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Short Communication

Design of Band-Stop Filter Composed of Array Rectangular Split Ring Resonators

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Metamaterials are artificial pseudo-homogeneous structures with electromagnetic properties not found in nature. This paper presents a microwave band-stop filter making use of rectangular split-ring resonator (RSRR). This filter combines a conventional microstrip bandstop filter characteristics and negative permittivity metamaterial to establish a metamaterial filter. This structure is designed in the band [1-4] GHz, using relatively dielectric constant substrate material (RO3210) $\varepsilon_r = 10.2$ and tangential losses ($tg(\delta) = 0.003$). Numerical calculations using the Finite Element Method (MEF) based the High Frequency Structure Simulator (HFSS) software are presented to design this filter.

Keywords: Metamaterials, Split Ring Resonators (SRRs), Band-stop filter, Design.

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1. INTRODUCTION

Left-handed metamaterials with simultaneously negative permittivity and permeability have received considerable attention in both scientific and engineering communities [1-2]; it is due to the possibility for the design of novel microwave components with more compact size and better performance [3]. One component of a communication system which needs often an improvement is a microwave filter. Because of the increasing demand on size miniaturization and low cost, many microstrip filters designs have been proposed for size miniaturization [4]. The aim of this paper is to apply a band stop filter synthesis proposed in the literature based on SRRs, to design a very compact microwave bandstop filter [5].

Recently split ring resonators (SRRs) proposed by Pendry and al. [6] attracted much attention as a canonical metamaterial structure that gives rise to an effective magnetic response without the need for magnetic materials. SRRs have been successfully applied to the fabrication of LHM (some times called Double Negative Materials or Negative Refractive Index Materials) [1-6]. SRRs are a pair of concentric annular rings with splits in them at opposite ends. The rings are made of nonmagnetic metal like copper and have a small gap between them as shown in Fig. 1. In an SRR the capacitance between the two rings balances its inductance. A time-varying magnetic field (**H**) applied perpendicular to the rings surface induces currents which, in dependence on the resonant properties of the structure, produce a magnetic field that may properties of the structure, produce a magnetic field that may either oppose or enhance the incident field. At frequencies below the resonant frequency of the SRR, the real part of the magnetic permittivity $Re\,(\varepsilon_{eff})$ of the SRR becomes large (positive), and at frequencies higher than resonance, $Re(\varepsilon_{eff})$ becomes negative when the axis of the ring is parallel with the magnetic field component. This negative permittivity can be used with the negative electric permittivity of another structure to produce negative refractive index materials [7-8].

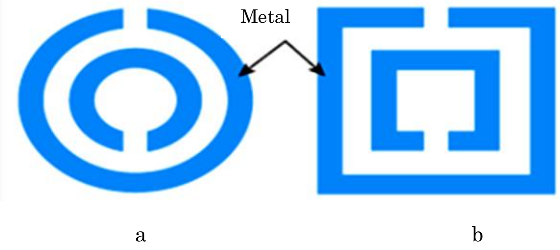

Fig. 1 – Split Ring Resonators (a) circular and (b) square [9]

In this paper, we will do a detailed investigation of SRR based on stopband filters: starting with a single SRR etching in the ground plane, finding its stopband characteristics, after that the effect of number of SRR and periodicity on the stopband filter performance is investigated.

2. EXTRACTION OF EFFECTIVE PARAMETERS

The extraction of the effective parameters from the coefficients of reflection and transmission, is known as the method name of Nicolson-Ross-Weir (NRW) [10], To obtain the effective electromagnetic parameters of the structure, a theory of homogenization is used. The main purpose of this theory is to describe in a simple and macroscopic way the microscopic complexity of the response of objects to an incident electromagnetic radiation. Indeed, the idea was to model the metamaterial as an isotropic homogeneous slab, and to calculate the effective parameters ε, and μ of the homogenous slab from the transmission and reflection coefficients obtained by simulations under Matlab.

For an isotropic homogeneous slab in a vacuum space, the transmission t, and reflection r have the following relations with the refractive index n, and the impedance z, of the slab [11]:

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$$t^{-1} = \left[\cos(nkd) - \frac{i}{2}\left(z + \frac{1}{z}\right)\sin(nkd)\right] \quad (1)$$

$$\frac{r}{t} = \left[-\frac{i}{2}\left(z - \frac{1}{z}\right)\sin(nkd)\right], \quad (2)$$

where k and d are the wave vector and the thickness of the slab respectively.

