Gap coupled Orthogonal Shorting Dual Band Multilayer Micro-strip patch antenna for C-Band Application

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Abstract

In this paper, Multilayer dual band Micro-strip patch antenna for C-Band application is proposed. This antenna is composed of the combination of multilayer FR-4 – air –FR-4 materials. The multilayer has been used to enhance the operating bandwidth of the antenna. The compactness, circular polarization and dual band characteristics have been improved by orthogonal shorting pin. The optimum dimension of ground plane has selected to 0. 5λ for reduction in the reflected wave between layers. This antenna array has configured by using the concept of stack geometry. The simulated results indicate that optimum impedance matching and ≤ 3dB, axial ratio bandwidth have achieved in two bands, 4GHz to 5.25 GHz (27%) in the first band and 5.5GHz to 6.75GHz (20%) in the second band. The propose antenna can be used in the sub-6 GHz 5G-Band (4.8-5 GHz bands), Wi-Max and satellite communication.

Keywords: Multilayer Microstrip patch antenna, orthogonal shorting pin, Gap coupled. C-Band application

I. INTRODUCTION

A Micro-Strip antenna has many advantages such as light weight, low profile, small volume, and flexibility in installation. All the features of the Micro-strip antenna insist researchers to investigate various configurations to satisfy recent scenario requirements. However, it usually has few disadvantages of low gain, narrow bandwidth and the axial ratio bandwidth could not simultaneously increase with the impedance bandwidth of the antenna, All of these are bound the applications of Micro-strip antenna. The Micro-strip antenna has been using versatile in various communication like mobile Communication, satellite communication, Bluetooth, Wi-Fi and many more. Many numbers of researchers worked to improve the performance of antenna in past decades. At the time of invention of antenna it was designed on single layer with larger size. However, in past decades, many approaches have invented to increase the operating bandwidth of the antenna.

Many excellent methods have been proposed to improve the operating bandwidth of a Micro-strip patch antenna. First, the positive and negative mutual coupling is a part of antenna designing. Many researchers work on different techniques to improve the negative mutual coupling and improve the pass band response to provide wide impedance bandwidth [1-2].

Second the Various shapes of slots U-Slot, L-Slot, meander slots, H –slot and C-Slot are used to improve the operating bandwidth of antenna [3 – 6]. Third The shorting post terminating on the left and right side of the walls, this technique has been used to improve the bandwidth of the antenna 13.2% (|S11 ≤ 10 dB) (5.13 GHz – 5.85 GHz) with 1. 29λ_0 x 0. 73λ_0 x 0.036 λ_0 of design dimension.

In today scenario needed such type of antenna that will be operated over broadband and have compact in size. In 20TH century the explosive growth of the wireless radio a communication system is presently observed in the microwave band. To meet wide impedance bandwidth, various inventions have been made by researchers, This includes the use of defected grounded structures (DGS) [8], parasitic patches [22-24], stack patch geometry[20-21], slotted meander-line resonator (SMLR) [12], the split ring and complementary split ring resonators (SRR & CSRR), electromagnetic band gap (EBG) structures [7], via hole techniques, shorting pin and shorting post, various feeding techniques, meta-materials [9-10], a combination of the above [13-14]. The rapid development of 5G communication technology has stimulated many new opportunities for telecommunication vendors as well as imposing many technology challenges. In 2017, the sub-6 GHz band, i.e., 3.3-3.6 GHz and 4.8-5 GHz bands, has been officially announced in China for indoor and outdoor 5G services [15].

II. DESIGN CONSIDER FOR MULTILAYER MICROSTRIP ANTENNA

A Multilayer Microstrip Antenna, designed at 5.8 GHz resonant frequency using the transmission line model. In this design procedure of the Microstrip antenna, the desired resonant frequency, thickness and dielectric constant of the substrate are known and selected initially. The L and W of the rectangular patch antenna calculated using transmission line model.

