Design and Development of Metamaterial Based High Performance Microstrip Antenna

N. Subramanyam Mahesh and D. Varun

Abstract The primary objective of this paper is to design a high performance metamaterial antenna and benchmark the performance with a microstrip antenna. A circular microstrip patch antenna is considered for demonstrating the performance of the antenna with and without the metamaterial structures. This paper clearly brings out the advantages of the metamaterial circular patch antenna as compared to the standard circular microstrip antenna. Simulations and measurements are carried out for comparison purpose. The developed metamaterial based patch antenna shows a significant reduction in size by 25% when compared to a circular patch antenna. It has been found that reduction of size in developed metamaterial based antenna does not degrade the directivity performance which is found to be 6.5 dB. Further, the bandwidth of the metamaterial based antenna is found to be same as that of microstrip antenna. RCS simulation has shown reduction in RCS by 9 dBsm.

Keywords Metamaterial · Microstrip patch antenna · Radar cross section · Return loss

1 Introduction

Recent trend towards miniaturization and devices with RF technologies, antenna size reduction, efficiency play a very vital role. Size, weight, ease of installation, cost and performance are critical parameters. Microstrip antennas meet the said requirements. The microstrip patch antenna is also well suited for MMIC designs. Depending on the shape of the patch structure and mode selected, patch antennas are very versatile in terms of resonance, polarization, pattern and impedance. There have been several attempts to reduce the size of the microstrip patch antenna by using aperture stacked sheets and other variations. It has been found that the use of metamaterials results in size reduction in antenna. A comparative study in [1, 2] depicts the advantages of circular patch antenna when compared to rectangular patch. It is found the circular

N. Subramanyam Mahesh · D. Varun (✉)
Department of ECE, M. S. Ramaiah University of Applied Sciences, Bengaluru, India
e-mail: varun.ec.et@msruas.ac.in

G. R. Kadambi et al. (eds.), *Emerging Trends in Photonics, Signal Processing and Communication Engineering*, Lecture Notes in Electrical Engineering 649,
https://doi.org/10.1007/978-981-15-3477-5_15

patch antenna uses a lesser surface as compared to a rectangular microstrip antenna. There are a significant number of papers that elaborate on metamaterial based rectangular patch antenna. However, there are not many papers in the open source that have included circular patch antenna in the studies. The paper by [3–5] delve into the metamaterial based circular patch antenna but does not deliberate at size reduction. The paper [4] highlights the different methods to incorporate metamaterial structures in the antenna design such as the superstrate based antenna design or the CSRR perforated ground plane based design. The literature [6–9] shows that there is a size reduction in the patch array with the use of CSRR in the ground plane. However, the study in [5] has not simulated the performance of the antenna with the CSRR loaded and the antenna tuned to the original frequency for which it was designed. It is found that the intended frequency of antenna design increases and the dimensions of the resonator structures decrease. The interaction between the resonators also play a very critical role and this is dictated by the distance between the resonators which is again a function of the frequency [4]. As a result of the dimension restrictions, the fabrication of these materials requires a complex photo lithography mechanism. From the above observations based on the literature survey, it can be inferred that the circular patch antenna offers some inherent advantages. It is also seen that there are not many literature that have carried out a detailed analysis of the circular patch antenna with metamaterial structures. Hence there is a motivation to look into the behaviour of a circular microstrip antenna with metamaterial structures in the ground plane and compare its performance with a circular microstrip antenna. In this paper, an attempt has been made to develop a metamaterial specifically aimed at an X band circular path antenna and reduce the size of the said patch. It is also to be noted that the gain of the antenna is not reduced.

2 Antenna Modelling, Simulation and Optimization

The antenna has been developed by selecting X band frequency. X band is the chosen frequency due to the antenna aperture size restrictions for RADAR applications. The modelled antenna has been further optimized for its performance. The design goals for the high performance metamaterial antenna are as follows:

- Frequency Range: X—Band
- Resonant frequency: ~10 GHz
- Directivity(Goal): >4 dBi
- Input return loss < -14 dB

2.1 Design of the Circular Patch Antenna

An appropriate substrate suitable for 10 GHz has been selected with negligible (tan δ) losses. Based on a survey, it has been identified that the substrate material RT5880 from Rogers or the Arlon Diclad880 is suitable for X-band low loss applications. Arlon Diclad880 substrate has been selected for all simulation and fabrication purposes. Based on the antenna specifications and the substrate chosen, the following data is necessary for antenna development.

