Comparative analysis of a $30 \times 30 \times 1.6\mathrm{mm}^3$ MSPA Antenna Loaded with Circular Patch using FR4, RT Duroid and Taconic

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Abstract: *A trial investigation of circular microstrip patch antenna on three unique substrates, FR4 with a permittivity of 4.4, RT Duroid with a permittivity of 2.2 and Taconic substrate with a permittivity of 3.2 is presented. The measured outcomes for S11, resonant frequencies, radiation efficiency and radiation pattern for the planned design of patch antenna with openings in the ground plane are given. The total dimension of the proposed antennas is* $\mathbf{30 \times 30 \times 1.6}\boldsymbol{mm^3}$*. the point of this survey paper is to think about and display a reasonable substrate for microstrip patch antenna which can deliver great radiation efficiency, gain, return loss and better radiation pattern alongside the multiband activity.*

Index Terms - *Circular Patch, FR4, TLC, RT-Duroid, Multiband*

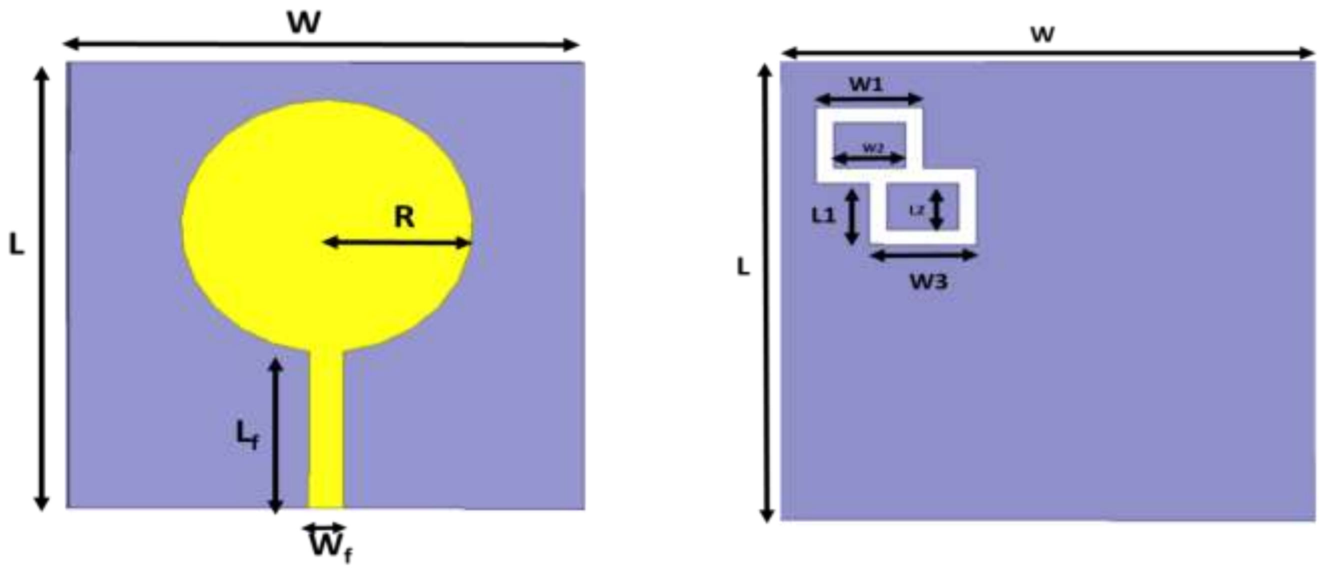
I. INTRODUCTION

The idea of MSPA was first presented in the 1950s by G. A. Deschamps. Anyway , this thought needed to hold up about 20years to be acknowledged after the advancement of the Printed circuit board (PCB) innovation in the 1970s.Since then MSPA is a standout amongst the most favored antennas because of their position of safety ,light weight ,minimal effort ,planar arrangement ,unrivalled versatility and instance of manufacture .Their large scale manufacturing is conceivable by utilizing PCB innovation which additionally prompts low creation cost ,permit both linear and circular polarization. And furthermore take into consideration double and triple band recurrence activity perfect with MMIC outlines [1-2].MSPA has wide zone of uses for military applications, for example, TV ,radio broadcasting ,mobile systems ,RFID ,Wi-Fi ,Wi-Max ,GPS ,warships, RADAR , natural imaging ,rocket direction etc.[3]. Aside from the favorable circumstances, it has impediments as narrow band width, low again and low efficiency. A Microstrip Patch Antenna comprises of a patch of any non-planar or planar geometry on one side of a dielectric substrate and a ground plane on opposite side of the substrate .The dielectric constant of the substrate ought to be in the scope of $2.2 \leq \varepsilon \leq 12$ [4]. There are various substrates that can be utilized for the design of MSPA relying upon properties like conductivity, dielectric