Effect on Lefthandedness from SRR Rotational Disorder

D. Rönnow[1], **M. Shahbazali**[1], **W. Baki**[1], **and M. R. Tripathy**[2]

[1]Department of Electronics, Mathematics and Natural Sciences
University of Gavle, Gavle SE-801 76, Sweden
[2]Department of Electronics and Communication Engineering
Amity School of Engineering and Technology, Amity University Campus
Sector-125, Noida (U.P.)-201303, India

Abstract— The split ring resonator (SRR) is the key element to obtain left handedness at microwave frequencies The orientation of the SRR relative to the electromagnetic field is decisive for achieving lefthandedness. We investigate by simulations how the lefthandedness is affected by rotational disorder of the SRRs in an array of 2×11 SRRs. Rotational disorder of the inner ring has a minor effect on the lefthandedness. Combined rotational disorder of inner and outer ring has a similar effect as rotational disorder of the outer ring only. Rotational disorder causes a shift in the frequency range of lefthandedness.

1. INTRODUCTION

The split ring resonator (SRR) combined with a conducting wire is the most commonly used elements for achieving left handedness (real part of refractive index $n < 0$) at microwave frequencies [1]. The orientation of the SRR — or more precisely the gaps of the SRR — relative the wire and electromagnetic field is decisive for lefthandedness [2].

It has been suggested that lefthandedness is sensitive to disorder and that breakdown of lefthandedness may occur [3]. The effect on the resonance in the S-parameters of the dimension of arrays of SRRs was investigated in [4]. It was found that larger arrays have wider stop bands around their reference frequency. In [5] arrays of SRRs with different orientations were investigated. The resonance in the transmission spectra of SRRs was affected by the orientation and the interaction of the SRRs. Papasimakis et al. [6] showed that in an ensemble of SRRs the resonance became broader and eventually disappeared with disorder. In [4, 5], and [6] the effect of disorder or SRR orientation on lefhandednesss was not investigated.

The effect of disorder on lefthandedness would be of importance in applications of metamaterials. In manufacturing of microwave components there are always some deviations from the desired geometry and material properties; such deviations become more pronounced in low cost manufacturing techniques. When striving for lefthanded materials at THz or optical frequencies, the effect from disorder — caused by manufacturing imperfections – will be of higher importance than at microwave frequencies.

In this paper we investigate by simulations the effect on lefthandedness of arrays of SRRs and wires from rotational disorder.

2. THEORY AND SIMULATIONS

The refractive index, n, of a material is given by $n = \sqrt{\varepsilon_r \mu_r}$, where ε_r is the relative permittivity and μ_r is the relative permeability. In lefthanded material $\mathrm{Re}(n) < 0$ and this is achieved if ε_r and μ_r simultaneously are negative [1]. We investigate the effective refractive index of slabs with SRRs in a waveguide. We determine the real and imaginary part of the complex refractive index, n, from the scattering parameters using the method in [7]

$$n = \frac{1}{k_0 d} \left\{ (\mathrm{Re}(\gamma) + 2m\pi) - i\mathrm{Im}(\gamma) \right\} \tag{1}$$

where

$$\begin{aligned} \gamma &= X \pm i\sqrt{1 - X^2} \\ X &= \frac{1}{2S_{21}} \cdot (1 - S_{11}^2 + S_{21}^2) \end{aligned} \tag{2}$$

and k_0 is the wave number in vacuum and d is the physical thickness of the slab. The sign is determined from the requirement that $\mathrm{Im}(n) \geq 0$. The integer m is related to the branch of $\mathrm{Re}(n)$.

For the imaginary part there is a unique solution but for the real part there are multiple solutions given by m. Equation (1) was derived for the case the $S_{11} = S_{22}$ and $S_{12} = S_{21}$.

The investigated structure is shown in Fig. 1. There are two rows with 11 SRRs in each row. There are also 11 wires. The dielectric substrate was FR4 ($\varepsilon = 4.4$, $\tan\delta = 0.02$) with thickness 0.9 mm. The wires and SRR are Cu of thickness 0.035 mm. The width of the strip is 0.2 mm. The inner diameter of the SRR is 0.3 and 1.3 mm, respectively. The width of the SRR strips is 0.25 mm. The total slab thickness is 5 mm and the size of the slab's cross section with the waveguide is given by the X-band waveguide (22.86 mm × 10.16 mm). The SRRs were rotated in the simulations with angles ϕ_2 nd ϕ_1 as shown in Fig. 2. In Table 1 the simulated structures are summarized. Case I is the reference case, which is an ordered array with all SRR oriented the same way. In case II the SRRs are randomly oriented with $\phi_2 = \phi_1$. The inner ring was rotated and the outer was not in case III. In case IV the outer was rotated and the inner was not. The positions of the SRR and wires were not changed.

