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Original Research

REDUCING THE CROSS-POLARIZATION PATTERN IN A DUAL-POLARIZED ANTENNA USING SPIRAL AND SPLIT RING RESONATORS

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Abstract: This paper introduces the design of a new dual-polarization rectangular microstrip patch antenna based on metamaterial structures at the X-band. The work focuses on two distinct configurations of a microstrip patch antenna utilizing metamaterials. Pairs of spiral ring resonators are loaded into a rectangular patch antenna system in the first design. The second strategy involves inserting a split ring resonator at the end of microstrip feed lines. The utilization of metamaterial structures in the microstrip antenna system compensates for the patch antenna's asymmetric current distribution flow, resulting in a symmetrical current distribution. The simulation results display an important enhancement in cross-polarization discrimination (XPD) and good port decoupling. The antenna system has various characteristics, including a basic structure and metamaterial inclusions that take up a small amount of space, making the suggested metamaterial inclusions more beneficial for dual-linear polarized patch antenna construction. These prototypes are suitable to work for polarimetric radars.

Keywords: *Dual linear polarization; metamaterial; split ring resonator; patch antenna.*

1. Introduction

Modern wireless and satellite communications and radar applications all benefit from dual linear polarized (DLP) microstrip antenna arrangements. It has the capability of providing two communication channels. As a result, communication systems capacity can be doubled. However, cross-polarization patterns and isolation between two input ports are two main drawbacks [1-4]. These problems are caused by various factors, including the current distribution on the radiator being asymmetrical, which results in reduced isolation and increases in cross-polarization patterns. The current distribution is asymmetrical because the two microstrip feeds line are naturally printed on the closest two sides. While the other two sides are left unexcited [5] [6-8]. Using metamaterial inclusions like a spiral and split ring resonators (S-RR and SRR respectively) can alter and control the distribution of fields through a microstrip patch antenna system. Therefore, the patch's current distribution is compensated by employing S-RR and SRR structures. This leads to an increase the isolation and improves the XPD. Based on the above discussion, it is proposed that spiral and split ring resonators, (S-RR and SRR) are based on a single negative medium [9] [10] [11].

Metamaterial (MTM) structure [12, 13] has been utilized to construct antenna system microwave circuits with particular features [14, 15]. This research is based on the employing of metamaterial such as spiral and split ring configurations to demonstrate a stop band filter. This work is divided into two sections: Spiral ring resonators (S-RR), situated closest to the patch, are used in the first part.

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The performance of the DLP antenna system is enhanced by using a pair of S-RRs. Compar to the traditional microstrip patch, the theoretical results exhibit an enhancement in the cross-polarized ratio in the principal planes. SRR is positioned at the end of two microstrip feed lines, the second strategy. The antenna system's XPD has been enhanced, with a simulation showing an improvement in XPD when compared to a traditional antenna system in principle planes.

The antenna system was modeled using a full wave (FW) electromagnetic (EM) simulation using the HFSS program. This work is organized as follows: Section 2 provides the design and study of the proposed DLP patch utilization S-RR. Next, the SRR design is used to create DLP microstrip patch in part 3. Finally, the conclusions are presented in part 4.

2. Dual-linear Polarized Antenna System Design Utilizing S-RR

The structure of the spiral ring resonator is depicted in Figure 1(a). It consists of pairs of spiral ring resonators joined together by a microstrip line with dimensions (ℓ₁ × w). Figure 1(b) shows the equivalent circuit of a spiral ring resonator. The optimal spiral ring resonator size is (a=2.7 mm, b=2.7 mm, w=0.31 mm, g=0.22 mm, and ℓ₁=1.2 mm).

