Modified Circular Patch Based Microstrip Antenna for Multi-Band Application

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Abstract— one of the most important component of RF and microwave communication is an antenna. The advance technological development in the field of Monolithic microwave integrated circuits (MMIC) plays very important role in the growth of printed antenna, due to the various advantages of microstrip antennas such as compactness, easy to fabricate and relatively very cost effectiveness these antennas are very hot choice for the researchers in present days. The paper presented here is a modified circular patch based microstrip antenna in which which we presented three design the final design is the learning outcome of first two circular patch antenna (CPA). This paper presents the simulation results using ansys HFSS software. The performance analysis of proposed antenna is based on result parameters like Peak gain, VSWR, Return Loss, Bandwidth and number of operating frequency bands. The frequency range under test is chosen as 1 GHz to 10 GHz.

Keywords— Circular Patch Antenna (CPA); Peak Gain; Monolithic microwave integrated circuits (MMIC; Parasitic Patch Fringing Effect; FR4

I. INTRODUCTION

The concept of printed antenna was not neproposed by deschamps [1] in 1953, but after the growth of Monolithic microwave integrated circuits (MMIC) technology this concept gain pratical application. As the application range of microstrip patch antenna (MPA) is very wide such as cell phone, WiFi dongal etc. the need for single antenna applicable for wide range applications like GSM 4G and 5G technology motivate us as to design a multiband antenna with better bandwidth and high peak antenna gain. Thus in this paper we proposed three novel design based on circular patch, is presented and learning different inputs in all design we proposed a final modified circular patch antenna (CPA) which is used in multi frequency range the observation is taken between 1 GHz to 10 GHz of frequency. The presented antenna is grown on FR-4 material (ε_r=4.4) as substrate with thickness of 1.6 mm, as this thickness of substrate is easily available in 1.6 mm and also very economical. On the basis of proposed design we get five (multi) band antenna which work in 1 GHz to 1.271 GHz, 4 .4 GHz to 4.54 GHz, 4.6 GHz to 4.914 GHz, 8.4 GHz to 8.59 GHz and 9.1 GHz to 9.39 GHz with bandwidth of 271 MHz, 140 MHz, 314 MHz, 195 MHz and 390 MHz respectively. Peak gain for the proposed antenna is -11.75 dB at 1.1 GHz, 2.44 dB at 4.5 GHz, 314dB at 4.8 GHz, 4.50 dB at 8.5 GHz, 7.48 dB and at 9.2 GHz respectively.The rest of the paper is organized in the different section, section II represents theory and various important parameters used in microstrip circular patch antenna (CPA) designing. Section III represents Physical insight of different proposed design of antenna, for multiband application in the frequency range of 1 to 10 GHz. Section IV represents the simulation result and performance parameter for the proposed designs, in section V conclusion and future work is proposed.

II. THEORY OF CPA

The circular patch is one of the most demanding patch design among researcher, after rectangular patch, the interest or researcher is not only on CPA but also on CPA array [1,3]. The basic model of CPA is same as that of RPA, which consists of matelic patch on top ground plane on bottom and substrate dielectric material in between above two shown in figure 1.

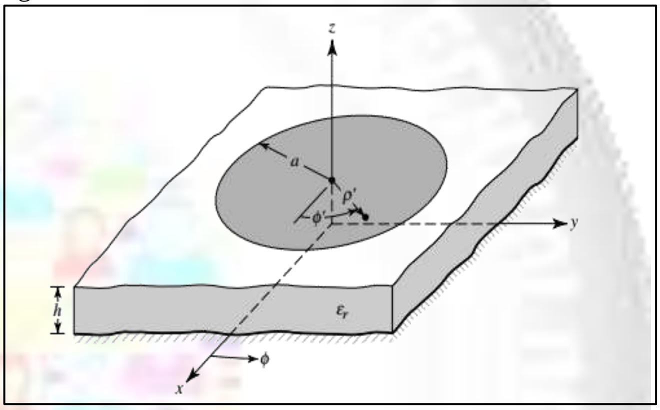

Fig. 1: Geometry of circular microstrip patch antenna.