constants, temperature, and dimensional stability [5]. To conquer the restrictions of MSPA, quantities of strategies are proposed. Defected ground structure (DGS) is one of the techniques to enhance the antenna performance which is simple as for outline and size. DGS is a imperfection in the ground plane of a planar transmission line [6]. It is acknowledged by presenting a shape defected on a ground plane. Most Commonly utilized states of DGS Structures are Rectangular, Square, Circular, Dumbbell, and Spiral-Shaped, Concentric ring, U and V Shaped and joined Structures [7]. This will change the protected current dispersion relying upon the shape and measurement of the defect .The aggravation at the protected current distribution will impact the input impedance and the flow of current MSPA .It can likewise control the excitation and electromagnetic waves proliferating through the substrate layers [8]. DGS have different applications, for example, reduction of antenna size, reduction in cross polarization, mutual coupling lessening in array antenna and so on. The impediment is that DGS increment the zone of the circuit [9].

In this paper, we compare and present an experimental investigation of the radiation performance of circular patch [10] microstrip patch antennas on three different substrates, FR4, RT Duroid and Taconic with dielectric constants 4.4, 2.2 and 3.2 respectively. After studying the different antenna simulations we propose a circular patch antenna using Taconic substrate. The proposed Taconic substrate circular patch antenna resonates at 3.2, 4.7, 7.2, 8.2 and 8.2 GHz (5 bands) frequency bands. The proposed antenna gives good radiation efficiency with acceptable impedance bandwidth and can support more number of wireless standards simultaneously. The design and simulation of these structures are carried out in ANSYS High Frequency Structure Simulator (HFSS) v.13.0 software. The substrate used for the simulation is FR4, RT Duroid and Taconic which has a thickness of 1.6 mm.

II. ANTENNA DESIGN APPROACH

The proposed antenna is designed using HFSS v.14.0 software. The substrate material for the proposed design is FR4, RT Duroid and Taconic with dielectric constant 4.4, 2.2 and 3.2, h=1.6mm and loss tangent δ=0.01, 0.0004 & 0.002 respectively. Finite element method approach is used to design the proposed antenna. The overall proposed design and optimized dimensions are illustrated in Figure. 1 and Table 1.



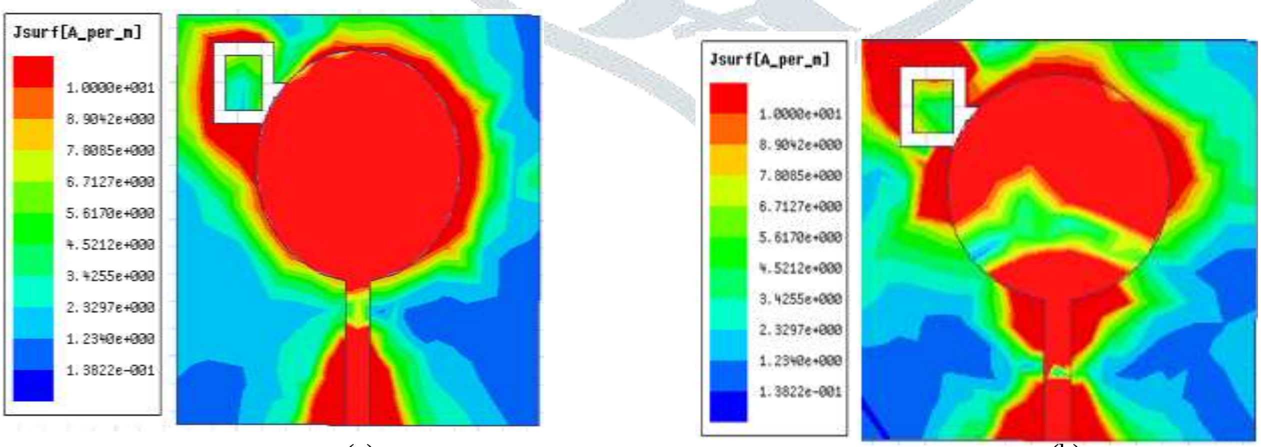
(a) (b)