Equations (1) and (2) can be inverted to calculate n and z from t, and r. By completing this inversion, we obtain:

$$z = \pm\sqrt{\frac{(1+r)^2 - t^2}{(1-r)^2 - t^2}}, \quad (3)$$

$$\cos(nkd) = \frac{1}{2t}\left(1 + t^2 - r^2\right). \quad (4)$$

By using the S_{ij} parameters, the effective material parameters can be extracted [12]:

$$z = \pm\sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}}, \quad (5)$$

$$re(n) = \pm Re\left[\frac{\cos^{-1}\left(\frac{1}{2S_{21}}\left(1 - S_{11}^2 + S_{21}^2\right)\right)}{kd}\right], \quad (6)$$

$$im(n) = \pm im\left[\frac{\cos^{-1}\left(\frac{1}{2S_{21}}\left(1 - S_{11}^2 + S_{21}^2\right)\right)}{kd}\right], \quad (7)$$

The ambiguity on the signs of the equations (5), (6) and (7) is prevented if account is held owing to the fact that the real part of the impedance is positive if it is about a passive medium, and the imaginary part of the refractive index is positive to ensure that the incident wave amplitude decreases inside the structure.

Then, the effective permittivity and permeability can be computed from the equations:

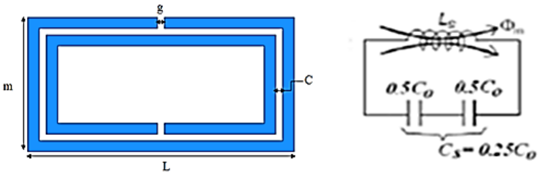
$$\varepsilon = \frac{n}{z} \quad (8)$$

$$\mu = nz. \quad (9)$$

3. THE SPLIT RING RESONATORS LOADED BY A MICROSTRIP LINE

The resonance frequency obtained from this inclusion (SRR) is typically much smaller than that corresponding to the classical ring or square open loop resonators of similar dimensions. This feature is related to the large distributed capacitance between the two rings. The small electrical size of the SRRs suggests the possibility of applying this peculiar configuration (or some suitable modified version) to the design of compact filters. There are many different parameters that affect the resonance frequency of a SRR, most dominant being the permittivity of the substrate and the length of the resonator. In the microstrip technology, they produce negative effective permittivity $Re(\varepsilon_{eff}) < 0$ [9]. The SRR topology and equivalent circuit model are illustrated in Fig. 2. The SRR unit cell was designed to operate around 2.9 GHz. The geometry of the cell is as follows: $c = d = 0.2$ mm, $g = 0.2$ mm, $m = 3.8$ mm and $L = 7.11$ mm. The substrate used is a RO3210 having the following characteristics (relative permittivity $\varepsilon_r = 10.2$, loss tangent $\text{tg}(\delta) = 0.003$ and thickness $h = 1.27$ mm). The resonator is simulated by using 3D full-wave solver (Ansoft HFSS).

The capacitance 0.5Co is related with each two SRR halves and depends on per unit length capacitance (Cp) and circumference with average radius (r) between rings. This relation can be written as in (10). The self inductance (Ls) of resonator between two metallic rings induces flux density (Φm) when the current flows inside rings. Therefore, the angular frequency which results from this circuit model can be calculated from (11) [13].



a b

Fig. 2 – (a) SRR particle with relevant dimensions; (b) unit-cell equivalent circuit of a SRR-loaded microstrip line

$$C_0 = 2\pi r C_P, \quad (10)$$

$$f = \frac{1}{2\pi\sqrt{L_s C_s}}. \quad (11)$$

Fig. 3 shows the S_{ij} parameter characteristics of the rectangular SRR and it can be observed that the rectangular unit cell resonates at 2.19 GHz with a return loss equal to – 18.7 dB with narrower bandwidth, which makes it suitable for lower band.

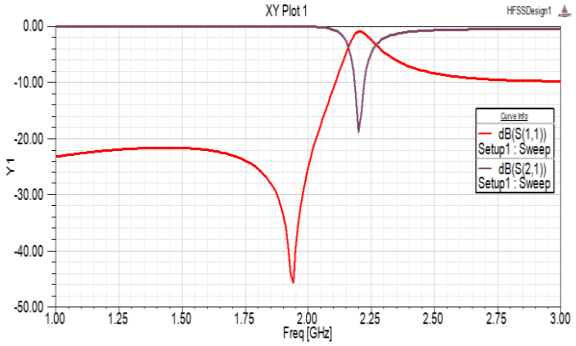


Fig. 3 – Simulated S_{ij} parameters of split ring resonator

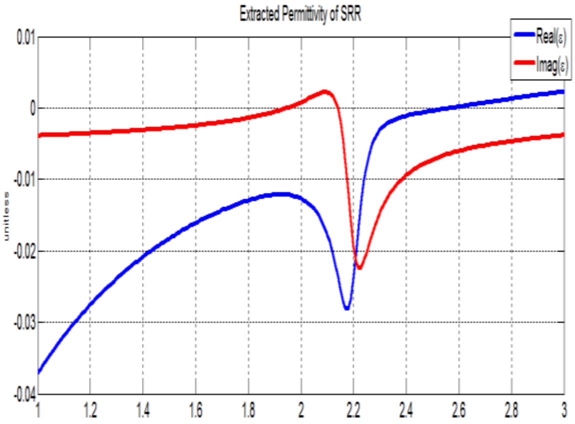


Fig. 4 – Real and imaginary parts of permittivity

As shown in Fig. 4, the real part of the permittivity shows Lorentz response behavior, it is negative in the frequency range between 1 GHz and 2.5 GHz.

