Design of a Tri- Band Frequency Reconfigurable Monopole Antenna for GSM UMTS and Wi-Fi Applications

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Abstract
This paper highlights the proposed design for a Tri band Monopole antenna using a Rectangular complementary Split Ring Resonator and fed through a 50Ω feed over the FR4 substrate for GSM, UMTS and Wi-Fi applications. The novelty of this work lies in using the Rectangular Complementary Split ring resonator in the Ground plane for creating an additional tuning to the three frequency bands of interest. The proposed antenna resonates at 0.9GHz, 2.1GHz and 2.4 GHz covering the GSM, UMTS and Wi-Fi frequency bands repectively.The proposed Antenna resulted in a Gain of 5.3dBi, 6.32dBi and 8.0dBi for GSM, UMTS and Wi-Fi respectively. The proposed Antenna size is 100mm by 40mm. The results were validated using Antenna simulation tool Ansoft HFSSTM version15.0.

Keywords
Monopole Antenna, RCSRR, GSM, UMTS, Wi-Fi,Wi-Max.

I. Introduction

In recent years there has been a tremendous development in the field of wireless communications. With the explosive growth of different wireless standards supporting different frequencies, the Antennas used in these devices need to support a large number of wireless standards such as GSM,Wi-Fi,Wi-Max,UMTS to increase the data rate and improve the channel capacity. The current Antennas need to be replaced with reconfigurable Antennas that can dynamically change the radiation characteristics of the Antenna in real time such as operating frequency, pattern and polarization[1]. In [2], a novel 9-shaped multiband frequency reconfigurable monopole antenna was designed using PIN diodes for wireless applications on a 1.6 mm thick FR4 substrate loaded with a truncated metallic ground surface. The designed antenna operated for both single and dual frequency band based on switching states. When the switch was turned OFF, the antenna operatedin a single band mode namely Wi-Max, resonating at 3.5 GHz. Consequently when the switch was turned ON, the Antenna resonated at 2.45 GHz and 5.2 GHz .The proposed structure resulted in a gain of 1.48dBi, 2.47dBi and 3.26dBi for 2.45 GHz, 3.5 GHz and 5.2 GHz respectively. The proposed antenna showed a reasonable value of VSWR below 1.5 for all the three frequencies indicating a good impedance match.In [3], a tri-band monopole antenna for WLAN/Wi-Max applications was proposed which consists of a horizontal H-shaped patch, an L-shaped open ended stub loaded with deformed inverted T-shaped strip. The bandwidths of the proposed antenna were 340MHz (2.4-2.74 GHz), 340MHz (3.41-3.75 GHz) and 640MHz (5.24-5.88 GHz) for WLAN, lower Wi-Max and upper Wi-Max bands respectively. The Antenna Gain reported were 2.08dBi, 1.93dBi and 2.48dBi for 2.5GHz, 3.5GHz and 5.8GHz respectively. The proposed antenna resulted in a compact size along with nearly omnidirectional radiation characteristics. In [4], a novel compact dual-band monopole antenna using Defected Ground Structure (DGS) was presented for resonating at 2.5GHz and 3.5GHz respectively. The proposed antenna resulted in a Bandwidth of 400MHz and 530MHz for 2.5GHz and 3.5GHz respectively. The radiation pattern was nearly Omni directional with constant Gain in both the Frequency bands of interest. In [5], a compact triple-band printed monopole antenna for WLAN and WiMAX applications was proposed. The antenna consists of a rectangular patch with two straight open-ended slots whose position and size when changed, resulted in three different current paths for desired frequency bands. The antenna resulted in a -10dB impedance bandwidth of 100 MHz (2.4-2.5 GHz), 500 MHz (3.25-3.75 GHz), and 610 MHz (5.22-5.83 GHz), covering 2.4/5.2/5.8 GHz WLAN and 3.5/5.5 GHz WiMAX bands. The proposed Antenna resulted in a nearly Omni directional radiation pattern along with stable Gainsof 1.55dBi, 1.6dBi and 2.05dBi for 2.45GHz, 3.5GHz and 5.6GHz respectively. In [6], novel design of a dual-band Microstrip antenna loaded with Complementary Split Ring Resonators (CSRRs) resonating at 3.71GHz and 5.28GHz were presented. The resultant Antenna showed a Gain of 5.2dBi and 6.4dBi for 3.7GHz and 5.2GHz respectively. The dual band was realized by etching three CSRRs in the ground plane of a conventional patch antenna. The proposed antenna shows good performances at both resonant frequencies. The CSRRs embedded in the ground plane primarily affected the first operating band but showed minor effect on the second operating band. The radiation pattern was nearly omni directional in the 3.7GHz band and hemispherical for the 5.7GHz band. In [7], a dual band antenna operating in S band and C band were designed and developed with the help of metamaterial based planar structure. The proposed Antenna resonated at 2.7 and 5.7GHz respectively. The proposed structure resulted in a gain of 5.82dBi and 6.2dBi for the lower and the upper bands respectively. In [8], thedesign of dual-band metamaterial inspired microstrip antenna was presented. By etching metamaterial unit cells in the Ground plane resulted in the dual band operation at 3.5GHz and 5.5GHz respectively.The Antenna reported a gain of 4.5dBi and 5.0dBi for the lower and the upper bands respectively. In [9],an electrically small multiband monopole antenna based on complementary split-ring resonators, resonating at 2.5GHz,3.5GHz and 5.2GHz were designed using Rogers TMM3 substrate. The proposed Antenna resulted in a Gain of 1dBi, 1dBi and 4.0dBi for the lower, middle and the upper bands respectively. The radiation pattern was nearly omni directional in the E plane for all the three frequency bands of interest. In [10], a dual band meta material inspired patch Antenna with a U-slot resonating at 3.78GHz and 5.74GHz on a FR4 substrate was proposed. The proposed structure resulted in a Gain of 6.0 dBi for the lower frequency band of interest. In [11],a novel Frequency Reconfigurable U-Slot Antenna has been designed for SDR Application The proposed antenna, operates at three different frequencies namely 1.85 GHz, 1.9 GHz and 2.4 GHz respectively depending on the switching states of PIN diodes. The proposed Antenna reported a variation in Gain from 2.5dB to 1.7dB with the increase in the frequency.In [12], a new antenna structure that can be adjusted for both narrow band as well as Wideband Applications were investigated. The proposed antenna resonated at 800 MHz

