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# A FURTHER INVESTIGATION ON THE PERFORMANCE OF THE BROADSIDE COUPLED RECTANGULAR SPLIT RING RESONATORS

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**Abstract**—In this paper, a numerical study based on the Finite Element Method (FEM) formulation of Ansoft's High Frequency Structure Simulator (HFSS) is reported to investigate the performance of a conformal Broadside Coupled Rectangular Split Ring Resonators (BC-SRR) of negative effective permeability around a resonant frequency of 1.27 GHz for non-linear polarization applications. The size of the BC-SRR is 15 mm × 15 mm × 0.8 mm on a polyimide substrate with a relative permittivity of 3.5 and a loss tangent of 0.004. The performance of the BC-SRR is characterized in terms of reflection and transmission spectra, effective relative permittivity and permeability, and the dispersion diagram for both flat and twisted profiles. The flat BC-SRR operates over the frequency range from 1.2615 to 1.2842 GHz. The twisted BC-SRR inclusions are investigated at 90°. It has been found that the resonant frequency is changed to 1.1064 GHz and bandwidth becomes from 1.08 GHz to 1.0537 GHz for the twisted profile. Moreover, it is found that the unit cell of the twisted BC-SRR profile is based on two BC-SRRs inclusions. Furthermore, it is found that the twisted profile exhibits negative relative permittivity and permeability simultaneously.

## 1. INTRODUCTION

Split ring resonators (SRR)s are limited to the linear polarization and negative permeability [1]; however, recent technologies require SRRs with a negative permittivity simultaneously with negative permeability as well as can be suitable for non-linear polarization applications.

In [1], the behavior of a single SRR inclusion and the coupling among other SRR inclusions was reported numerically and

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experimentally. Furthermore, the performance of tunable triangular SRRs based wire strips of concentric and non-concentric configurations was reported in [2]. A planar SRR structure of spiral elements which provide multiple left-handed modes was proposed in [3] and compared against the classical split-loop spiral arrays. The effects of gap number and their position in the SRRs structure of a single rectangular geometry of one, two and four gaps were studied in [4]. The author in [5] investigated the characteristics of magnetic resonance and band gaps for SRRs in terms of band gap width with respect to the resonance frequency. The effects of the orientation of the SRRs with respect to both electric and magnetic fields on the frequency resonances were reported in [6]. The effects of considering individual and coupled inclusion in one unit cell of the SRR on their electromagnetic properties are studied in [7].

In this paper, the performance of the flat BC-SRR in terms of $S$-parameters, effective constitutive parameters, dispersion diagram and the number of BC-SRR inclusions in their unit cell are compared to the twisted BC-SRR for the frequency range from 1.6 GHz to 2.1 GHz. The rest of the paper is organized as follows. In Section 2 we present the flat and twisted BC-SRR profiles. In Section 3, the numerical results and performance of each profile are discussed. Finally, conclusions are provided in Section 4.

## 2. BC-SRR GEOMETRY AND ITS CORRESPONDING

The BC-SRR under consideration consists of the classical geometry deposited on flexible polyimide substrate with a relative permittivity of $\varepsilon_r = 3.5$ and loss tangent of $\tan\delta = 0.004$. The BC-SRR has a complex effective magnetic permeability, $\mu_{eff} = \mu'_r - j\mu''_r$, of Lorenzo distribution within the frequency band of interest [8]. In this section, we consider one of the most popular BC-SRR shown in Fig. 1. The unit cell of the BC-SRR inclusion is inspired from the initial design dimensions that is reported in [9] where the substrate has been changed from Rogers RO4350 of $\varepsilon_r = 3.48$ and $\tan\delta = 0.004$ to the flexible polyimide substrate. The BC-SRR consists of equal sides, 12 mm in length with a strip width of 1 mm. The BC-SRRs have opposite cut gap of 1 mm within the metallic rings deposited on a square substrate, 0.8 mm in thickness and of 15 mm in length and width.

Next, the flat BC-SRR presented in Fig. 2(a) is twisted at 90°, which is the extreme case, as shown in Fig. 2(b). We considered the repetition of one BC-SRR and two BC-SRRs in the numerical model to report the effect of twisting on the unit cell periodicity.