- $F_0 = 10$ GHz
- Substrate permittivity, $\varepsilon_r = 2.17$
- Loss tangent(D) = 0.0009

The Shen formula for computing the radius of the microstrip patch antenna is given by Eqs. (1) and (2).

$$a = \frac{F}{\sqrt{\left\{1 + \frac{2h}{\pi \varepsilon F}\lceil \ln(\pi F|2h) + 1.7726\rceil\right\}}} \tag{1}$$

$$F = \frac{8.791 * 10^9}{f_0 \sqrt{\varepsilon}} \tag{2}$$

a = radius of the circular patch
μ = permittivity of the substrate
ε = permittivity of the substrate
h = thickness of the substrate in cm
f_0 = Resonant frequency of antenna

On substituting the values for the resonant frequency and the permittivity, the radius of the circular patch was found to be 5.9 mm. The antenna has been modelled and simulated with a radius of 6 mm for the said frequency.

2.2 Design of the Metamaterial Square Split Ring Resonator

A rectangular split ring resonator has been designed using empirical equations in [10]. One of the important assumptions is that the resonator must be lesser than $\frac{\lambda}{10}$. The split ring resonator resonates at a frequency determined by the total distributed inductance and capacitance provided by the inner and outer rings. The split ring resonator has a stop band around the desired resonant frequency of the antenna with split ring resonator in the ground plane.

The average loop length is computed as given in the Eq. 3.

$$L = 4X - S - 4W \tag{3}$$

where X is the length of the ring, S is the spacing and W is the width.

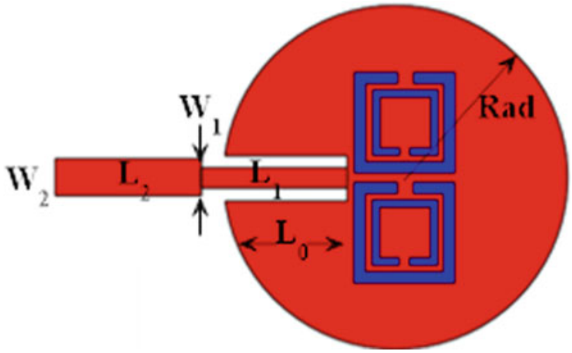

Fig. 1 Tuned circular patch with CSRR structures

Table 1 Tuned patch dimensions with CSRR loaded

Parameter	Dimension (mm)	Parameter	Dimension (mm)
Radius of the patch	6	Length of outer ring (X_1)	3.0
Inset length (L_o)	3.936	Width of outer ring (W_1)	0.33
Length of microstrip feed line (L_2)	5.47	Spacer (S_1)	0.57
Length of microstrip feed line (L_1)	5.47	Length of inner ring (X_2)	1.95
Width of microstrip (W_1)	1.1	Width of outer ring (W_2)	0.31
Width of microstrip (W_2)	1.67	Spacer (S_2)	0.21

2.3 Design of Circular Patch Antenna with Square CSRR

Once the metamaterial structure is loaded in the ground plane, the resonant frequency of the patch antenna shifts to a lower frequency. This indicates a reduction in the size of the antenna. So to tune the antenna back to 10 GHz resonance, the antenna needs to be designed for a higher frequency than 10 GHz which is the design goal. The antenna simulation has to be performed and an iterative optimization has to be done. Figure 1 depicts the circular patch antenna loaded with square metamaterial structure. Table 1 shows the dimensions of the antenna.

3 Results and Analysis

Antenna with and without the CSRR structures has been fabricated to compare the results of the simulation. The antenna return loss has been measured using a network analyser and results are validated. The simulation results in Fig. 2a depicts the return loss for the circular patch antenna with PEC ground. The simulation results depict the resonance at 10 GHz with a return loss of—15 dB. Similarly Fig. 2b depicts the simulated return loss for the optimized antenna with CSRR in the ground plane.