Figure 1: Proposed design (a) front patch and (b) Ground

Parameters	Dimensions
L	30
W	30
R	8.5
L_f	10.55
W_f	2
W_1	6
W_2	4
W_3	6
L_1	4
L_2	3

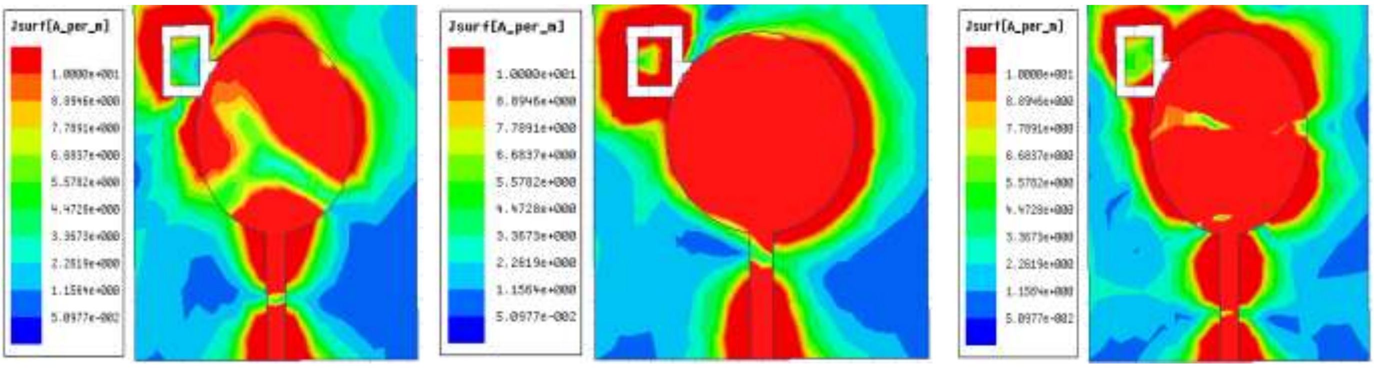
Table 1: Dimensions of the proposed design (mm)

The radiating part consists of circular patch. The slots in the ground plane are responsible for multiband resonances. The rectangular slots affects the current distribution of the radiating surface, thereby increasing total current length path, as a result of which antenna resonates at multiband. The effect of slots present in the ground plane and the effect of circular patch on current distribution are illustrated in Figures 2, 3 and 4 for all the three antennas i.e. RT Duroid, FR4 and Taconic substrates respectively.