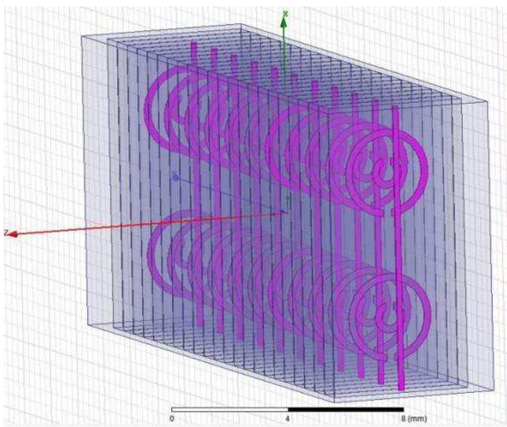

Figure 1: The simulated structure.

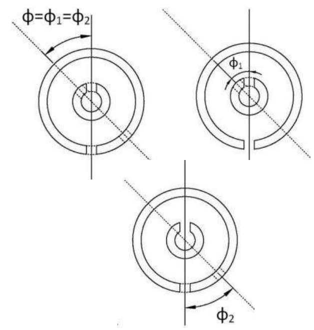

Figure 2: The different rotation cases of the SRR.

Table 1: The angles of the inner, ϕ_1, and outer, ϕ_2, rings used in the simulations. The angles ϕ_1 and ϕ_2 ere varied randomly in the given intervals.

Case	ϕ_1	ϕ_2
I	0	0
II	$[-15°, +15°]$	$\phi_2 = \phi_1$
III	$[-15°, +15°]$	0
IV	0	$[-15°, +15°]$

Simulation were made in Ansoft's HFSS (High Frequency Structure Simulator). The scattering parameters were simulated in the frequency range 9–11 GHz (i.e., in the X-band).

3. RESULTS

The S-parameters for the reference structure are shown in Fig. 3. There is a clear structure around 10.5 GHz in the magnitude and phase. In Fig. 3(c) the refractive index for the reference structure is shown. There is a clear frequency range, 10.2–10.6 GHz, where $\mathrm{Re}(n) < 0$, i.e., the material has lefthanded properties. The S-parameters and refractive index resemble those e.g., in [8].

In Fig. 4 the real and imaginary part of the refractive index is shown for different types of rotational disorder. For the case with the inner ring being rotated and the outer ring fixed ($\phi_1 = \pm 15°$, $\phi_2 = 0$) the difference from the ordered array is small. The cases with both rings rotated the same angles ($\phi_1 = \phi_2 = \pm 15°$) and the case with only the outer ring being rotated ($\phi_1 = 0$, $\phi_2 = \pm 15°$) give similar results and larger deviations from the ordered array. The rotational disorder of the outer ring seems to have a larger effect on the lefthandedness than the inner ring.

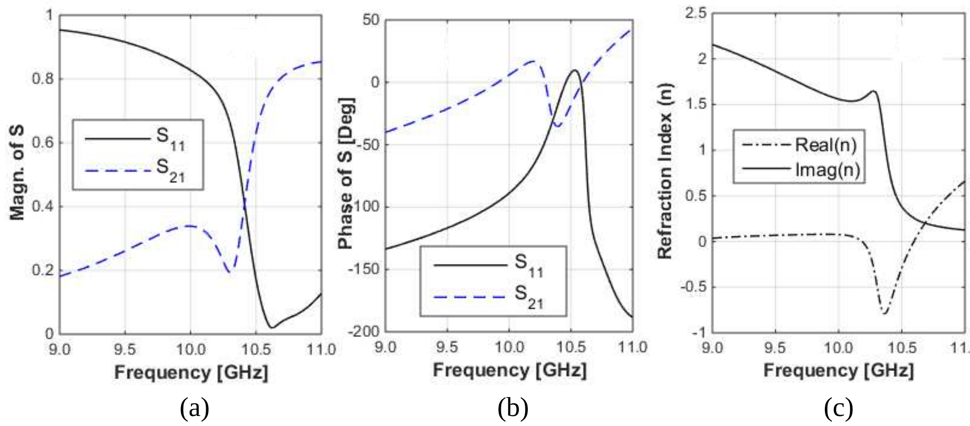

Figure 3: (a) The magnitude, and (b) the phase of the S-parameters of the reference structure (no SRR rotations). (c) The refractive index for the reference structure.