The ε_{eff} (effective dielectric constant) calculated in terms of ε_{eq} and ε_{eq1}, all calculation did after considering the fringing effect.

For designing of antenna used FR-4 and air dielectric substrate. FR-4 dielectric constant has ε_r=4. 3, h=59 mil and tanδ=. 019. Air dielectric constant has ε_r=1, Δ=3 mil (air gap between layer) and tanδ=0.

The design completed in combination of FR4-air gap – FR-4, Total height is h= 121mil. All specifications of designing are shown in below table. The IE3D™ full-wave electromagnetic simulator is used for design and simulation purpose. This simulator work on the principle of method of moments. All the parameters return loss plot, VSWR, current distributions, radiation patterns, etc., of the Patch antenna can be easily analyzed in IE3D™ simulator.

A. Transmission line model for Multilayer micro-strip antenna

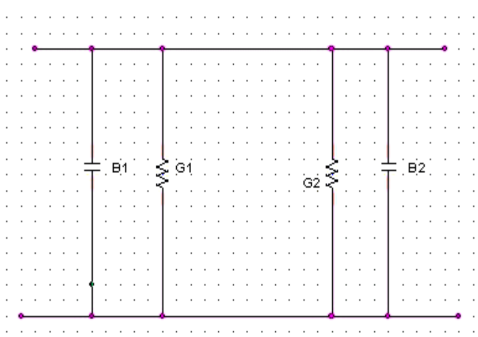


Figure 1 Transmission line model

For the fundamental mode TM_{10} , the length L of the patch antenna should be slightly less than λ/2, where λ is the wavelength in the dielectric medium. Here λ is equal to

$$\lambda = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \qquad (1)$$

Where ε_{eff} is the effective dielectric constant and λ_o is the free space wavelength of the Patch. The value ε_{eff} is slightly less than ε_r, because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also in the air .

The mathematical analysis has done in the following steps

Step 1. Calculated the value of ε_{eff} For multilayer using the transmission line model.

$$\varepsilon_{eq1} \cong \frac{\varepsilon_{r_1}\varepsilon_{r_2} \times (h_2 + \Delta)}{\left(\varepsilon_{r_1}\varepsilon_{r_2}\ \Delta + (h_2 + \Delta)\right)} \qquad (2)$$

ε_{eq1} = 3.56

ε_{eq1} Is a dielectric constant due to h2 and Δ (height of air gap),

$$\varepsilon_{eq2} \cong \frac{\varepsilon_{r_3}\varepsilon_{eq1} \times (h_1 + h_2 + \Delta)}{\left(\varepsilon_{r_3}\varepsilon_{eq1} (\Delta + h_1) + (h_1 + h_2 + \Delta)\right)} \qquad (3)$$

ε_{r1}=1, ε_{r2}=4.3, ε_{r3}=4.3

ε_{eq2} =1.7310

Where ε_{eq2} Is the dielectric constant due to h_1, h_2 and Δ. Effective dielectric constant ε_{eff} is calculated in terms of ε_{eq2}, Total height h=h1+h2+Δ and Width of patch antenna

$$\varepsilon_{eff} = \frac{\varepsilon_{eq2}+1}{2} + \frac{\varepsilon_{eq2}-1}{2}\left[1+\frac{10h}{w}\right]^{-\frac{1}{2}}$$

(4)