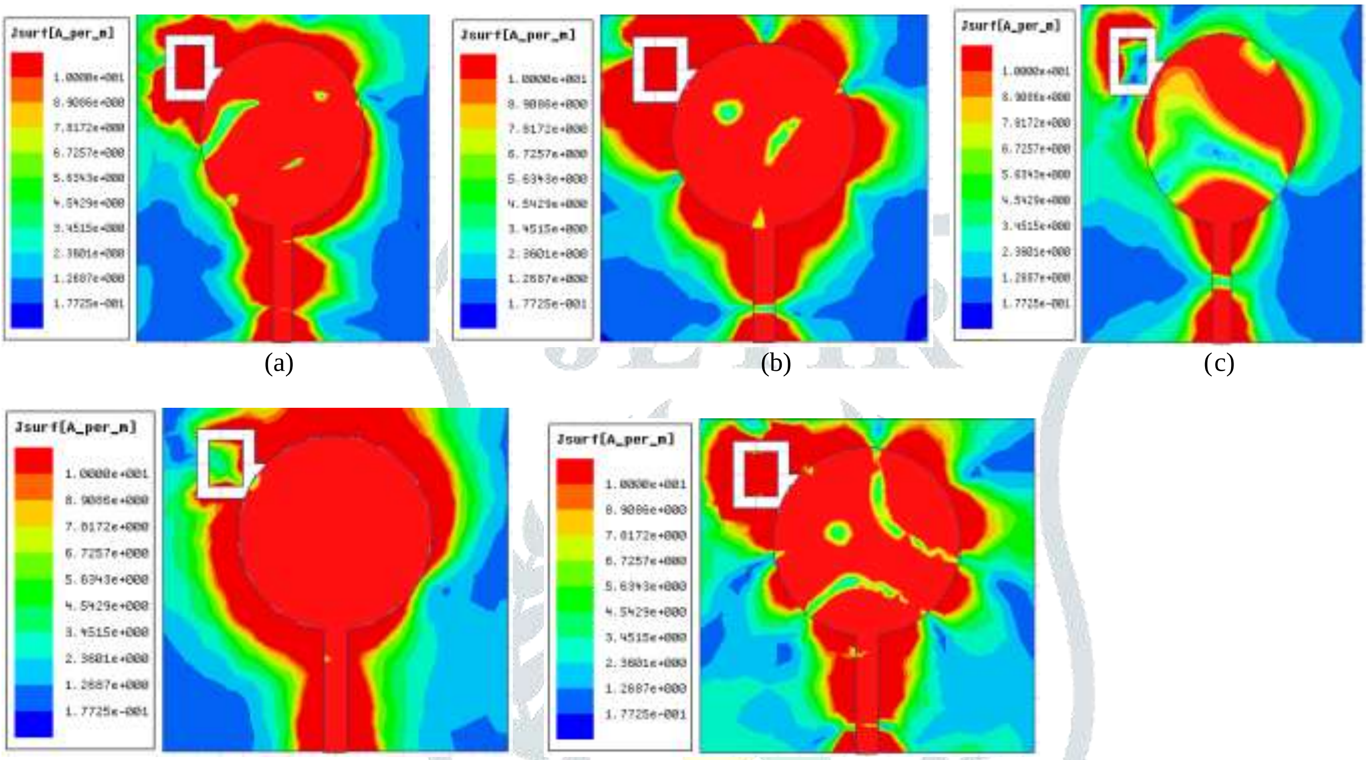
(a) (b)

Figure 2: Current distribution for RT Duroid at (a) 5.7 and (b) 9.3 GHz



(a) (b) (c)

Figure 3: Current distribution for FR4 at (a) 4.2 (b) 7.0 and (c) 9.2 GHz



(a) (b) (c)

(d) (e)

Figure 4: Current distribution for Taconic at (a) 3.2 (b) 4.7, (c) 7.2, (d) 8.2and (e) 8.8 GHz

From the above figures it is very clear that antenna resonates at more than one mode (multiband). The current distribution is more intense around the feed line area, the radiating circular patch and the ground slots thereby providing good impedance matching of antenna at all the resonance.

III. ANTENNA DESIGN EQUATIONS

Following calculations will be taken to design a rectangular microstrip patch antenna.

$$\lambda = \frac{c}{f} \quad (1)$$

$$W = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_{r+1}}} \quad (2)$$

$$L = L_{eff} - 2\Delta L \quad (3)$$

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{reff}}} \quad (4)$$

Where,

W= patch width
L= patch length
C=velocity of light
ε_r=Permittivity of the substrate
ε_{reff}=Effective dielectric constant

The normalized extension of length is given by

$$\Delta L = \frac{0.412h(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h}{W}]^{\frac{-1}{2}}$$

Substrate length and width is given by

$$L_g = L + 6h$$
$$W_g = W + 6h$$

Where h is given by

h = $\frac{0.0606\lambda}{\sqrt{\varepsilon_r}}$

IV. RESULTS AND DISCUSSIONS

The Antenna simulations are carried out using the finite element method (FEM) based electromagnetic (EM), Ansoft's HFSS. Simulated results of all the three antennas using FR4, RT Duroid and Taconic substrates is illustrated below.

Figure 5 depicts the simulated S_{11} of the antenna for FR4 substrate. The antenna has three bands at 4.2, 7.0 and 9.2GHz with a S_{11} bandwidth of about 19.6, 9.3 and 5.1% under simulation. The measured radiation pattern of the proposed antenna at 4.2, 7.0 and 9.2 GHz is illustrated in Figure 6.

