Depiction and Comparative Survey of Circularly Polarized Circular Microstrip Patch antenna for various Dielectric Material Substrates at 5.9GHz

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Abstract - Circular microstrip patch antennas with various dielectric material substrates (Taconic, FR-4, Bakelite, Rogers RT/Duroid 6006) with peripheral cuts to attain circular polarization (CP) are depicted and surveyed here. Design process focused on optimizing axial ratio (AR) bandwidths to get good CP characteristics. *5.9GHz* has been chosen as the design frequency for this work. Amongst all the substrate materials the highest simulated -10dB return loss bandwidth of *739MHz* and the highest circular polarization 3dB axial ratio bandwidth of *173MHz* has been obtained for the Taconic TLC substrate (ε_r=3.2). Simulations and optimizations are performed in High Frequency Structure Simulator (HFSS) software.

Keywords: Circular Microstrip Antenna, Polarization, HFSS, Dielectric Substrate.

I. INTRODUCTION

Circular microstrip antenna (CMSA) with circular polarization has many applications. CMSAs are compact in size which suits the requirements of device miniaturization [1-3]. This work uses coaxial feeding mechanism for the proposed antennas. Coaxial feeding enables compact structure [3] and also facilitates in generating circular polarization [4]; as coaxial feeding mechanism does not disturb the symmetry of the structure. Symmetrical structure of CMSA makes it suitable choice for creating an antenna with circular polarization capability. Circular polarization is generated through CMSAs by introducing small asymmetry as a result of mathematical/simulation driven design changes, in the otherwise symmetrical structure. Circular polarization antennas eliminate the orientation settings requirement which otherwise are essential in case of linear polarization antennas. Generation of circular polarization by modifying ordinary circular patch antenna has two major design aspects to be taken care of: (1) gain (2) circular polarization bandwidth (axial ratio bandwidth). As the modification generally means cutting slots from the patch; which certainly degrades gain performance. So care must be taken to cut very small slots optimum for the purpose so as not to degrade the gain performance considerably and at the same time it must be solving the purpose of generating circular polarization. Unlike return loss (impedance) bandwidth axial ratio (circular polarization) bandwidth values are smaller. So maximizing axial ratio is a big design concern for microstrip antenna with circular polarization characteristics. Bandwidth enhancement can be achieved either by increasing the thickness of the substrate or by reducing the dielectric constant of the substrate. In literature [6-15] various circular patch antennas have been proposed. Many of these have proposed the trade-offs between dielectric constant and other parameters.

II. LITERATURE REVIEW

Kai-Fong Lee et al. (1984) proposed CP circular microstrip antenna with an air gap between the substrate and the ground plane. Coaxial feeding has been utilized for the design. Wen-Shyan et al. (1998) proposed a circular microstrip antenna with cross slot for size reduction and two peripheral cuts for circular polarization. Significant size reduction and good CP performance has been reported by them. N. A. Zakaria at el. (2008) proposed a circular microstrip antenna at *2.4GHz* The circular microstrip antenna had been optimized and analyzed based on required parameters viz. the feed-point position, size of the circular patch and length of the microstrip line. Sachin Rai at el. (2010) presented the analysis and design of a circular microstrip antenna using cavity model and fields within the cylindrical cavity, radiation pattern and resonant frequency had been calculated. K. V. Rop at el. (2012) presented their work on maximizing bandwidth by properly selecting the dielectric material of the substrate of the microstrip antenna. They suggested that larger bandwidth can be achieved by using a thicker substrate with a lower dielectric constant value. Kiran Jain at el. (2013) discussed different dielectric substrate frequently used in microstrip patch antenna to enhance overall efficiency of antenna. Various substrates like Foam, Duroid, Benzocyclobutane, Roger 4350, FR4, Duroid 6010 were compared which are in use to achieve better gain and bandwidth. V. Saidulu at el. (2013) presented their work on variation of superstrate thickness and their effect on characteristics of a circular microstrip antenna. B.T.P.Madhav et al. (2014) presented their study on effect of various parameters like material used, dielectric constant, loss tangent, permeability, frequency of operation, dimensions etc. Lokesh K. Sadrani et al. (2015) proposed a modified circular microstrip patch antenna with embedded circular slots to attain harmonic suppression and peripheral cuts for generating circular polarization (CP). Sant Sharan Shukla et al. (2015) investigated the effect of Substrate material on the performance of microstrip antenna.

This work is an effort to buildup on the works proposed in literature [6-15]. This paper presents the results of optimization and analysis of four different dielectric substrate circular microstrip antenna with circular polarization capability. Optimizations have been performed to get maximum gain and axial ratio bandwidth for the four different materials viz. Taconic TCL, FR-4, Bakelite, Rogers RT/Duroid 6006. The design frequency of *5.9GHz* has been chosen to be used in all the designs. Simulation software High Frequency Structure Simulator (HFSS) [5] is used to design, simulate and optimize the proposed antennas.

