Micro-Strip Antenna Design for 5G Sub 6 GHz and Wi-Fi Applications

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Abstract: ***In this paper The Proposed antenna is designed using two C type Slot inserted in top layer patch and five vertical slots design on middle patch. Dual Band Multilayer Micro-strip antenna using LTCC (Low Temperature Ceramic co-efficient) and FR-4 materials for C-X- Band applications has been designed. The properties of two materials LTCC and FR-4 substrates have been mixed to improve the radiation characteristics and return loss of design antenna from 4 to 6GHz. This antenna is used to improve the return loss and operating impedance bandwidth. The impedance bandwidth S11 • - 10dB achieves 34% of C-Band from 4.1 to 5.8 GHz and can be used in Wi-Fi bands and 5G sub 6 GHz. The Axial ratio bandwidth achieved • 1dB, so that design antenna included circular polarization characteristics from 4 to 6GHz. This proposed design provided return losses from - 10dB, to -52 dB. In this work has been simultaneously improved impedance bandwidth and axial ratio bandwidth. The linear and circular directivity has been improved simultaneously.***

Keywords: 5G sub 6 GHz, Hybrid material, Hybrid slotting techniques. Beam forming

1. Introduction

When the fifth generation (5G) technology is upcoming technology wireless communication system in many countries. The antenna design for 5G technology is on most demanded for the latest wireless applications, such as multimedia devices, mobile communication, satellite communication, internet of thing, advanced wireless systems and so on [1]–[3]. Broad band beam focusing antenna for 5G sub 6 GHz WiFi communication systems and have many possibility of upcoming research in the field of 5G Micro-strip Patch antenna in terms of compactness and broadness. However, a in today exits Micro-strip patch antenna has many limitation of less operating bandwidth, axial ratio bandwidth and impedance bandwidth cannot improve simultaneously.

In paper [2] discussed about the out of pass coupling concept for improving the operating bandwidth. In [3] presented varies methods to improve the operating impedance bandwidth. The optimization technique of Micro-strip patch antenna discussed in [4] using parasitic patch array concept. Multilayer Slit Loaded Gap coupled Orthogonal Shorting Post technique had been used in Micro-strip Antenna to improve L-Band operating bandwidth [5]. Some researchers has used Hybrid Modeling [6], E-shape Micro-strip patch [7], Radome effect[8], Mutual Coupling Reduction[9], Slit, Strip, and Loop Loading Techniques [10], U-Slot [11-14], V-Slot these techniques have been used to improve the operating bandwidth of antenna. Other more interesting techniques have been invented to enhance the operating impedance and axial ratio bandwidth, by stacked patches geometry [16], parasitic resonators [17], and capacitive coupled feed technique [18], in today scenario most prefer technique was meta-material, meta material is a artificial material is used to reconfigure the electrical parameters of design antenna and significantly improve the operating impedance bandwidth [19]–[20]. [6] In some papers included electromagnetic band gap for further enhancement of the operating impedance bandwidth of antenna. In this work has been simultaneously improved impedance bandwidth and axial ratio bandwidth. The linear and circular directivity has been improved simultaneously.

2. Mathematical Analysis

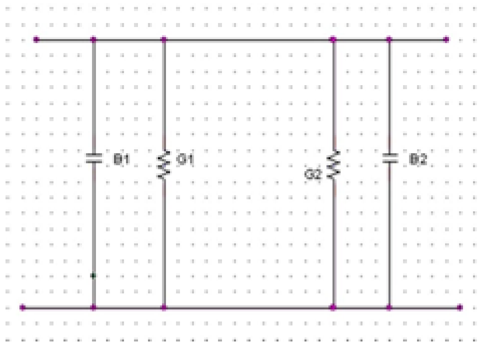

Figure 1: Transmission line model

The effective length of the path should be slightly less than λ/2, where λ is the wavelength in the dielectric medium. Here λ is equal to

$$\lambda = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}$$

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 , The LTCC and

FR-4 dielectric materials are used to reduce the effective dielectric constant and improve the bandwidth of the design antenna.