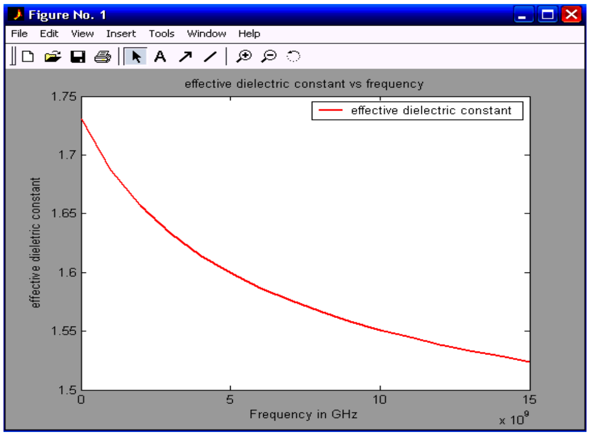


Figure 2 Effective Dielectric Constant Vs Frequency

Step2. Calculated the length of patch antenna in terms of L_e and ΔL

$$\Delta L = \frac{h}{\sqrt{\varepsilon_{eff}}} \qquad (5)$$

$$L_e = \frac{c}{2 f_0 \sqrt{\varepsilon_{eff}}} \qquad (6)$$

(3.2.5)

$$L_e = L + 2\Delta \qquad (7)$$

All the graphs are showing the variation of micro-strip antenna parameters L, W and effective dielectric constant with respect to frequency. The MATLAB tool used for demonstrating all the parameter variations

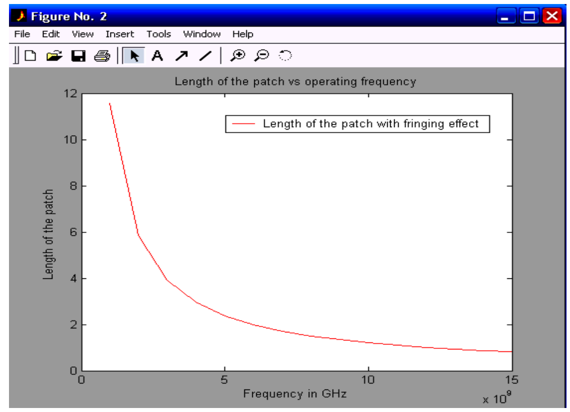


Figure 3 Length of the Patch Vs Frequency

Step3. Calculated the width of patch antenna in terms of We and ΔW

$$W = \frac{c}{2 f_o \sqrt{\frac{\varepsilon_{eff}+1}{2}}}$$

(8)

$$W_e = W + 2\Delta W$$

(9)

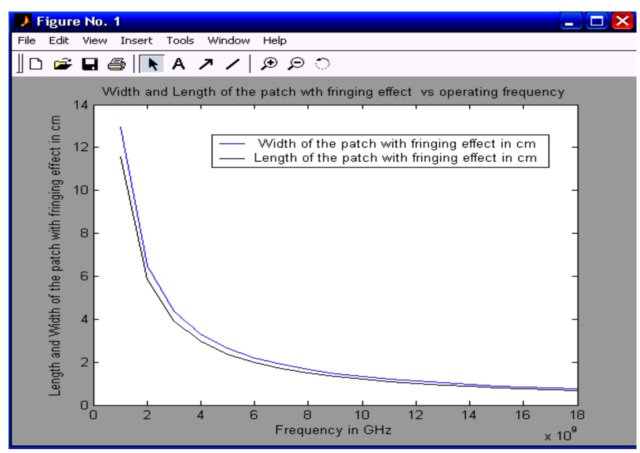


Figure 4 Widths and Length of the Patch vs. Frequency

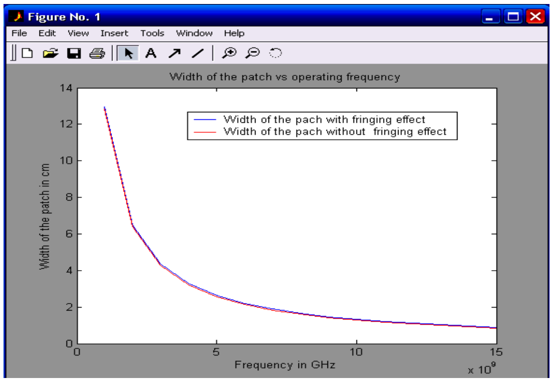


Figure 5 Width of the Patch vs. Frequency

Step 4. Calculate the radiation resistance of an antenna

$$R_r = 120\left(\frac{\lambda_o}{W_e}\right) \quad W_e > 2\lambda_o \tag{10}$$

$$R_r = \frac{1}{\left[\frac{W_e}{120\lambda_o} - \frac{1}{60\pi^2}\right]} \quad .35\lambda_o < W_e <= 2\lambda o \tag{11}$$

$$R_r = 90\left(\frac{\lambda_o}{W_e}\right)^2 \quad .35\lambda_o <= W_e, \tag{12}$$

