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Design and Performance Characteristics of Ircular Microstrip Patch Antenna Arrays

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Abstract: In wireless communication era, we need the antennas with low profile, light weight, planar but can meet the characteristics of non-planar structures, with ease of fabrication, flexibility in terms of electromagnetic parameters like radiation pattern, gain, impedance, polarization etc. Microstrip patch antennas, which come at low cost, size, good performance, ease of installation and easy integration to circuits, high efficiency, are suitable in that context. The Principle of slot is used on the patch which decreases the radius of the circular patch antenna, so as to reduce the size. In this work various Ircular microstrip patch antenna arrays are intended for the application of WLAN and Wi-Max at 2.4GHz for the improvement of gain. Single microstrip patch antenna and planar arrays of 1x2 and 2x2 ircular microstrip patch antennas are designed using strip line feeding technique and simulated on FR4 substrate. The planar antenna arrays are simulated using the High Frequency Structure Simulator (HFSS) software version v17.2 and the parameters like gain, return loss, Bandwidth and VSWR are evaluated at 2.4GHz frequency and the same are presented.

Index Terms: Ircular Microstrip Patch Antenna, FR-4 Substrate, Strip line feed, Planar Arrays, HFSS Software.

I. INTRODUCTION

Antennas are backbone of the wireless communication applications. It requires light weight, small size, ease of installation of the antennas. Microstrip patch antennas have the advantages of small profile, relatively very minor in dimensions, light weight such that they can fulfill the requirements of wireless networking. A Microstrip patch antenna is modest in its structure as it contains a dielectric substrate with dielectric constant (ε_r) inserted between the conducting patch and the ground plane [1]. The patch can be of any suitable shape nonetheless circular and rectangular configurations are the best frequently used configurations as they have better characteristics. Circular patch is considered for the design in obtaining higher bandwidth than the rectangular patch [3, 9].Dielectric substrate FR4 (FR stands for flame retardant and 4 indicates the type of glass epoxy with ε_r=4.4) is used for maximum radiation in this work. FR4 is selected since it is easily available and also relatively cheap in the market. Microstrip multiple lines feed is adopted in this work.

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The slotted patch has a good advantage as it reduces the radius for the same resonant frequency [2, 5].

It also provides good coupling between the patch and the feed. Slot will reduce the size of antenna. Further, it also provides better gain than the patch without slot at the same reduced dimensions. Slotted circular microstrip patch antenna is referred as Ircular microstrip patch antenna or simply Ircular patch antenna. Microstrip antennas remain flexible and are compatible to produce a desired pattern which can't be obtained with one element. Also, they are used to determine the radiation pattern of the antenna that enhances the directivity and execute many other parameters that become complex with single element. The elements could be fed with single line or by multiple lines in the network [6-8]. So in this work arrays have been used to extend the performance of this ircular microstrip patch antenna. The most important characteristics for Microstrip patch antenna design is the Frequency of working (f_r).The WLAN and Wi Max Systems use the frequency range from 2.4GHz to 2.48GHz. Therefore the designed antenna needs to be competent to function at the selected frequency of operation. 2.4 GHz resonant frequency is chosen for this design.

II. DESIGN PROCEDURE

In this paper, the value of the substrate (FR4), which has ε_r = 4.4 and thickness of the substrate h = 1.6 mm are selected. The other dimensions are determined as follows:

Width (W): The patch antenna width is calculated by

$$w = \frac{c_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Effective dielectric constant (ε_{reff}): The substrate and air have different dielectric constants and the radiations passing through the 2 mediums will have their effects (Fringing effect). So the effective dielectric constant will be determined as follows

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2}, \frac{w}{h} > 1$$

Length (L): The length of the patch antenna can be calculated using this equation

$$L = L_{eff} - 2\Delta L$$

Where, $L_{eff} = \frac{c_0}{2f_r\sqrt{\varepsilon_{reff}}}$

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

Due to fringing, electrically the size of the antenna is increased by an amount of (ΔL). Therefore the actual increase in the patch antenna length is calculated using the equation $\frac{\Delta L}{h}$.