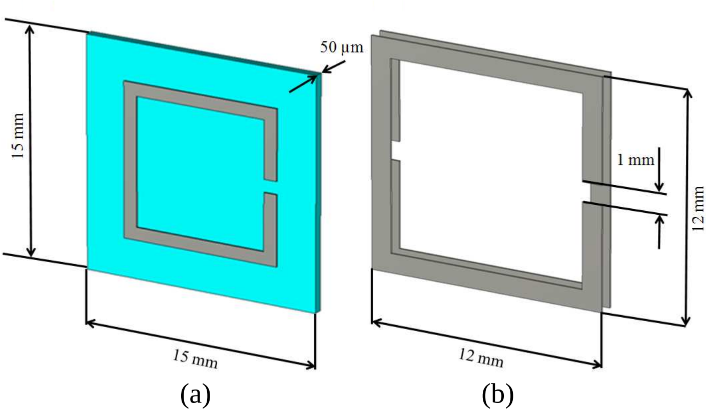


**Figure 1.** 3D view for the proposed SRR; (a) along with the substrate and (b) without the substrate.

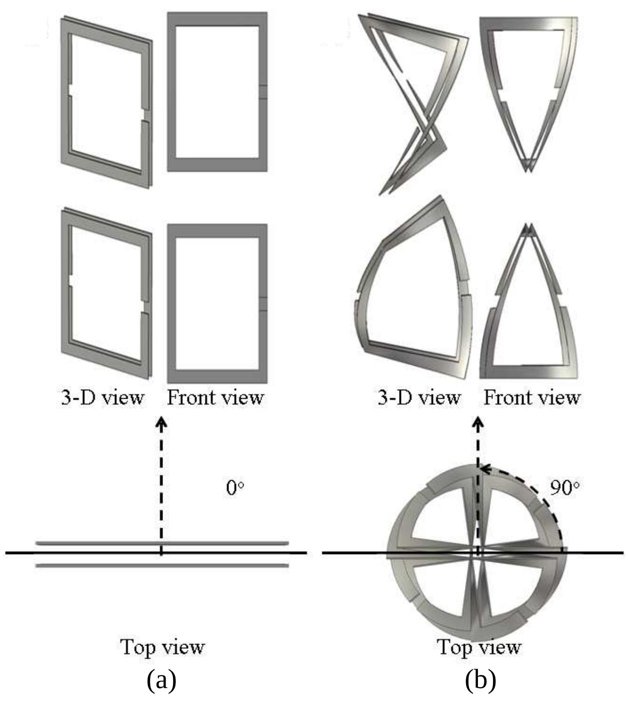


**Figure 2.** 3D view for the proposed SRR without showing the substrate; (a) flat profile and (b) twisted profile.

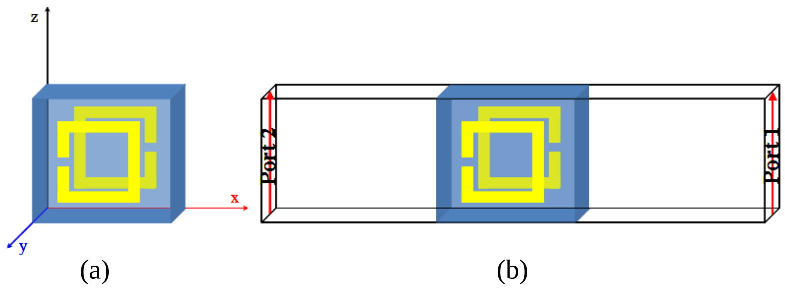


**Figure 3.** The numerical setup to study the performance of the BC-SRR; (a) 3-D view of the unit cell, (b) unit cell centered inside the factious waveguide structure. The electric and magnetic fields are along the $z$-axis and $y$-axis, respectively.