Instead of using the above expression, the following single line formula could be used to better Efficiency

$$R_r = \frac{w_e^2}{6\left(60+w_e^2\right)} \tag{13}$$

$$k_o = \frac{2\pi}{\lambda_o} \tag{13.1}$$

Where $w_e = k_o W_e$,

$k_o =$ Free space wave propagation.

Step 5. Calculate the resonance input resistance of the antenna

$$R_{in} = \mathrm{R_e} \sin^2\left(\frac{\pi x}{L}\right) \tag{14}$$

$$\mathrm{R_e} = \frac{1}{2\left(G_r + G_m\right)}$$

$$F_g = J_o(l) + \frac{\rho^2}{24-\rho^2} J_2(l) \tag{15}$$

$$l = k_o(L + \Delta L) \tag{16}$$

$$\rho = k_o \Delta L \tag{17}$$

J_o (l) and J_2 (l) are zero and second-order Bessel functions, respectively. Where G_r is the slot conductance and G_m is the mutual conductance Substrate thickness should be chosen as large as possible to maximize bandwidth, but not so large to minimize the risk of surface wave excitation. The substrate should also have a low dielectric constant in order to achieve high efficiency. Since the effective length of the patch has been extended by ΔL on each side, the effective length of the patch is expressed as

Step 6. Calculated the return loss, VSWR and reflection coefficient

$$\textbf{Reflection coefficient} = \frac{\text{Rin} - \text{Ro}}{\text{Rin} + \text{Ro}}$$

$$\text{RL} = 20\log_{10}(\textbf{Reflection coefficient})$$

$$VSWR = \frac{1 + \text{Reflection coefficient}}{1 - \text{Reflection coefficient}}$$

Step 7. Calculation of elevation and azimuth electric field

I. Elevation Field Calculation

$$E_\theta = \frac{\sin\left(\frac{k_o \Delta L \sin(\theta)}{2}\right)}{\frac{k_o \Delta L \sin(\theta)}{2}} \cos\left(\frac{k_o \left(L + \Delta L\right)}{2} \sin\theta\right)$$

(15)

II. Azimuth Field Calculation

$$E_\phi = \frac{\sin\left(\frac{k_o W_e}{2} \sin(\theta)\right)}{\frac{k_o W_e}{2} \sin(\theta)} \cos(\theta)$$

(16)

Step 8. Calculation of bandwidth, equivalent capacitor and equivalent inductor

$$C = \varepsilon_o \varepsilon_{eq2} \frac{WL}{h} \qquad (17)$$

$$BW \cong \frac{\text{h}}{\left(\sqrt{\varepsilon_{eff}}\right)}$$

(18)

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

(19)

In below section specified flow chart for theoretical analysis of multilayer microstrip antenna

