Design of a compact dual-band-rejection microwave filter based on metamaterials transmission lines.

BACHIR BELKADI 1, ZOUBIR MAHDJOUB 1

1 Communication networks, structures and multi-media laboratory.
Department of Electronics.
University of Djillali Liabes.
BP 89, 22000 Sidi Bel Abbes
Algeria.
Email: belkadi_bachir@yahoo.fr bachir.belkadi@univ-sba.dz

Abstract: - In this paper, a practical study and simulations about the transmission lines and microwave filters metamaterials at the base of the resonance elements is proposed. The Split Ring Resonator (SRR) and the Complementary SRR (CSSR) are coupled with the transmission lines in order to show the electromagnetic properties of metamaterials devices, and their transmission and reflection characteristics for each structure. A novel concept of a compact dual band rejection microwave filter with a high selectivity in the frequency and miniature size is designed. The theory of metamaterials, the NRW approach (Nicolson-Ross-Weir), are briefly introduced.

Key-Words: - metamaterials; filter; SRR; Complementary SRR; hyperfrequency; microstrip; dual-band-rejection; HFSS.

1 Introduction

Metamaterials are artificial pseudo-homogeneous structures with electromagnetic properties not found in nature. The particular property that is renowned metamaterials [1] is the possibility of having a negative permeability and permittivity simultaneously. At microwave frequencies, these structures have a structure where the electrical length of the unit cell is much smaller than the wavelength of the guided wave. The electromagnetic properties of these hypothetical media were systematically studied by the Russian physicist VICTOR.G. Veselago in 1968 [2], he has also developed the theory of left-handed propagation in such environments. In 1999, J.PENDRY [3] presented a resonant double ring, the latter is considered as the basic element of the first metamaterial realized.

The type of metamaterial transmission line resonance can be achieved by loading a host line with a SRR and inductive shunt elements [4], or alternatively by loading a host line with CSRR and capacitive elements in series [5-6]. The CSRR is a double counterparty of SRR; they are formed to show a left handedness in planar transmission media by etching these resonators in the ground plane of the microstrip transmission line. Due to the presence of CSRR, inhibition of the propagation of the signal is given to a resonance frequency as a narrow band; this phenomenon interprets the negative effective permittivity of the medium. The capacitive series gaps are added to the structure, in order to obtain the negative permeability as well as a bandwidth with the wave propagation in the left-handed [7].

Fig.1 Schematic view of (a) circular SRR, (b) square SRR, (c) circular CSSR and (d) square CSRR.
Therefore, the transmission lines based on SRR and CSRR act as frequency selective structures with the dimensions of the unit cell electrically small.

The metallic wires or the conductive strips of the transmission line have a negative permittivity $\varepsilon < 0$, and the periodic array of SRR has a negative permeability $\mu < 0$ around the resonant frequency. By bringing the two networks in a composite structure, this medium then gives us a negative refractive index $n < 0$ in the vicinity of the resonance frequency of the SRRs. The electromagnetic properties of the SRRs having been analyzed [8-9], this analysis shows that the SRR behaves LC resonator which can be excited by an external magnetic flux, having a strong diamagnetism above the first resonance. The CSRR behaves essentially as an electric dipole which can be energized by an axial electric field.

The purpose of this article is to make a comparison between several structures developed by a new approach to the design of metamaterials filters, where the microstrip line is loaded by SRR and CSRR, in order to achieve miniaturization, as well as performance and selectivity improved considerably.

2 Modeling of the structures CSRR / SRR

Based on the approach of the type metamaterial transmission lines, the implementation of these lines is done either by means of SRR, or their complementary [10], or both within the same structure. We opted for the latter we will implement with both circular and square shapes CSRR (see Fig.1(c, d)).

Simulations are performed for two designs, Omega and Circular SRR; these structures are shown in Fig.2 and consist of: a microstrip line loaded by two single Omega SRR Fig.2(a) or a microstrip line loaded by two single circular SRR Fig.2(b). For both structures, SRR are at the same plane as the conductive strip with and without gap, when the CSRR is etched in the ground plane above the conductive strip Fig. 2(c).

The model of the equivalent circuit [11] (lumped elements of the unit cell of these lines) is depicted in Fig.3. Where $L$ and $C$ are the inductance and capacitance respectively per unit length of the microstrip line.

The single SRRs on the top are inductively coupled with the line through the mutual inductance $L_M$ while the CSRR on the ground plane is capacitively coupled to the line through a mutual capacitance $C_M$.
The gap in the conductive strip is modeled by $C_g$ and $C$ account for the electrical coupling between the line and the CSRR. For all simulations, a Rogers substrate Ro 3210 with a thickness of 1.28mm and a dielectric constant $\varepsilon_r=10.2$ are used. Each structure consists of a microstrip line in width of conductive strip 0.8 mm and corresponding to a characteristic impedance of 50 $\Omega$. The dimensions are as follows: $a=1.2\text{mm}; s=0.4\text{mm}; g=0.2\text{mm}; w=0.2\text{mm}; r_{\text{ext}}=2.12\text{mm}; s'=0.3\text{mm}; d'=0.3\text{mm}; d=0.2\text{mm}$, the gap in the strip is 0.4 mm and the length of the unit cell (period) $P=7\text{mm}$. The four structures are artificial lines with circular CSRR, the simulation results are represented in the: Fig.4 for a microstrip line loaded with circular CSRR /SRR; the Fig.5 for the same structure but with a gap etched onto the conductive strip; in Fig.6 to a microstrip line with Omega shape CSRR/SRR and finally to the fig.7 for the Omega CSRR/SRR with the presence of a gap in the conductive strip.