Length and Width of Ground plane and Substrate: The length and widths of ground plane are determined by [2]:

$$L_g = 6h+L$$

$$W_g = 6h+W$$

Patch Radius: The circular Patch radius is estimated by [1-3]:

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

$$Where \quad F = \frac{8.791X10^9}{f_r\sqrt{\varepsilon_r}}$$

The widths for each of the feed lines that are reliant on their impedance values for 50Ω and 100Ω lines are also determined by [4]:

$$Z_c = \begin{cases} \frac{60}{\sqrt{\varepsilon_{reff}}}\ln\left[\frac{8h}{w}+\frac{w}{4h}\right], & \frac{w}{h}\le 1 \\ \frac{120\pi}{\sqrt{\varepsilon_{reff}}\left[\frac{w}{h}+1.393+0.667\ln\left(\frac{w}{h}+1.444\right)\right]}, & \frac{w}{h}>1 \end{cases}$$

The inter-element spacing for the 1x2 and 2x2 Ircular patch antenna arrays need be selected between $\frac{1}{2}\lambda_g$ mm and λ_g mm [6-8].

Further, the Return loss, Gain, VSWR, Bandwidth are determined for single circular and ircular patch antennas. Then the work can be extended to evaluate the above mentioned parameters to 1x2 and 2x2 Ircular patch antenna arrays by using the HFSS software version v17.2

III. DESIGN OF SINGLE CIRCULAR AND IRCULAR MICROSTRIP PATCH ANTENNA AND ARRAYS

3.1 Configuration of Single Circular Patch Antenna

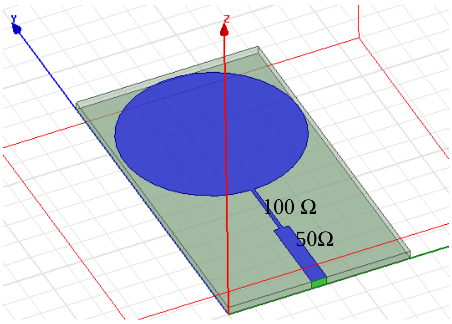

Figure 3.1: Configuration of single circular patch antenna

Dimensions are designed using above equations. To optimize the parameters parametric analysis is performed in HFSS software. The dimensions are given in table3.1:

TABLE 3.1: Dimensions of single circular patch antenna

Substrate Length (L)	38mm
Substrate width (W)	64mm
Patch Radius (R)	17.4 mm
Length and widths of the 50Ω strip line feed	16mm,3mm
Length and widths of the 100Ω strip line feed	12mm, 0.7mm

3.2 Configuration of Single Ircular Patch Antenna

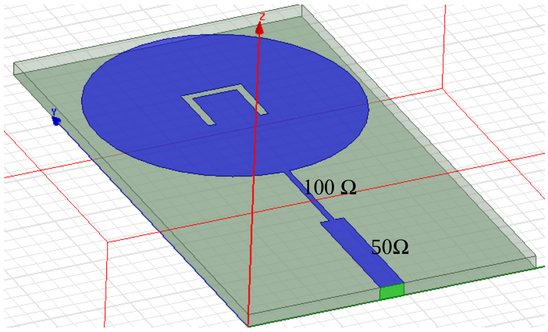

Figure 3.2: Configuration of single ircular patch antenna

The modified dimensions are tabulated in the table 3.2:

TABLE 3.2*:* Dimension of single Ircular patch antenna

Substrate Length (L)	36mm
Substrate width (W)	62mm
Patch Radius (R)	16.3 mm
Slot lengths (clockwise)	7mm,7.5mm,7mm
Slot Width	1mm

3.3 Design Analysis for 1x2 Ircular Patch Antenna Array

Same values are used for dimensions at the design frequency except the length of substrate, which changes with the inter-element distance of 44.69mm, for 1x2 Ircular patch antenna array.

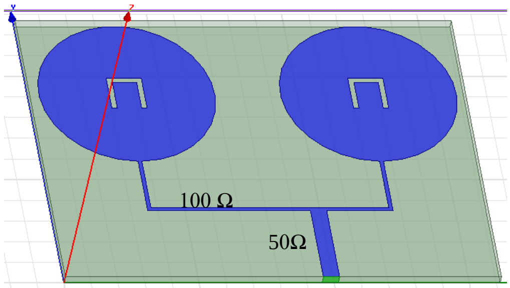

Figure 3.3: Configuration of 1x2ircular patch antenna array

Each of the patch is associated to 100Ω feed line. The equivalent at the junction of the two 100Ω lines is 100Ω. A 50Ω feed-line is connected to edge feed. The asymmetric feed position used for better parameters. The modified dimensions are given in table 3.3:

TABLE 3.3: Patch & Feed-line Dimensions of 1x2 Ircular patch antenna array

Length of the substrate and ground (L)	80.69mm
Inter-element spacing (0.75λ_g)	44.69mm
Length of the middle arm of the slot	6.5mm
Feed position from origin	47.75mm

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3.4 Design Analysis for 2x2 Ircular Patch Antenna Array

Same values are used for dimensions of antenna at the design frequency. But the substrate length and widths are altered according to the inter element distance i.e. 53.63mm.