The basic CPA associated with the resonant frequency for TEM_{mn0} mode is given by

$$(f_r)_{mn0} \cong \frac{1}{2L\sqrt{\varepsilon\mu}}\left(\frac{x'_{mn}}{a}\right) \quad (1)$$

Where x'_{mn} represents the zeros of the derivative of bessel function $J_m(x)$, which determine the order of the resonent frequency, a represents the radius of circular patch and other symbol are having usual meaning. The first four value of $x'_{mn}$is given [1] as:

$$x'_{11} = 1.8412 \quad (2.1)$$
$$x'_{21} = 3.0542 \quad (2.2)$$
$$x'_{01} = 3.8318 \quad (2.3)$$
$$x'_{31} = 4.2012 \quad (2.4)$$

Based on equation (1) and (2.1,2.2.2.3 and 2.4) the TEM_{110} and its resonant frequency is given as:

$$(f_r)_{110} \cong \frac{1.8412}{2\pi a\sqrt{\varepsilon\mu}} = \frac{1.8412\, c_0}{2\pi a\sqrt{\varepsilon_r}} \quad (3)$$

Where c_0 is the speed of light in free space, when we introduced fringing effect, the effective radius of circular patch changes and represented as:

$$a_e = a\left\{1 + \frac{2h}{\pi a\varepsilon_r} ln\left(\frac{\pi a}{2h}\right) + 1.7726\right\}^{\frac{1}{2}} \quad (4)$$

Thus the effective resonant frequency is given as:

$$(f_r)_{110} \cong \frac{1.8412}{2\pi a\sqrt{\varepsilon\mu}} = \frac{1.8412\, c_0}{2\pi a_e\sqrt{\varepsilon_r}} \quad (5)$$

The basic design of CPA starts with ε_r, f_r(in Hz) and h (in cm) and after that we find the dimension of circular patch using following formula:

$$a = \frac{F}{\left\{1+\frac{2h}{\pi a \varepsilon_r} ln\left(\frac{\pi a}{2h}\right)+1.7726\right\}^{\frac{1}{2}}} \quad (6)$$

Where,

$$F = \frac{8.791\times10^{9}}{f_r\sqrt{\varepsilon_r}} \quad (7)$$

III. Design

In this section we have taken three designs first two are modified CPA [7,8] and the final proposed design is extracted insight of the above two design, first two are represented as design A and design B and final design is represented as design C in the upcoming sub-section. All of the designs are simulated on FR4 substrate material of thickness of 1.6 mm.

A. Design A CPA Model

The first design is a modified circular patch in which an extra circular patch is embedded on the main circular patch the radius of main patch is 20 mm and embedded circular patch has a radius [4,5,6] of 10 mm., the radiating part of main patch reduced by extracting a circle of radius of 10 mm. for the excitation of proposed design we use a step indexed feed line of the dimension shown in figure 2. The substrate and ground plane has same area of dimension 80 mm x 80 mm and height of substrate is 1.6 mm. the ground plane is simple basic copper based rectangle with no modification.

B. Design B CPA Model

In the second design we use two circular patch which is connected with each other back to back with the dimension of 6 mm radius and 8 mm radius shown in figure 3. The antenna is excited by a feed line of dimension 10 mm x 2 mm. The substrate and ground plane has same area of dimension 40 mm x 40 mm and height of substrate is 1.6 mm. the ground plane is simple basic copper based rectangle with no modification.

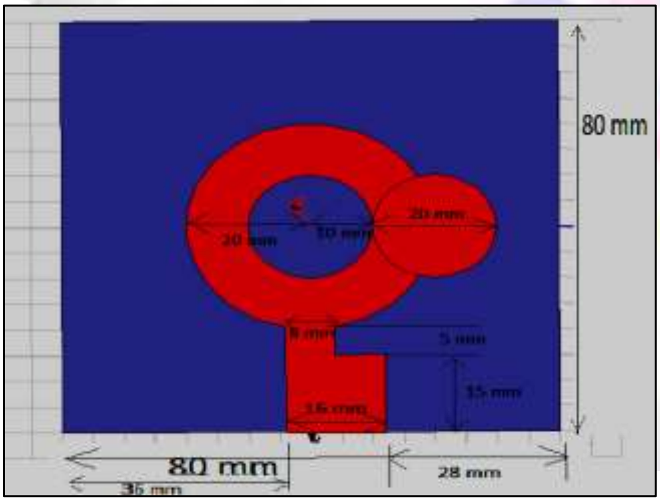

Fig. 2: Top view of Design *A* CPA model.