Fig.4 Results for (a) the transmission characteristics of the structure circular CSRR / SRR; (b) effective refractive index (real and imaginary part).

Fig.5 (a) the transmission characteristics of the circular CSRR / SRR structure with a gap etched on the metal strip; (b) effective refractive index of the model.
Fig. 6 Results obtained for (a) the transmission characteristics of the Omega CSRR/SRR structure; (b) effective refractive index.

We analyzed the structures studied to present the reflection $S_{11}$, transmission $S_{21}$ characteristics, and the negative index of refraction. The results of simulations are obtained from the simulator HFSS V13 [12]. The Figs (4; 5; 6 and 7) for the circular and Omega CSRR/SRR (with and without gap) shows that there are zeros of transmissions and negative refractive indices around these resonant frequencies.

We repeated the same simulations for structures almost identical, with the same dimensions, but with a square CSRR. Square shape CSRR dimensions are: the external width of the outer square is 5 mm; his inner width of 4.6 mm; those of the internal square are respectively 4.2 mm and 3.8 mm; the distance between the square of the rings is 0.2 mm. The support is always considered Rogers Ro3210 with a dielectric constant $\varepsilon_r = 10.2$ and its thickness $h = 1.28$ mm.

The results obtained are shown in Figs (8, 9, 10 and 11).

Fig. 7 (a) Transmission characteristics $S_{11}$ and $S_{21}$ of the Omega CSRR/SRR structure with a gap etched on the metal strip; (b) effective refractive index of the model.

Fig. 8 Results for (a) the transmission characteristics of the circular CSRR/SRR structure; (b) effective refractive index (real and imaginary part).
Fig.9 (a) the transmission characteristics of the circular CSRR/SRR structure with a gap etched on the metal strip; (b) effective refractive index of the model.

Fig.10 Results achieved for (a) the transmission characteristics of the Omega CSRR/SRR structure; (b) effective refractive index.

Fig.11 (a) Transmission characteristics S11 and S21 of the Omega CSRR/SRR structure with a gap etched on the metal strip; (b) effective refractive index of the model.
3 Design metamaterial dual band rejection filter

The band-stop metamaterials filters allowing all pass to the output except certain frequencies, are used to eliminate howling and some disturbances of interference signals. Furthermore, the use of a dual band rejection filter provides and present a physical size smaller than conventional two cascaded filters, with single band stop and different frequency bands for each of them.

Several effective approaches to design dual band rejection filter exist, such as applying composite right/left handed metamaterial transmission lines [13], different length open stubs [14], stepped-impedance resonators [15], and so on.

From these data, a dual-band rejection filter based on SRR and CSRR was designed. The proposed filter (Fig.12) is composed of two unit cells of the structure shown in Fig.2(a) where we have two single Omega SRR coupled with CSRR etched on the ground plane. We always keep the same dimensions as the previously mentioned structures. The length of the period P is 7 mm, the filter size is small, with dimensions of (8mm x 12 mm).

The effective refractive index must be extracted from the complex coefficients of transmission and reflection of the structure simulated with HFSS software. The conventional procedure for extraction of the effective parameters is known as the method of Nicholson-Ross-Weir (NRW) [16].

NRW method is simply based on the classic calculation of interference giving the transmission and reflection of a layer of material according to its effective index, its effective impedance and its thickness. By reversing these formulas, the value of $n_{eff}$ is deduced according to the thickness of the simulated layer, the transmission $t'=S_{21}$ and reflection $r=S_{11}$ coefficient [17]:

$$Re(n_{eff}) = \pm Re \left( \frac{\arccos \left( \frac{1}{2m} \left[ 1 - (r^2 - t'^2) \right] \right)}{kd} \right) + \frac{2\pi m}{kd}$$

$$Im(n_{eff}) = \pm Im \left( \arccos \left( \frac{1}{2m} \left[ 1 - (r^2 - t'^2) \right] \right) \right)$$

Where $m$ is an integer;

The result of the simulation Fig. 13(a) shows that there are two transmission zeros (two bands of rejection) on both sides of the passband, which are: 4.19 GHz and 7.70 GHz at -43dB and -42dB respectively, and a refractive index (Fig.13(b)) negative around these two frequencies. The passband insertion losses are less than -1 dB within 5.05 GHz and 6.35 GHz, and return loss greater than 10 dB.

Fig.12 schema of the dual-band-rejection filter Omega shape CSRR/SRR.

Fig.13 (a) Transmission characteristics S11 and S21 for Omega CSRR / SRR dual-band-rejection filter; (b) effective refractive index.
4 Conclusion

The theory of transmission lines, microstrip lines, the SRRs and the CSRRs, the dual-band-rejection filter and its transmission with reflection characteristics, as well as the approach of NRW are introduced in this work. The band-stop filter is based on a novel concept; the performance and compact size are achieved through the loading of the transmission line by SRRs and CSRRs. The filter adapts better to reduce interference in wireless communication systems due to the simplicity of design, compact size and high selectivity.

References: