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DESIGN AND ANALYSIS OF QUAD BAND ANTENNA FOR WIRELESS SYSTEMS

Kuldeep Galav and M.L. Meena
Department of Electronics Engineering, Rajasthan Technical University, India

Abstract

In this topic we are going to design a compact size antenna which is used for different band using a single antenna. The term compact means the size of antenna is very less, which is 24×30mm². In this antenna designing we are using partial ground plane and is fabricated on Roger RTduroid 5880 with thickness of 0.79mm. In this antenna we have three inverted L shaped stub and a stub of combination of inverted L shape and T shape. This antenna resonates at three frequencies 2.54/3.51/4.38/5.3GHz. So the operating range of antenna covers these frequencies so main use of this antenna is in Wi-MAX (wide interoperability for microwave access) and WLAN (wireless local area network) and radio altimeter, satellite communication, cordless telephones and weather radar systems. All the parameters and details are examined in following points.

Keywords:

Antenna, Roger RTduroid 5880, Wi-MAX, WLAN

1. INTRODUCTION

In electronics and wireless equipment market the requirement or demand of small size equipment are high because they require less space and the heat sinking is also easy due to latest technology and availability of space. For reducing the size of wireless system we need to reduce the size of antenna used in system. Our antenna is mainly designed to use in Wi-MAX, WLAN, radio altimeter, cordless telephone and weather radar system. A number of antennas are design to meet the requirements of this system. For providing a perfect antenna for this requirement we study a no of publish papers to get the knowledge of design and measurements of antenna. A number of multiband antennas have been reported by researchers having good efficiency, Design and implementation of reconfigurable quad band micro strip antenna for MIMO wireless communication applications [1] with dimension of 60mm×50mm×1.6mm. A Novel Quad Band Antenna for Wireless Application [2] with dimension of 38mm×25mm, [5] represents the Quad-band Micro strip Patch Antenna for WLAN/Wi-MAX/C/X Applications. Design of Multi-Band Antennas for Wireless Communication Applications [6], Quad-band Dual-mode Resonator with Dual-Square Loop for WLAN and Wi-MAX Systems shown in [9], A Compact Quad-Band Band pass Filter with High Skirt Selectivity Based on Stub-Loaded Resonators and λ/4 Resonators [11]. Design Analysis of a Semi-Circular Floral Shaped Directional UWB Antenna Integrated with Wireless Multiband Applications in [15]. So many more references are given from which we are taking help to design our proposed antenna. In our work we are only mention the main references [1]-[10].

All these paper researcher already created multiband antenna with different dimension 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 consist 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 different height of inverted L stub (and T stub) they resonates at different frequencies which feature is very useful for us to use a single antenna for different frequency bands. It is a triple layer antenna with partial ground plane which means the bottom layer is 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. For validation purpose we have to fabricate and design the antenna. 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 and 4.2-4.4GHz for radio altimeter and 4.38GHz for cordless telephones and weather radar systems.

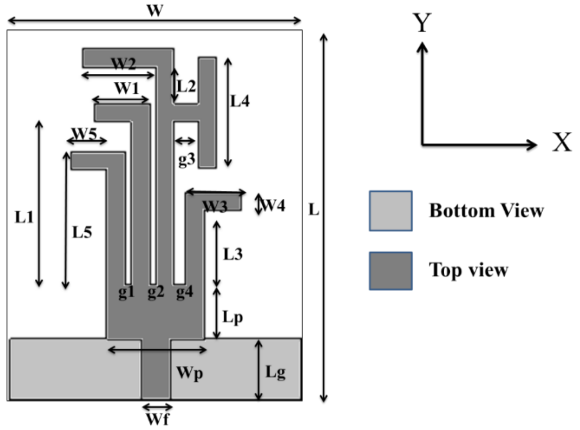


Fig.1. Geometry of proposed compact printed Quad band antenna

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 and 4.38GHz for radio altimeters and satellite communication and cordless telephones.