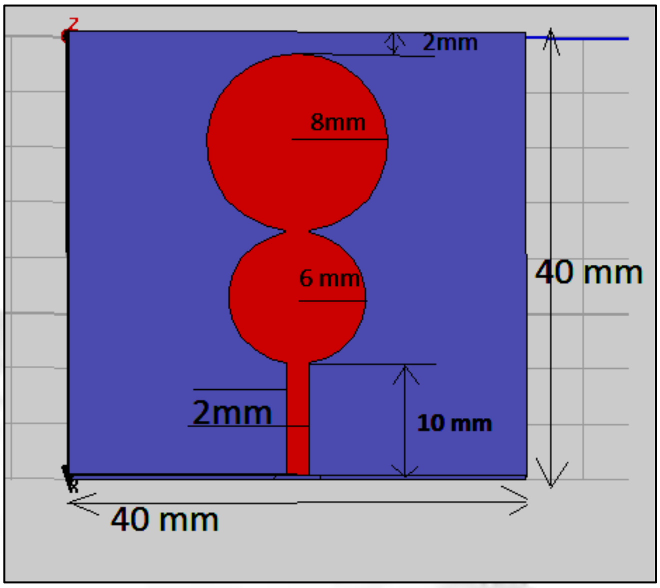

Fig. 3: Top view of Design *B* CPA model.

C. Design C of CPA Model

The final design is a modified circular patch which is extracted insight of the above two design, an extra circular patch is embedded on the main circular patch the radius of main patch is 20 mm and embedded circular patch has a radius of 10 mm. we also add one more circular patch back to back of main circular patch of radius 8 mm this radiating circular patch is connected to main circle by as strip line of 5 mm long and 3 mm width , the radiating part [10,11,12] of main patch reduced by extracting a circle of radius of 10 mm. for the excitation of proposed design we use a step indexed feed line of the dimension same as that of design A. we also introduce on rectangular patch of lingth of 70 mm and width of 5 mm shown in figure 4. This strip line gives better result in terms of bandwidth, high gain and large number of operating band. The substrate and ground plane has same area of dimension 80 mm x 80 mm and height of substrate is 1.6 mm. the ground plane is simple basic copper based rectangle with no modification. The principal objective of the manuscript is variation of patch geometry and dimension.

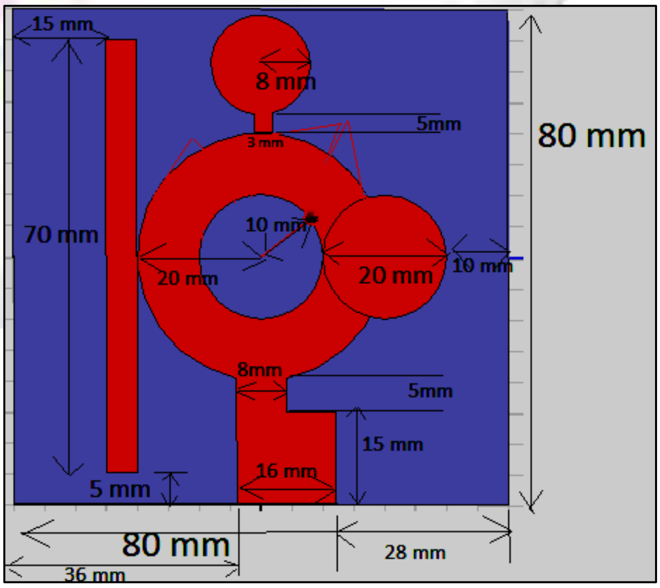

Fig. 3: Top view of Design *C* CPA model.

IV. Results & discussion

In main performance parameter [13,14] of MPA which is presented here is Return Loss, VSWR, Bandwidth, Number of operating band and peak Gain for the proposed three design. For design (A) we achieve two strong operating bad and multiple bands (three) of very narrow bandwidth, hence we calculate the various performance parameter for only two wide-range of operation with center frequency 8.5 and 9.2 GHz. On the other hand for design B, and C we achieve dual band of radiation nd five band of radiation respectively, the overall results obtained by all three designs are shown in table 1.