B. Flow Chart Based On Usual Design Procedure for Rectangular Patch Antenna

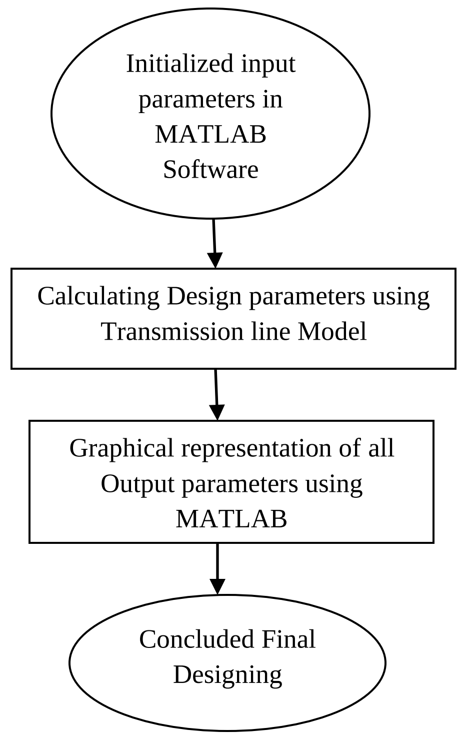


Figure 6 Flow chart for analyses of rectangular patch antenna

This flow chart shows the step of MATLAB analyses from start point to the last point. Initially the operating frequency and properties of dielectric materials are defined. The MATLAB and transmission line models are used to analyze the all parametric variations from first step to seven steps. All the graphs are generated. The effective dielectric constant for multilayer structure calculated. This flow chart has shown how the micro-strip patch antenna is designed in MATLAB. After doing all the analysis in MATLAB, they concluded that how the impedance bandwidth of an antenna will improve using multilayer structure and effective dielectric constant.

3.4 Calculation summary table

S	Designing Parameters	Theoretical Value
1	Width Of Top Patch	446 mil
2	Length Of Top Patch	411 mil
3	Width Of Ground Plan	1172 mil
4	Length Of Ground Plan	1137 mil
5	Feeding Type	Coaxial
6	Position Of Feeding	X=-125mil, y=-199
7	Used Dielectric Material	FR-4, AIR
8	Loss Tangent Used	tanδ=.019, tanδ=0
9	Total Height of Antenna	121mil

C. Design of Proposed Micro-strip Patch Antenna

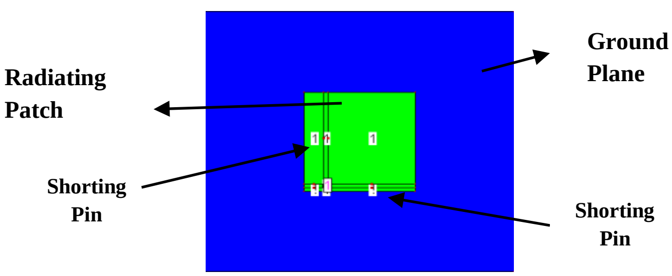


Figure 7 Propose design Multilayer

Firstly, using the MATLAB analyzed the designing parameters of Micro-strip patch antenna has shown in section –II. Conventional Micro-strip patch antenna designed at the operating frequency 5.8 GHz. The optimum dimension of ground plan is considered 0.5λ. to reduce mutual coupling between the layer therefore impedance matching to be increased in C-Band. As per as the theory of broadband antenna the height should be effective and low dielectric constant should be minimum for that objective multilayer geometry with appropriate air is chosen. The air gap exists in the electromagnetic band gap between the layer so that large quantities of signal couple to patch. The orthogonal shortest is used in proposing design to generate dual band and gives the compactness of total geometry. Because of shorting pin surface current in radiating patch increase, therefore this antenna to be used in lower frequency. The horizontal shorting pin supports to higher frequency 5.5GHz to 6.75GHz in this band surface current increase sharply so that the reduction of reflections is found and provide 20% impedance matching bandwidth. On the other hand vertical shorting pin improves the surface current at low frequency 4GHz to 5.25 GHz in this band surface current increase sharply so that the reduction of reflections is found and provide 27% impedance matching bandwidth. Hence the orthogonal shorting pins give a dual band response. The propose antenna and its model has shown in figure 7 & 8. For designing and simulation IE3D^{TM} Simulator used. For the designing low cost FR-4 Dielectric material is used.

$$BW \cong \frac{h}{\left(\sqrt{\varepsilon_{eff}}\right)}$$

The multilayer structure reconfiurge the dielectric constant, therefore the inductance and capacitance of geometry or reconfigure because of this effect total impedance bandwidth is optimized and achieved broad bandwidth in dual band. The optimal ratio of inductance and capacitance are found using equation (17) and (20), the different operating modes are found with respect to operating frequency using the equation (19).