III. ANETENNA DESIGN AND SIMULATIONS

While designing a circular microstrip antenna taking into account the fringing [9] the expression for the radius of the circular patch becomes

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{1/2}} \quad (1)$$

where

$$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}}$$
(2)

h=height of the substrate,

ε_r=dielectric constant of substrate

Initial calculations based on the above design formulae (1) and (2) for the radius of the basic circular microstrip antenna and optimized values of substrate thickness and feeding point positions are given in *Table 1*. Feeding point is obtained from HFSS optimization for *50Ω* terminal impedance to avoid use of any impedance matching network between patch and coaxial cable. Feed point is optimized so that it must exhibit terminal impedance equal to the characteristic impedance of a coaxial cable (*50Ω*).

Table 1: Calculated radii and optimized height of substrate and feeding point locations of circular patch antennas made with different substrate materials.

Substrate Material	ε_r	*Radius of patch R(in mm)*	*Height of substrate h(in mm)*	*Feeding point location $(0, y_f)$ in mm*
Taconic TCL	*3.2*	*7.797*	*1.5*	*3.4*
FR-4	*4.4*	*6.708*	*1.6*	*2.7*
Bakelite	*4.8*	*6.457*	*1.5*	*2*
Rogers RT/Duroid 6006	*6.15*	*5.866*	*0.635*	*1.8*

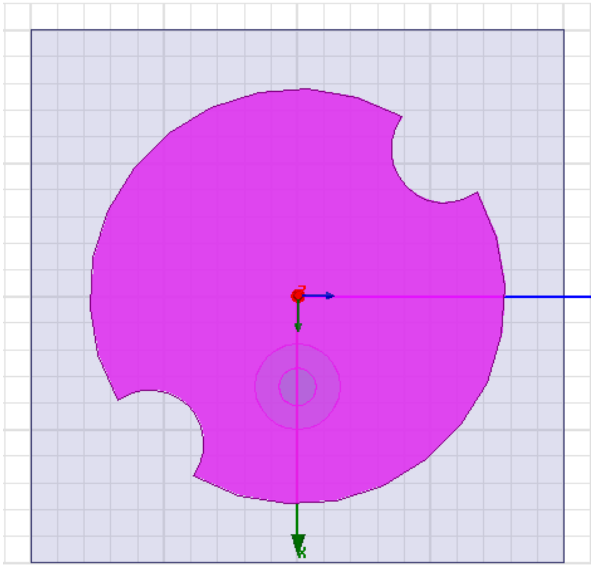

Figure 1: Proposed circular microstrip antenna for circular polarization at 5.9GHz

The proposed antenna is shown in *Fig.1*. Two peripheral circular cuts are introduced in the patch at a line 45° clockwise to vertical central line of the patch. This excites two orthogonal field components which are equal in magnitude and opposite in phase; resulting in circularly polarized radiation. This placement of peripheral cuts generates Right Hand Circular Polarization (RHCP) to obtain LHCP the *45°* line has to be shifted at a position which is mirror image of that used in RHCP at vertical plane.

For different substrate materials plots of axial ratio vs. frequency are shown in Fig.2.

Fig. 2 clearly indicates reduction in resonance frequency with increase in dielectric constants. Also it can be observed that axial ratio performance degrades with increase in dielectric constant.

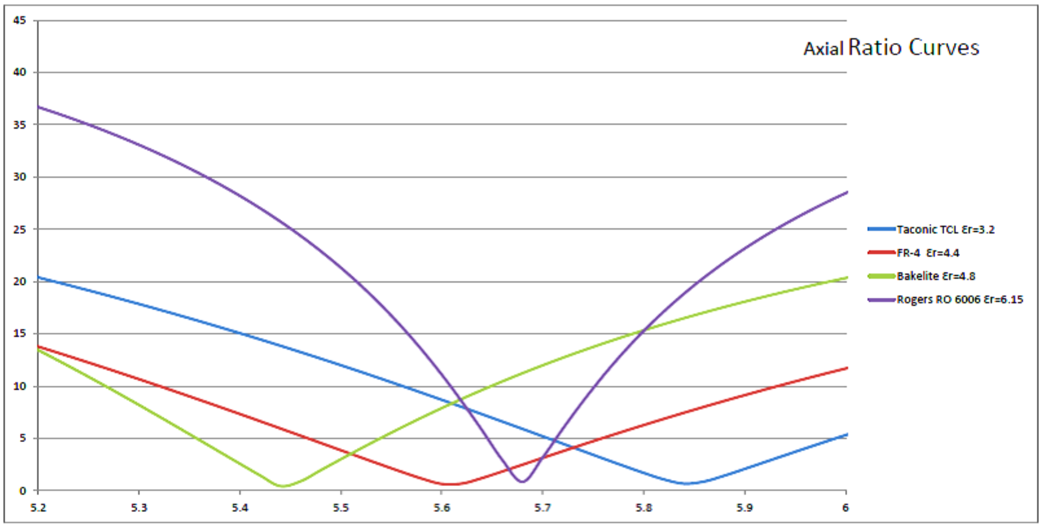

Figure 2: Axial ratio curves for different substrate materials.