Design	Radiating Frequency (GHz)	BW (-10dB) (MHz)	Gain (dB)	Return Loss	VSWR
A	8.5 GHz	180	+5.58	-12.49	1.622
	9.2	305	+6.34	-19.95	1.223
B	5.5	105	+2.67	-12.52	1.61
	9.1	460	+5.65	-26.69	1.09
C	1.1	271	-11.75	-19.46	1.238
	4.5	140	+2.44	-13.0	1.580
	4.8	314	+3.27	-12.90	1.586
	8.5	195	+4.50	-13.06	1.570
	9.2	390	+7.48	-17.34	1.314

Table I: Result analysis of Patch antenna.

The figure 4, 5 and 6 represents the above parameter like return loss S11, -10 dB Bandwidth gain and VSWR respectively for design A.

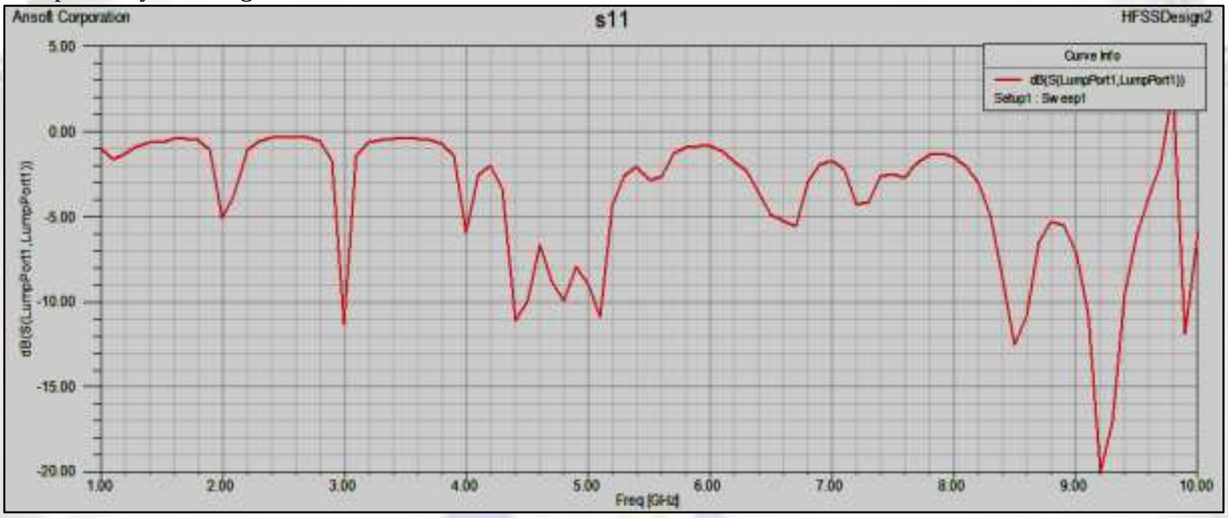

Fig. 4: S11 for Design A

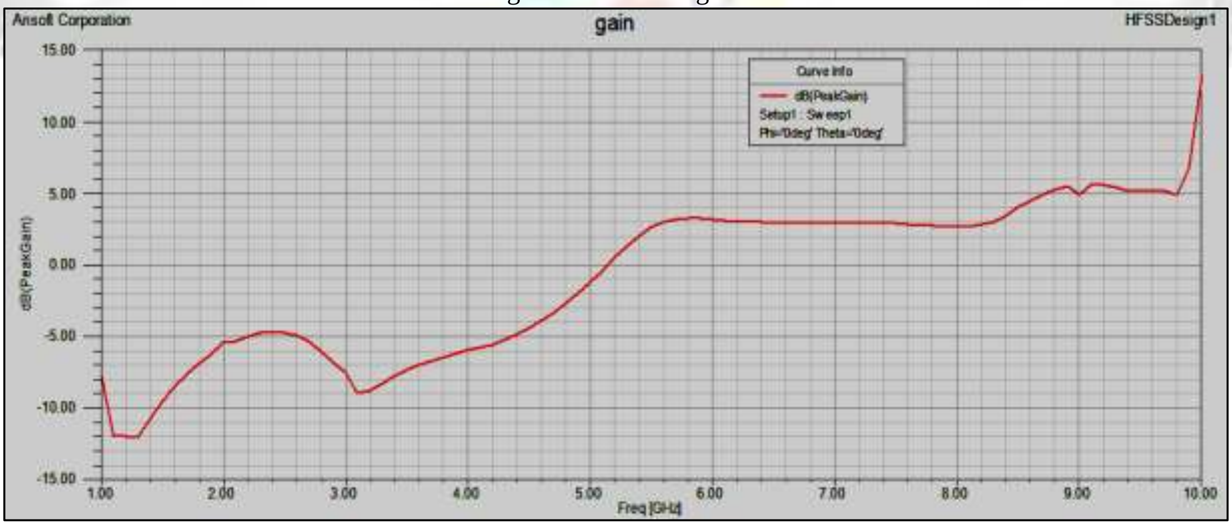

Fig. 5: Gain for Design A

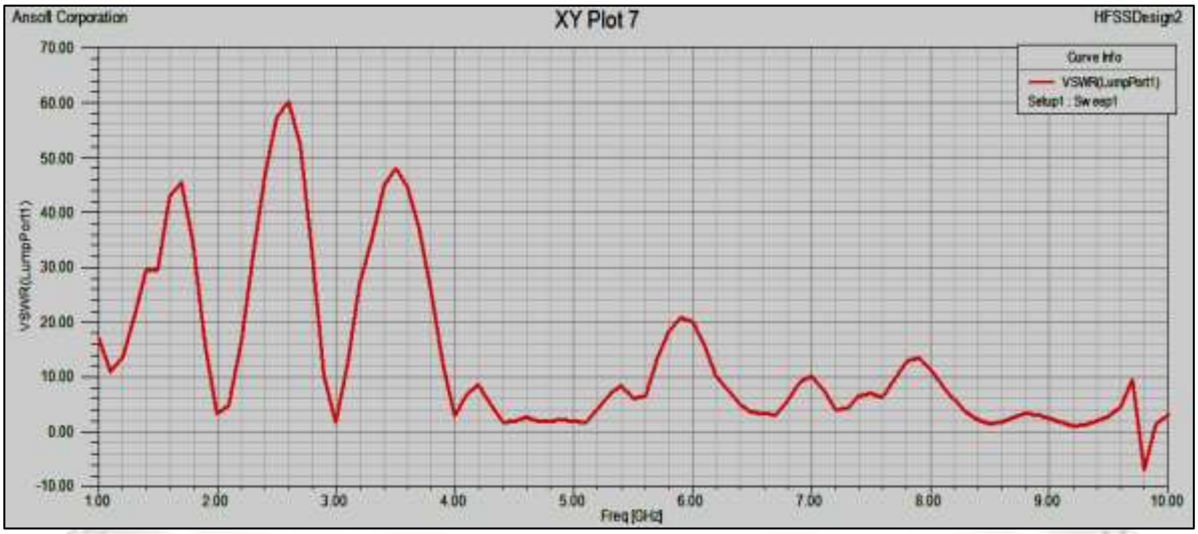

Fig. 6: VSWR For Design A

The figure 7, 8 and 9 represents the above parameter like return loss S11, -10 dB Bandwidth gain and VSWR respectively for design B.