Figure 1(c) shows the reflection and transmission parameters of the S-RR, and it is noticed that the unit cell offers a stop-band property (S_{21}= -25 dB) at 10 GHz. Figure 1(d) displays the magnitude of permeability and permittivity. The magnitude of permeability is negative in certain frequency regions (about x-band), while the magnitude of permittivity is not negative in this region. Therefore, stop-band function is produced in this band. Nicolson-Ross-Weir's approach is used to extract the permeability (μ) and permittivity (ε). Antenna's scattering parameters can be expressed as [16-19].

$$S_{11} = \frac{R_{01}\left(1 - e^{j2n\beta h}\right)}{1 - R_{01}^2 e^{j2n\beta h}} \tag{1}$$

$$S_{21} = \frac{\left(1 - R_{01}^2\right)e^{j2n\beta h}}{1 - R_{01}^2 e^{j2n\beta h}} \tag{2}$$

$$R_{01} = \frac{z-1}{z+1} \tag{3}$$

$$z = \pm\sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}} \tag{4}$$

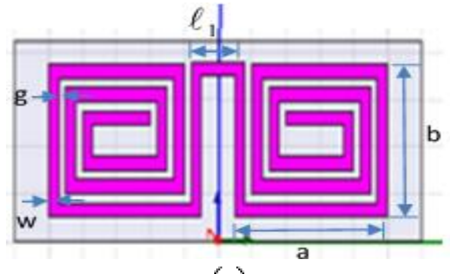
$$e^{jn\beta h} = \frac{S_{21}}{1 - S_{11}\frac{z-1}{z+1}} \tag{5}$$

$$n = \frac{1}{\beta h}\left[\left\{\left[\ln\left(e^{jn\beta h}\right)\right]'' + 2m\pi\right\} - j\left[\ln\left(e^{jn\beta h}\right)\right]'\right] \tag{6}$$

The reflection and transmission coefficients are S_{11} and S_{21}, respectively; β is the wave number; z is the impedance; n is the index of refraction. The following formulas can be used to compute the permittivity (ε) and permeability (μ) [20] [21][22]:

$$\varepsilon = n / z \tag{7}$$

$$\mu = nz \tag{8}$$



(a)