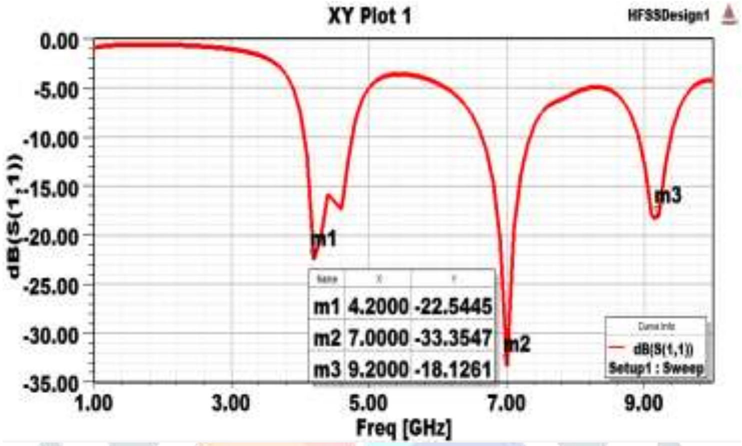
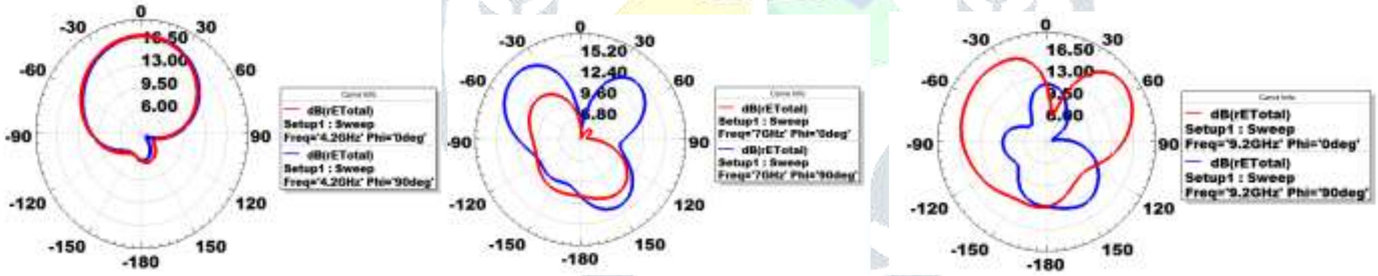


Figure 5: Simulated reflection coefficient of FR4 substrate



(a) (b) (c)

Figure 6: Simulated Radiation pattern of FR4 substrate at (a) 4.2 (b) 7.0 and (c) 9.2 GHz

Figure 7 depicts the simulated S_{11} of the antenna for RT Duroid substrate. The antenna has two bands at 5.7 and 9.3GHz with a S_{11} bandwidth of about 12.6 and 109% under simulation. The measured radiation pattern of the proposed antenna at 5.7 and 9.3 GHz is illustrated in Figure 8.

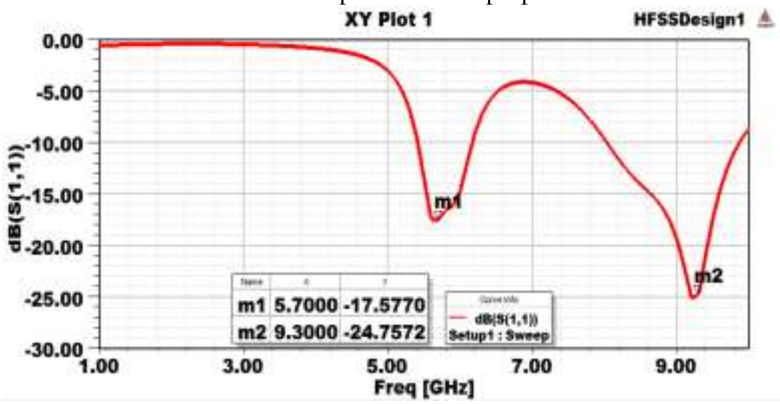
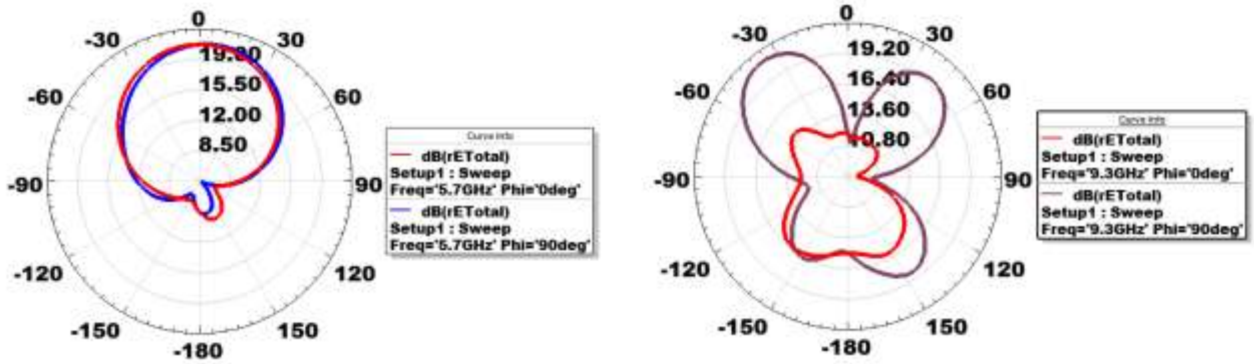