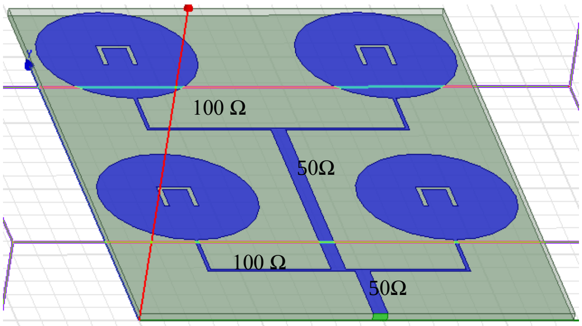

Figure 3.4: Configuration of 2x2 Ircular patch antenna array

The Patches are associated to 100Ω strip lines. Each two are linked to another 100Ω strip line. The corresponding each of the pair is connected to the 50Ω feed line of length 53.63mm at the junction and another 50Ω line is connected to the edge feed. The modified dimensions are tabulated in the table 3.4:

TABLE 3.4: Patch &Feed line Dimensions of 2x2 Ircular patch antenna array

Substrate Length (L)	80.63 mm
Substrate Width (W)	115.63mm
Inter-element spacing(0.9λ_g)	53.63 mm
Length of the middle arm of slot	7mm

IV. SIMULATION RESULTS OF SINGLE CIRCULAR PATCH ANTENNA, SINGLE IRCULAR AND IRCULAR ANTENNA ARRAYS IN HFSS

The projected antenna is designed and simulated in HFSS software. There are three solution types available in HFSS namely Discrete, Fast and Interpolating. Discrete is the most accurate and takes the longest time to simulate out of the three types of solutions. Fast is the least accurate and takes the shortest time for simulation. Interpolating is moderately accurate and takes moderate time for simulation. Interpolating method is adopted in this paper.

4.1 Simulation Results of Return Loss and Impedance Bandwidth:

Figure 4.1 (a), (b), (c) and (d) shows the Return Loss [S_{11}] of the projected antennas in dB. S_{11} Produces the return Loss at the feed position at which input is applied to the Microstrip patch. It must be less than -10 dB for an acceptable operation. From the figures 4.1 (a), (b), (c) and (d), it is observed that the proposed single circular patch antenna, single ircular patch antenna, 1x2 ircular patch antenna array and 2x2 ircular patch antenna array are operated at the resonant frequency of ~2.4GHz. The Return Loss values obtained at the resonant frequency are as follows -29.70dB, -21.75 dB, -31.16 dB and -28.65 dB respectively.

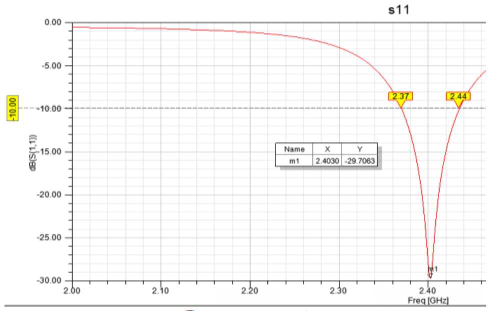

Figure 4.1 (a): Return loss S_{11} obtained for the single circular patch antenna