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under narrow band operation with an impedance Bandwidth of 3.7%.The UWB Antenna design exhibited a 54% bandwidth from 2.6 GHz to 4.5GHz. The return loss was below -10 dB for all the frequency bands of interest. In [13], the authors had designed a Monopole Antenna on a FR4 substrate for Wi-Fi and WLAN Applications. The peak Gain remained at 2.04 dBi and 2.83dBi for Wi-Fi and WLAN Frequency Bands respectively. In [14], the authors designed a dual band Frequency reconfigurable Planar Dipole Antennaloaded with a Dual-Band Artificial Ground plane The proposed Antenna gave a Bandwidth of 12.5% and 6.7% at 2.4GHz and 5.2 GHz respectively. In [15], the authors designed a dual band parabolic slotted Ground plane for Wi-Fi and WLAN Applications. The proposed Antenna resulted in a Gain of 1.68dBi and 2.33 dBi for Wi-Fi and WLAN bandsrespectively.

II. Geometrical Specifications of the Antenna

The geometry of the proposed antenna is shown in fig. 1. The antenna is designed on a FR4 substrate with a relative permittivity is 4.4, thickness 1.6mm and dielectric loss tangent of 0.02. The dimensions of the proposed antenna are shown in Table 1. The length and width of the ground plane is selected such that the Antenna is able to resonate in dual band mode. The Length and width of the feed are properly optimized to get the required 50 Ohm impedance matching for the frequency bands of interest. The Rectangular complementary split ring resonator is placed on the Ground plane so as to cause additional tuning to the Frequency bands of interest and improve the return loss curve. The dimensions are appropriately optimized to get the desired frequency bands of interest.