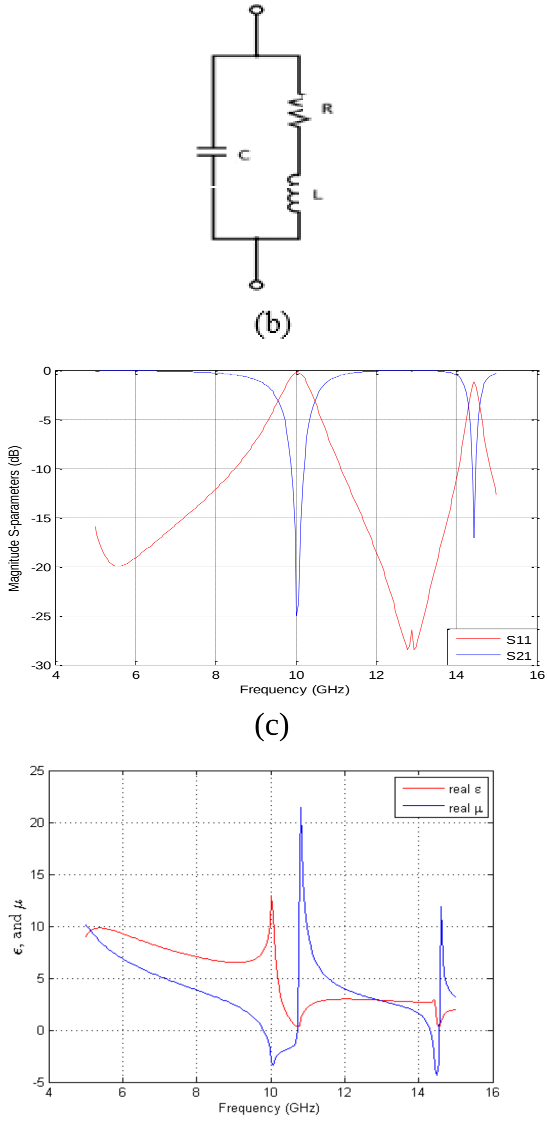


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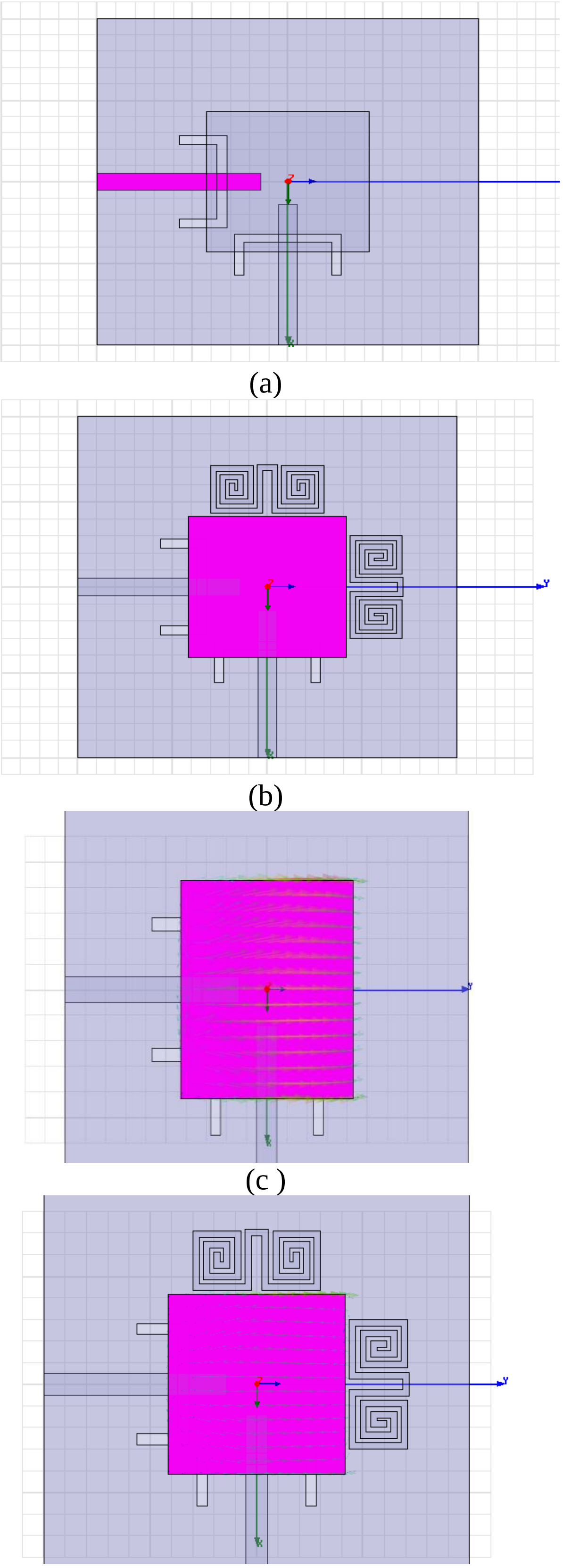
Figure. 1 S-RR unit cell a) 2D S-RR geometry b)unit cell equivalent circuit c) Scattering parameters of S-RR d)real values of permeability and permittivity.

The 2-D structure of the suggested microstrip patch antenna without and with insertion of the pair S-RR unit cells are shown in Figs 2 (a and b). At a frequency of 10 GHz, the antenna system is designed to excite a dual-linear polarized. In this paper, the length and width of the rectangular patches are L=14mm and W=18mm. It is printed on the first substrate layer. In the proposed antenna system, the top substrate layer is a Roger (RT-duroid 5880) substrate, with characteristics of ε_r=2.2 and height of 1.576 mm. The bottom layer, is made of Roger RO/4350 with a height of 0.5 mm and ε_r= 3.4.

The two ports feeding network is placed from the bottom of the second substrate layer. There is a ground plane between two substrate materials, containing two orthogonal apertures. The cross-polarization discrimination may be accurately predicted by figuring out the field distribution across the suggested configuration. The field distribution before and after the addition of a metamaterial structure is illustrated in Figures 2(c and d). After adding pairs of S-RR, the present distribution becomes more symmetrical. Therefore, cross-polarization discrimination can be enhanced in such a setting.

