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Series Feed CSRR Based 2.45 GHz Microstrip Patch Antenna Array

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Abstract

In this paper a series feed array patch antenna design at 2.4 GHz. First complementary circular ring resonator as has been modeled and designed for single element patch antenna which resonance at 2.45 GHz. The designed CSRR suitable for its applications in patch size reduction because it gives negative real permeability and permittivity over a wide frequency band. The effect of loading the metamaterial shows a patch dimensional space reduction from 38.6 mm x 48 mm to 24.5 mm x 26 mm while providing better gain characteristics. The patch antenna without loading the metamaterial and loaded with the metamaterial provides a similar radiation efficiency and angular width however there is some difference in gain and the bandwidth of its operation. Then, the proposed antenna is designed for three array elements in a series-fed. The proposed antenna has 5.56 dB gain with -18 dB return loss. The proposed antenna is perfectly suited for wireless communications. It also used as image rejection filter in receiver system because of the metamaterial characteristics which can yield negative value of effective permittivity of a material.

Keywords: *Array, Metamaterial, CSRR, Reflection coefficient, Radiation pattern.*

1.Introduction

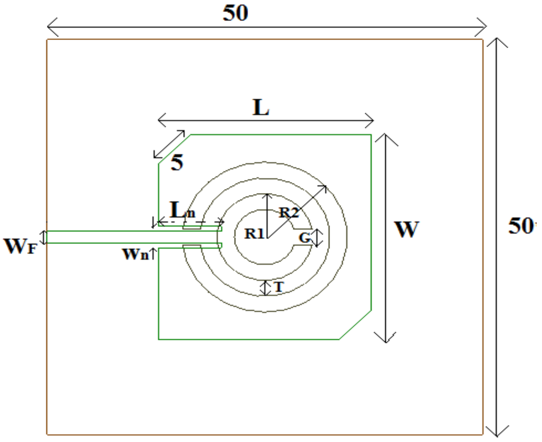
Patch antenna are widely used in modern communication systems due its exceptional capabilities like antenna miniaturization, light weight and feasibility in fabrication. These antennas can be integrated with design cost with other circuit components for its applications [1]. However, the size of the antenna is limited based on the operating wavelength of the antenna and has direct influence on the radiation characteristics. Hence lot of researches has been carried to improve antenna performance without increasing the size of the antenna. Meta-materials, Electromagnetic Band gap (EBG) structures and complementary split ring resonator (CSRR) are ways to improve antenna performance characteristics. Enhance of gain using cascaded EBG structures is presented in [2]. The antenna utilizes EBG structures periodically arranged to retard the antenna fields in a way to direct the radiation in desired direction for enhancing the gain characteristics. Antenna with CSRR structures loaded in the ground plane is demonstrated. These structure improves bandwidth [3] and gain characteristics [4]-[5] of the antenna. The model comprises of CSRR structure etched in the ground plane for improving its performances. This eliminates the need for impedance matching network which save the space for additional resources [6]-[7]. An array of patch antenna inspired by CSRR loading in the ground structure is presented [8]-[11]. These antennas further improve gain by appropriately exciting each elements of the antenna array.

In this paper a novel patch antenna array loaded with CSRR structure etched in the ground plane is presented. The antenna is excited through series fed method to eliminate the need for matching circuit and are modelled on single layer low cost substrate for simplicity. The performance of the antenna is tuned through parametric analysis of vital antenna parameters through simulation and its performance is validated through measurements. The antenna achieves better gain characteristics in the entire operating band and thus suitable for ISM band applications including biomedical devices, mobile devices and wireless sensors for acquisition of data's in industries.

2. Methodology

2.1 Single SRR Antenna

The geometry of the antenna is given in Figure 1. The geometry comprises of a rectangular patch whose corners are truncated to achieve circular polarization along with complementary split ring resonators for improving the antenna performances.