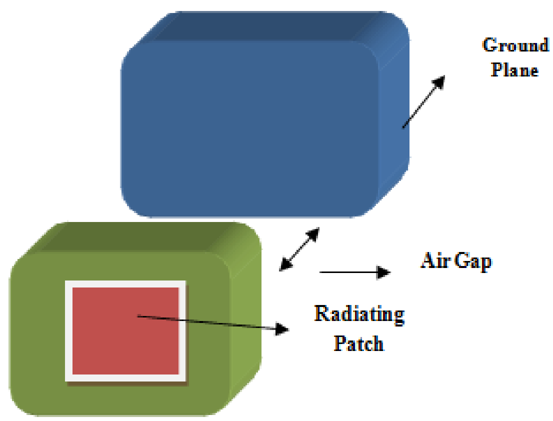


Figure 8 Propose Model

$$C = \varepsilon_o \varepsilon_{eq2} \frac{WL}{h} \qquad (17)$$

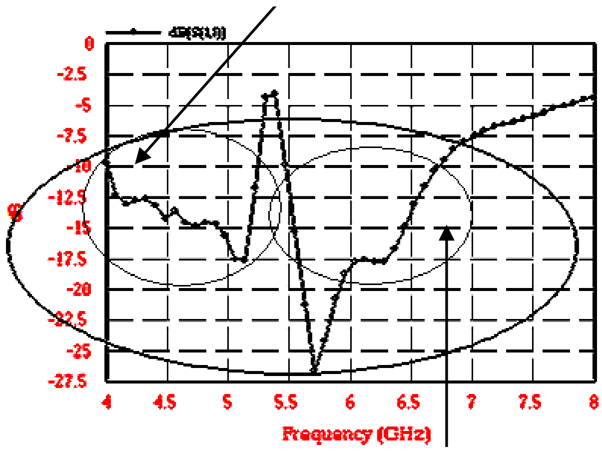
$$f_o = \frac{1}{\sqrt{L_{nd} C}} \qquad (20)$$

$$f_o = \frac{c}{2\sqrt{\varepsilon_{eff}}}\left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2\right]^{\frac{1}{2}} \quad (19)$$

III. RESULTS AND DISCUSSION

A. Return losses vs. Frequency

27%, -10 dB impedance bandwidth of C-Band



20 %, - 10 dB impedance bandwidth of C-Band

Figure 9 Return losses vs. Frequency

The return losses Vs Frequency analysis has shown in figure 9. From the simulation of multilayer microstrip antenna patch in IE3D simulator, obtained two bands of -10 dB impedance bandwidth in C-Band. First band from 4GHz to 5.25 GHz of 27% and second band 5.5GHz to 6.75GHz of 20%. From this analysis this antenna is used in C-Band application. This antenna will use the sub-6 GHz 5G-Band (4.8-5 GHz bands). Also used for Wi-Max and satellite communication.

B. VSWR vs. Frequency

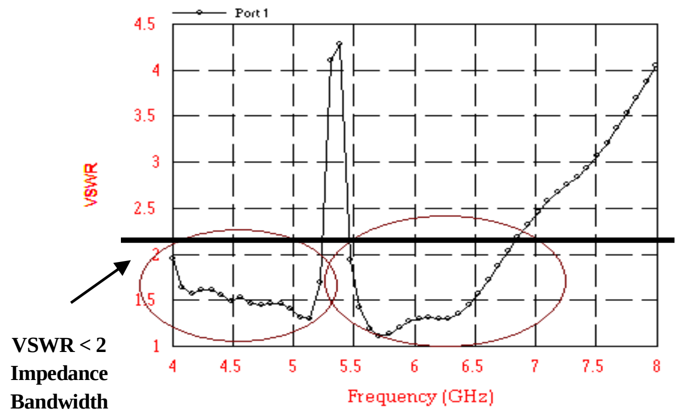


Figure 10 VSWR vs. Frequency

The VSWR vs. Frequency analysis has shown in figure 10 and obtained 1.25GHz and 1.25GHz bandwidth slot of VSWR < 2, between 4 to 5.25GHz and 5.5GHz to 6.75GHz respectively.