Figures 3(a and b) display the linear radiation patterns in principle planes for suggested and traditional DLP antennas. Insertion of metamaterial in the form of S-RR does not affect co-polarization patterns in both cases. However, there is an improvement in cross-polarization discrimination compared to the traditional DLP antenna. The simulation shows a 7.9 dB enhancement in cross-polarization discriminating over the traditional patch antenna. Figure 4 displays the mutual coupling and reflection coefficients of feeding ports with and without metamaterial structures. At the center frequency, the mutual coupling decreases by 3 dB, also the return loss is S_{11}=-19.2 dB and S_{22}=-18.51 dB for first and second ports, respectively. The performance of the proposed dual-polarized antenna is displayed in Table 1.



(a)

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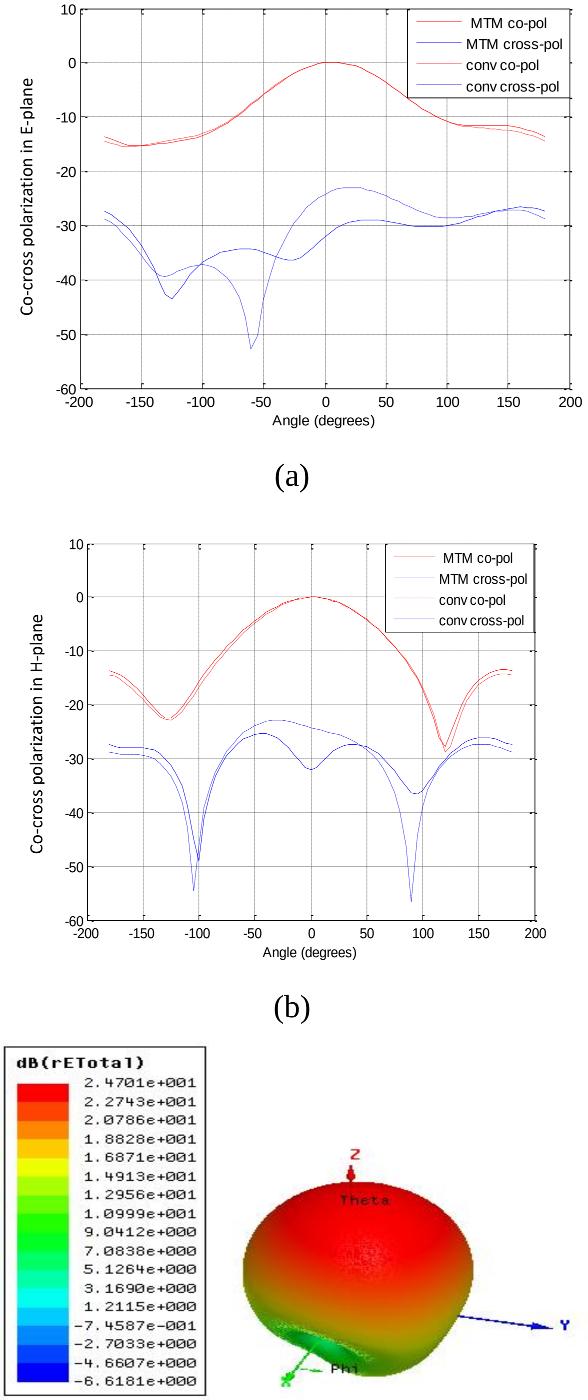
Figure 2. (a) 2D structure of traditional dual linear polarization antenna (b) 2D configuration of suggested antenna system (d) current distribution with S-RR unit cells.



(a)

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(c)

Figure. 3 Radiation co-cross polarizations patterns with and without metamaterial in a) E b) H-planes c) 3D radiation pattern

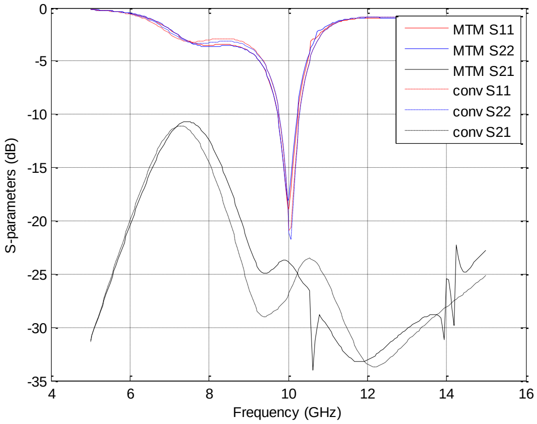


Figure. 4 mutual coupling and reflection coefficients between two perpendicular ports with and without S-RR unit cell.