(a)

(b)

Figure 1. (a) Antenna Geometry (b) Prototype

The antenna is modelled on low cost FR4 substrate having a thickness of 1.5 mm whose permittivity is equivalent to 4.4 and loss tangent of 0.02. The antenna is designed on single layer substrate fed by means of 50Ω SMA connector. The parameters of the rectangular patch along with SRR are calculated from equations given below.

For a specific center frequency and permittivity, the substrate thickness is calculated using

$$h \geq 0.06 \frac{\lambda_{air}}{\sqrt{\varepsilon_r}} \tag{1}$$

Then the width of the patch of the patch is determined based on

$$W_p = \frac{V_o}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{2}$$

The factor Wp gives the physical width of the patch. However, the electrical length of the patch is much more than the physical width due to the presence of the fringing effects.

Hence the effective dielectric constant of the substrate for a particular substrate height and width of the patch is determined using

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W_p}\right]^{-1/2} \tag{3}$$

for $W_p / h > 1$

Then using effective dielectric constant, the normalized extension of the length due to fringing effect is determined based on

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W_p}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W_p}{h} + 0.8\right)} \tag{4}$$

$$L_p = \frac{V_o}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta L \tag{5}$$

The length and width of the patch is determined from feed Line Impedance of the antenna.

$$Z_o = R_{in}\cos^2\left[\frac{\Pi}{L_p}d\right] \tag{6}$$

For an antenna to radiate effectively, the impedance of the antenna must match with the input impedance and hence the length and width of the feed line is chosen to match antenna input impedance. Slip ring resonator is placed on the ground plane to improve the performance of the antenna. The geometry of the complementary split ring resonators is calculated based on equation given below.

$$n = \frac{1}{kd}\cos^{-1}\left[\frac{1}{2S_{21}}(1 - S_{11}^2 + S_{21}^2)\right] \tag{7}$$

$$Z = \sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}} \tag{8}$$

$$\varepsilon = \frac{n}{z} \tag{9}$$

$$\mu = nz \tag{10}$$

Where n is the refractive index and z is the wave impedance. For an operating frequency of 2.45 GHz the dimension of the Complementary split ring resonators is determined. The gap region G is determined from calculations given below

$$f_r = \frac{V_o}{\sqrt{2\times\varepsilon_{eff}}}\,\frac{4.6\times10^{-14}}{g} + \frac{f}{1.01}$$

$$f = \frac{V_o}{\sqrt{2\times\varepsilon_{eff}}}\,\frac{4.6\times10^{-14}}{g} + \frac{f}{1.01}$$

$$f - \frac{f}{1.01} = \frac{V_o}{\sqrt{2\times\varepsilon_{eff}}}\,\frac{4.6\times10^{-14}}{g}$$

$$\frac{.01f}{1.01} = \frac{V_o}{\sqrt{2\times\varepsilon_{eff}}}\,\frac{4.6\times10^{-14}}{g}$$

$$G = \frac{V_o}{\sqrt{2\times\varepsilon_{eff}}}\,\frac{4.65\times10^{-12}}{f} \tag{11}$$

The effect of length of the slot has critical effect on the operating frequencies of the antenna and the length of corner slot is taken as primary design parameters for analyzing the performance of the antenna.

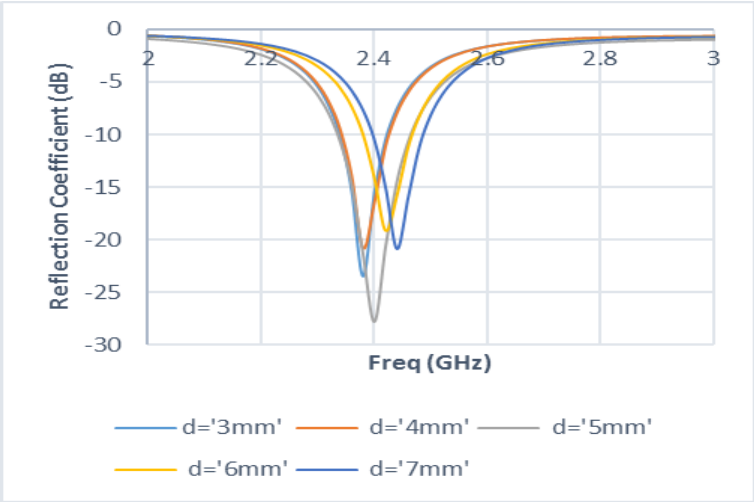


Figure 2: Effect of length of the corner slot length (d) of reflection coefficient.

