Microstrip Stop-Band Filter using Split-Ring Resonator

Mohammed Bendaoued
LMEET FSTS, University of Hassan 1st, Morocco
mohammed.bendoued@gmail.com

Rachid Mandry
LMEET FSTS, University of Hassan 1st, Morocco
mandryrac@yahoo.fr

Aytouna Fouad
Faculty of Sciences Tetuan, Morocco
Aytouna2002@gmail.com

Terhzaz jaouad
Regional Center for the Trades of Education and Training (CRMEF), Casablanca-settat, Morocco

ABSTRACT

In this work we present the design and simulation of a novel compact Microstrip Band-stop filter (BSF) using metamaterial structures in the top side of the substrate. The technique proposed in this study is based on the use of stepped-impedance resonators (SIR). The double Split-ring Resonator (SRR) shape are used as metamaterial structures to realize the stop-band characteristic and the stepped-impedance resonators are utilized to reduce the size of the filter structure. The simulation results show good performances in the rejected band which validate the function of the microstrip filter.

KEYWORDS

Microstrip, Band-Stop, Metamaterial, Split-Ring Resonator.

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1 INTRODUCTION

Microstrip bandstop filters are become more attractive in modern wireless communication system because of their low cost and simplicity of integration with other RF/microwave circuits. Its exists many techniques to design microstrip bandstop filters. One of them is to use shunt open-circuited resonators that are quarter-wavelength long, Which has advantage to filter out narrowband signals [1-2].

We can also find more techniques used to design such band stop filter structures like the use of periodic structures, defected ground plane structure, they are more demanded for wide band communication systems.

Stop-band filters are typically used in RF/microwave field research which has many advantages as the suppression of undesired responses, reject unwanted frequencies and pass desired frequencies and the elimination of interfering signals.

The stop-band characteristic can be obtained by using many dsign techniques. In this study we use the metamaterial structures which have several advantages.

A metamaterial is a material engineered to have a property that is not found in nature [3]. They are made from assemblies of multiple elements fashioned from composite materials such as metals or plastics. They have both negative permittivity and permeability.

The materials are usually arranged in repeating patterns, at scales that are smaller than the wavelengths of the phenomena they influence. Metamaterials derive their properties not from the properties of the base materials, but from their newly designed structures. Their precise shape, geometry, size, orientation and arrangement gives them their smart properties capable of manipulating electromagnetic waves: by blocking, absorbing, enhancing, or bending waves, to achieve benefits that go beyond what is possible with conventional materials.

The double negative metamaterials have been first introduced theoritically by Veselago in 1968 [4-6]. In which he made a description of materials exhibiting different combinations of positive or negative values of the dielectric permittivity and the magnetic permeability. As mentioned by the dispersion equation, the relation between the frequency and the wavevector k is given, in general form as :

$$\frac{\omega^2}{c^2}\varepsilon_{ij} - k^2\delta_{ij} + k_i k_j = 0 \quad (1)$$

This becomes, in the case of isotropic substance:

$$k^2 = \frac{\omega^2}{c^2} n^2, \quad \text{where} \quad n^2 = \epsilon\mu \quad (2)$$

From the equation, it can be seen that a solution for n^2 will exist whenever $\mathcal{E}>0$ and $\mu>0$ or when $\mathcal{E}<0$ and $\mu<0$.

A big step in the implementation of left hands material was given, when Pendry [7] proposed a novel type structure called Split Ring Resonator (SRR). The shape consists on a pair of concentric rings, with slits etched in opposite sides. The initial study takes into account an array of metallic wires. Considering the average of magnetic field values induced when an incident H_0 field is applied parallel to an array of metallic wires as shown in Fig.1.

$$H_{ave} = H_0 . \frac{1+i.\frac{2\sigma}{\omega r \mu_0}}{\left[1-\frac{\pi r^2}{a^2}\right]+i.\frac{2\sigma}{\omega r \mu_0}} \quad (3)$$

A value for the effective magnetic permeability of this medium can be obtained as:

$$\mu_{eff} = 1 - \frac{\frac{\pi^2}{a^2}}{1+i.\frac{2\sigma}{\omega r \mu_0}} \quad (4)$$

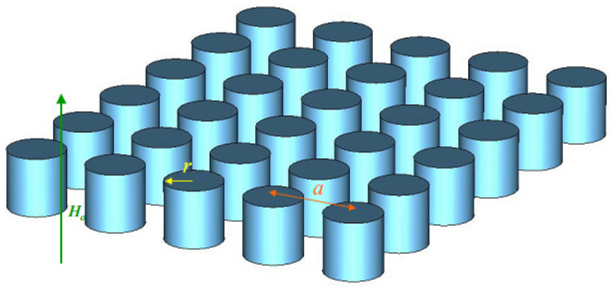


Figure 1: Array of metallic wires. The wires have radius r and a lattice constant equal to a. The incident magnetic field is parallel to the axis of the cylinders.