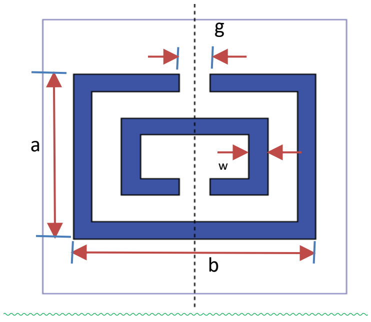
Table. 1 performance of the proposed antenna using S-RR

parameters	Conventional antenna	Proposed antenna
S_{11} (dB)	-21	-19
S_{22} (dB)	-21.5	-18.5
S_{21} (dB)	-27	-24
XPD (dB)	24.2	32.1
G(dB)	7.12	6.9
BW1(GHz)	0.53	0.524
BW2(GHz)	0.525	0.501

3. **Design of an Antenna System using SRR an X-band**

Figure 5(a) depicts the SRR structure and equivalent circuit. As seen in Fig. 5(b). Magnetic field lines are created around the microstrip feed line and surround it. The microstrip feed lines significantly increase the magnetic field lines' level of excitation. As a results, SRR absorbs some of magnetic fields with appropriate polarization resulting in a negative values of permeability (µ) at resonant frequency. A characteristic impedance of roughly 50 Ω is obtained by adjusting the microstrip feed line's width to 1.1 mm.

A substrate material made of RO-4350 with the parameters height h=0.51 mm and ε_r=3.34 is used to print the split ring resonator. The band stop filter has the following dimensions: a = 4.8 mm, b = 4.5 mm, w = 0.5 mm, and g= s=0.22 mm. Fig. 5(c) displays scattering parameters of SRR metamaterial. At the resonance frequency, it is discovered that the SRR unit cell gives a stop-band characteristics (S_{21}=-19.1 dB). The magnitude of permeability and permittivity are presented in Fig. 5(d). The magnitude of permeability is negative, generating a stop band in this band, as may be seen.



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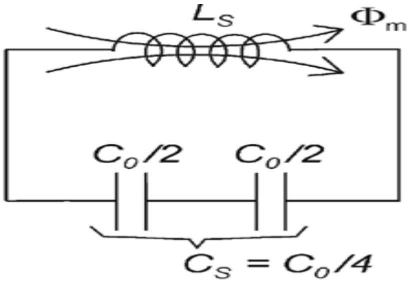

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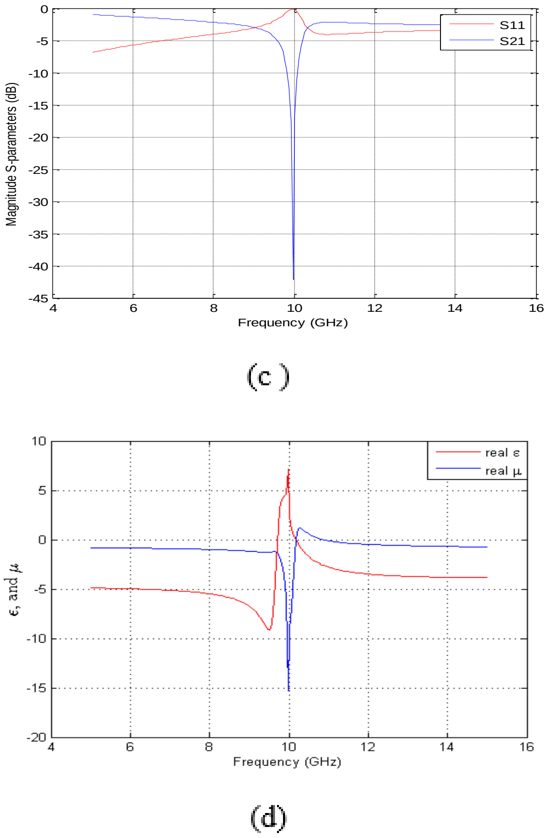