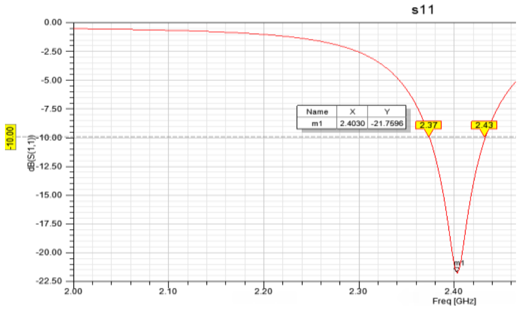

Figure 4.1 (b): Return loss S_{11} obtained for the single Ircular patch antenna

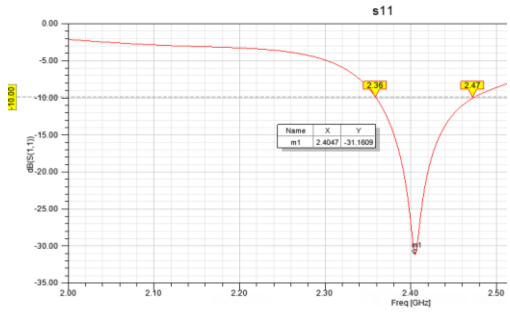

Figure 4.1 (c): Return loss S_{11} obtained for the 1x2 Ircular patch antenna array

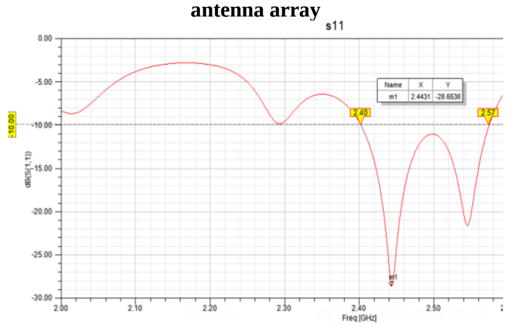

Figure 4.1 (d): Return loss S_{11} obtained for the 2x2 Ircular patch antenna array

The simulated impedance bandwidth values are 70MHz, 60MHz, 110 MHz and 170 MHz for single circular patch antenna, single ircular patch antenna, 1x2 ircular patch antenna array and 2x2 Ircular patch antenna array respectively that are tabulated in table 4.

4.2 Simulation Results of VSWR:

Figure 4.2 (a), (b), (c) and (d) shows the VSWR (Voltage Standing Wave Ratio) plots for all the cases ofsingle circular patch antenna, single Ircular patch antenna, 1x2 ircular patch antenna array and 2x2 ircular patch antenna array respectively.

Here the VSWR value for the proposed cases of single circular patch antenna, single ircular patch antenna, 1x2 ircular patch antenna array and 2x2 ircular patch antenna array were obtained as 1.676, 1.177, 1.056 and 1.076 respectively at the resonating frequency of 2.4GHz.