Figure 7: Simulated reflection coefficient of RT Duroid substrate



(a) (b)

Figure 8: Simulated Radiation pattern of RT Duroid substrate at (a) 5.7 and (b) 9.3 GHz

Figure 9 depicts the simulated S_{11} of the antenna for Taconic substrate. The antenna has 5 bands at 3.2, 4.7, 7.2, 8.2 and 8.8GHz with a S_{11} bandwidth of about 11.7, 3.9, 3.6, 3.3 and 12.5% under simulation. The measured radiation pattern of the proposed antenna at 3.2, 4.7, 7.2, 8.2 and 8.8GHz is illustrated in Figure 10.

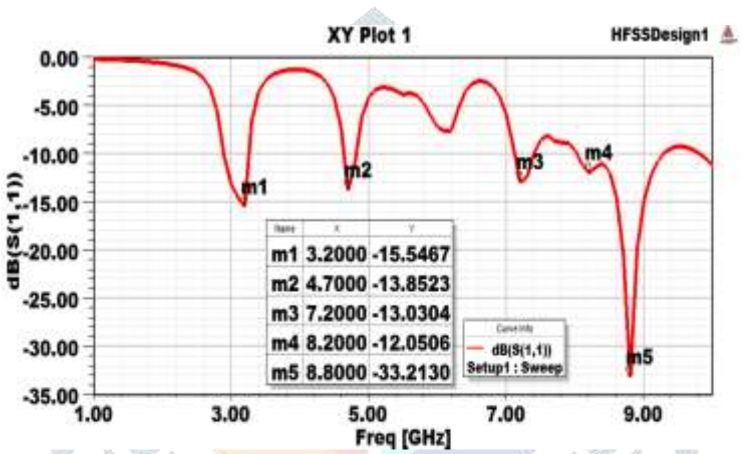
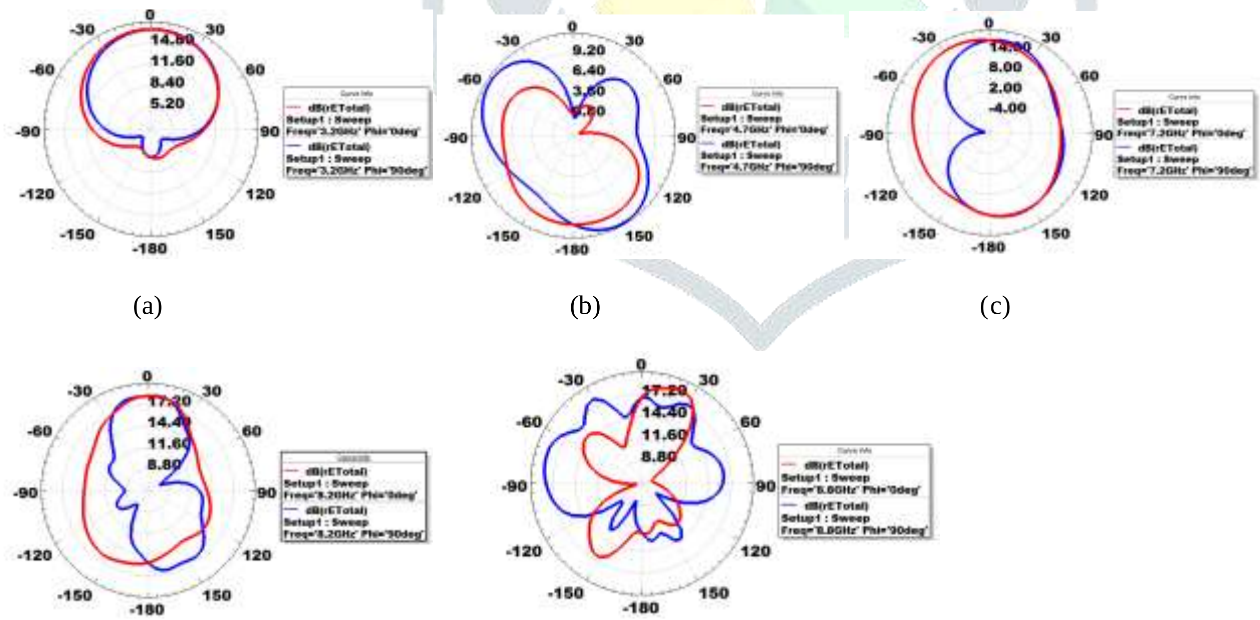