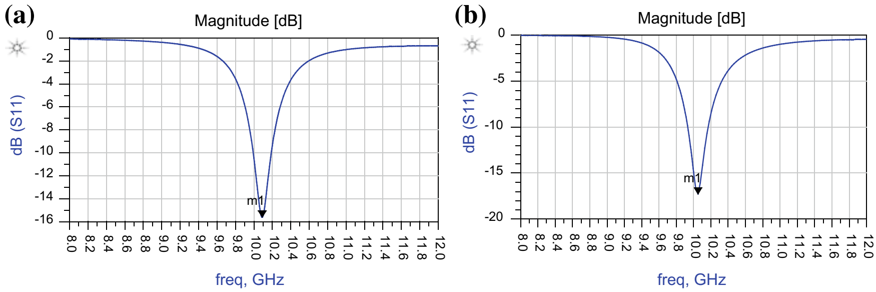

Fig. 2 Simulated return loss results for circular patch antenna **a** without CSRR **b** CSRR loaded

Comparison of simulated results depicts similar return loss results between PEC loaded and CSRR loaded antenna. It is pertinent to note the CSRR loading results in a 25% reduction in size. The CSRR loaded antenna fabricated is shown in Fig. 3. The return loss is measured to be at—12.33 dB from Fig. 4a in case of PEC ground

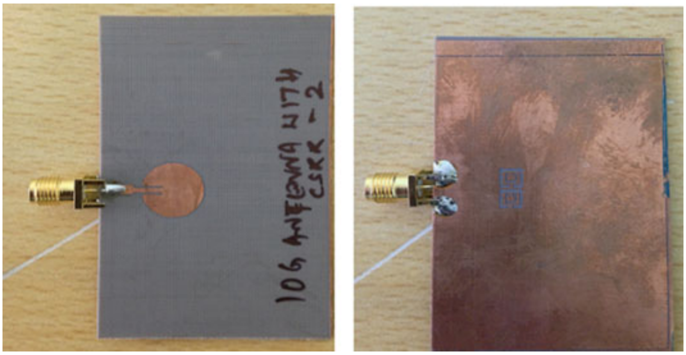

Fig. 3 Fabricated circular patch antenna (CSRR loaded)

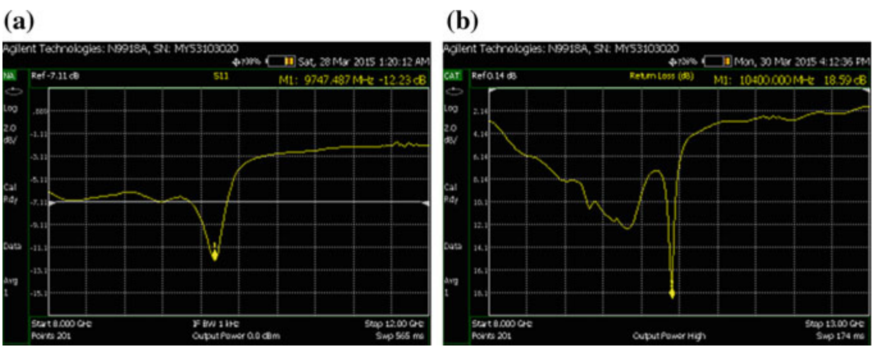

Fig. 4 Measured return loss for circular patch antenna **a** PEC Ground **b** CSRR Loaded

plane. Figure 4b shows the measured return loss of—18.5 dB for antenna loaded with CSRR. The error between the simulated and the fabricated antenna is less than 5%. The error can be attributed to the fabrications techniques that were used and also SMA connectors that were used at the feed point has not been modelled in the simulation. The antenna with the square CSRRs loaded in the ground plane was simulated for its directivity performance. The directivity is 6.26 dBi and is 1 dB lower than the circular patch antenna with PEC ground. The reduction in directivity is attributed due to reduction in the aperture size after CSRR loading.

4 Computation of Radar Cross Section (RCS) of the Antenna

The developed antenna with PEC ground and antenna with CSRR structures have been further simulated for its RCS performance. The layout of the antenna is developed, modelled and simulated using Method of Moments. The antenna under test is excited by a point source that produces a planar wave front to excite the antenna. The simulation setup has been configured for a monostatic radar configuration at $\theta = 0°$ and $\phi = 0°$. The reflections from the antenna under test have been captured by the sensor and the RCS plots are plot. The analysis has been carried at 10 GHz excitation frequency. Figure 5a shows the RCS for the patch antenna with PEC ground. The maximum RCS is at 0° theta and is—23 dBsm at 10 GHz. Figure 5b shows the RCS performance with CSRRs loaded on to the patch antenna. The RCS at 10 GHz is found to be—32 dBsm with the CSRRs.

The results in Fig. 5 shows a reduction in RCS as compared to the patch antenna with PEC ground. There is a reduction of 9 dBsm in the RCS. This clearly shows that using metamaterial structures, there is a reduction in the RCS and also a considerable reduction in the size of the metamaterial antenna.