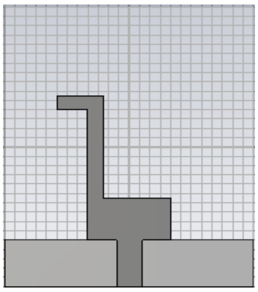
2. CONFIGURATION AND ANALYSIS OF ANTENNA

The 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.1.

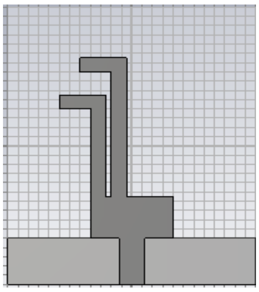
Table.1. Parameter of proposed antenna

Parameters	L	W	L_p	L_g	W_f	W_p	L_1	L_2	L_3	L_4
Values (mm)	30	24	4.5	5	2.44	8	13.5	3	6.15	9.1
Parameters	L_5	W_1	W_2	W_3	W_4	W_5	g_1	g_2	g_3	g_4
Values (mm)	11	3	6	4.5	1.5	3	0.5	0.5	2	1

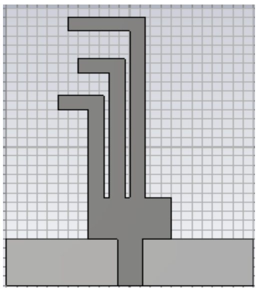
The antenna is design on low loss dielectric Roger RTduroid 5880 substrate with partial ground plane. Thickness of dielectric substrate is 0.79mm and value of dielectric constant is 2.2 and loss tangent is 0.0009. Antenna is designed using a 50 ohm micro strip feed line with partial ground plane and three 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 called it resonator 1. Now it provides resonance at 4.05GHz where as our purpose to design the antenna used at 2.5/3.5/5.5GHz for Wi-MAX and 5.2/5.5GHz for WLAN and other applications. 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 antenna resonating at 4.37GHz and 3.48GHz. Now we again add a largest inverted L-stub called it resonator 3 which is resonating at 2.74GHz, 3.5GHz and 4.37GHz. Now we add a horizontal T-stub to the largest inverted L-stub, which is called resonator 4. Due to T-stub the lower frequency reduces and second resonance remains same. Both resonator 1 and resonator 2 are called dual band antenna because they are resonating at two different frequencies. And resonator 3 and resonator 4 are called triple band antenna because they are resonating at three different frequencies. For designing the proposed quad band antenna we have to add extra inverted L stub to the right most side of rectangular patch and at a gap of g_2 from the largest inverted L-stub which is called as resonator 5. 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 seen in Fig.4.



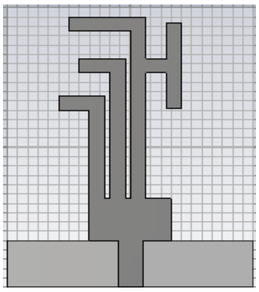
(a) Antenna 1



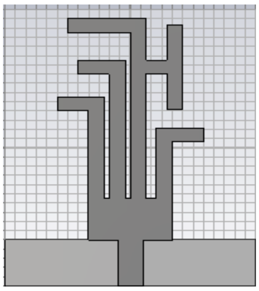
(b) Antenna 2



(c) Antenna 3



(d) Antenna 4



(a) Antenna 1

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

We conclude that four encircled region defines the three resonance mode in the proposed antenna which is observed as 2.54, 3.51, 4.38, 5.3GHz. We are also got some important parameter for proposed antenna in simulation which is reflection coefficient $|S_{11}|$ shown in Fig.3 (vs. frequency).