The mathematical analysis has done in the following steps

Step 1. Calculate the value of ε_{eff} for multilayer structure using the transmission line model.

$$\varepsilon_{eq} \cong \frac{\varepsilon_{r_1}\varepsilon_{r_2} \times (h_2 + h_1)}{(\varepsilon_{r_1}\varepsilon_{r_2} h_1 + (h_2 + h_1))} \quad (2)$$

Where ε_{eq} is the dielectric constant due to h_1 and h_2. Effective dielectric constant ε_{eff} is calculated in terms of ε_{eq}.

$$\varepsilon_{eff} = \frac{\varepsilon_{eq}+1}{2} + \frac{\varepsilon_{eq}-1}{2}\left[1+\frac{10h}{w}\right]^{-\frac{1}{2}} \quad (3)$$

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

$$\Delta L = \frac{h}{\sqrt{\varepsilon_{eff}}} \quad (4)$$

$$L_e = \frac{c}{2 f_0 \sqrt{\varepsilon_{eff}}} \quad (5)$$

$$L_e = L + 2\Delta \quad (6)$$

Step 3. It involves calculation of the width of patch antenna in terms of We and ΔW

$$W = \frac{c}{2 f_o \sqrt{\frac{\varepsilon_{eff}+1}{2}}} \quad (7)$$

$$W_e = W + 2\Delta W \quad (8)$$

Step 4. It involves calculation of the radiation resistance of an antenna

$$R_r = 120\left(\frac{\lambda_o}{W_e}\right) \quad W_e > 2\lambda_o \quad (9)$$

$$R_r = \frac{1}{\left[\frac{W_e}{120\lambda_o} - \frac{1}{60\pi^2}\right]} \quad .35\lambda_o < W_e <= 2\lambda o \quad (10)$$

$$R_r = 90\left(\frac{\lambda_o}{W_e}\right)^2 \quad .35\lambda_o <= W_e, \quad (11)$$

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

$$R_r = \frac{w_e^2}{6(60 + w_e^2)} \quad (12)$$

$$k_o = \frac{2\pi}{\lambda_o} \quad (12.1)$$

Where $w_e = k_o W_e$,
$k_o =$ Free space wave propagation.

Step 5. It involves calculation of the resonance input resistance of the antenna

$$R_{in} = R_e \sin^2\left(\frac{\pi x}{L}\right) \quad (13)$$

$$R_e = \frac{1}{2(G_r + G_m)} \quad F_g = J_o(l) + \frac{\rho^2}{24-\rho^2} J_2(l) \quad (14)$$

$$l = k_o(L + \Delta L) \quad (15)$$

$$\rho = k_o \Delta L \quad (16)$$

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.

Step 6. It involves calculation of the return loss, VSWR and reflection coefficient

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

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

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

Step 7: It involves calculation of the elevation and azimuth electric field

I. Elevation Field Calculation

$$E_\theta = \frac{\sin\left(\frac{k_o \Delta L \sin(\theta)}{2}\right)}{\frac{k_o \Delta L \sin(\theta)}{2}} \cos\left(\frac{k_o(L+\Delta L)}{2} \sin\theta\right) \quad (17)$$

The equations (18) and (19) are used to calculate the electric fields in θ and ϕ direction and plot the radiation pattern for characterization of radiation property of design antenna.

II. Azimuth Field Calculation

$$E_\phi = \frac{\sin\left(\frac{k_o W_e}{2}\sin(\theta)\right)}{\frac{k_o W_e}{2}\sin(\theta)} \cos(\theta) \quad (18)$$

Step 8. It involves calculation of the bandwidth, equivalent capacitor and equivalent inductor

$$C = \varepsilon_o \varepsilon_{eq2} \frac{WL}{h} \quad (19)$$

$$BW \cong \frac{h}{\left(\sqrt{\varepsilon_{eff}}\right)} \quad (20)$$

3. Design Consideration

a) Antenna Design summary table

Table I: Antenna Design summary

S. No.	Designing Parameters	Theoretical Value
1	Width of Top Patch	800 mil
2	Length of Top Patch	700 mil
3	Width of Ground Plan	1200 mil
4	Length of Ground Plan	1100 mil
5	Feeding Type	Coaxial
6	Position of Feeding	X=-94mil, y=-276
7	Used Dielectric Material	LTCC, FR-4
8	Loss Tangent Used	tanδ=.019, tanδ=0.005
9	Total Height of Antenna	118 mil

The table-I has shown the designing dimension of propose antenna. All the dimensions of propose antenna calculated using transmission model.

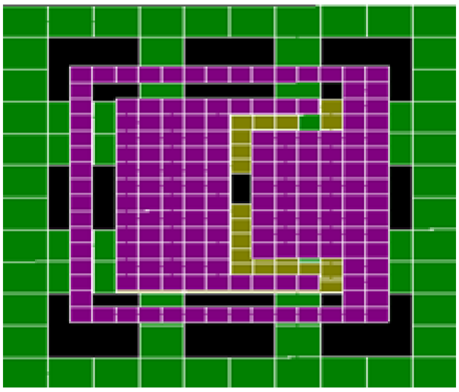

Figure 1: Propose Antenna design

This antenna is designed as per theory of parasitic array. The antenna design did in two aspects, Firstly using hybrid material in this mix the properties of two material and reshape the electrical properties of antenna after that did slotting on the three layer. The two C-Slots are used in the top layer and five square slots are used in middle layer, middle layer used as driven element and top layer used as director. The group plane has nine square slots.

b) Top layer C-Slots

To improve return loss response it is must to reduce the reflection of geometry of antenna to full fill this requirement two C-Slots are inserted in top layer. As we know that the inductance is pre dominant in micro- strip antenna structure because of this value of inductance the reflections are dominant for compensation of inductance C-Slotting techniques are used, slotting techniques are generated capacitance and compensate inductance and gives significant improvement in impedance bandwidth response.

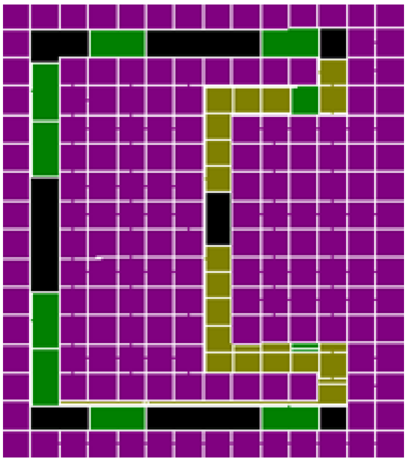

Figure 2: Top Layer Design

Middle layer Square Slots

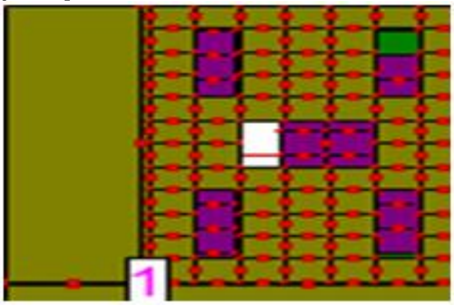

Figure 3: Middle Layer Design

For further compensation of the inductance of the design antenna, the five square slots are inserted in the middle layer. Four slots are vertical and one slot is horizontal. The vertical slots are supporting the improvement of low frequency response and horizontal slot is supporting high frequency response.

c) Slotting in ground Plane

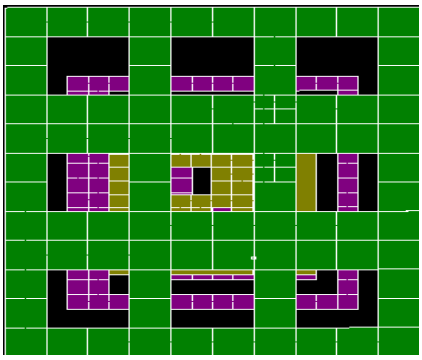

Figure 4: Ground Plane Design

The mutual inductance between FR-4 and LTCC layer nine Square slots are used in the ground plan. For designing and simulation IE3D^{TM} Simulator used. For the designing low cost FR-4 Dielectric material is used.

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

therefore the inductance and capacitance of geometry are reconfigure because of this effect total impedance bandwidth is optimized and achieved broad band width in dual band. the optimization ratio of capacitance are found using equation (19), the different operating modes are found with respect to operating frequency using the equation (2).

$$C = \varepsilon_o \varepsilon_{eq2} \frac{WL}{h} \quad (19)$$

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

$$f_o = \frac{c}{2\sqrt{\varepsilon_{eff}}} \left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2 \right]^{\frac{1}{2}} \quad (21)$$

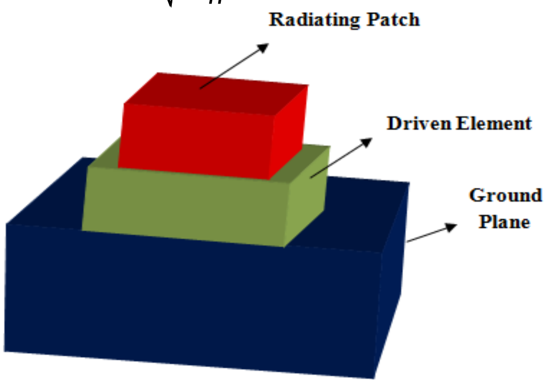

Figure 5: Propose Model

The proposed model of the design antenna is shown in figure 5.

4. Results and Discussion

a) Return losses vs. Frequency

S11≤ -10 dB operating impedance bandwidth achieved 34% from 4.1 to 5.8 GHz

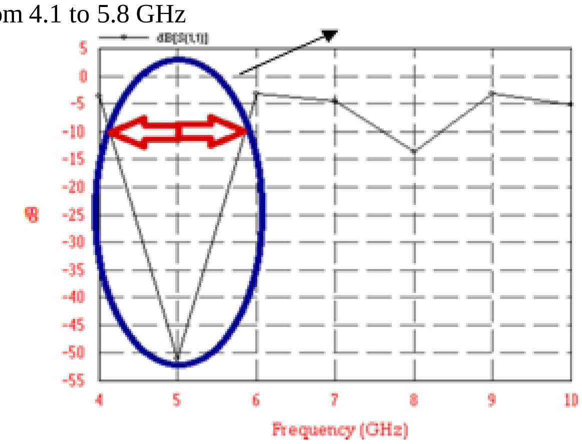

Figure 6: Return losses vs. Frequency

The figure 6 has been shown return losses analysis. From the simulation result of return losses in IE3D simulator, S11 ≤ -10 dB impedance bandwidth in has been obtained from 4.1 GHz to 5.8 GHz. At 5 GHz the value of return loss is -50dB. The return losses analysis has conclude that the design antenna can be used in C-Band application like sub-6 GHz 5G-Band (4.1-5.8 GHz bands).

b) Smith Chart

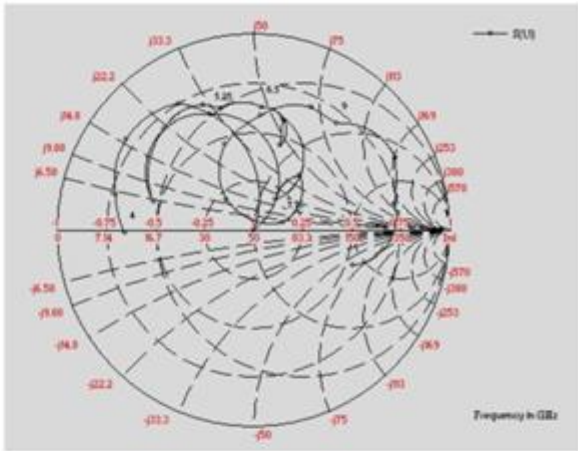

Figure 7: Smith Chart

The figure 7 has shown the simth chart for propose antenna. Two small circles are showing impedance matching for dual where optimum impedance matching exists. While above the axis the appear circle shows the inductive part is dominating in the impedance of antenna for other bands of frequency and there will be also chance to further improvement in operating bandwidth by the future optimization technique of inductance.

c) Directivity vs. Frequency

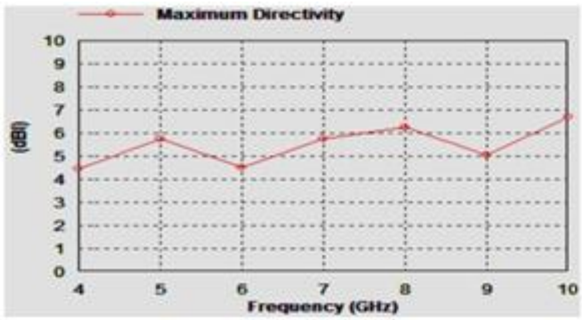

Figure 8: Directivity vs. Frequency

The figure 8 is showing the directivity vs frequency response. From this graph directivity achieved up to 6dBi at 5 GHz and between 7GHz to 9 GHz frequency. While for other frequencies the directivity of antenna are showing in graph.

d) Axial ratio vs. Frequency

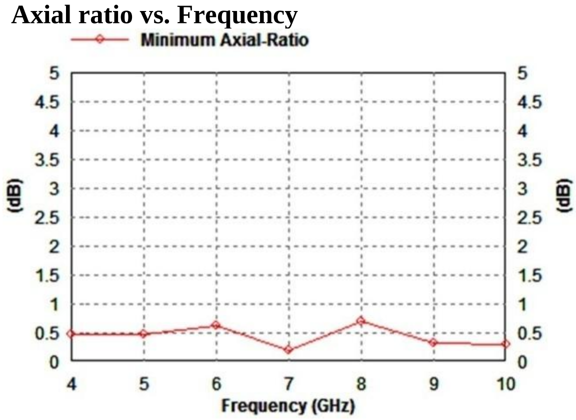

Figure 9: Axial ratio vs. Frequency

The axial ratio of an antenna in have shown figure 11. The axial ratio achieved between 0.5 to 0.7 dBi. 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 have the characteristics of circular polarization.

e) Radiation Pattern of Antenna

Elevation Radiation Pattern of Antenna

Elevation pattern shows the design patch antenna radiates unidirectional so that this antenna is beam focusing properties. The radiation pattern and Below figure show the 2D radiation pattern of the antenna at the designed frequency for different Φ (azimuth angle) and Θ (Elevation angle).