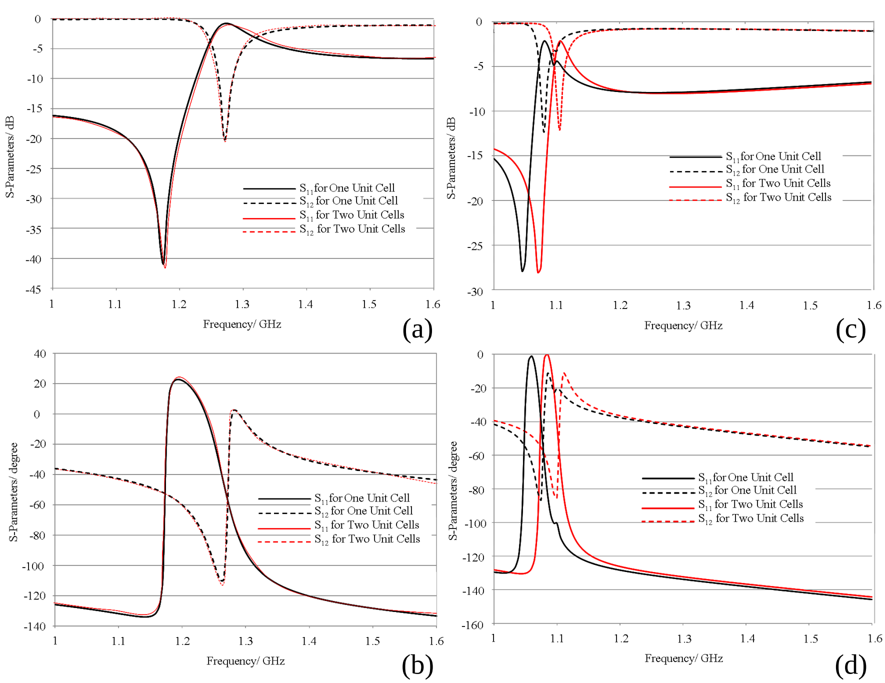


**Figure 4.** $S$-parameters of the BC-SRR unit cell inclusion extracted from the waveguide; for flat (a) magnitude and (b) phase and for twisted (c) magnitude and (d) phase.

## 3. NUMERICAL SIMULATIONS AND DISCUSSION

The effects of twisting are observed on the $S$-parameters, effective constitutive parameters, and dispersion diagram for one and two BC-SRR inclusions in the unit cell. The $S$-parameters spectra, in terms of $S_{11}$ and $S_{12}$, of BC-SRR arrays of the flat and twisted profiles are evaluated by surrounding the unit cell by an air box as a fictitious waveguide using Ansoft's HFSS full-wave simulator [10]. The unit cell of the BC-SRR is centered inside the fictitious waveguide as shown in Fig. 3 to mimic a transverse electromagnetic mode at both ports. The top and bottom sides of the waveguide are assigned as perfect electric walls (PECs) and the other two sides as perfect magnetic walls (PMCs).

To characterize the BC-SRR numerically, the unit cell is positioned in such a way that the incident magnetic field is perpendicular to the axis of the inclusion. In Fig. 4, the magnitude