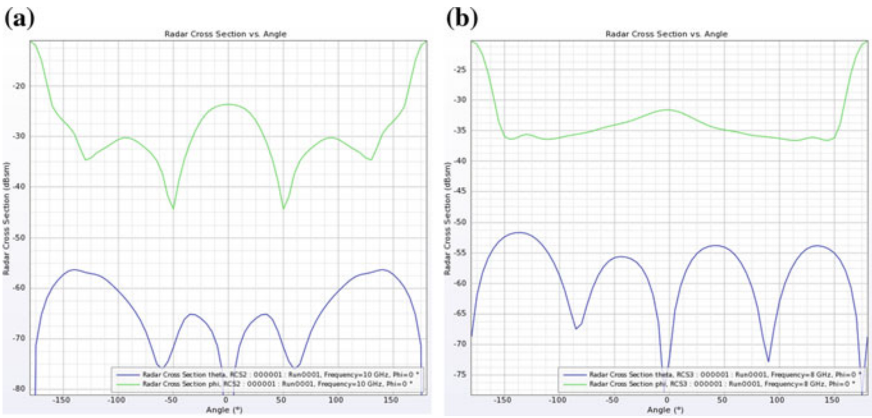

Fig. 5 Simulated RCS results—circular patch antenna (10 GHz) **a** PEC ground **b** CSRR loaded

5 Conclusion

This work attempts to highlight the advantages of two split ring resonators (CSRR) in an antenna. The CSRR results in size reduction, improved gain and decreased RCS based on simulation and measured results. A circular patch antenna with and without metamaterial structures has been simulated using EM solvers. It has been found the antenna size has been reduced by 25%. The Directivity and gain performance of the antennas are also validated. The circular patch antenna with CSRR structures is simulated and fabricated for the given design criteria. Developed metamaterial loaded antenna has a gain of 6.4 dBi and directivity of ~6.4 dBi. The RCS computation has also been carried out by simulating the antenna in the far field using a point source in an EM solver. RCS simulation shows a considerable reduction in RCS (~9 dBsm) for developed antenna with metamaterial structure. RCS reduction is due to the application of metamaterial structure in the ground plane of the antenna. The importance of using metamaterial structures in the design of microstrip circular patch antenna with a reduced size and RCS without altering the gain and directivity has been exemplified.

References

1. Burokur SN, Latrach M, Toutain S (2005) Study of the effect of dielectric split-ring resonators on microstrip-line transmission. Microw Opt Technol Lett 44(5):445–448
2. Dalli A, Zenkouar L, Bri S (2012) Comparison of circular sector and rectangular patch antenna arrays in c-band. J Electromagn Anal Applications 4(11):457
3. Garcia-Garcia J, Aznar F, Gil M, Bonache J, Martin F (2007) Size reduction of SRRs for metamaterial and left handed media design. PIERS Online 3(3):266–269
4. Gay-Balmaz P, Martin OJ (2002) Electromagnetic resonances in individual and coupled split-ring resonators. J Appl Phys 92(5):2929–2936
5. Luna DR, Neto VP, Vasconcelos CF, D'Assunção AG (2013) Microstrip patch antennas with metamaterial inspired substrates and superstrates. In: 2013 SBMO/IEEE MTT-S international microwave and optoelectronics conference (IMOC), 4 Aug 2014, pp 1–4. IEEE
6. Jang HA, Kim DO, Kim CY (2012) Size reduction of patch antenna array using CSRRs loaded ground plane. In: Progress in electromagnetics research symposium proceedings, KL, Malaysia, 27 Mar 2012, p 1487
7. Limaye AU, Venkataraman J (2007) Size reduction in microstrip antennas using left-handed materials realized by complementary split-ring resonators in ground plane. In: Antennas and propagation society international symposium, 9 Jun 2007, pp 1869–1872, IEEE
8. Majid HA, Abd Rahim MK, Masri T (2009) Microstrip antenna's gain enhancement using left-handed metamaterial structure. Prog Electromagn Research 8:235–247
9. Saha C, Siddiqui JY (2011) A comparative analyis for split ring resonators of different geometrical shapes. In: Applied electromagnetics conference (AEMC), 18 Dec 2011, pp 1–4, IEEE
10. Engheta N (2002) An idea for thin subwavelength cavity resonators using metamaterials with negative permittivity and permeability. IEEE Antennas Wirel Propag Lett 1(1):10–13