Figure 9: Simulated reflection coefficient of Taconic substrate



(a) (b) (c)

(d) (e)

Figure 8: Simulated Radiation pattern of Taconic at (a) 3.2, (b) 4.7, (c) 7.2, (d) 8.2 and (e) 8.8 GHz

The radiation efficiency of the proposed configuration is illustrated in Figure 9. The antenna has a radiation efficiency of 97% and 99% for RT Duroid at 5.7 and 9.3 GHz, 73%, 82% and 85% for FR4 at 4.2, 7.0 and 9.2GHz and 97%, 91%, 97%, 99% and 93% for Taconic at the resonant frequencies of 3.2, 4.7, 7.2, 8.2 and 8.8 GHz respectively.

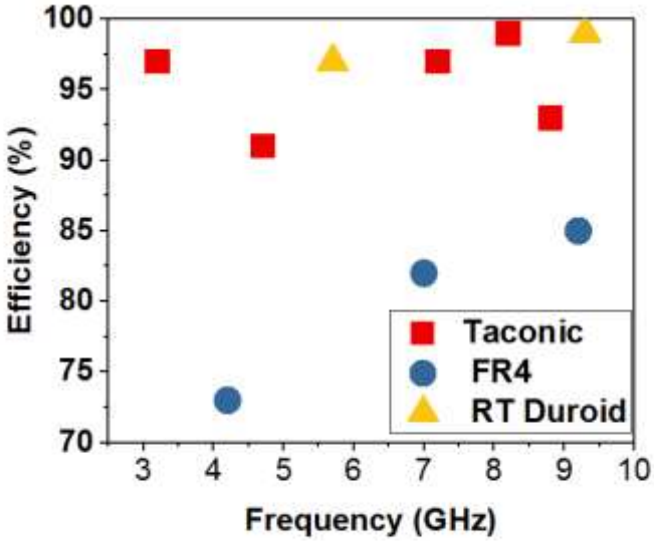


Figure 9: Simulated Radiation Efficiency of MSPA for all the three substrates

V. Conclusion

To know the significance of the proposed design its comparative analysis has been done and is given in Table 2.

Substrate	Resonant Freq. (GHz)	S_{11}	% BW	Efficiency (%)
RT Duroid	5.7	-17.577	12.6455	97
	9.3	-25.1275	109.49	99
FR4	4.2	-22.5445	19.667	73
	7.0	-33.3547	9.3159	82
	9.2	-18.1261	5.1258	85
Taconic	3.2	-15.5467	11.767	97
	4.7	-13.8523	3.9885	91
	7.2	-13.0304	3.6281	97
	8.2	-12.0506	3.34166	99
	8.8	-33.2130	12.571	93

Table 2: Comparisons analysis of simulated results

Three unique substrates FR4, Taconic and RT Duroid, which can be utilized for the creation of MSPA, have been contemplated keeping the dimensions of the antenna as $30 \times 30 \times 1.6mm^3$. All the three substrates have been studied and simulated and it has been found that Taconic provides better radiation efficiency along with the multiband operation over the other two substrates as it can be outlined with a measurement of $30 \times 30 \times 1.6mm^3$. Hence it can be concluded that Taconic provides better performance with a good radiation efficiency and multiband operation.

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