After many years of research Split-Ring Resonators (SRR) are widely used in the most important structures in the design and the fabrication of filters and diplexers.

In this paper a microstrip loaded Split-Ring Resonators are used to design a novel stop-band filter structure. By using this technique an elementary unit cell has been theoretically studied to show the behavior of the metamaterial structures. If we vary the metamaterial geometry, the corresponding permeability and permittivity can be altered and thus we can control the position of the stop band as we desire.

The proposed microstrip band-stop filter is composed from periodic SRR which will be discussed in this study.

Since the practical appearance of Metamaterials in 2001, researchers have proposed filter structures based on Metamaterials [8-9], with the aim of making filters more compact and reconfigurable.

The first work of the Burokur team was the realization of a band-cut filter based on a network of RAF (Fused Ring Resonator) cells and a 50Ω transmission line, the results obtained by this team show a stop-band around the frequency of resonance of the cell RAF. After that many research studies were done by using others shape like SRR, the results obtained permit to eliminate the parasitic bands of the filters, as well as improve their level of rejection.

In this part we present a conventional double split-ring resonator unit cell and its equivalent LC model. The Fig. 2 shows double split-ring resonator unit cell, its consists of two concentric square-shaped rings.

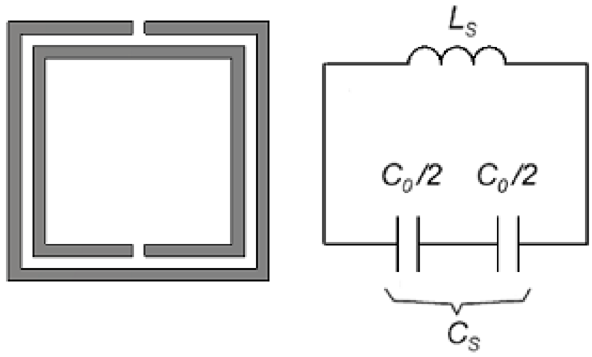


Figure 2: Conventional SRR unitcell and LC model

Based on this model, the resonance frequency of SRR is given by

$$f_0 = \frac{1}{2\pi\sqrt{L_s C_s}} \quad (5)$$

The permittivity and permeability are given by the equations:

$$\varepsilon_{eff}(\omega) = 2\varepsilon_p - \frac{g}{\omega^2 L_0 d} \quad (6)$$

$$\mu_{eff}(\omega) = 2\mu_p - \frac{g}{\omega^2 C_0 d} \quad (7)$$

Where ϵ_p and μ_p are positive parameters of the line, g is a geometrical factor that gives the relation between wave impedance of the effective medium and the characteristic impedance of the transmission line network and the unit cell dimension. There are also two frequencies f_{c1} and f_{c2} known as plasma frequencies at which $\varepsilon_{eff}(\omega)$ and $\mu_{eff}(\omega)$ becomes zero [10].

$$f_{c1} = \frac{1}{2\pi} - \frac{g}{\mu_p C_0 d} \quad (8)$$

$$f_{c2} = \frac{1}{2\pi} \frac{g}{\varepsilon_p L_0 d} \quad (9)$$

2 DESIGN PROCEDURE

Firstly, we have started the design of this structure by passingfrom a simple microstrip line, then we have inserted two double square shape split-ring resonators as metamaterial structures. Then we have implemented in each side of the center line two double square shape (SRR) structures. After many series of optimization using methods integrated in ADS (Advanced Design System), we have validated into simulation the proposed microstrip SBF presented in Figure 3. The final SBF structure contains 4 double square SRR uni tcell.

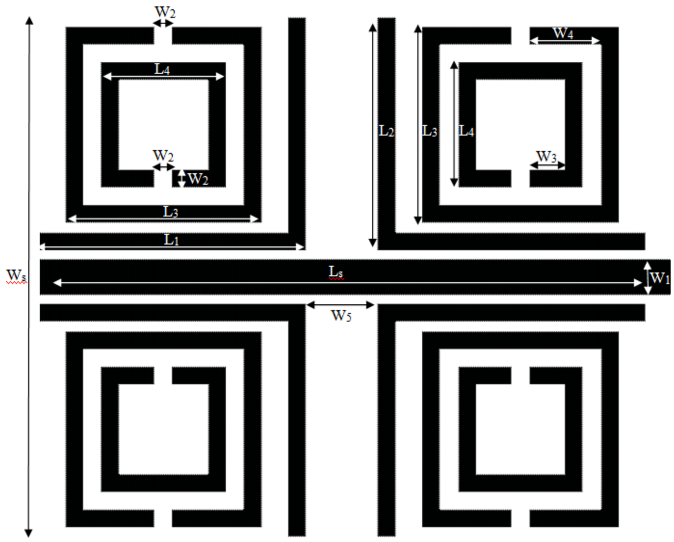


Figure 3: Geometry of the proposed SBF structure.