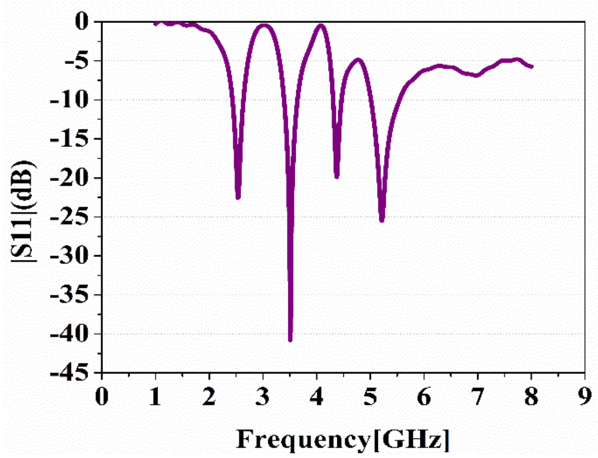


Fig.3. Reflection coefficient ($|S_{11}|$dB) against frequency

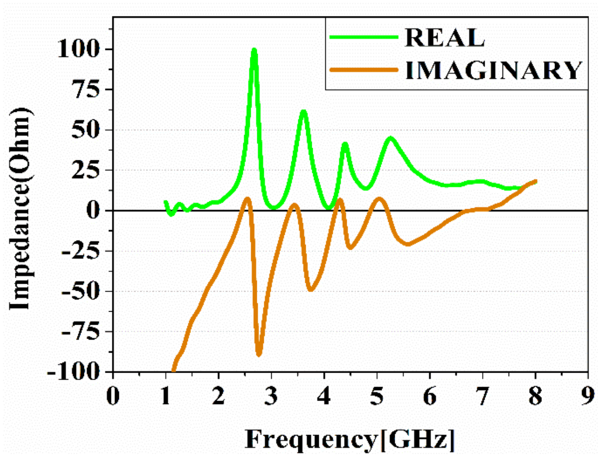


Fig.4. Input impedance against frequency

To understand the antenna working and resonating phenomenon we observed the current distribution of the antenna (given in Fig.6). We resonates the antenna at four frequencies which is 2.54 GHz, 3.51GHz, 4.38GHz, 5.51GHz and define the role of each stub for their frequency resonance.

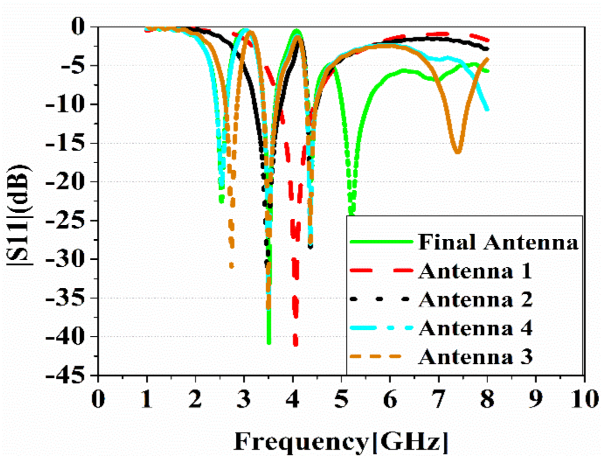


Fig.5 $|S_{11}|$ against frequency for above all antenna

First we resonance the proposed antenna at 2.54GHz and observed the surface current distribution is mainly in the resonator-4, which is combination of inverted L-stub and horizontal T-stub. So the resonance frequency 2.54GHz is occurred due to resonator-4. It is shown in Fig.6(a). Again we observe the surface current distribution in proposed antenna at second resonance frequency i.e. 3.51GHz. At this resonance frequency the most of surface current flows in second left most inverted L-stub in the antenna. So we conclude that the second resonating frequency (3.51GHz) is occurred due to second left most inverted L-stub as shown in Fig.6(b). Again we observed the surface current distribution in proposed antenna at third resonance frequency i.e. 4.38GHz occurred due to left most inverted L stub. At this frequency most of surface current is flows in left most inverted L-stub.