4. RSRR BAND STOP FILTER DESIGN

Therefore, if RSRR is loaded on microstrip line, a conventional bandstop filter based on a 50 Ω [14].

First, we present a bandstop structure obtained by a network of RSRRs. The substrate employed is the RO3210 with a copper layer thickness of 35 microns on each side the geometry shown in Fig. 5, The transmission line has a width of $W = 1.12$ mm and a length of $L_1 = 0.445$ mm. The periodicity of SRRs network is 7.11 mm.

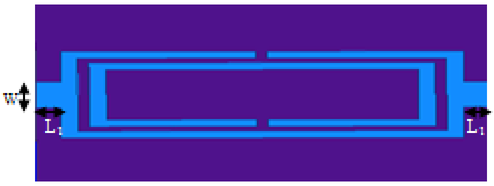


Fig. 5 – Bandstop filter topology using line loaded with RSRR

Then we added two RSRRs cells are used and the distance between two adjacent RSRRs is 0.89 mm as shown in Fig. 6.

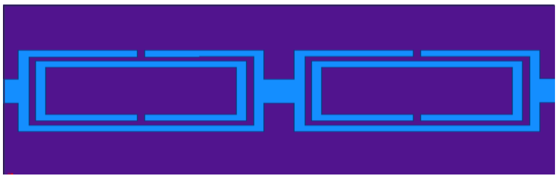


Fig. 6 – Bandstop filter topology using line loaded with two RSRRs

The three cells of RSRR in the load of microstrip line are shown in Fig. 7.

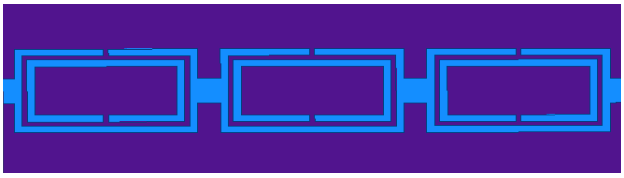


Fig. 7 – Band-stop filter topology using line loaded with 3* RSRRs

We present on the Fig. 8. Frequency response of cells RSRR on the band-stop filter in a single RSRR cell the simulated insertion loss ($S21$) and return loss ($S11$) of this filter. The maximum attenuation of $|S21|$ is approximately – 34 dB at 2.8 GHz and the bandwidth of stopband is equal to 870 MHz.

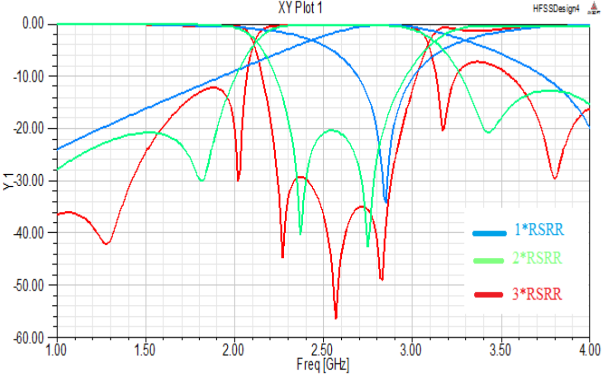


Fig. 8 – Frequency response of cells of RSRR

We have two cells of RSRR the maximum attenuation of $|S21|$ Approach of 20.45 dB at 2.45 GHz and bandwidth of stopping band equal to 1 GHz.

The structure is simulated for the frequency band [1-4] GHz In three cells RSRRs. A bandstop behavior is obtained in the band [2.09-3.75] GHz around the resonant frequency of RSRRs. Where the maximum attenuation of $|S21|$ is approach to 30 dB and bandwidth of stopband equal to 1.66 GHz. We conclude that when increasing the number of cell SRRs we noticed the difference between the level of rejection (S_{21}) and the increase of the frequency band.

5. CONCLUSION

In this paper, a compact stop band microstrip filter based on RSRRs has been proposed, successfully designed and simulated. The resulting device is very compact, produces very high rejection with sharp cutoffs in the forbidden band, and exhibits a flat and lossless Bandstop. This behaviour has been interpreted as corresponding to a frequency band with negative valued permittivity provided by the RSRRs. The size of the structure could be further reduced by tailoring RSRR dimensions, the SRR does not occupy extra space for this reason it is highly suitable for designing of size miniaturized microwave filters devices.

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