The optimized dimensions are presented in Table 1.

Table 1: Dimensions of the proposed SBF structure

Parameters	Values (mm)
LS	35.5
WS	29
L1	15
L2	13
L3	11
L4	7
W1	2
W2	1
W3	2
W4	4
W5	4

The final microstrip SBF 'Stop Band Filter' structure is mounted on an FR4 substrate having a thickness of 1.6mm, a dielectric permittivity Ɛr =4.4 and loss tangent tanδ=0.025. After many series of optimization using Momentum electromagnetic solver, we have validated the proposed stop band filter depicted in Fig.3.

The proposed microstrip filter is simulated by using electromagnetic solver ADS. The Fig. 4 illustrates the S parameters of the final filter structure.

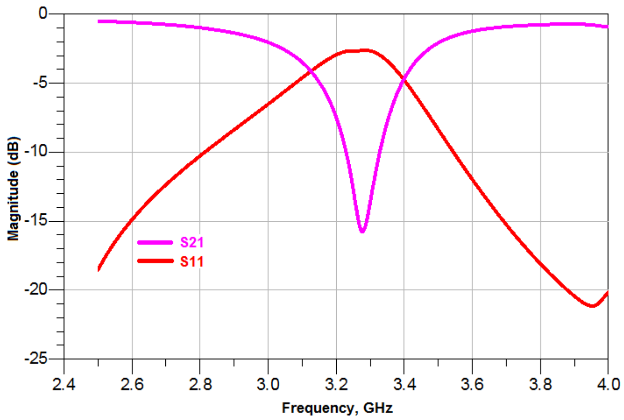
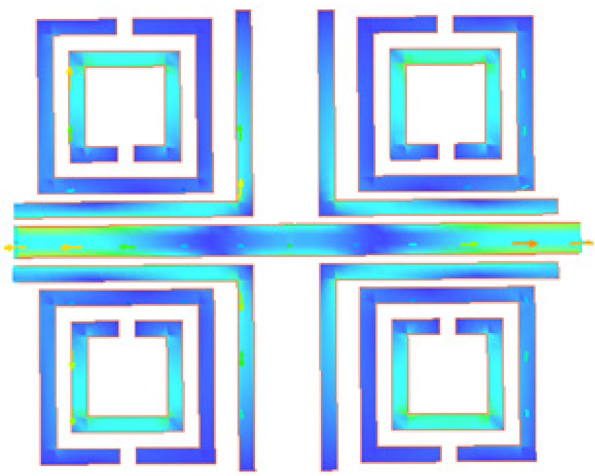


Figure 4: The S parameters of the proposed SBF structure.

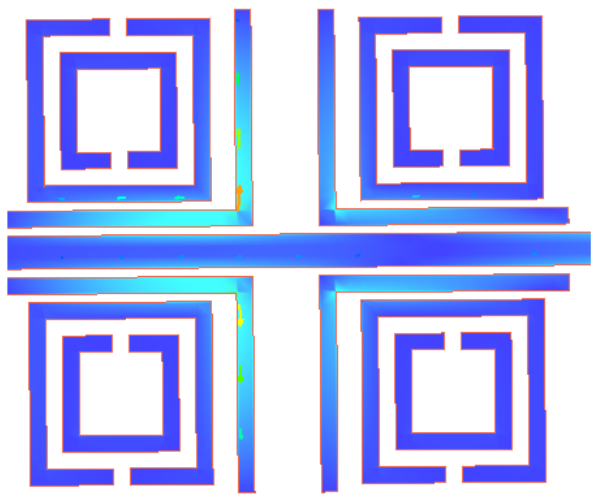
As shown in figurecccc 4 we have obtained good results in term of insertion loss around -15dB in the rejected band and a stop band wide of 138 MHz centered at 3.279 GHz.

These results are due to the insertion of the double square SRR up and down of the microstrip line, as metamaterial structure which permit to obtain the rejected band and also permit a miniaturization of the microstrip filter structure.

After the validation of the final filter structure, we have launched a simulation which confirms the function of the proposed microstrip filter. Fig. 5 presents two current distributions, one out of pass band at 4 GHz and another in the stop-band at 3.291 GHz which confirm the operation frequency bands of the proposed microstrip filter.



(a) At 4 GHz



(b) At 3.291 GHz

Figure 5: the current distribution at 4 GHz (a) and at 3.291 GHz (b).

3 CONCLUSION

This work comes with a new configuration of SBF structure. This topology is based on the use of microstrip technology and the use of metamaterial structures. The choice of the patterns is based on theoretical study to improve the stop-band obtained in the simulation results. The idea was to insert double square split-ring resonator in the two sides up and down of the microstrip line which permits to obtain the stop-band filter with a rejected frequency band of 138 MHz. The methodology followed in this work can be used to achieve an others stop-band filters for many applications by using metamaterial structures. The final circuit is miniature having total of area of 35.5 x 29 mm^2.

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