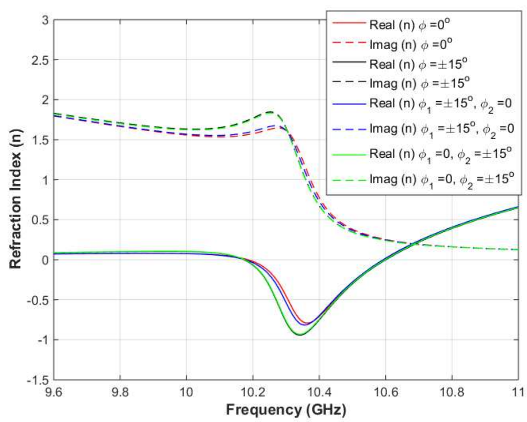

Figure 4: Real and imaginary part of the refractive index vs. frequency for different types of SRR rotational disorder.

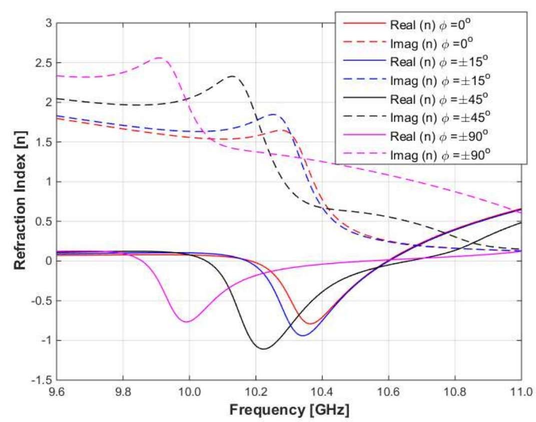

Figure 5: Real and imaginary parts of the refractive index vs. frequency for the case of SRR rotational disorder of $\phi_1 = \phi_2 = \phi$ with different values of maximum rotation.

In Fig. 5, the real and imaginary parts of the refractive index are shown for the cases with $\phi_1 = \phi_2 = \phi$ for increasing rotational disorder. The frequency range of the left-handedness, $\mathrm{Re}(n) < 0$), is shifted, but the lefthandedness does not disappear.

REFERENCES

1. Marques, R., F. Martin, and M. Sorolla, *Metamaterials with Negative Parameters*, Wiley, NY, 2008.
2. Li, Z., K. Aydin, and E. Ozbay, "Determination of the effective constitutive parameters of bianisotropic metamaterials from reflection and transmission coefficients," *Phys. Rev. B*, Vol. 79, 026610-1–026610-7, 2009.
3. Zharov, A. A., I. V. Shadrivov, and Y. S. Kivshar, "Suppression of left-handed properties in disordered metamaterials," *J. Appl. Phys.*, Vol. 97, 113906-1–113906-4, 2005.
4. Ekmekci, E., K. Topalli, T. Akin, and G. Turhan-Sayan, "Effects of array dimensions on the resonance characteristics of SRR type metamaterial arrays with small sizes: Simulations and experiments," *PIERS Proceedings*, 83–86, Moscow, Russia, August 18–21, 2009.
5. Kitahara, H., Y. Yakiyama, K. Takano, and M. Hangyo, "Orientational dependence of inter-meta-atom interactions in the split-ring and circular-ring resonator arrays," *Proc. 38th IRMMW-THz*, 1–2, 2013.
6. Papasimakis, N., V. A. Fedotov, Y. H. Fu, D. P. Tsai, and N. I. Zheludev, "Coherent and incoherent metamaterials and order-disorder transitions," *Phys. Rev. B*, Vol. 80, 041102-1–041102-5, 2009.

7. Chen, X., T. M. Grzegorczyk, B.-I. Wu, J. Pacheco, Jr., and J. A. Kong, "Robust method to retrieve the constitutive effective parameters of metamaterials," *Phys. Rev. E*, Vol. 70, 016608-1–016608-7, 2004.
8. Smith, D. R., D. C. Vier, T. Koschny, and C. M. Soukoulis, "Electromagnetic parameter retrieval from inhomogeneous metamaterials," *Phys. Rev, E*, Vol. 71, 036617-1–036617-5, 2005.