Cross Polarization Discrimination Enhancement of a Dual Linear Polarization Antenna Using Metamaterials

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Abstract—This paper presents a novel approach to enhance the cross polarization discrimination in a dual linear polarization microstrip patch antenna at the frequency of 5.5 GHz. Two different designs of a dual linear polarization antenna using metamaterials are considered. In the first design, microstrip patch antenna is loaded with two pairs of spiral ring resonators, and in the second design, two orthogonal microstrip feed lines are loaded with pairs of split ring resonators. The addition of metamaterial inclusions to the antenna structure allow compensation for an asymmetric current distribution flow on the patch antenna and thus result in symmetrical current distribution on it. This compensation leads to a significant improvement in the cross polarization discrimination in comparison to the conventional dual linear polarized antenna. The simulation shows an improvement of 12 dB for the first design, and 6.6 dB for the second design in cross polarization discrimination as compared to the conventional antenna.

Keywords-component: Dual linear polarization antenna; metamaterials

I. INTRODUCTION

Dual linear polarization antenna configurations are popular and extraordinary candidates for high performance satellite, wireless communication, and radar applications. It can provide two communication channels. Therefore, it can double the capacity of communication systems [1] [2] [3]. However, it suffers from two main drawbacks; cross-polarization pattern and higher mutual coupling between two input ports [4], these drawbacks belong to several reasons, such as an asymmetrical current distribution on the patch antenna which leads to higher coupling and generates cross polarization pattern. The reason of an asymmetrical current distribution belongs to design natural of two orthogonal feeds, which are placed on nearest two edges, while remaining other two edges without any excitation [5]. The propagation of electromagnetic waves through a microstrip patch antenna and microstrip feed lines can be manipulated and controlled by spiral ring resonator (S-RR), and split ring resonator (SRR) inclusions. Hence, the metamaterials are used to compensate the current distribution on the patch antenna which leads to enhancement in the cross polarization discrimination (XPD) and mutual coupling between the two microstrip feed lines. According to this aforementioned discussion, an S-RR, and SRR-based on band-reject filter have been designed.

Metamaterials (MTM) [6] have been used to develop antennas and microwave circuits with unusual properties [7], and this study is based on using metamaterials in forms of S-RR, and SRR structures to represent single-negative medium and exhibited a band stop filter. This paper is divided into two scenarios; the first scenario is based on using S-RR metamaterial in the near environment of the rectangular patch antenna. With pair of S-RR technique, the XPD of the antenna system is improved, and the simulation displays an improvement of 12 dB in XPD as compared to the conventional antenna in E-and H planes. The second scenario is based on loading the microstrip feed lines with pairs of SRR. The XPD of the antenna system is improved and the simulation displays an improvement of 6.6 dB, in XPD as compared to the conventional antenna in E and H-planes. The structure has been simulated using a full wave simulation is performed by using High-Frequency Structure Simulator (HFSS) software. The paper is organized as follows: The dual linear polarization antenna using S-RR design is presented in section II. Section III is devoted to a dual linear polarization antenna using SRR design. Lastly, section IV contains the conclusion.

II. DESIGN OF A DUAL LINEAR POLARIZATION ANTENNA USING SPIRAL RING RESONATOR (S-RR)

A. Design and Characterization of Spiral Ring Resonator (S-RR) as Band Stop Filter

The proposed structure of spiral ring resonator and its equivalent circuit are shown in Fig. 1(a), which consists of two S-RR connected with a line of length \((l_1)\) and width \((w)\). The dimensions of S-RR unit cell were optimized as \(a = 4.5\) mm, \(b = 3.25\) mm, \(g = 0.2\) mm, \(w = 0.3\) mm, \(l_1 = 1.6\) mm. Fig. 1(b) shows transmission and reflection coefficients of unit cell, it is noticed that S-RR provides stop band \((S_{21} = -31\) dB\) with center frequency of 5.5 GHz. Fig. 1(c) represents the real values of permittivity, and permeability, it is noticed that the real values of permeability are only negative that leads a stop band in this region. Nicolson-Ross-Wier approach was used to extract the permittivity and permeability \((\varepsilon \text{ and } \mu)\). The S-parameters of this system can be written as [8].

\[
S_{11} = \frac{R_{in} \left(1 - e^{-2j\beta_0}\right)}{1 - R_{out}^2 e^{-2j\beta_0}}
\]

\[
S_{21} = -\frac{R_{out}^2 e^{-2j\beta_0}}{1 - R_{in}^2 e^{-2j\beta_0}}
\]
\[
\begin{align*}
    z &= \pm \sqrt{\frac{(1 + S_{21})^2 - S_{22}^2}{(1 - S_{11})^2 - S_{12}^2}} \\
    \exp(j\beta h) &= \frac{S_{21}}{1 - S_{11}} \frac{z - 1}{z + 1} \\
    n &= \frac{1}{\beta h} \left[ \left( \ln\left(\exp(j\beta h)\right) \right) + 2m\pi \right] - j\left[ \ln\left(\exp(j\beta h)\right) \right]
\end{align*}
\]