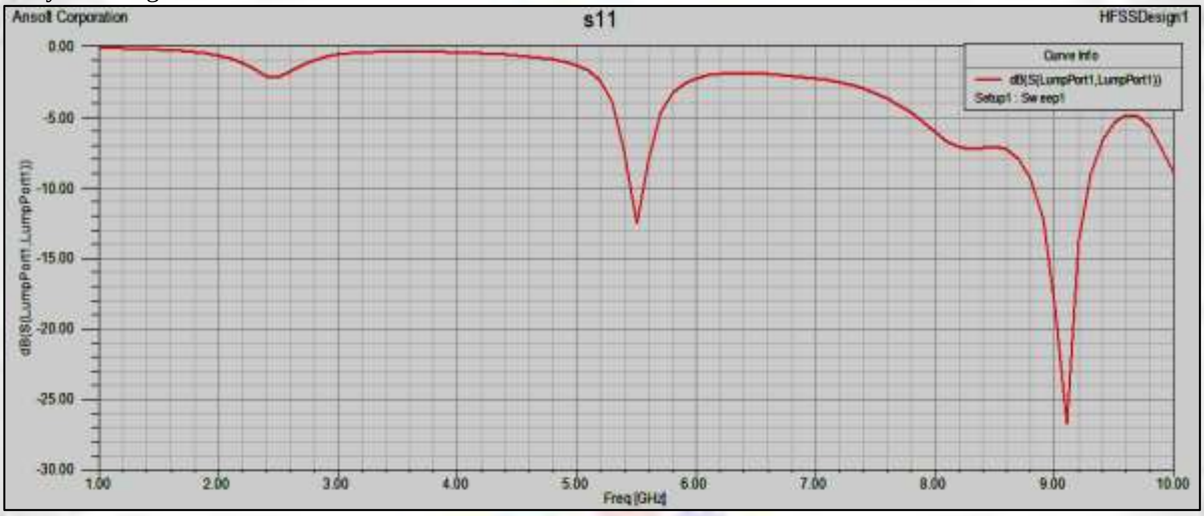

Fig. 7: S11 for Design B

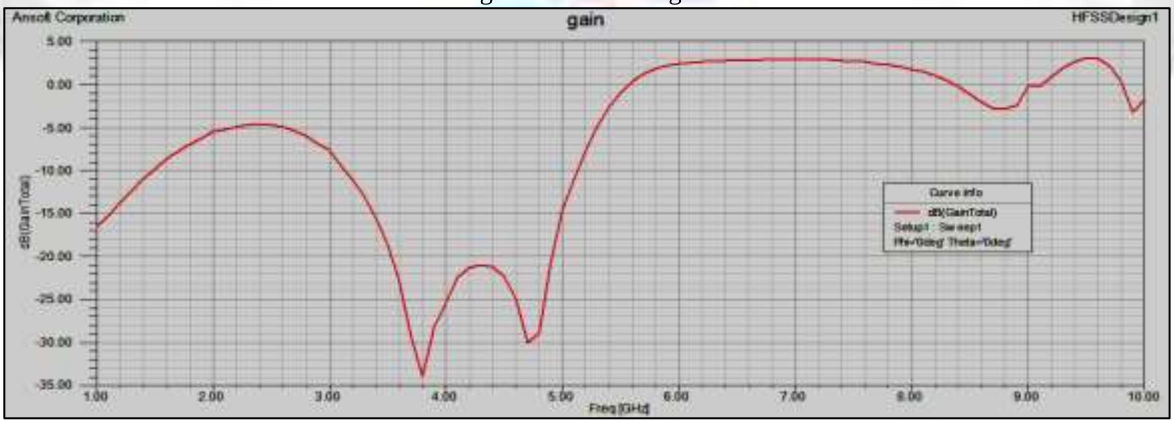

Fig. 8: Gain for Design B

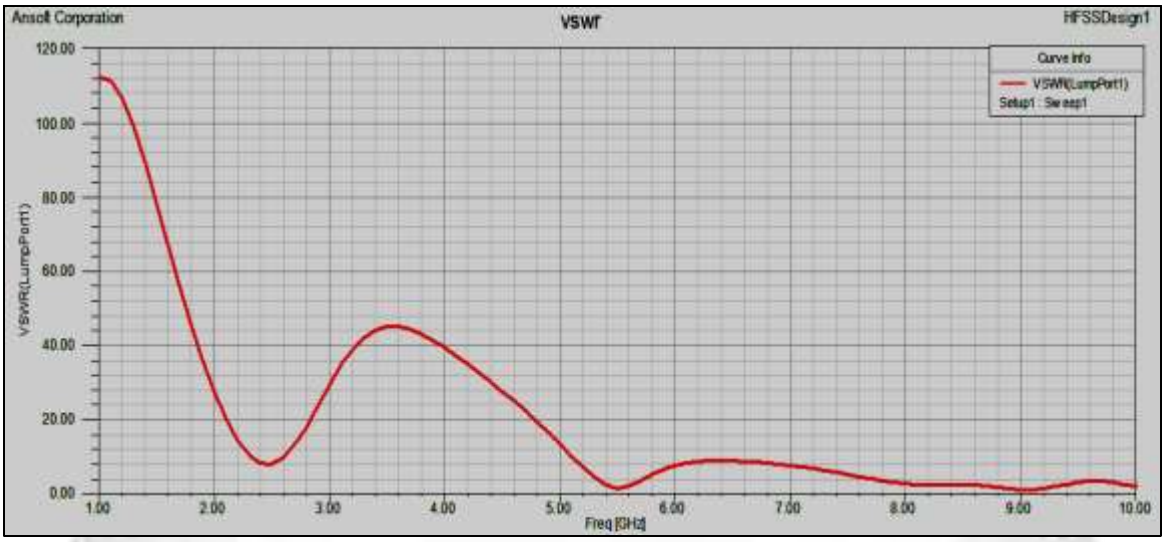

Fig. 9: VSWR for Design B

The figure 10, 11 and 12 represents the above parameter like return loss S11, -10 dB Bandwidth gain and VSWR respectively for design C.

