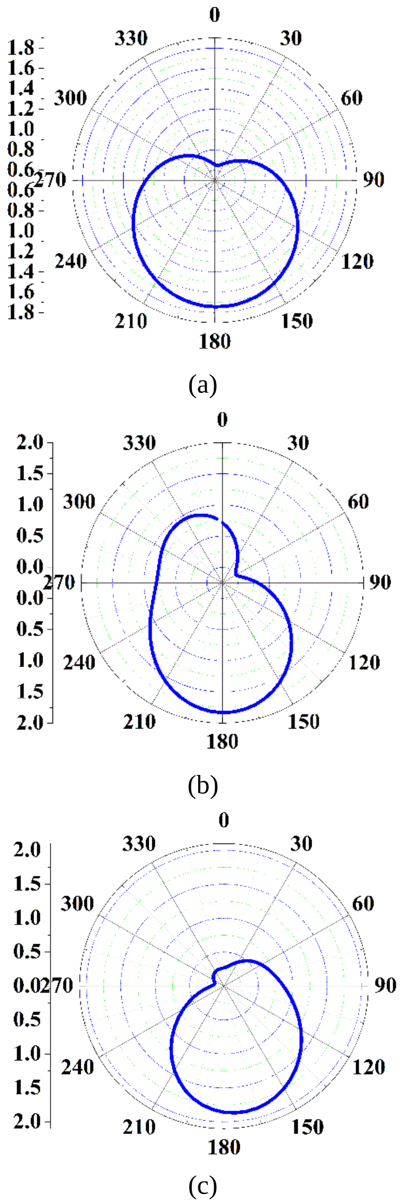

Fig.13. Radiation pattern of proposed antenna at resonance frequencies (a) 2.57GHz (b) 3.52GHz (c) 5.51GHz

6. CONCLUSION

We successfully designed the proposed multiband antenna and also simulated it on CST microwave studio and got three resonance frequencies - 2.57GHz, 3.52GHz, and 5.51GHz. So, we call it as multiband antenna. The dimension of the proposed antenna is 24×30×0.79 ($0.2\lambda_o \times 0.25\lambda_o \times 0.006\lambda_o$) which is comparatively smaller to other antennas referenced for the purpose of this study.

Every stub in this proposed antenna is responsible for the achieved resonance frequencies. Resonator-1 is responsible for resonance frequency 3.52GHz, Resonator-3 responsible for resonance frequency 2.57GHz, and Resonator-4 is responsible for the resonance frequency 5.51GHz. This antenna has lots of advantages like multiband, easy design, compact size, and omnidirectional pattern; and these features elevate this antenna to be a preferred component for Wi-MAX and WLAN equipment.

REFERENCES

[1] J. Li, J. Guo, B. He, A. Zhang and Q.H. Liu, "Tri-Band CPW-Fed Stub Loaded Slot Antenna Design for WLAN/Wi-MAX Applications", *Frequenz*, Vol. 70, No. 11-12, pp. 521-526, 2016.

[2] C.Y.D. Sim, H.D. Chen and C.H. Yeh, "Small Size Triple Band Monopole Antenna with a Parasitic Element", *Microwave and Optical Technology Letters*, Vol. 57, No. 2, pp. 342-348, 2015.

[3] Z. Tang, K. Liu, Y. Yin and R. Lian, "Design of Compact Triband Monopole Antenna for WLAN and Wi-MAX Applications", *Microwave and Optical Technology Letters*, Vol. 57, No. 10, pp. 2298-2303, 2015.

[4] G. Liu, Y. Liu and S. Gong, "Compact Tri-Band Wide-Slot Monopole Antenna with Dual-Ring Resonator for WLAN/Wi-MAX Applications", *Microwave and Optical Technology Letters*, Vol. 58, No. 5, pp. 1097-1101, 2016.

[5] S.A. Goswami and D. Karia, "A Compact Monopole Antenna for Wireless Applications with Enhanced Bandwidth", *AEU-International Journal of Electronics and Communications*, Vol. 72, pp. 33-39, 2017.

[6] X. Yang, F. Kong, X. Liu and C. Song, "A CPW-Fed Triple-Band Antenna for WLAN and Wi-MAX Applications", *Radio Engineering*, Vol. 23, No. 4, pp. 1086-1091, 2014.

[7] Y. Xu, C. Zhang, Y. Yin and Z. Yang, "Compact Triple-Band Monopole Antenna with Inverted-L Slots and SRR for WLAN/Wi-MAX Applications", *Progress in Electromagnetics Research Letters*, Vol. 55, pp. 1-6, 2015.

[8] X.L. Sun, J. Zhang, S.W. Cheung and T.I. Yuk, "A Triple-Band Monopole Antenna for WLAN and Wi-MAX Applications", *Proceedings of IEEE International Symposium on Antennas and Propagation*, pp. 1-2, 2012.

[9] A. Gupta and R.K. Chaudhary, "A Compact Planar Metamaterial Triple Band Antenna with Complementary Closed-Ring Resonator", *Wireless Personal Communications*, Vol. 88, No. 2, pp. 203-210, 2016.

[10] A. Kundu and A.K. Bhattacharjee, "Design of Compact Triple Frequency Micro Strip Antenna for WLAN/Wi-MAX Applications", *Microwave and Optical Technology Letters*, Vol. 57, No. 9, pp. 2125-2129, 2015.

[11] Yu Ma, Bing Liu, Zijun Guo, Renrong Zhao, Xiangyun Wei, Wenqiang Xing and Yuting Wang, "A Compact Quad-Band Bandpass Filter With High Skirt Selectivity Based on Stub-Loaded Resonators and λ/4 Resonators", *Proceedings of IEEE International Symposium on Wireless*, pp. 1-4, 2018.

[12] Madan L. Meena and Asheesh Gupta, "Design Analysis of a Semi-Circular Floral Shaped Directional UWB Antenna Integrated with Wireless Multiband Applications", *Progress in Electromagnetics Research C*, Vol. 90, pp. 155-167, 2019.