where \( (\cdot)' \) represents the real component and \( (\cdot)'' \) represents the complex component of the complex number; \( S_{21} \) and \( S_{11} \) are transmission and reflection coefficients, respectively; \( n \) is the refractive index; \( \beta \) is the phase constant; \( R_{01} \) is \( (z-1)/(z+1) \); \( z \) is the impedance; \( h \) is the thickness of substrate material; \( m \) is the branch due to the periodicity of the sinusoidal function. The permittivity \( (\epsilon) \) and permeability \( (\mu) \) can be calculated by the following expressions [9]:

\[
\begin{align*}
    \epsilon &= n / z \\
    \mu &= n z
\end{align*}
\]

B. Design of a dual linear polarization antenna using spiral ring resonator (S-RR)

The basic configuration, 2D geometry of the proposed microstrip patch antenna for exciting a dual linear polarization at a single frequency of 5.5 GHz is depicted in Figs. 2 (a and b) before and after the addition of the two unit cells respectively. The antenna consists of a rectangular microstrip patch antenna with dimensions \( (W \times L) \), which is supported on the first substrate layer that used Roger RT/duriod 5880 substrate with thickness of 1.575 mm and relative permittivity of 2.2. The feeding networks consist of two orthogonal aperture microstrip feed lines, which are printed on the bottom of the second substrate layer that used Rogers RO4350 substrate with a thickness of 0.508 mm and relative permittivity of 3.38. The ground plane is inserted between two substrate materials, which contain two slots.

Determination of the current distribution along the proposed structure gives a good prediction for the cross-polarization discrimination. And it is noticed that the current distribution becomes more symmetric after adding two unit cell as shown in Figs. 2(c, and d), which represent the current distribution before and after the addition of S-RR due to vertical port respectively. In such scenario, the cross polarization discrimination can be improved.

Figs. 3(a, and b) show the linear co-cross polarization radiation patterns in \( E \), and \( H \) planes for two antennas (conventional dual linear polarized and proposed antennas). Co-polarization patterns in two cases are compact and are not affected by adding the metamaterial spiral resonator. On the other hand, we get a significant improvement in cross polarization discrimination in comparison to the conventional dual linear polarized antenna. The simulation shows an improvement of 12 dB in cross polarization discrimination as compared to the conventional antenna. Fig. (4) shows the reflection and mutual coupling coefficients between two orthogonal input ports with and without S-RR inclusions. It is noticed that the mutual coupling becomes worse by 2 dB, and the reflection coefficients for two input ports are \( S_{11}=-28.4 \, \text{dB} \), and \( S_{22}=-30.3 \, \text{dB} \) at the center frequency. Table (I) lists the dimensions of a dual linear polarization antenna system.

![Figure 1. Spiral ring resonator. a) 2D geometry of spiral ring resonator and its equivalent circuit. b) S-parameters of unit cell. c) Real values of permittivity, and permeability.](image-url)
TABLE I.  DIMENSIONS OF DUAL LINEAR POLARIZATION ANTENNA
(ALL DIMENSIONS IN MM)

<table>
<thead>
<tr>
<th>parameters</th>
<th>L</th>
<th>W</th>
<th>h</th>
<th>W-slot</th>
<th>W-slot</th>
<th>h_eq</th>
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<td>5.9</td>
<td>5</td>
<td>1</td>
<td>0.4</td>
<td>0.25</td>
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</table>

III. DESIGN OF A DUAL LINEAR POLARIZATION ANTENNA USING SPLIT RING RESONATOR (SRR)

This part deals with the design of a dual linear polarization microstrip patch antenna, which loads two microstrip feed lines with pairs of SRR inclusions on both sides of them, to build microstrip band stop filters and absorb the fields that radiated on both sides of two microstrip feed lines.

A. Design and Characterization of SRR as Band Stop Filter

Recently, there has been an increasing interest in using the split-ring resonator (SRR) as constituent inclusions for the design of antennas or novel planar microwave components, in particular with either negative permeability ($\mu < 0$) or permittivity ($\varepsilon < 0$) or negative both parameters ($\mu < 0$, and $\varepsilon < 0$) which lead to band-stop or band-pass filters respectively [10][11]. This type of resonator is characterized by being significantly smaller in size than conventional resonator structures (optimally less than or
equal to one-tenth of the free space wavelength), which facilitates the design of very compact filters [12].