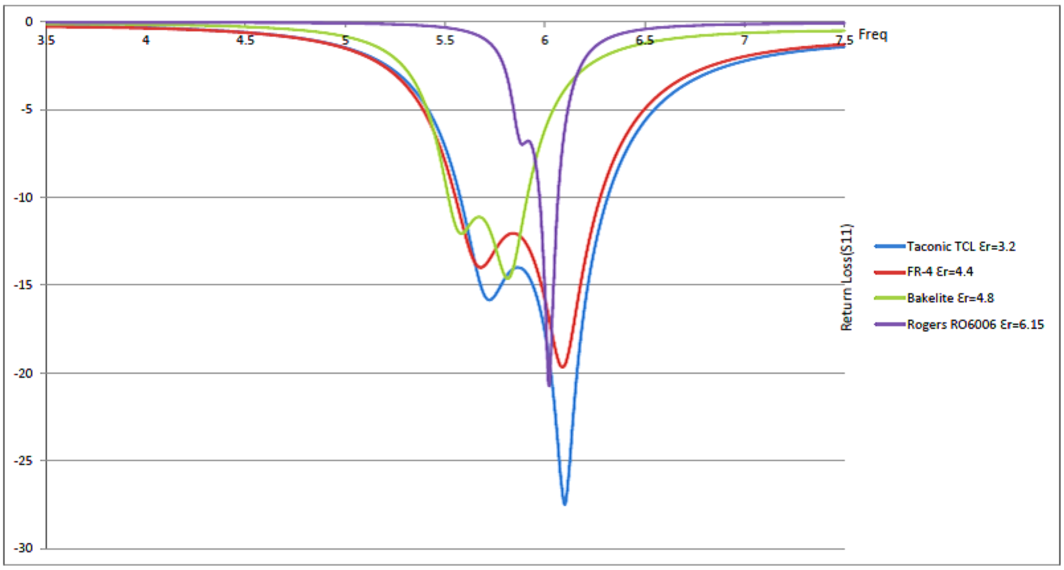

Figure 3: Return loss curves for different substrate materials.

Fig. 3 shows the various return loss curves for different dielectric constant material substrates. It is evident from the above curves that return loss values at resonance frequency (minimum return loss) is decreasing (absolute values) with increase in dielectric constants. Also the -10dB return loss bandwidth performance is also deteriorating with increase in dielectric constants.

IV.RESULTS

Antenna design obtained after parametric and optimization analysis through HFSS simulations exhibits circular polarization properties. Due to change in path length of current on the patch new resonant frequency of the proposed antenna shifts towards lower end of the spectrum. That means for the same frequency the proposed antenna takes less space as compared to a conventional circular microstrip antenna. Axial ratio plot of Fig. 2 clearly indicates the presence of circular polarization as the axial ratio curves pass through the 3dB level near the design frequency of 5.9GHz.

Table 2 shows a comparison of different properties of the proposed circular microstrip patch antenna design for different dielectric constant substrate materials. This design is for generating Right Hand Circular Polarization (RHCP); to get LHCP the position of the peripheral cuts has to be shifted at a position which is the mirror image at a plane passing through a vertical line from the centre of the circular patch. The highest simulated -10dB return loss bandwidth of 739MHz and the highest CP 3dB axial ratio bandwidth of 173MHz have been obtained for the Taconic TLC substrate.

Table 2: Comparison of properties of different dielectric substrate material antennas.

S.No.	Substrate\Parameter	ε_r (Dielectric Constant)	h (height of Substrate) mm	Radius of Circular Patch in mm	S_{11}(Impedance Bandwidth) (MHz)	Axial Ratio Bandwidth (MHz)
1	Taconic TLC	3.2	1.5	7.797	738.6	172.8
2	FR-4	4.4	1.6	6.708	725.3	171.3
3	Bakelite	4.8	1.5	6.457	393.3	107.9
4	Rogers RT/Duroid 6006	6.15	0.635	5.866	94.9	39.2

V.CONCLUSION

Proposed designs with peripheral cuts for generating CP exhibit good gain characteristics while the circular polarization (*3dB* axial ratio bandwidth) values follows the rules found in literature i.e. decreases with increase in dielectric constant at design frequency of *5.9GHz*. Design process focused on optimizing axial ratio (AR) bandwidths to get good CP characteristics. Comparison table has been prepared to summarize the founding of the work. Higher dielectric constant substrate materials can be chosen for the CP antenna fabrication only by trading-off the values of return loss and AR bandwidths.

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