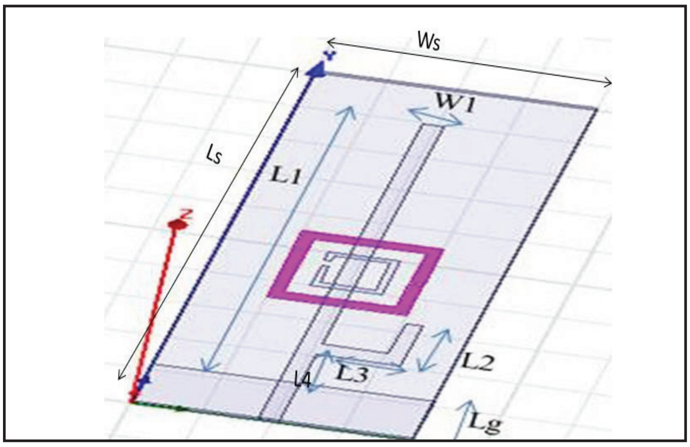

Fig. 1: Snapshot of the Proposed Antenna in HFSS

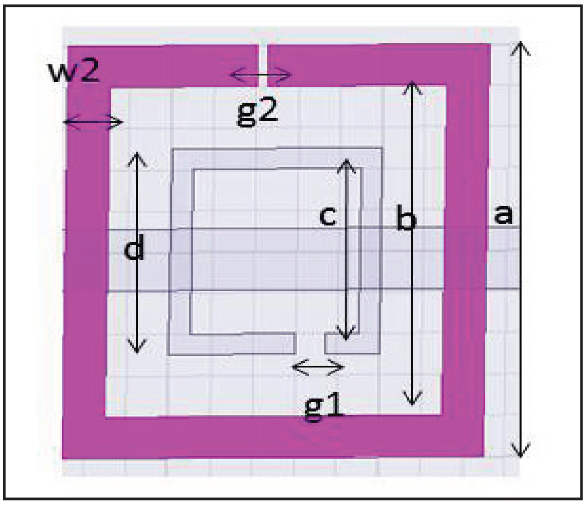

Fig. 2: Snapshot of the Proposed Rectangular Complementary Split Ring Resonatorin HFSS

Table 1: Showing the Geometrical Specifications of the Monopole Antenna

S.no.	Particulars	In mm
1	Feed length Lf	11.9mm
2	Feed width (W1)	3.0mm
3	Main Length(L1)	78.0mm
4	Side Length (L2+L3+L4))	50mm
5	Ground plane Length(Lg)	11.9mm
6	Substrate Length(Ls)	100mm
7	Substrate Width(Ws)	40.0mm
8	Substrate thickness (h)	1.6mm
9	Substrate Type	FR4
10	Substrate permittivity	4.4

Table 2: Showing the Geometrical Specifications of the Rectangular Complementary Split Ring Resonator Inserted in the Ground Plane

S.no.	Particulars	In mm
1	Outer length of outer SRR (a)	20.0mm
2	Inner Length of outer SRR(b)	8.0mm
3	Width of the outer SRR(W2)	2.0mm
4	Width of inner SRR(W1)	1.0mm
5	Inner Gap length of the inner SRR(g1)	1.4mm
6	Outer Gap Length of the outer SRR(g2)	0.5mm

III. Mathematical Modelling of the Antenna

A. Design of the Monopole Antenna

$$L1 = L_{0.9GHz} = \frac{\lambda g}{4} \quad (1)$$

Where L1=Length of the Main Monopole resonating at 0.9GHz.

λg = Guide wavelength.

$$\lambda g = \frac{\lambda_0}{\sqrt{\varepsilon_{reff}}} \quad (2)$$

Where ε_{reff} = Effective electrical permittivity of the dielectric substrate.

Where λ_0 = Free space wavelength corresponding to frequency of operation.

$$\varepsilon_{reff} = \left[\left(\frac{\varepsilon_r+1}{2}\right) + \left(\frac{\varepsilon_r-1}{2}\right)\left(1+\frac{12h}{W}\right)^{\frac{-1}{2}}\right] \quad (3)$$

Where ε_r Relative permittivity of the substrate.

W=Width of the Monopole Antenna

h= substrate thickness.

$$Z = \frac{60}{\sqrt{\varepsilon_{reff}}} ln\left[\frac{8h}{W} + \frac{W}{4h}\right] \quad (4)$$

Where Z=50 Ohms (port Impedance)

W=Width of the Monopole.

$$L2+L3+L4=L_{2.4GHz} = \frac{\lambda g}{4} \quad (5)$$

Where L2, L3 and L4 represent the side Lengths of the Monopole Section.