Hence parametric analysis of length of slot on antenna performance is shown in Figure 2. It is inferred that the increasing the corner slot shifts the operating frequency toward higher bands and final optimized value of the corner length is determined. Based on the designed equations, the design parameters of the antenna and its specifications are given in Table 1.

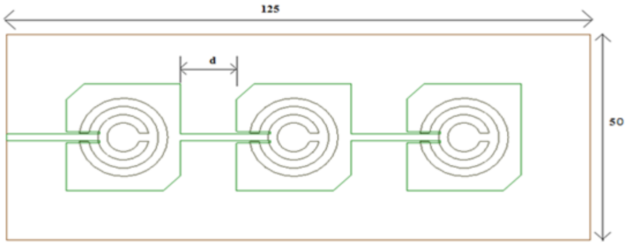
Table 1. Design Parameters

Design Parameters	Specifications (mm)
Width of the patch W	26
Length of the patch L	24.5
Height of the substrate (h)	1.5
Width of the feeding line (WF)	2
Width of the substrate and ground plane	50
Length of the substrate and ground plane	50
Width of the notch (Wn)	2.75
Length of the notch (Ln)	7.25
Corner Cut	5
External radius of the CSRR (R2)	9.5
Averaged radius of the CSRR (R1)	6.5
Width of the rings (T)	2
Width of the splits (G)	2

2.2 SRR Antenna Array

The SRR antenna array is given on Figure 3. The antenna comprises of 1x3 elements arranged in linear fashion separated by equal distance d. The first element is excited with

50Ω SMA connector and the remaining cells are excited by means of immediate previous antenna cell. The radiation characteristics of the antenna is simulated and are compared with measured characteristics.



(a)

(b)

Figure 3. Antenna Geometry of series fed antenna

The distance between the antenna elements is optimized to get better performance characteristics. Hence it is taken as a vital parameter for optimizing the performance of the antenna. The effect of spacing between the antenna elements on operating frequencies is shown in Figure 4.

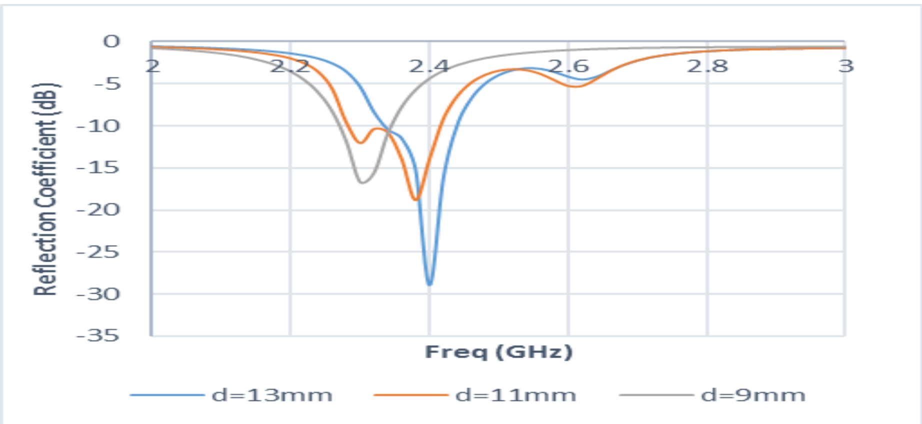


Figure 4. Effect on spacing d on antenna impedance characteristics

The effect of spacing between the antenna elements on antenna gain (dB) is shown in Figure 5. Three elements connected series, the space between two elements is optimized to get good gain as well as maintain the minimum size of the antenna. While optimizing the space of the array the value of d was taken in 5 units.

