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Analysis of C-shape Slotted MSPA for 5G Sub Band Applications on Three Different Substrates

P Nagaraju, D H Sachina, Imran Khan*, H V Kumaraswamy, and K R Sudhindra

***Abstract*—A comparative analysis of a compact planar Square patch Microstrip Multiband antenna on three different substrates is proposed. The proposed design has a C-shaped slot etched on the square radiating part and the antenna is energized using microstrip feed line. RT Duroid ($\varepsilon_r = 2.2$), Taconic ($\varepsilon_r = 3.2$) and FR4 ($\varepsilon_r = 4.4$) substrates are used for simulation analysis. The flow of current is modified by the C-shaped slot making the antenna to resonate at 3/4 and 6 bands for RT Duroid/Taconic and FR4 substrates respectively suitable for 5G sub GHz applications. The antenna has a compact dimension of $32 \times 32 \times 1.6mm^3$and exhibits a return loss, S_{11} of less than -10dB for all the resonating frequencies for all three substrates. The analysis has been done by considering the S_{11} (Return loss <-10 dB), Directivity, Antenna Gain, VSWR and surface current distribution. Table II provides the comparison of parameters for different substrate material.**

***Keywords*—C-shape; RT Duroid; Taconic (TLC); FR4; 5G**

I. Introduction

SMALL-CELL and Internet of thing device usage has increased, resulting in increase of traffic. The current network has been transformed into 5G technology, which requires more capacity, faster data rates and ultra-low latency. 5G is a next-generation mobile communication technology that provides greater capacity and data speeds than the previous generation Long Term Evolution technology (LTE) [1]. Vehicle-to-everything (V2X) communication systems have got a lot of interest, thanks to the rapid development of autonomous vehicle technology. The demand for the creation of an automobile antenna for LTE and 5G communication bands has risen drastically as part of the connected car system [2]. A number of strategies for achieving multiband antenna configuration have been proposed in the literature, including slots [3-7], fractals [8], arrays [9], and so on. Different substrate materials have been studied to investigate the effect of dielectric material on antenna performance. The performance is taken into account for the 5G application. A comparison research was conducted on many parameters, taking into account different dielectric substance. The proposed patch antenna with a substrate made of RT Duroid performs well in 5G communication [10].

This paper provides a comparative analysis of C-shaped slotted MSPA and its simulation for 5G applications. The proposed slotted antenna consists of a rectangular radiator $(L2 \times W2)$ in which a C-shaped slot is etched out. The flow of current is modified by the C-shaped slot thereby tuning the antenna to operate at various useful bands. There is no requirement of impedance matching circuit externally and the impedance matching is solely achieved at these bands by using a rectangular microstrip feed line with dimension of $(L5 \times W7)$. The simulation is performed for this antenna using RT duroid, TLC and FR4 substrates and the results are compared.

II. Antenna Design Methodology

The proposed antenna structure is modelled on RT Duroid/Taconic and FR4 substrates with a compact size of $32 \times 32 \times 1.6mm^3$, the details about the proposed structure is given in Fig. 1 and the dimensions are tabulated in Table I. The proposed antenna design consists of a ground plane and a radiating patch equipped with C-shaped slot with the dimensions $(L3 \times W3 \times L4 \times W4)$ on the patch. The C-shaped structure is easy to implement in various portable devices. The C-shaped structure is the elementary structure. The existence of this C slot will change the current path length so that antenna can resonate in the multiband mode. The designed patch antenna is excited by microstrip feed line using lumped port excitation to achieve good impedance match at the operating bands.

TABLE I
DIMENSIONS OF THE PROPOSED DESIGN

Parameters	Dimensions (in mm)
W1,L1	32
W2	20
L2	16
W3	15
L3, L4	6
W4	13
W5, W6	9
L5	10
W7	2

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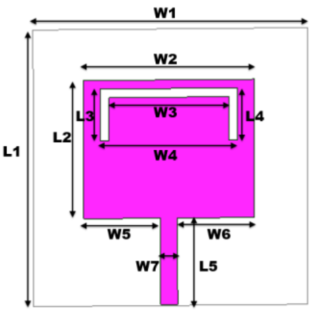


Fig. 1. Physical layout of the proposed antenna

III. RESULTS AND DISCUSSIONS

Simulated results of C-shaped slot MSPA using RT Duroid, TLC and FR4 substrates are illustrated in this section.

A. RT Duroid

Firstly, the simulation of the proposed design structure of the antenna shown in Fig. 1 is performed using HFSS tool on RT Duroid substrate with ε_r of 2.2 and thickness of 1.6mm. The simulated S_{11} of the design is illustrated in Fig. 2 and it is observed that the MSPA using RT duroid substrate resonates at 3 frequencies (Tri band) 6.3/8.8 and 10.9GHz with the bandwidth of 185/340 and 250MHz respectively suitable for 5G applications. Its radiation patterns at $0^0$and 90^0 degrees is shown in Fig. 3.

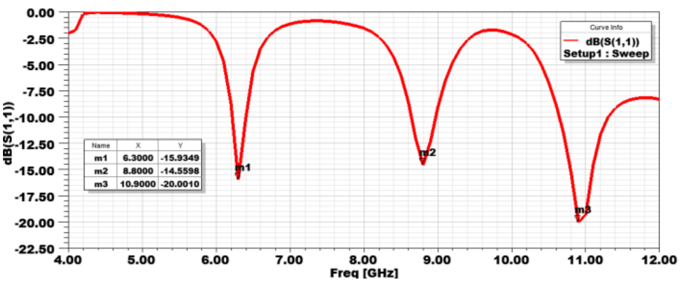
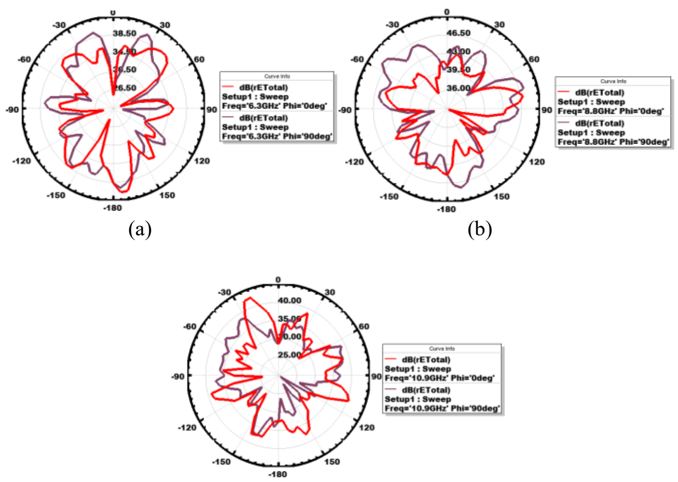


Fig. 2. S_{11} of the proposed design using RT Duroid

Radiation pattern for the Tri band frequencies are directional in nature and they are plotted at 0^0 and 90^0 are as shown in the Fig. 3.

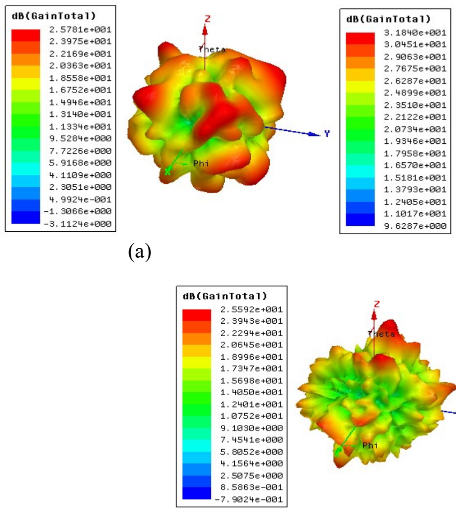


(a) (b)

(c)

Fig. 3. Radiation pattern at frequencies (a) 6.3, (b) 8.8 and (c) 10.9GHz

The 3D gain plots resulting a gains of 2.57/3.18 and 2.55dB for the resonant frequencies of 6.3/8.8 and 10.9GHz are shown in Fig. 4. At all resonance frequency, this antenna demonstrates good gain.



(a) (b)

(c)

Fig. 4. Gain at: (a) 6.3, (b) 8.8 and (c) 10.9GHz

The proposed configuration's simulated VSWR is depicted in Fig. 5. For all the three band operation, the antenna has a VSWR between 1 & 2.

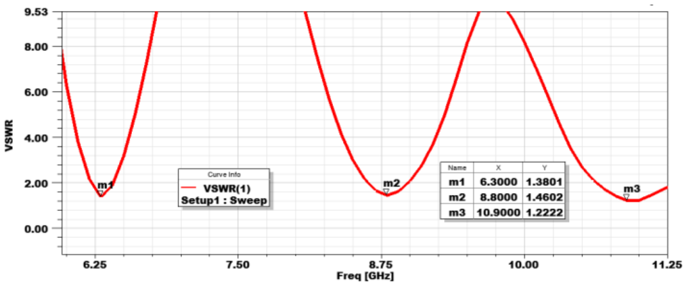
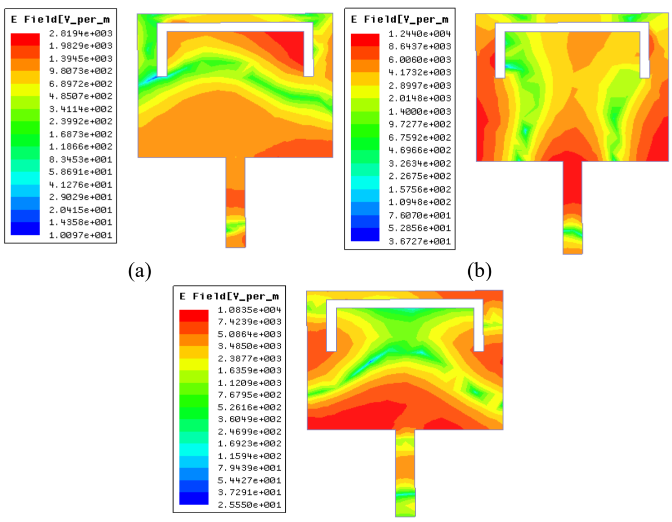


Fig. 5. VSWR at: (a) 6.3, (b) 8.8 and (c) 10.9GHz

Fig. 6. describes the current distributions at the antenna's surface at various operating frequencies.



(a) (b)

(c)

Fig. 6. Current Distribution at: (a) 6.3, (b) 8.8 and (c) 10.9GHz

B. *Taconic Substrate*

Secondly, the results obtained for the proposed C shaped slot MSPA using Taconic substrate are discussed in this section. Using TLC substrate the proposed antenna in Fig. 1 results in 4 bands of 5.3/7.3/9.0 and 10.1GHz. The reflection coefficient obtained at 4(Quad band) bands is shown in Fig.7.

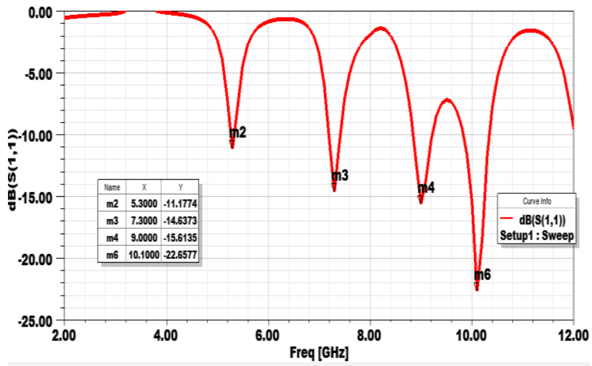
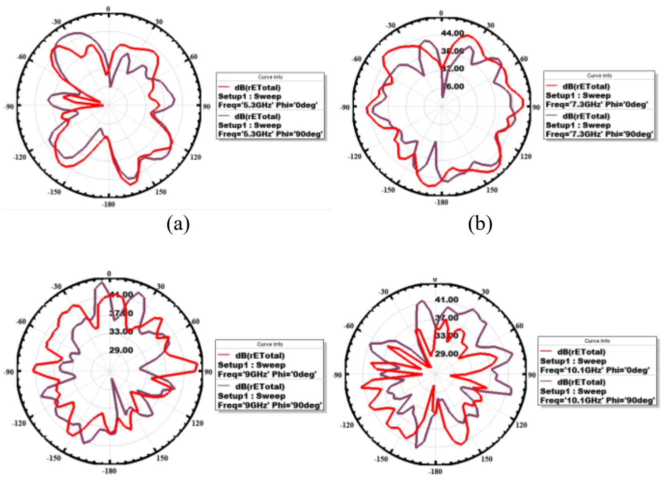


Fig. 7. S_{11} of the proposed design using TLC substrate

Radiation pattern for the quad band frequencies are directional in nature and they are plotted at 0^0 and 90^0 are as shown in the Fig. 8.

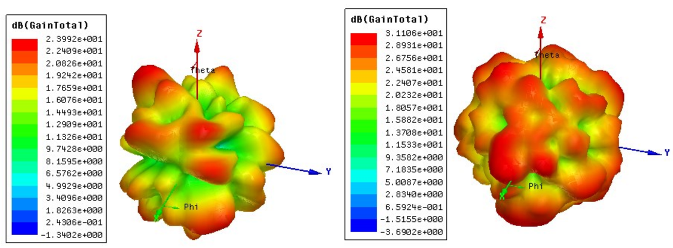


(a) (b)

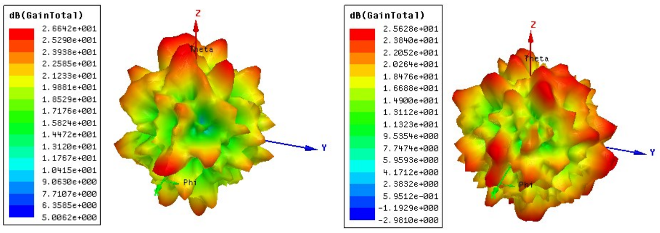
(c) (d)

Fig. 8. Radiation pattern at: (a) 5.3, (b) 7.3, (c) 9.0 and (d) 10.1GHz

The 3D gain plots resulting a gains of 2.39/3.11/2.66 and 2.56dB for the resonant frequencies of 5.3/7.3/9.0 and 10.1GHz are shown in Fig. 9. At all resonance frequency, this antenna demonstrates good gain.



(a) (b)



(c) (d)

Fig. 9. Simulated gain at frequencies: (a) 5.3, (b) 7.3, (c) 9, (d) 10.1GHz

The proposed configuration's simulated VSWR is depicted in Fig. 10. For all the four band operation, the antenna has a VSWR between 1 & 2.

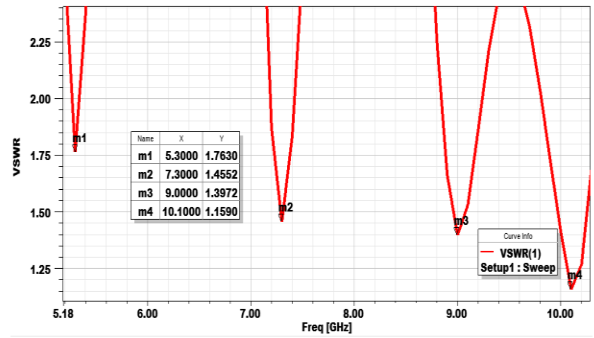
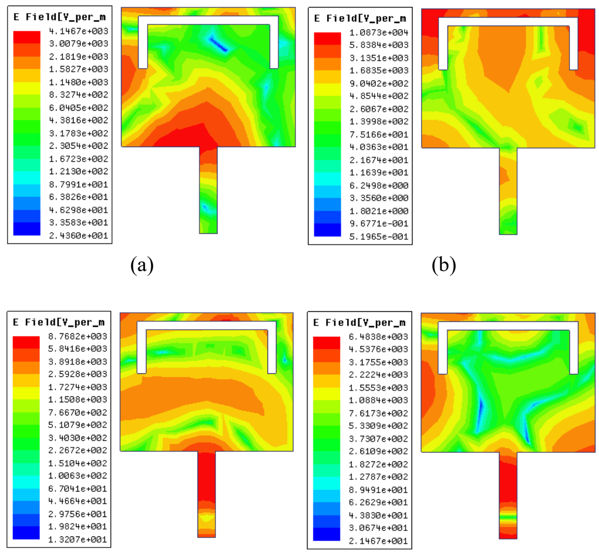


Fig.10. VSWR

Fig. 11. describes the current distributions at the antenna's surface at various operating frequencies.



(a) (b)

(c) (d)

Fig. 11. Current distribution at: (a) 5.3, (b) 7.3, (c) 9.0, (d) 10.1GHz

C. *FR4 Substrate*

Finally, the simulation of the design structure of antenna in Fig. 1 is performed by using HFSS on easily available and cost effective FR4 substrate with value of ε_r of 4.4 and height of 1.6mm. The simulated S_{11} of the proposed antenna structure is illustrated in Fig. 12. From the simulation results it is observed that the antenna provides six bands (Hexa) of operation with resonances at 4.7/6.5/7.9/9.0/10.6 and 11.7GHz.

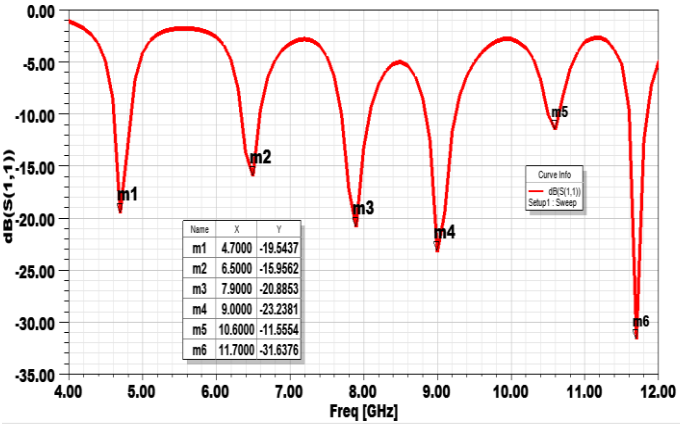
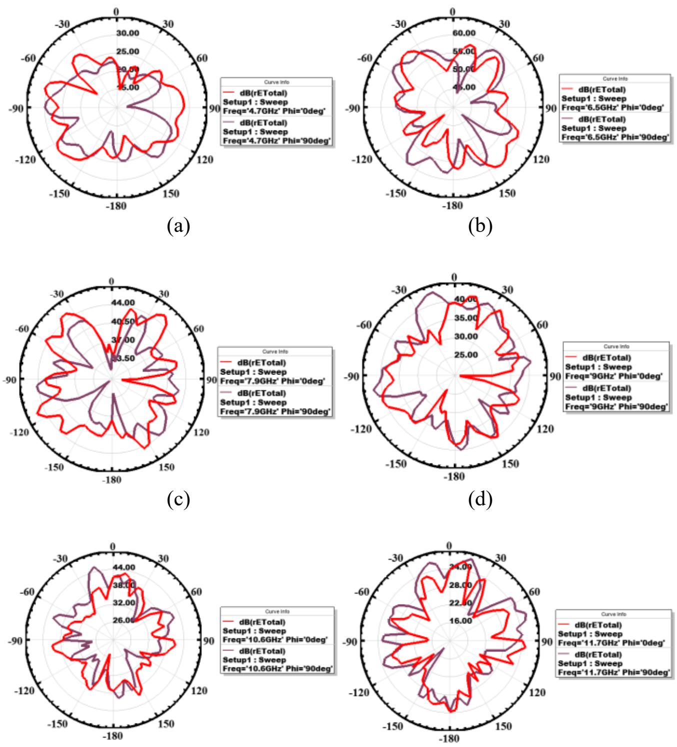


Fig. 12. S_{11} of the proposed design using FR4 substrate

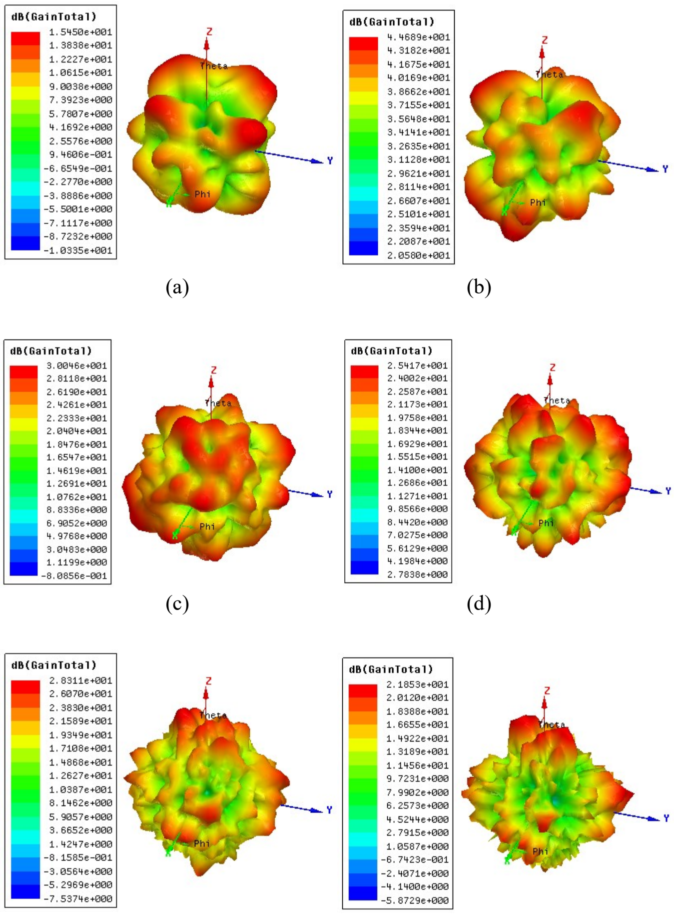
The -10dB impedance bandwidth for the frequencies of 4.7/6.5/7.9/9.0/10.6 and 11.7GHz are 236/255/380/410/148 and 245MHz respectively. The bandwidth achieved is adequate to meet the necessity of 5G applications. The radiation patterns for the respective resonated frequencies are obtained as shown in Fig. 13.



(a) (b) (c) (d) (e) (f)

Fig. 13. Radiation pattern at: (a) 4.7, (b) 6.5GHz, (c) 7.9, (d) 9.0, (e) 10.6 and (f) 11.7GHz

The 3 dimensional gain plots of the design proposed are shown in Fig. 14. From the gain plots it is observed that the antenna has an excellent gain at all the resonant bands even though it has a compact size. At frequencies 4.7/6.5/7.9/9.0/10.6 and 11.7GHz a gain of about 1.54/4.46/3.00/2.54/2.83 and 2.18dB is obtained respectively.



(a) (b) (c) (d) (e) (f)

Fig. 14. Gain at: (a) 4.7, (b) 6.5, (c) 7.9, (d) 9.0, (e) 10.6 and (f) 11.7GHz

The proposed configuration's simulated VSWR is depicted in Fig. 15. For all the six band operation, the antenna has a VSWR between 1 & 2

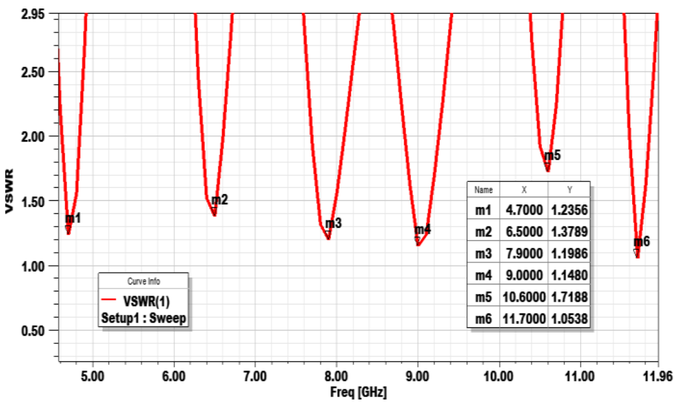


Fig. 15. VSWR at: (a) 4.7, (b) 6.5, (c) 7.9, (d) 9.0, (e) 10.6 and (f) 11.7GHz

The below figure shows the current distribution in the proposed MSPA for all the resonated frequencies.

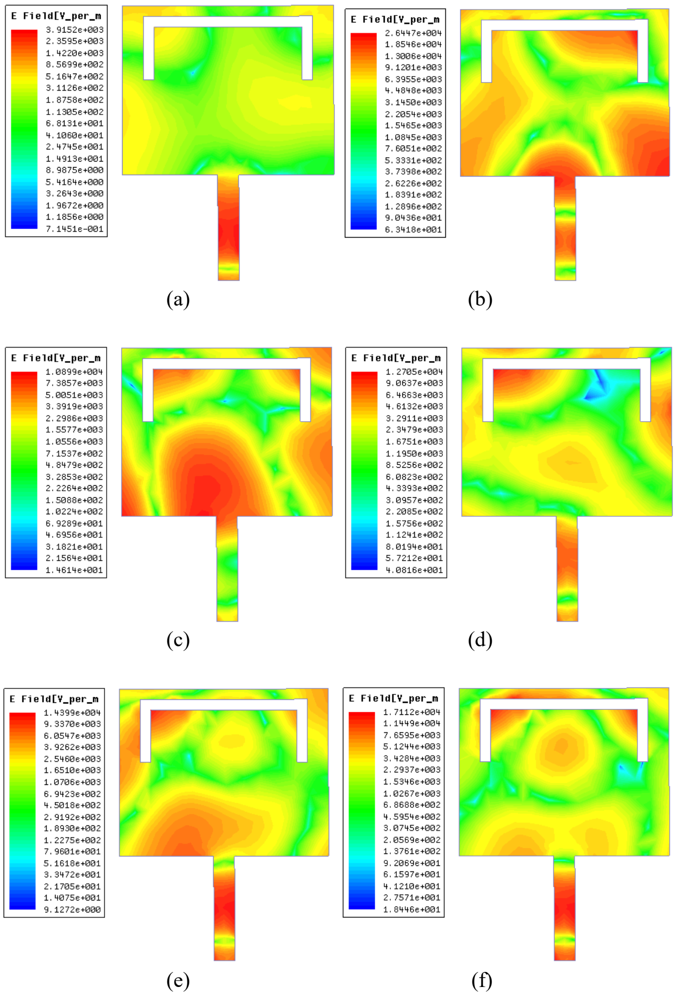


Fig. 16. Current Distribution at: (a) 4.7, (b) 6.5, (c) 7.9, (d) 9.0, (e) 10.6 and (f) 11.7GHz

IV. Conclusion

A simulation-based analysis of MSPA employing three distinct substrate materials: RT Duroid/TLC and FR4 with antenna size of $32 \times 32 \times 1.6mm^3$ is presented. The simulated findings demonstrate that the FR4 substrate performs better than the RT Duroid and TLC substrates with six bands (4.7/6.5/7.9/9.0/10.6 and 11.7GHz), steady radiation patterns and gain of 1.54/4.46/3.00/2.54/2.83 and 2.18dB. Its benefit is that it is inexpensive and readily available in the market. With gain of 2.57/3.18 and 2.55dB and enough bandwidth, the RT Duroid provides three bands at 6.3/8.8 and 10.9GHz. TLC generates four bands at 5.3/7.3/9.0 and 10.1 GHz, with gain of 2.39/3.11/2.66 and 2.56dB respectively. As a result, all three substrates have been simulated, and it has been observed that FR4 delivers better radiation and six band operation than the other two.

As an outcome, the proposed patch antenna under consideration with a substrate containing a dielectric material FR4 with $\varepsilon_r = 4.4$ produces good results with antenna gains of 1.54/4.46/3.00/2.54/2.83 and 2.18dB and resonant frequencies of 4.7/6.5/7.9/9.0/10.6 & 11.7GHz, which may be used for 5G communication. Table II summarizes the significance of the proposed design and its comparative analysis.

TABLE II
SUMMARY OF THE PROPOSED DESIGN

Substrate	Freq. (GHz)	S_{11} (dB)	BW (MHz)	Gain (dB)
RT Duroid	6.3	-15.93	185	2.57
	8.8	-14.55	340	3.18
	10.9	-20.00	250	2.55
TLC	5.3	-11.17	110	2.39
	7.3	-14.63	280	3.11
	9.0	-15.61	380	2.66
	10.1	-22.65	400	2.56
FR4	4.7	-19.54	236	1.54
	6.5	-15.95	255	4.46
	7.9	-20.88	380	3.00
	9.0	-23.23	410	2.54
	10.6	-11.55	148	2.83
	11.7	-31.63	245	2.18

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