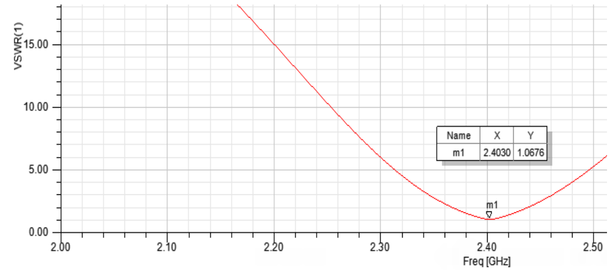

Figure 4.2 (a): VSWR obtained for the single circular patch antenna

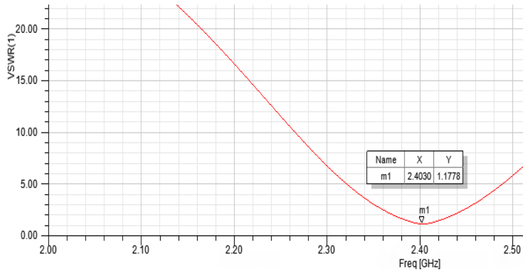

Figure 4.2 (b): VSWR obtained for the single ircular patch antenna

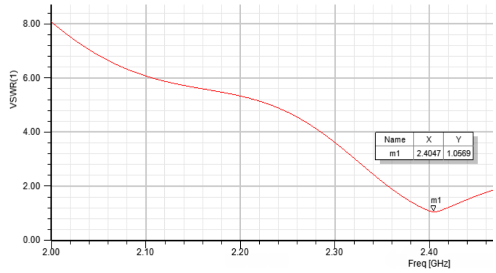

Figure 4.2 (c): VSWR obtained for the 1x2 Ircular patch antenna array

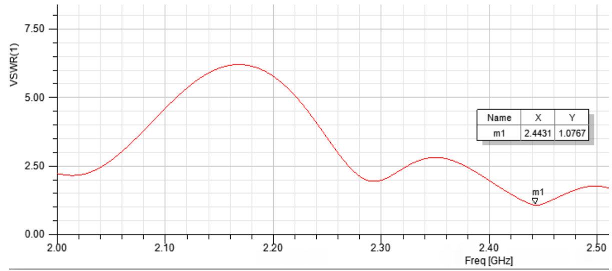

Figure 4.2 (d): VSWR obtained for the 2x2 Ircular patch antenna array

4.3 Simulation Results of Gain:

The peak gain values of the single circular patch antenna, single ircular patch antenna, 1x2 Ircular patch antenna array and 2x2 Ircular patch antenna array are 2.71dB, 2.00dB,4.34 dB and 5.97dB respectively that are presented in figures 4.3 (a), (b), (c) and (d).

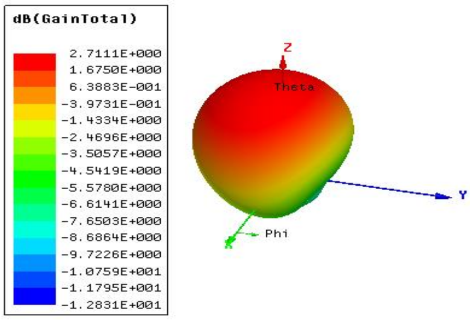

Figure 4.3 (a): Gain and 3D Radiation plot for the single circular patch antenna

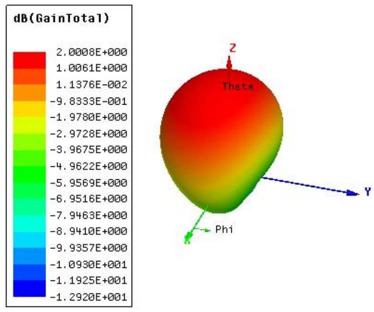

Figure 4.3 (b): Gain and 3D Radiation plot for the single Ircular patch antenna

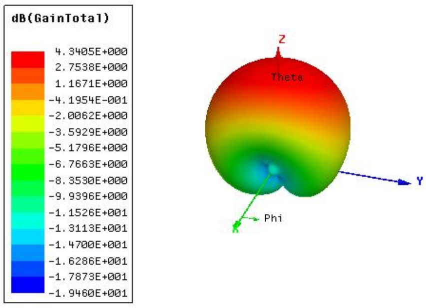

Figure 4.3 (c): Gain and 3D Radiation plot for the 1x2 Ircular patch antenna array

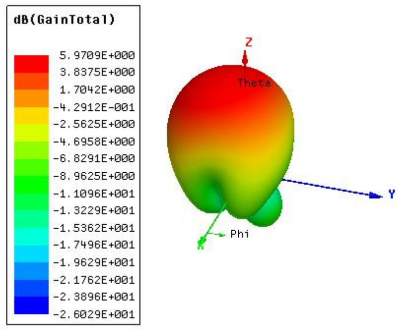

Figure 4.3 (d): Gain and 3D Radiation plot for the 2x2 Ircular patch antenna array

The above simulated results for single circular patch antenna, single Ircular patch antenna, 1x2 Ircular patch antenna array and 2x2 ircular patch antenna array are tabulated as below:

TABLE 4: Consolidated results obtained for all antennas

Antenna type	Return loss (dB)	Gain (dB)	VSWR	Impedance Bandwidth (MHz)	Radius of the patch (mm)

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Single Circular Patch	-29.70	2.71	1.067	70	17.4
Single Ircular Patch	-21.75	2.00	1.177	60	16.3
1x2 Ircular Patch Antenna Array	-31.16	4.34	1.056	110	16.3
2x2 Ircular Patch Antenna Array	-28.65	5.97	1.076	170	16.3

V. CONCLUSION

Microstrip patch antenna arrays of ircular shaped radiating elements were successfully designed and implemented using the FR4 Epoxy Glass substrate in HFSS. Through the Analysis of HFSS simulation software, it is observed that the antenna radius is reduced from 17.4 mm to 16.3 mm due to Ircular patch. It also provides better gain than the patch without slot at the same reduced dimensions.In this work, strip line feed technique was used for the simulation of all proposed antennas and are designed at the resonant frequency of 2.4 GHz. For the proposed design of ircular patch antennas, the maximum achieved gain obtained in the simulations is 5.97dB and the maximum Bandwidth is 170 MHz for 2x2 Ircular patch antenna array.

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