C. Smith chart

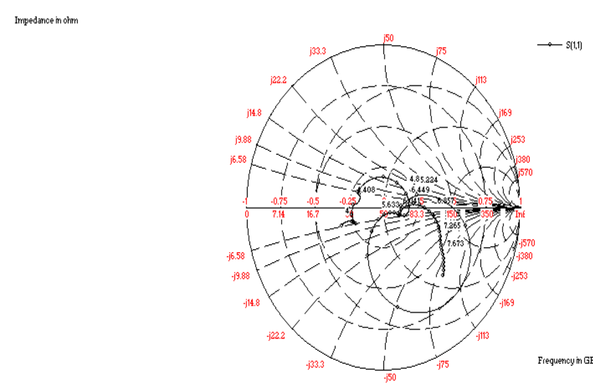


Figure 11 Smith Chart

The figure 11 shows the smith chart for proposing antenna. Two small circles are showing impedance matching for dual where optimum impedance matching exists. While below the negative axis the upper circle shows the capacitive part is dominating in the impedance of antenna for other bands of frequency and there will be also a chance to further improvement in operating bandwidth of the future optimization technique of capacitance.

D. Directivity vs. Frequency

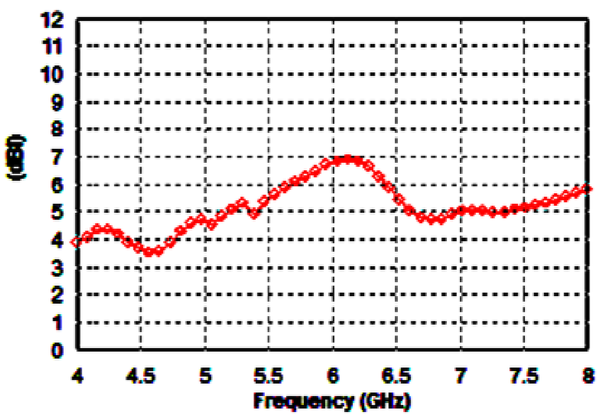


Figure 12 Directivity vs. Frequency

The figure 12 shows the directivity vs frequency response. From this graph directivity achieved up to 7dBi at 6 GHz frequency. While for other frequencies the directivity of the antenna are shown in the graph

E. **Gain vs. Frequency**

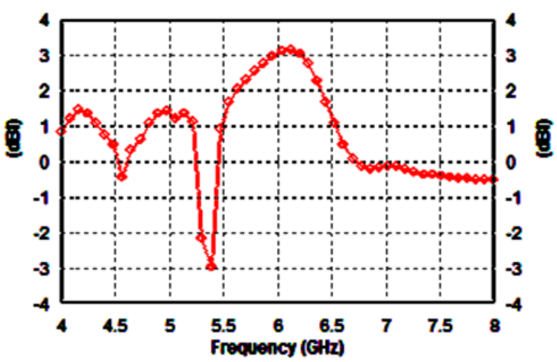


Figure 13 Gain vs. Frequency

An Omni directional gain of the antenna has shown in figure 13.

H. **Axial ratio vs. Frequency**

The axial ratio of an antenna in have shown figure 14. The axial ratio achieved between 0.5 to 1.18dBi. The ≤ 3dB, axial ratio bandwidth obtained in both dual band where return losses are less than -10dB, therefore in dual band the proposed antenna are giving circular polarization. Hence the propose antenna has the characteristics of circular polarization.