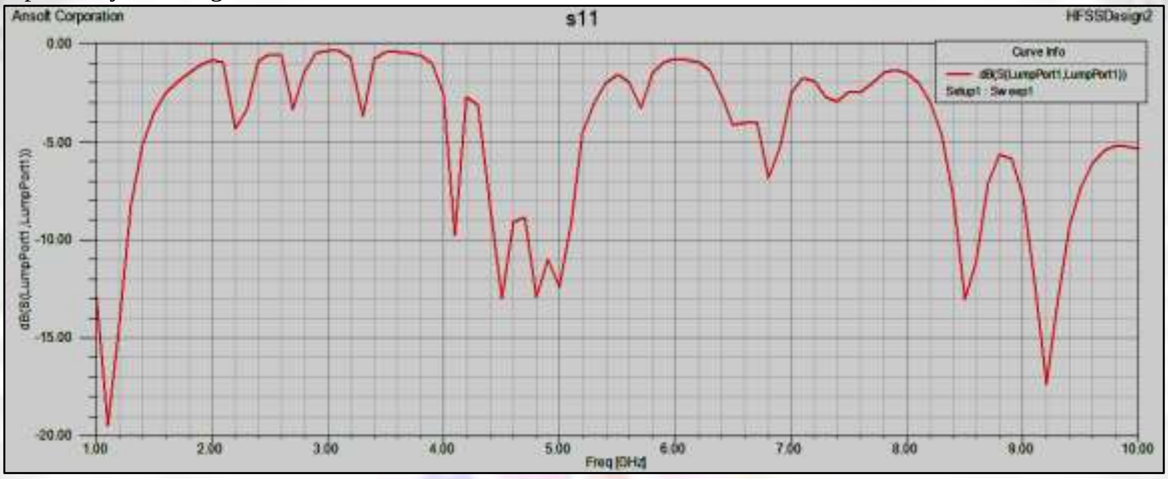

Fig. 10: S11 for Design C

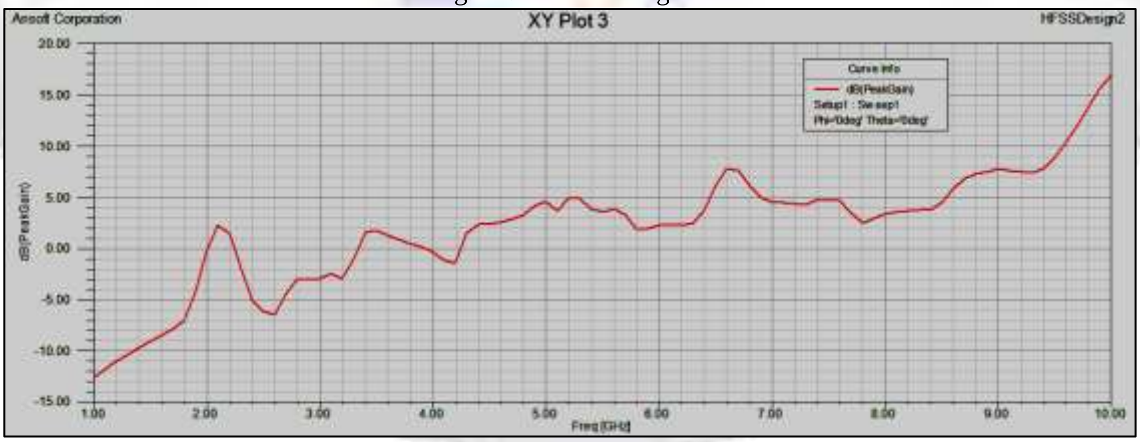

Fig. 11: Gain for Design C

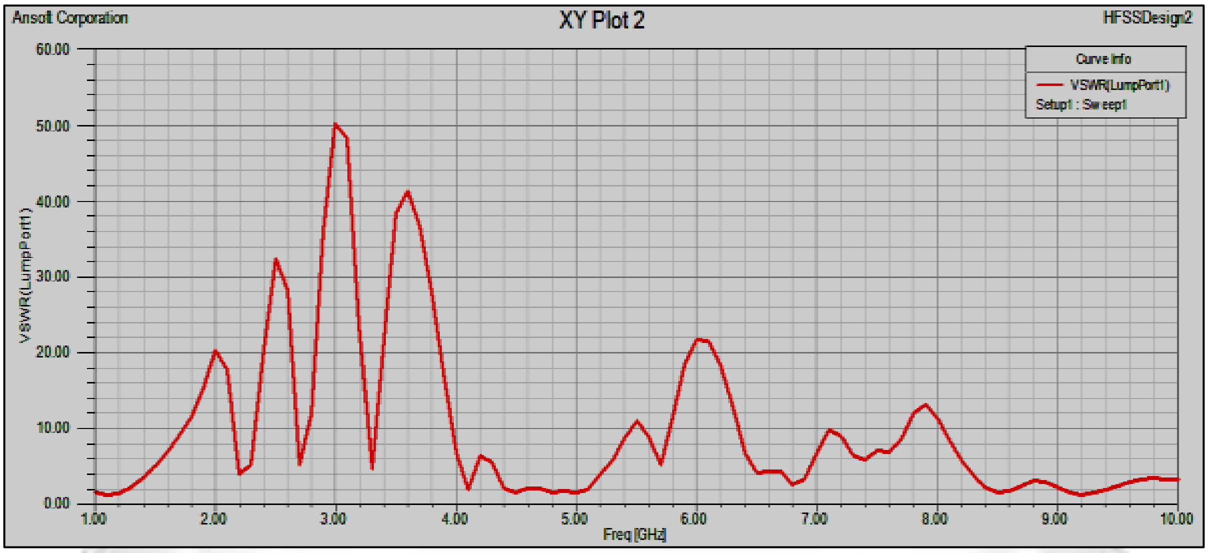

Fig. 12: VSWR for Design C

V. Conclusion & Future Work

In this paper a modified circular patch antenna is proposed, the final proposed antenna which is design extraction of first two designs. We observed that the design C produces multi-band actually five bands of bandwidth of 271 MHz, 140 MHz, 314 MHz, 195 MHz and finally 390 MHz at center frequency of 1.1 GHz, 4.5 GHz, 4.8GHz, 8.5 GHz and 9.2 GHz as center frequencies respectively. We also observed that the peek Gain is achieved at 9.2 GHz that is +7.48 dB. In design B we observe at that its bandwidth is 460 MHz and better return loss of -26.69 dB, but the gain is just about +5.5 dB, therefore we combined the two design to represents final design with improved gain of 7.48 dB. After analyzing the results in table 1 we can conclude that the introduction of different parasitic patch and extra circular patch improve the multi-band and high impedance patch composition boost the Gain with acceptable bandwidth and return loss. In design C the gain improves to 7.48 dB from 5.65 dB of design B, that is 32.38% better gain as compare of design B. The gain of Design C is around 18% better then Design A, with five (multiple) bands of acceptable bandwidth and return loss. In future the research can be extended in field of circular polarization between patch antennas by suppressing the surface wave and create different analytical model for the same.

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