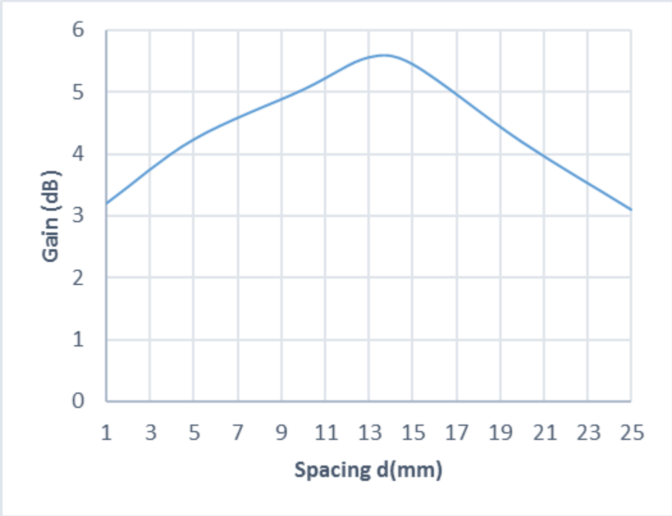


Figure 5. Effect on spacing d on antenna gain characteristics

The gain obtained in 10mm, 13mm, 15mm are nearly equal, optimizing again in between 10mm and 15 mm, and the 13 mm give optimum gain value for optimum space. It is observed that at the spacing of 13mm between the elements gives maximum antenna gain. Hence the spacing between the antenna elements is optimized to 13mm and antenna radiation characteristics at that spacing is plotted.

3. Results and discussions

In order to validate the performance of the antenna, the model is fabricated on FR4 and are tested. The measured reflection coefficient curve for the proposed single element SRR antenna is shown in Figure 6 and are compared with measured results. It is inferred that the antenna resonates in the 2.4 GHz S band having a measured bandwidth of 200MHz between 2.33-2.53 GHz.

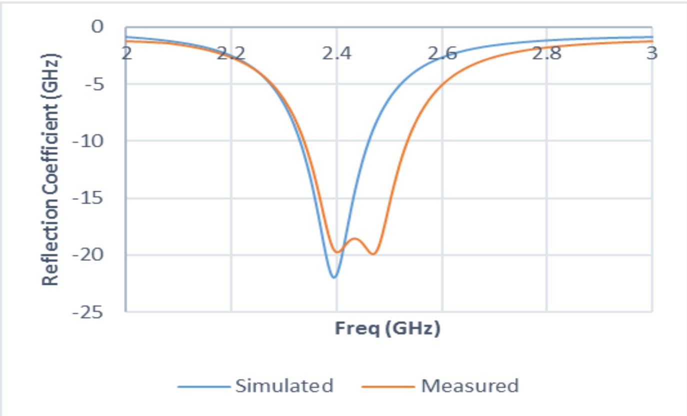
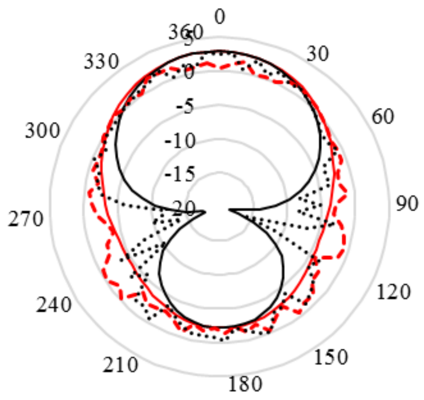
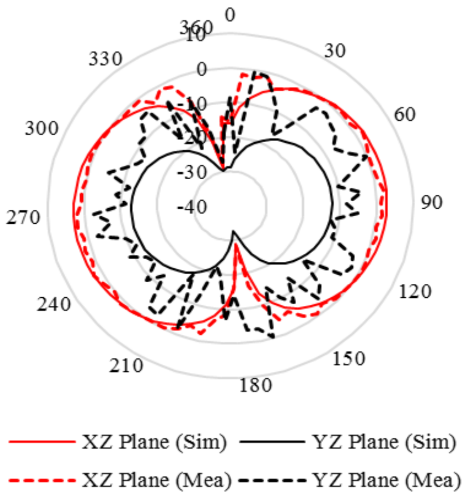


Figure 6. Reflection coefficient of single element SRR antenna.