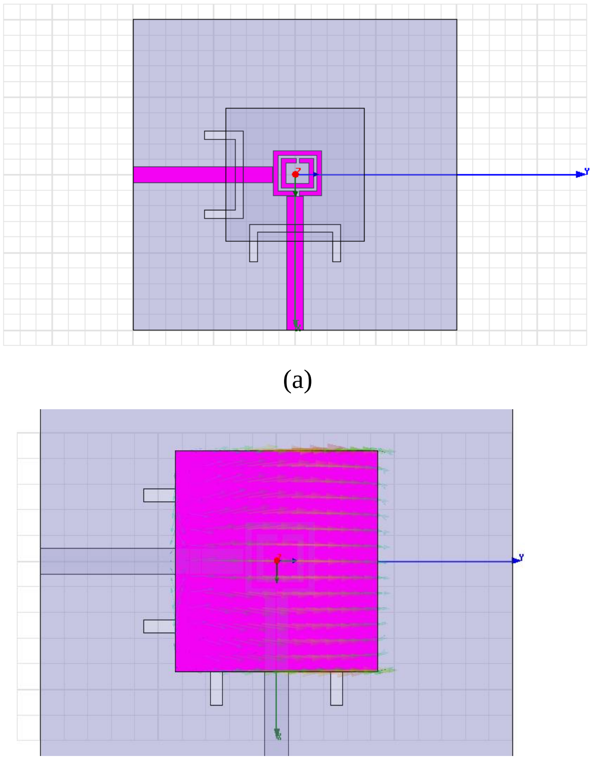
(c)

(d)

Figure. 5 SRR Unit cell a) SRR geometry b) SRR equivalent circuit c) scattering –parameters of SRR d) the magnitude of permeability and permittivity.

Figure 6 (a) displays the structure of a proposed DLP microstrip patch antenna utilizing split ring resonator metamaterial. The SRR is placed at the end of the feeding lines. The distance between the two feeding systems and SRR is 0.15 mm. The current distribution after inserting the metamaterial structure is displayed in Fig. 6 (b).

The current distribution has more symmetry after the addition of the metamaterial. The radiation patterns in principle planes are displayed in Fig. 7 (a and b). In comparison to the traditional DLP microstrip patch antenna, it is noticed that an important enhancement in XPD. The simulation results reveal an enhancement of 9.8 dB in the cross-polarization ratio. Figure 8 shows the S-parameters antenna system with SRR unit cell. It can be seen that the performance of the proposed antenna is demonstrated in Table (2).



(a)

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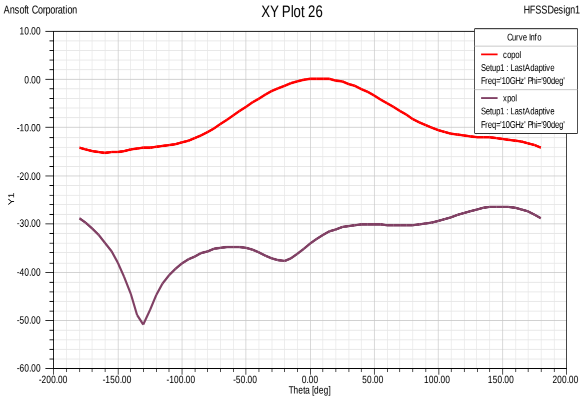
Figure. 6 Geometry of antenna system a) 2D configuration of proposed antenna system b) current distribution with SRR unit cell.