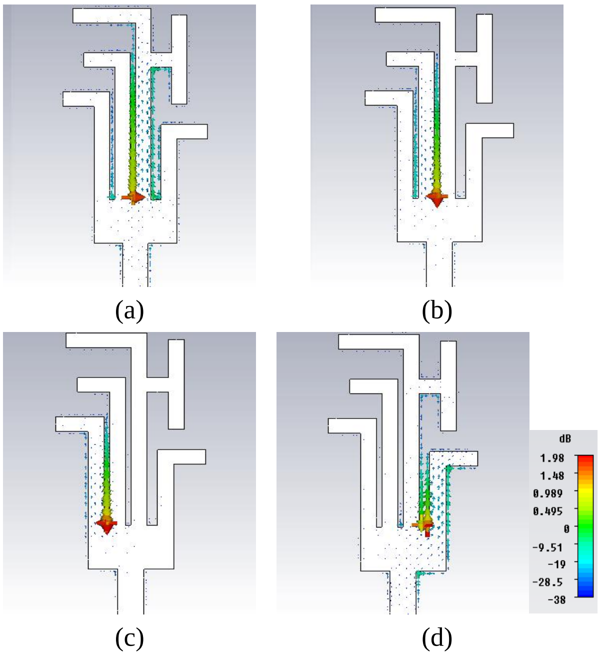


Fig.6. Surface current distributions at frequency (a) 2.54GHz (b) 3.51GHz (c) 4.38GHz (d) 5.3GHz

So we conclude that the third resonating frequency is occurred due to the right most inverted L-stub of the proposed antenna. Again we observed the surface current distribution in proposed antenna at fourth resonance frequency i.e. 5.3GHz. At this resonance frequency most of the surface current flows through right most inverted L stub. So we conclude that fourth resonance frequency occurred due to right most inverted L stub.

3. DESIGN PROCEDURE FOR PROPOSED ANTENNA

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

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

$$\varepsilon_{eff} \approx (\varepsilon_r+1)/2 \quad (2)$$

where

ε_r = dielectric constant of substrate = 2.2 (for Roger RTduroid dielectric),

L_{sn} = complete length of resonator which relate to f_{rn},

λ_g = guided wavelength

From above discussion, we all know that the first resonance frequency is occurred due to resonator-4 which included inverted L-stub and horizontal T-stub. So complete length of resonator-4 is approximated as $L_2 + W_2 + g_3 + L_1$. 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, and with L_{sn} = 24.5mm;

$$\varepsilon_{eff} = (2.2+1)/2= 1.6$$

From these values we calculate the first resonance with the help of Eq.(1) is f_{r1} = 2.42GHz. This is very close to the simulated resonance frequency 2.54GHz. With the help of above same procedure we are calculating the second and third resonating frequency. So the resonator 2 provided the second resonance frequency, complete length of resonator 2 is given as L_1+W_1.

$$L_{s2} = W_1 + L_1 \approx \lambda_g/4 \quad (4)$$

Getting these values from Table.1 and putting into Eq.(1), L_{s2} = 16.5mm and f_{r2} = 3.59GHz, which is very close to the simulated resonance frequency 3.51GHz. Now calculating these values or the third resonance frequency which is occurred due to resonator-1, so the complete length of the resonator-4 is calculated as L_5 + W_5, given as below,

$$L_{s3} = L_5+W_5 \approx \lambda_g/4 \quad (5)$$

All the values are collected from table 1 and put into above formulas we get, L_{s3} = 14mm and f_{r3} = 4.23GHz which is closer to the simulated resonance frequency 4.38GHz.

Fourth resonance frequency is occurred due to resonator 5, so the length of resonator 5 is L_3+W_3,

$$L_{s4} = W_3 + L_3 \approx \lambda_g/4 \quad (6)$$

All the values are collected from parameter table and put into Eq.(6), we get L_{s4} = 10.65mm and f_{r4} = 5.57GHz which is very close to 5.3GHz. So the antenna design justifies the both practical and theoretical approach.

Table.2. Comparison of above factors of Fig.2 antennas

Name of antenna	Pattern of antenna	Band width ($\|S_{11}\|\leq 10$)GHz	No. of bands
Antenna 1	First inverted L-stub from left	3.72-4.45	Single
Antenna 2	Second inverted L-stub from left	3.20-3.77 4.29-4.50	Double
Antenna 3	Antenna 2 and largest inverted L-stub from left	2.61-2.87 3.38-3.69 4.29-4.49	Triple
Antenna 4	Antenna 2 and largest inverted L-stub rom left with horizontal T-stub	2.40-2.67 3.37-3.68 4.29-4.49	Triple
Proposed antenna	Antenna 4 with right most inverted L-stub	2.42-2.66 3.38-3.66 4.29-4.49 5.00-5.57	Quad