Ls=6h+ L (6)

Lw=6h+W (7)

Where Ls=Substrate Length

Ws=Substrate Width.

B. Design of Rectangular Complementary Split Ring Resonator

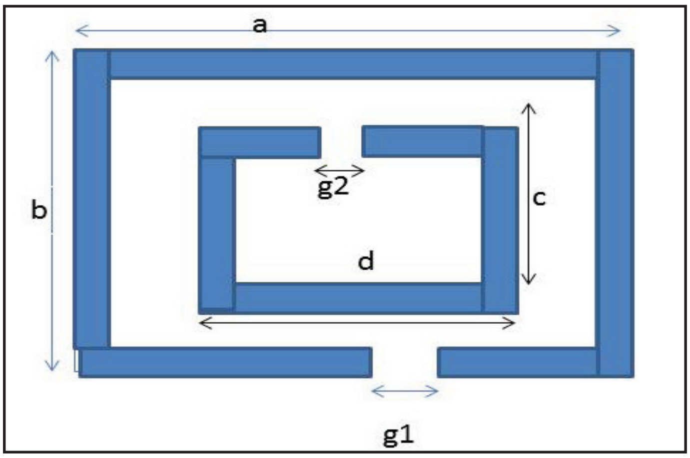

Fig. 3: Geometrical Specifications of Rectangular Complementary Split Ring Resonator

$$fr1 = \frac{a}{4(a + b - 2g1)\sqrt{\varepsilon_{reff}}} \quad (8)$$

Where c=Velocity of light=300000000m/sec
a= length of outer SRR
b= Width of the outer SRR
g1=gap width of the outer SRR
fr1=Resonant frequency corresponding to 0.9GHz

$$fr2 = \frac{d}{4(c + d - 2g2)\sqrt{\varepsilon_{reff}}} \quad (9)$$

c= length of inner SRR
d= Width of the inner SRR
g2=gap width of the inner SRR
fr2=Resonant frequency corresponding to 2.4GHz.

IV. Results and Discussions

The simulated return loss plot against resonance frequencies for three frequencies are as shown in fig. 4. The simulated return loss is well below -10 dB for all the bands.