Fig. 5(a) shows 2D geometry of SRR and its equivalent circuit. A microstrip feed line generates magnetic field lines that are adjacent upon themselves around the feed line as shown in Fig. 5(b). If a pair of SRRs is placed closely at both sides of the microstrip feed line as shown in Fig. 5(c), a significant portion of the magnetic field lines is induced by the line which are anticipated to cross the SRRs with the desired polarization giving rise to a negative-µ effect over a narrow band around the resonant frequency of the individual SRRs. Therefore, suppression of signal propagation over the region around the feed line can be achieved [12]. Based on this idea, SRRs have been designed as band stop microstrip filter as shown in Fig. 5(d) and absorb the surface waves radiated from two microstrip feed lines, where two pairs of SRR (i.e., 4 SRRs) have been employed. The width of the microstrip feed line is set to 1 mm to make the line’s characteristics impedance approximately 50 Ω. The filter has been implemented on a RO4350C high-frequency laminate (εr = 3.38, substrate height of 0.508 mm and metal thickness copper cladding of 35 μm). The parameters of this filter are: a = 4.8 mm, b =4.5, g = s =0.2 mm, w =0.5 mm. Fig. 5(d) shows transmission and reflection coefficients of unit cell, it is noticed that SRR offers stop band (S21=-19 dB) at center frequency of 5.5 GHz. The real values of permittivity, and permeability are shown in Fig. 5(e), and it is noticed that the real values of permeability are negative only causing a stop band in this region.

B. Design of a dual linear polarization antenna using two pairs of split ring resonators (SRR)

Fig. 6(a) shows the 2D geometry of a dual linear polarization antenna using two pairs of the unit cells. The two pairs of unit cell are placed on both sides of each microstrip feed line at the same level. The distance between SRRs and microstrip feed line is 0.2 mm. Fig. 6(b) shows the current distribution after adding of SRR due to vertical port. More symmetry in the current distribution is noticed after adding two pairs of unit cells. Fig. 7 shows the linear co-cross polarization radiation patterns in E, and H planes, we get a significant improvement in cross polarization discrimination in comparison to the conventional dual linear polarized antenna. The simulation shows an improvement of 6 dB in cross polarization discrimination as compared to the conventional antenna. Fig. 8 shows the reflection and mutual coupling coefficients between two orthogonal input ports with two pairs of SRR inclusions. It is noticed that the mutual coupling becomes better by 3 dB (S21=-26 dB), and reflection coefficients for the two input ports are S11 =-33.5 dB, and S22=-29.5 dB at the center frequency as demonstrated in the table (II).
Figure 6. Dual linear polarization antenna a) 2D geometry of a dual linear polarization antenna using two pairs of unit cells  b) current distribution after the addition of SRR due to vertical port.

Figure 7. Linear co-cross polarizations radiation patterns in E and H planes, for dual linear polarization with two pairs of SRRs unit cells.

Figure 8. Reflection and mutual coupling coefficients between two orthogonal input ports with two pairs of SRR inclusions.

Figure 9. Dual linear polarization antenna a) 2D geometry of a dual linear polarization antenna using four pairs of unit cells  b) current distribution after the addition of SRR due to vertical port.

C. Design of a dual linear polarization antenna using four pairs of split ring resonators (SRR)

Fig. 9(a) shows the 2D geometry of a dual linear polarization antenna using four pairs of unit cells. Each two pairs of the unit cell are placed on both sides of each microstrip feed line at the same level. Fig. 9(b) shows the current distribution after adding of SRR due to vertical port, and it is noticed that the current distribution becomes more symmetric after the addition four pairs of unit cells. Fig. 10 shows the linear co-cross polarization radiation patterns in E, and H-planes. We get a significant improvement in cross polarization discrimination in comparison to the conventional dual linear polarized antenna. The simulation shows an improvement of 6.6 dB in cross polarization discrimination as compared the conventional antenna. Fig. 11 shows the reflection and mutual coupling coefficients between two orthogonal input ports with four pairs of SRR inclusions. It is noticed that the mutual coupling becomes better by 5.5dB ($S_{21} = -28.5$ dB), and reflection coefficients for two ports are $S_{11} = -34$ dB, and $S_{22} = -23$ dB. Finally, table (II) shows the comparison between the conventional dual linear polarization and the proposed antenna using MTM by three different examples with respect to S-parameters, XPD, gain (G), and bandwidth (BW) for two input ports. From table (II). It is noticed that there is a good enhancement in XPD and little enhancement in mutual coupling especially in examples two and three. On the other hand, there is not a significant change in other characteristics such as gain (G), Bandwidth, and matching for two ports.
IV. CONCLUSION

In this paper, a new technique (using metamaterials S-RR, and SRR) is employed to improve the cross polarization discrimination for a dual linear polarization microstrip patch antenna with a frequency of 5.5 GHz. This improvement is achieved by placing two spiral ring resonators nearest from the microstrip patch antenna and placing pairs of split ring resonators on both sides for each microstrip feed line. An improvement in cross polarization discrimination by 12 dB as compared to the conventional dual linear polarized antenna is observed. The antenna system has several features including simple structure, and metamaterial inclusions occupied very small area, which makes the proposed metamaterial (S-RR, and SRR) more useful for the design of a dual linear polarization antennas. And hence, the resulting antenna is very compact (as compared to conventional of a dual linear polarization antenna).

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REFERENCES