4. PARAMETER VARIATION STUDY ON DESIGNED ANTENNA

For knowing the behavior of our designed antenna we have to change some dimensions of the antenna. We know that our antenna provide four resonance frequencies and every resonance frequency is occurred due a particular resonator present in the antenna. So we are going to change the horizontal length of resonators and keeping other parameter same as previous. We know that resonance frequency 2.54GHz is provided by resonator-4 and 3.51GHz is provided by resonator-2 and 4.38GHz is provided by resonator-1 and 5.3GHz is provided by resonator 5. So we are going to study the variation in W_1 of resonator-2, W_2 of resonator-4, W_3 of resonator-5, W_5 of resonator 1. In this variation study of length, 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.7. 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.

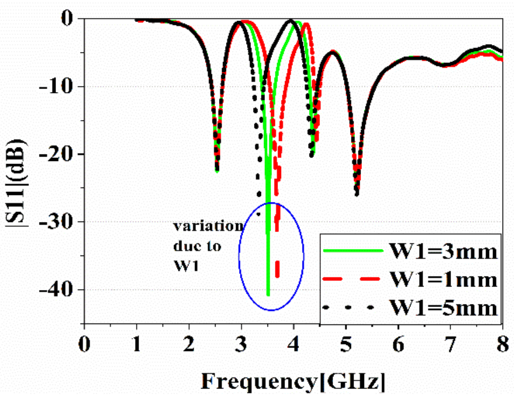


Fig.7. $|S_{11}|$ against frequency (with variation in W_1)

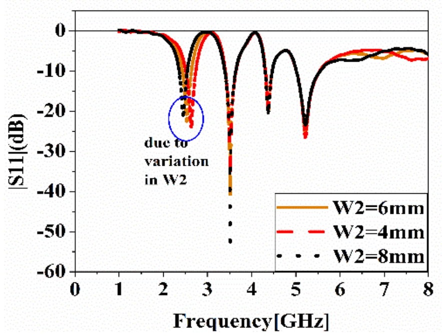


Fig.8. $|S_{11}|$ against frequency (with variation in W_2)

Same as above us 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.8). Now we consider same procedure for variation in W_5 for resonator-1. W_5 for proposed antenna is 3mm and we are going to study the variation at W_5 = 1mm and W_5 = 5mm. When W_5 is decreases to 1mm the resonance shifted toward right and when W_5 increases to 5mm then resonance shifted toward left. (As shown in Fig.10)

We are also considering same procedure for variation in W_3 for resonator-5. 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 9). We also observed that W_3 is most sensitive with compare to W_1 and W_2.

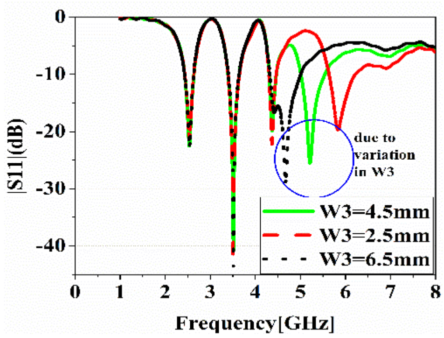


Fig.9. $|S_{11}|$ against frequency (with variation in W_3)

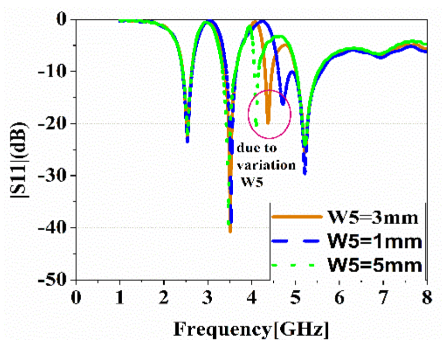
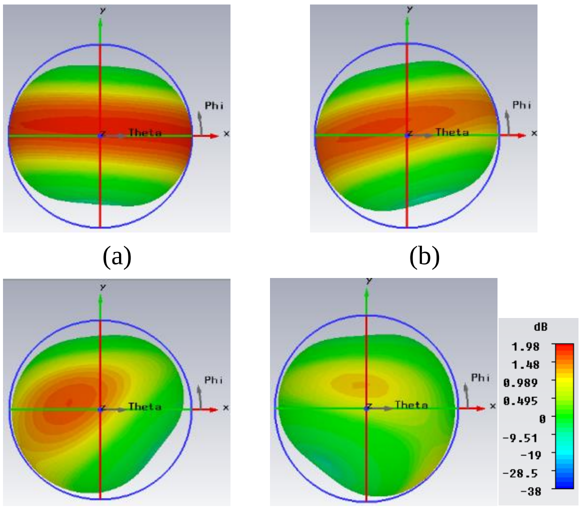