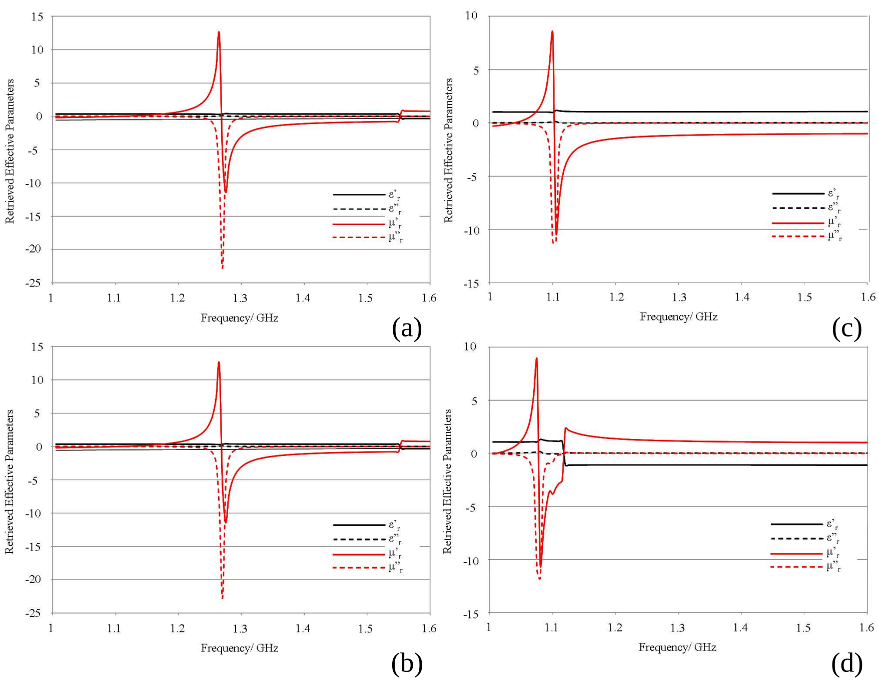


**Figure 5.** Effective constitutive parameters permeability $(\mu_r' + j\mu_r'')$ and permittivity $(\varepsilon_r' + j\varepsilon_r'')$ of the BC-SRR unit cell, extracted using the retrieval method in [10]; for twisted (a) one unit cell and (b) for two unit cells and for flat (c) one unit cell and (d) for two unit cells.

and phase of the $S$-parameters spectra are shown. It is clear from the $S_{12}$ spectra presented in Figs. 4(a) and (b), the maximum reflection of about $-20$ dB at 1.27 GHz. Therefore, the energy at 1.27 GHz is reflected within the inclusions which results no transmission at the resonance frequency. However, it is observed that for the twisted BC-SRR, the resonant frequency is changed by 0.19 GHz and bandwidth decreases. Moreover, it is found that the $S$-parameters of the twisted BD-SRR are not periodical with a single unit cell any more but it is periodical with a pair of BC-SRRs due to the change of the first Brillion zone as shown in Figs. 4(c) and (d). The real and imaginary parts of the effective constitutive parameters of the BC-SRR are shown in Fig. 5.

Next, eigenmode analysis using the fullwave 3-D simulation tool

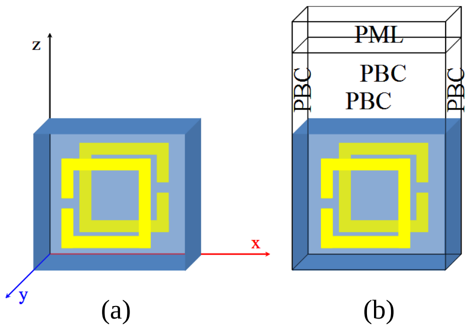


**Figure 6.** 3D view for the waveguide model used to characterize the dispersion diagram; (a) 3-D view of the BC-SRR and (b) numerical setup.

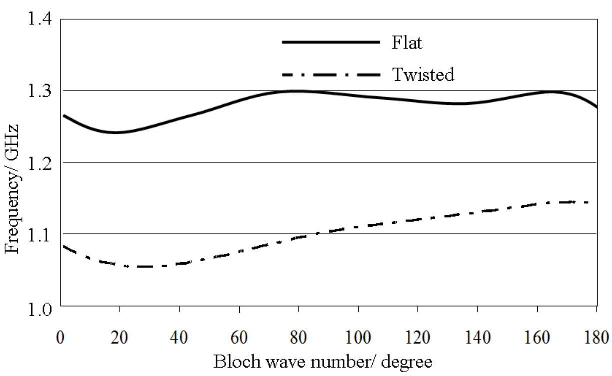


**Figure 7.** Dispersion diagrams.

Ansoft's HFSS is performed to evaluate the dispersion diagram at the first mode for the flat and twisted BC-SRR profiles as seen in Fig. 6. As seen in Fig. 7, the bandgap zones are observed for the BC-SRR within the first two modes around 1.27 GHz for the flat case and 1.08 GHz for the twisted profile.

## 4. CONCLUSION

A numerical study has been conducted to conformal BC-SRRs of negative relative permeability when subjected for twisting with respect to their flat profiles. The flat case of the BC-SRR shows negative effective relative permeability at 1.27 GHz. It is found that the BC-SRR when it is subjected for twisting, the unit cell is changed from one inclusion to two inclusions in differ with the flat profiles. The resonance frequency of the twisted BC-SRR is tuned and a negative relative permittivity is appeared when the BC-SRR is subjected for twisting. A sift is happened in the band gap of the flat profile in comparison to the twisted case.

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