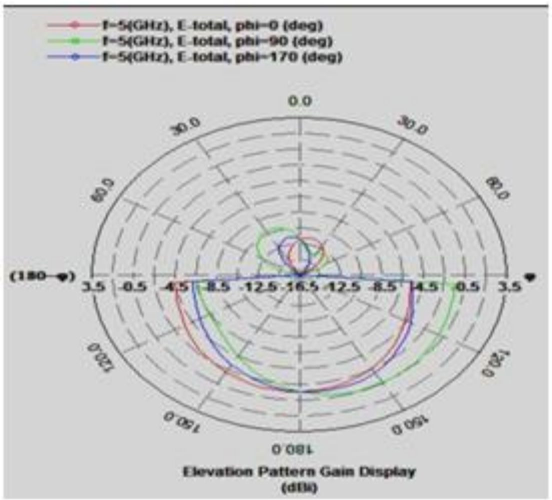

Figure 10: An Elevation Radiation Pattern at = 0, 90, 170

The figure 10 shows the design antenna is radiate unidirectional along the θ direction. This elevation pattern has plotted at constant value of φ = 0, 90, 170. The obtained beam width in θ direction is 82.245 deg.

Azimuth Pattern of Design antenna

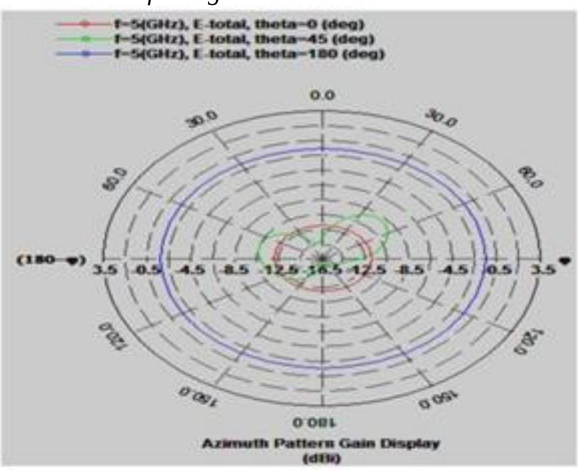

Figure 11: Azimuth Radiation Pattern of Antenna at = 0, 45,180

The figure 11 shows the design antenna is radiate omni directional in ϕ direction. This elevation pattern has plotted at constant value of θ= 0, 90, 170. The obtained beam width in ϕ direction is 107.562 deg.

Table 2: Patten Properties

Frequency	5 (GHz)
Incident Power	0.01 (W)
Linear Properties	
Linear Directivity	5.7292 dBi
Linear Maximum	at (140, 70) deg.
3dB Beam Width	(84.1555, 161.009) deg.
LH Circular Properties	
Circular Directivity	5.38502 dBi
Circular Maximum	at (145, 70) deg.
3dB Beam Width	(82.245, 107.562) deg.

Table 2 represents the radiation property of antenna at 5 GHz. From this table concludes that design antenna improve linear as well as circular directivity.

5. Conclusion

This paper successfully demonstrated antenna for sub 5G band C-Band, this antenna has been design using hybrid slotting and hybrid material. The hybrid slotting has designed using C and square slot on the top, middle and ground layer. The hybrid material has been constructed by LTCC and FR-4 material. the propose antenna is highly circular polarized and simultaneously obtaining ≤ 3dB, axial ratio bandwidth and -10dB, impedance bandwidth in both dual band From the results and discussion, this antenna achieved first band from 4.1 GHz to 5.8 GHz of 34% -10 dB impedance bandwidth and second band from 7.3 GHz to 8.2 GHz of 10%, -10 dB impedance bandwidth for C-Band application.

From the axial ratio bandwidth this antenna is circular polarized antenna use in circular polarized application. The Design antenna improves linear as well as circular directivity. The propose antenna will use the sub-6 GHz 5G-Band (4.1-5.8 GHz bands) and Wi-Fi band.

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