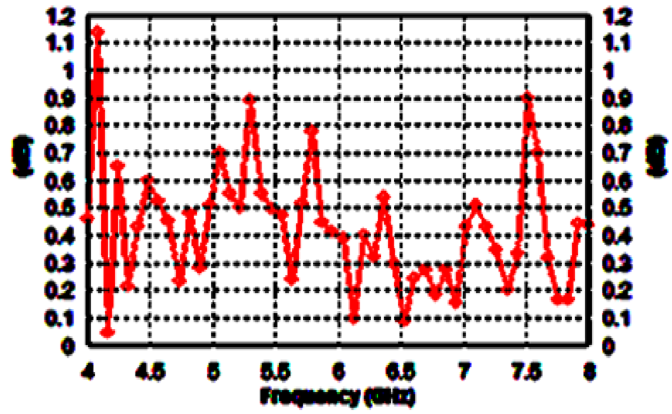


Figure 14. Axial ratio vs. Frequency

I. Radiation Pattern of Antenna

A. Elevation Radiation Pattern of Antenna

The figure 15 shows the 2D radiation pattern of the antenna at the designed frequency for different Φ (azimuth angle) and ϴ (Elevation angle). The radiation pattern depicted the radiation characteristics of antenna design

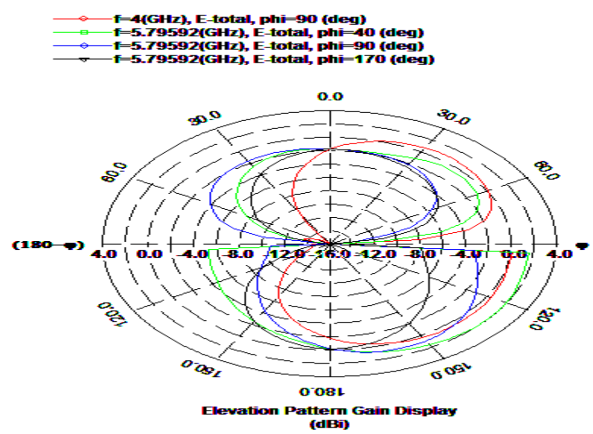


Figure 15 Elevation Radiation Pattern at φ = 90, θ= 40,170

B. Azimuth Radiation Pattern of Antenna

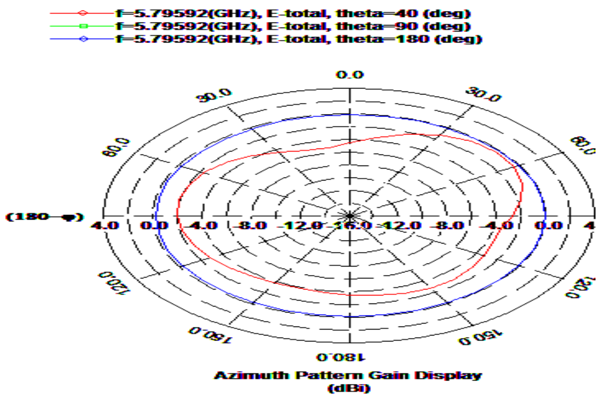


Figure 16. Azimuth Radiation Pattern of Antenna at θ = 40, 90, 180

The radiation characteristics of the propose antenna in the ϕ direction has shown in fig 16 at different frequencies.

IV. CONCLUSION

This paper has been successfully demonstrated dual notches in C-Band using Multilayer, air gap and orthogonal shorting pins techniques.

The proposed work concluded that the propose antenna is a dual band circular polarized and simultaneously obtaining the ≤ 3dB, axial ratio bandwidth and -10dB, impedance bandwidth.

In the results and discussion section, the proposed antenna has achieved 20% of -10 dB impedance bandwidth from 4GHz to 5.25 GHz and 27% -10 dB impedance bandwidth from 5.5GHz to 6.75GHz.

The axial ratio bandwidth analysis indicated that this antenna is highly circular polarized and could be used in the circular polarization application. The propose antenna could be used in the sub-6 GHz 5G-Band (4.8-5 GHz bands), WI-Max and satellite communication.

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