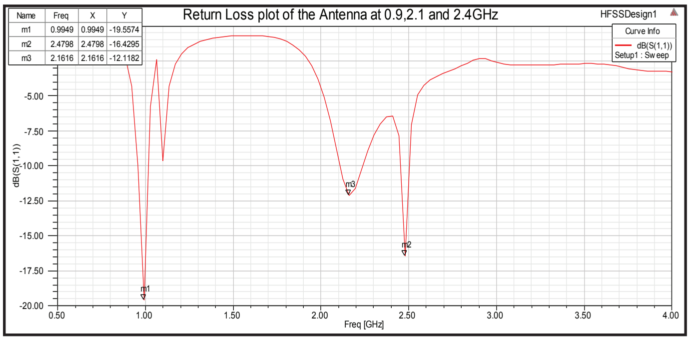

Fig. 4: Simulated Return Loss, S11 Results

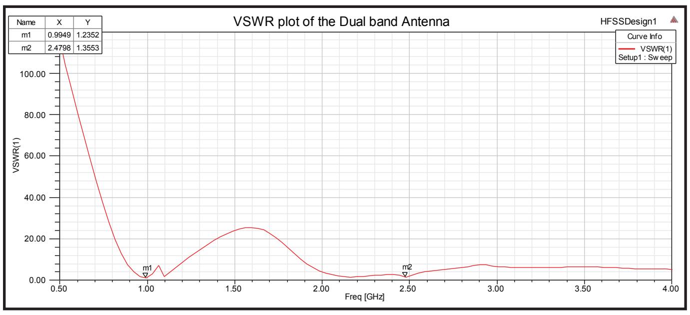

Fig. 5: VSWR Plot of the Antenna

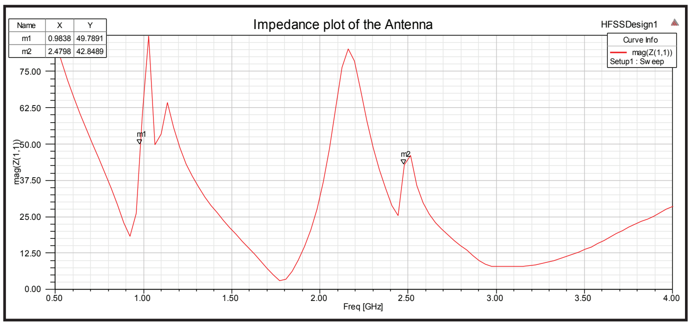

Fig. 6: Impedance Plot of the Antenna

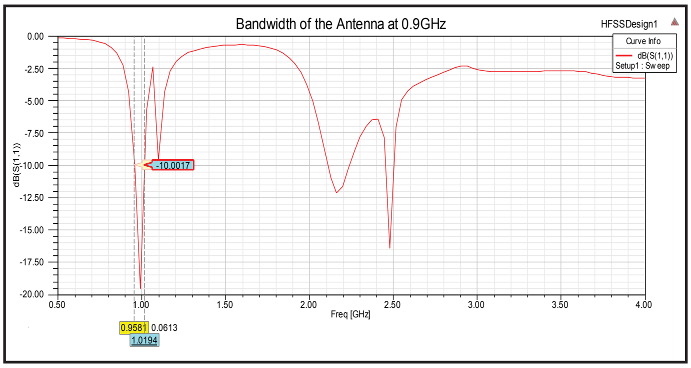

Fig. 7: Bandwidth of the Antennaat 0.9GHz

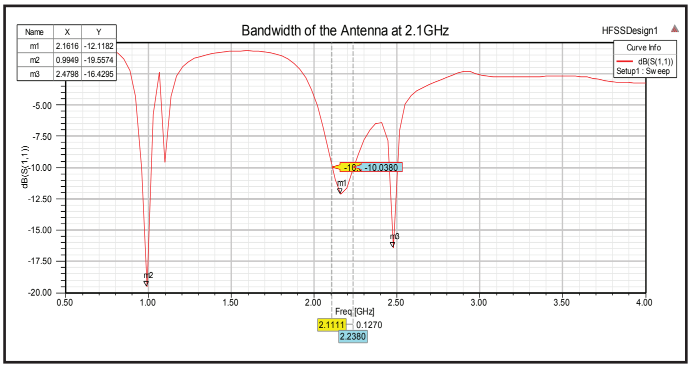

Fig. 8: Bandwidth of the Antenna at 2.1GHz

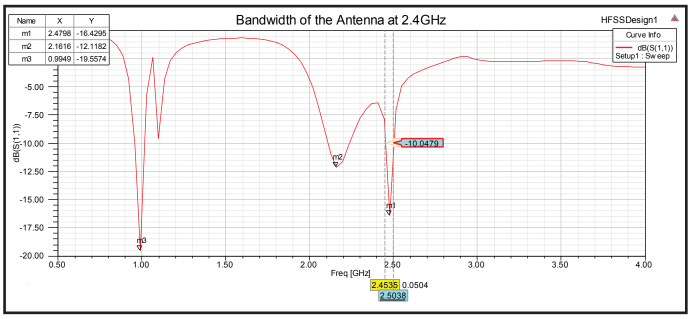

Fig. 9: Bandwidth of the Antenna at 2.4GHz

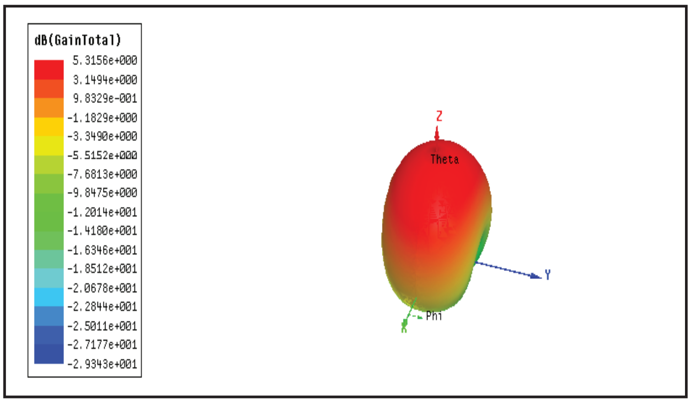

Fig. 10: Gain Plot of the Antenna at 0.9GHz

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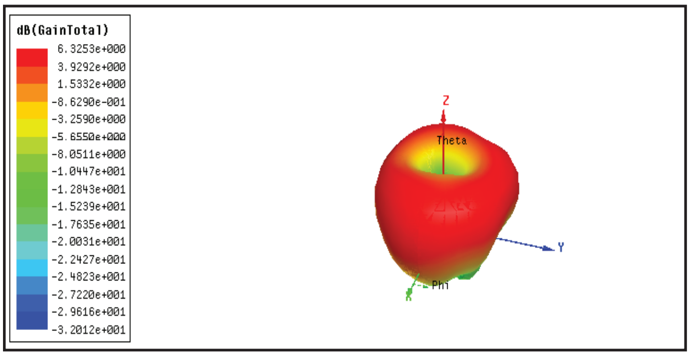