The simulated and measured gain characteristics of the antenna at E plane and H plane is plotted and are given in Figure 7. It is observed that the antenna gives symmetrical radiation with a simulated peak gain of 3.39 dB and measured peak gain of 3.19 dB in the operating band.



(a) E Plane



(b) H Plane

Figure 7. Radiation Characteristics of Single Element SRR antenna

The 3x1 antenna array geometry of the proposed unit cell SRR antenna is given in Fig.3. Each element is fed series from the previous antenna. The impedance characteristics of the array antenna of the simulated and measured results are shown in Figure 8.

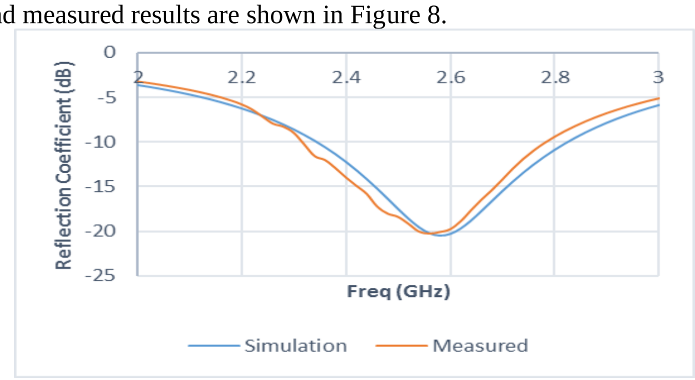


Figure 8. Reflection coefficient of SRR antenna array

It is observed that the antenna achieves a simulated impedance bandwidth of 2.32GHz – 2.76GHz and measured impedance bandwidth of 2.33GHz – 2.78GHz in the operating band.

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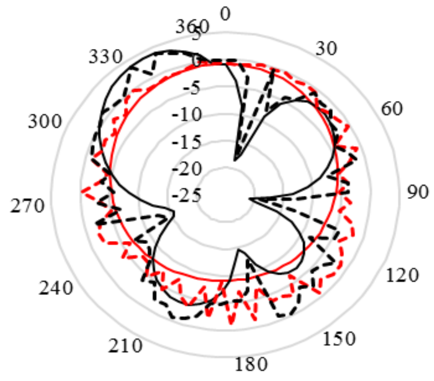
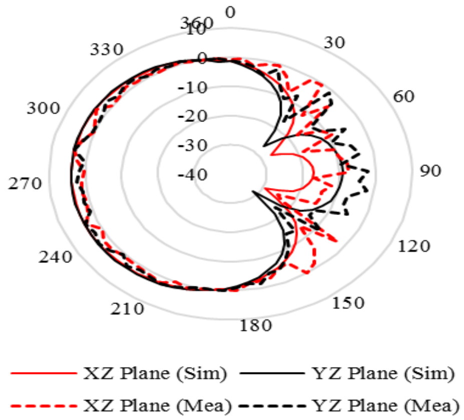


(a) E Plane



(b) H Plane

Figure 9. Radiation characteristics of an antenna array

The simulated and measured gain characteristics of the antenna at E plane and H plane is plotted and are given in Fig.9. It is observed that the antenna gives symmetrical radiation with a simulated peak gain of 5.82 dB and measured peak gain of 5.56 dB in the operating band.

4. Conclusion

The study on effect of slip ring resonator on the performance of the antenna array is discussed. The model comprises of rectangular patch antenna along with SRR etched on the ground plane for improving antenna performances. The antenna achieves better impedance characteristics with a measured peak gain of 5.56 dB in the operating band. Metamaterial antennas are tunable highly efficient, compact size and so its suitable for RF energy harvesting and other wireless applications. The antenna also used as image rejection filter in receiver system because of the metamaterial characteristics.

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