(a)

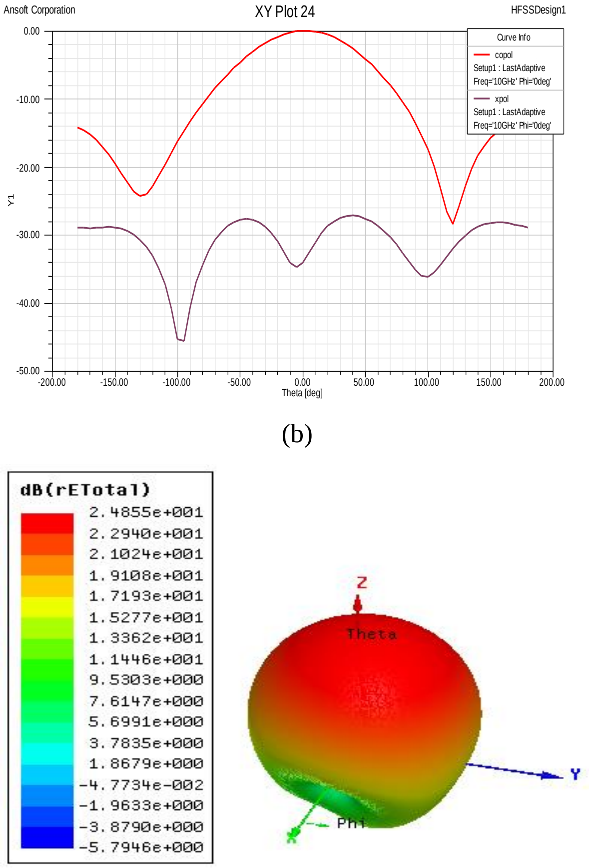


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Figure. 7 Radiation linear patterns in a) E b) H planes, for antenna system with SRR unit cell e) 3D radiation pattern.

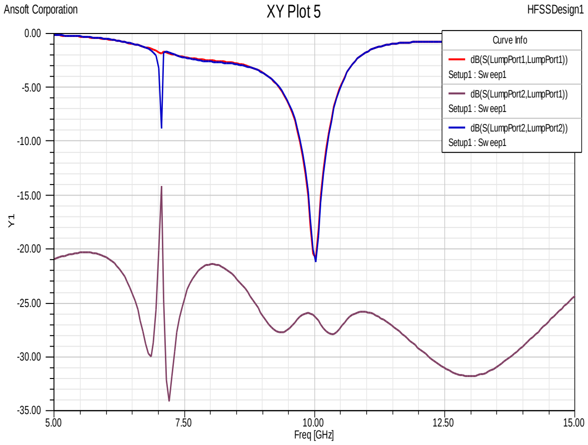

Figure. 8 Mutual coupling and reflection coefficients between two feeding ports with SRR metamaterial.

Table. 2 performances of the proposed antenna using SRR

parameters	**Conventional dual polarization antenna**	**Proposed antenna**
S_{11}(dB)	-21	-23
S_{22}(dB)	-21.5	-22
S_{21}(dB)	-27	-26.6
XPD (dB)	24.2	34
G(dBi)	7.12	7.1
BW1(GHz)	0.53	0.553
BW2(GHz)	0.525	0.549

4. **Conclusions**

A novel method is employing the inclusions S-RR and SRR with a dual-polarized antenna system that operates at X-band (10 GHz). As a result, it is found there are improvements in the XPD of the microstrip patch antenna. This enhancement is accomplished by inserting a pair of S-RR next to the radiator and putting SRR at the end of both two microstrip feed lines. In comparison to the traditional DLP rectangular microstrip patch antenna, a 9.8 dB enhancement in XPD is seen. In this work, the Antenna system was modeled using a full wave electromagnetic (EM) simulation using HFSS software.

This paper includes an analysis of the performance of the proposed DLP patch antenna such as patterns in E and H planes and mutual coupling between two ports (S_{21}) and reflection coefficient for each port. The proposed antenna has many merits including simple configuration, also S-RR and SRR take small area. As a result, the suggested unit cells (SRR and S-RR) are more advantageous in the rectangular dual-polarized antenna design. Therefore, the proposed DLP antennas are suitable to work in synthetic aperture radar (SAR).

Conflicts of interest

The authors declare that there is no conflict of interest in the publication of this article.

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