Fig. 11: Gain Plot of the Antenna at 2.1GHz

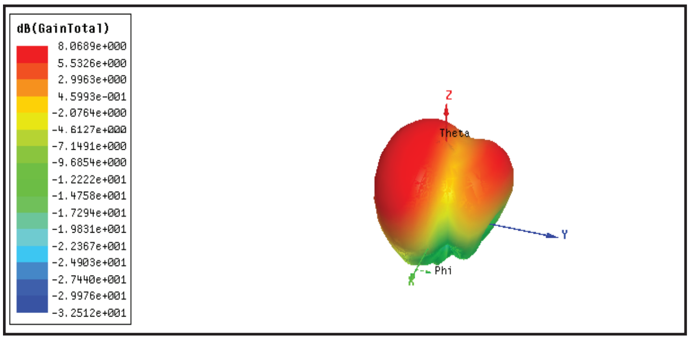

Fig. 12: Gain Plot of the Antenna at 2.4GHz

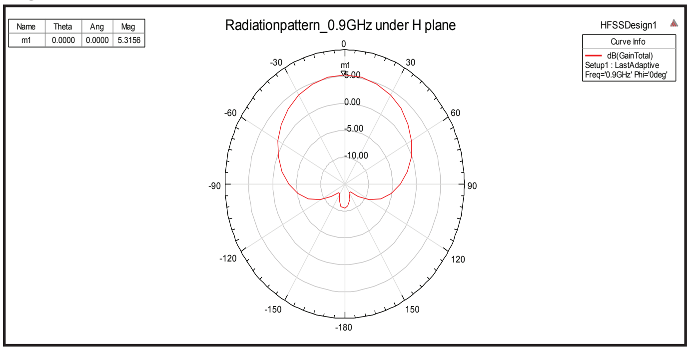

Fig. 13: Radiation Pattern of the Antenna Under H Plane for 0.9GHz

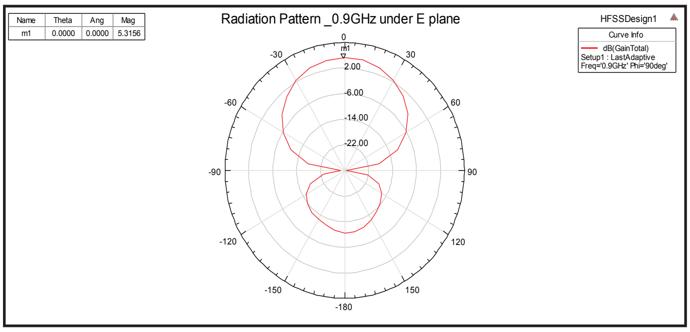

Fig. 14: Radiation Pattern of the Antenna Under E Plane for 0.9GHz

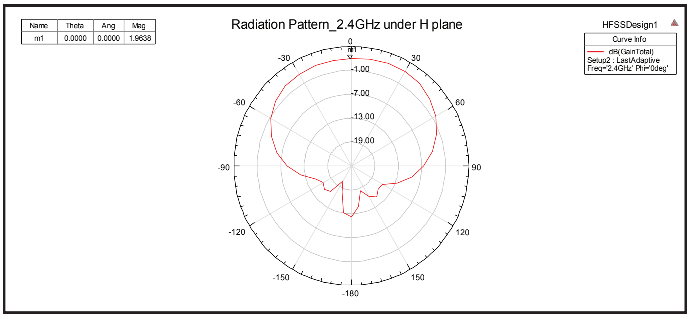

Fig. 15: Radiation Pattern of the Antenna Under H Plane for 2.4GHz

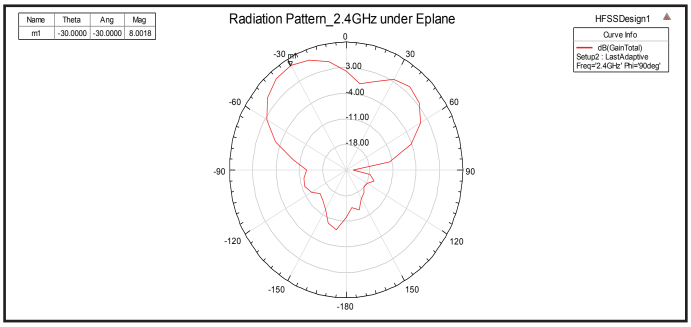

Fig. 16: Radiation Pattern of the Antenna Under E Plane for 2.4GHz

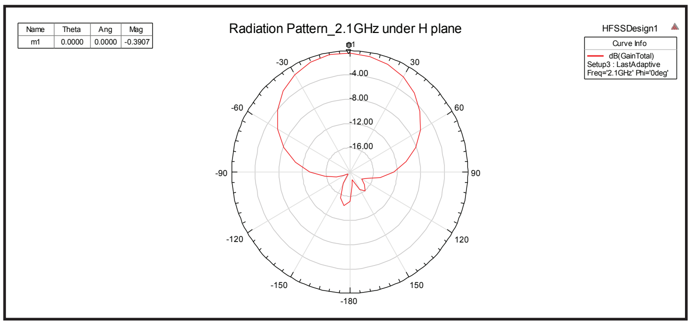

Fig. 17: Radiation Pattern of the Antenna Under H Plane at 2.1GHz.

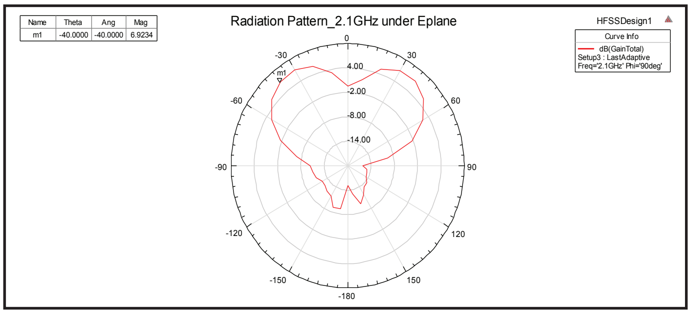

Fig. 18: Radiation Pattern of the Antenna under E Plane at 2.1GHz.

Table 3: Summarization of the Various Antenna Parameters Computed for the Three Frequency Bands of Interest

S. No	Antenna parameters	f1 0..9 GHz	f2 2.1 GHz	f3 2.4 GHz
1	Return Loss	-16.4dB	-12.1dB	-9.5dB
2	VSWR	1.0	1.3	1.5
3	Gain	5.31dB	6.32dB	8.0dB
4	Bandwidth	61.0 MHz	127.0 MHz	50.0 MHz
5	Port Impedance	49.0	62.0	42.5

V. Conclusion

From the results obtained it is clear that the return loss value is very low for the lower frequency band of interest namely 0.9GHz which is close to -16.4dB indicating that a good impedance match of 49 Ohms for the frequency band of interest. The VSWR value is close to 1.0 which indicates that the feed is properly matched to the Antenna. The Gains of the proposed Antenna reported a linearly increase from 5.3dB to 8.0dB when we move from lower band to higher bands signifying that as the frequency of operation increases ,subsequently the Gain also increases. The bandwidth of the Antenna reported is 0.127GHz at 2.1 GHz,which is the highest compared to other frequency bands of interest.Further the radiation pattern needs to be made more omni directional so that our proposed Antenna becomes the perfect solution for realizing the three Frequency bands of interest.

VI. Future Scope

The proposed Antenna Gain can be improved to increase the distance of coverage.EBG structures can be investigated to improve the Gain and Bandwidth for all the three frequency bands of interest.For cognitive Radio based applications where multiple narrow frequency bands are required for transmitting and receiving the information,our proposed Antenna can be a solution.

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