Fig.10. $|S_{11}|$ against frequency (with variation in W_5)

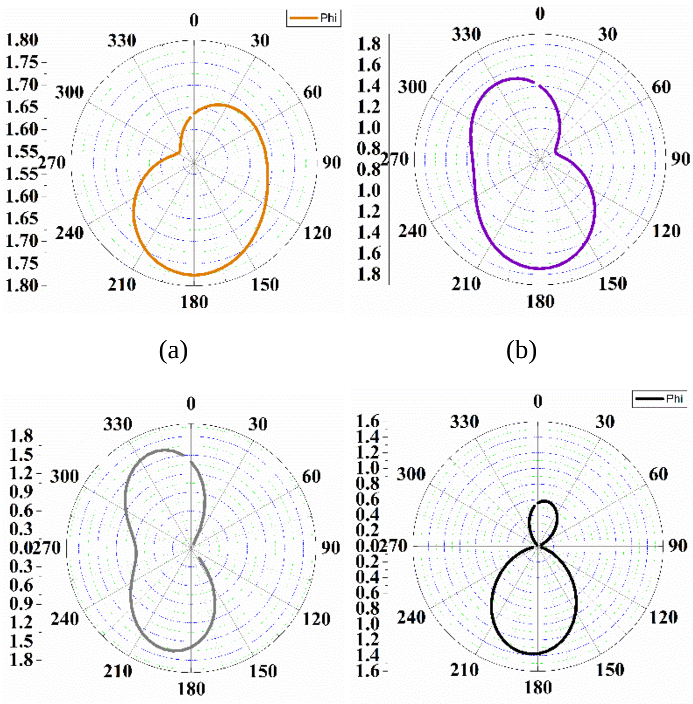
5. RESULT

After designing and simulation of proposed antenna on CST microwave studio, we got some result i.e. the proposed antenna radiates at four frequencies (2.54GHz, 3.51GHz, 4.38GHz and 5.3GHz). It is called as quad band antenna used for Wi-MAX, WLAN, radio altimeters, satellite communication, Wi-Fi devices, cordless telephones and weather radar systems. It provides better realized gain at these resonance frequencies.



(a) (b) (c) (d)

Fig.11. 3D-Radiation pattern of proposed antenna at resonance frequencies (a) 2.54GHz (b) 3.51GHz (c) 4.38GHz (d) 5.3GHz



(a) (b) (c) (d)

Fig.12. Radiation pattern of proposed antenna at resonance frequencies (a) 2.54GHz (b) 3.51GHz (c) 4.38GHz (d) 5.3GHz

In simulation process of this antenna we got some important result i.e. $|S_{11}|$ against frequency, VSWR against frequency, radiation pattern against frequency, input impedance against frequency, realized gain.

6. CONCLUSION

In this paper, we successfully designed a compact printed multiband antenna and simulate it on CST microwave studio and got three resonance frequency 2.57GHz, 3.52GHz, 5.51GHz due to which it is called as a multiband antenna. Dimensions of proposed antenna is 24×30×0.79 ($0.2\lambda_o \times 0.25\lambda_o \times 0.006\lambda_o$) which is very small to other references antenna and present antenna. Each stub in this proposed antenna is responsible for the particular resonance frequency. 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 have lots of feature like multiband, easy design, compact size, omnidirectional pattern and these are sufficient to use this antenna for Wi-MAX and WLAN.

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