

Microstrip band-stop filter based on double negative metamaterial

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ABSTRACT

In this work, we present a novel miniature band stop filter based on double negative metamaterial, this circuit is designed on a low-cost substrate FR-4 of relative permittivity 4.4 and low tangential losses 0.002. The proposed filter has a compact and miniature size of 15 mm in length and 12mm in width without the 50 Ω feed lines. The resonator was studied and analyzed with a view to achieving a band-stop behavior around its resonant frequency. The band-stop characteristics are obtained by implementing the metamaterial resonator on the final structure. The obtained results show that this microstrip filter achieves fractional bandwidth of 40% at 2 GHz. Furthermore, excellent transmission quality and good attenuation are achieved. This filter is an adequate solution for global system for mobile communications (GSM).

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1. INTRODUCTION

The microstrip circuits have very important applications in wireless and radio frequency (RF) systems because of the outstanding virtues of simple integration with the microwave components and other lumped elements [1]–[3]. More often than not, the planar filter kind is extensively used in modern wireless systems because of their significant role by suppressing harmonics and spurious signals [4]–[7]. The spreading of this type of circuits in these systems gives great attention to the design of a miniature circuit filter has excellent performances [8]–[11]. However, achieving these goals simultaneously is not available by using conventional methods. So, the advanced technical methods which are used to obtain size reduction and electrical performances improvements such as microstrip line with etched spiral resonators, metamaterial and defected ground structure have been studied in [12]–[16].

Recently, subwavelength resonators are extensively implemented in microwave circuits in order to design a miniature filter, antenna, and coupler [17]–[20]. These engineered materials are characterized by unusual electromagnetic properties, their effective constitutive parameters have a negative value that is not available in ordinary materials [21], [22]. these peculiarities allow us to get resonator structures are so smaller than the wavelength of the interacting signals which have many useful advantages of radiofrequency devices in term of circuit size and electrical performances [23]–[25].

This paper describes a new miniature band-stop filter based on metamaterial resonator unit cell. This proposed back surface field (BSF) has a good transmission quality in the first and second pass-band and an excellent rejection level in the stop-band. Moreover, its circuit is characterized by the small size, the easy

fabrication, and low cost. Furthermore, the proposed filter is a good solution for global system for mobile (GSM), long term evolution (LTE) and radio frequency identification (RFID) applications.

2. DESIGN PROCEDURES

With a view to achieve some objectives in terms of final circuit size and band stop filter electrical responses, a novel metamaterial unit cell has been studied analyzed and implemented. The concept of metamaterial was started by the physicist Victor Georgievich Veselago at the end of 1967 [23]. After 30 years, Pendry *et al.* [24], [25] are succeeded to propose a medium with negative permittivity and negative permeability. By using the split-ring resonators and metallic wires, David R. Smith could fabricate a medium media of metamaterial in 2001[26].

After the chosen of the flame resistant 4 substrate FR4, the unit cell parameters are chosen following numerous steps of optimization and analysis with a view to obtain and reach a desired resonant frequency which will be used as an operating frequency of the proposed circuit. The studied resonator is shown in Figure 1, and its simulated scattering parameters are displayed in Figure 2.

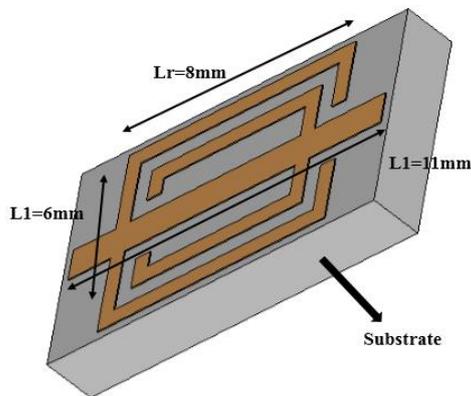


Figure 1. Metamaterial unit cell

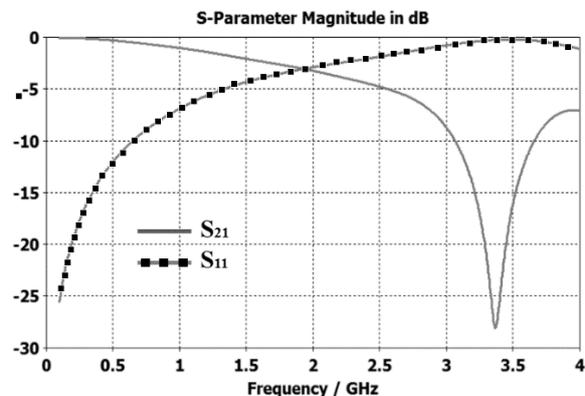


Figure 2. Metamaterial frequency responses

After the chosen of the optimized geometrical parameters of the metamaterial resonator and the obtainment of the desired range of frequencies. The investigation of unusual electromagnetic characteristics of this designed resonator was performed by using the s-parameter retrieval method. The effective permittivity, permeability, and refractive index are related to the S11 and S12 by the (1)-(4).

$$n = \frac{1}{\kappa_0} \cos^{-1} \left[\frac{1}{2S_{21}} (1 - S_{11}^2 + S_{21}^2) \right] \quad (1)$$

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

$$\epsilon_{eff} = \frac{n}{Z} \quad (3)$$

$$\mu_{eff} = Zn \quad (4)$$

Figure 3 shows the effective medium parameters and refractive index of the proposed double negative metamaterial unit cell. As might be seen, this resonator provides a negative refractive index, negative real permeability, and negative real permittivity close to its resonant frequency. The design steps of the final circuit, as well as the geometrical parameters of the proposed band stop filter, are displayed in Figure 4. The structure is composed of two 50 Ω microstrip lines connected with modified element microstrip line. Then, the proposed resonator is added and located in the center of the microstrip circuit. The optimized filter is very simple so that the manufacturing problems and complexity can be reduced. This filter has a miniature size of 12x21 mm² in comparison to its operating frequency.

The proposed structure without a metamaterial resonator is simulated with a view to understanding the influence of the chosen metamaterial unit cell. It is evident from Figure 5 that there is a normal and

simple transmission and that no rejected band is remarked. To meet the requirement of the stop band characteristics of proposed circuit in terms of size and electrical performance, several simulations have been carried out, studied, and analyzed in order to choose the best one that meets the specifications of the desired band stop filter. The proposed BSF structure is presented in Figure 6.

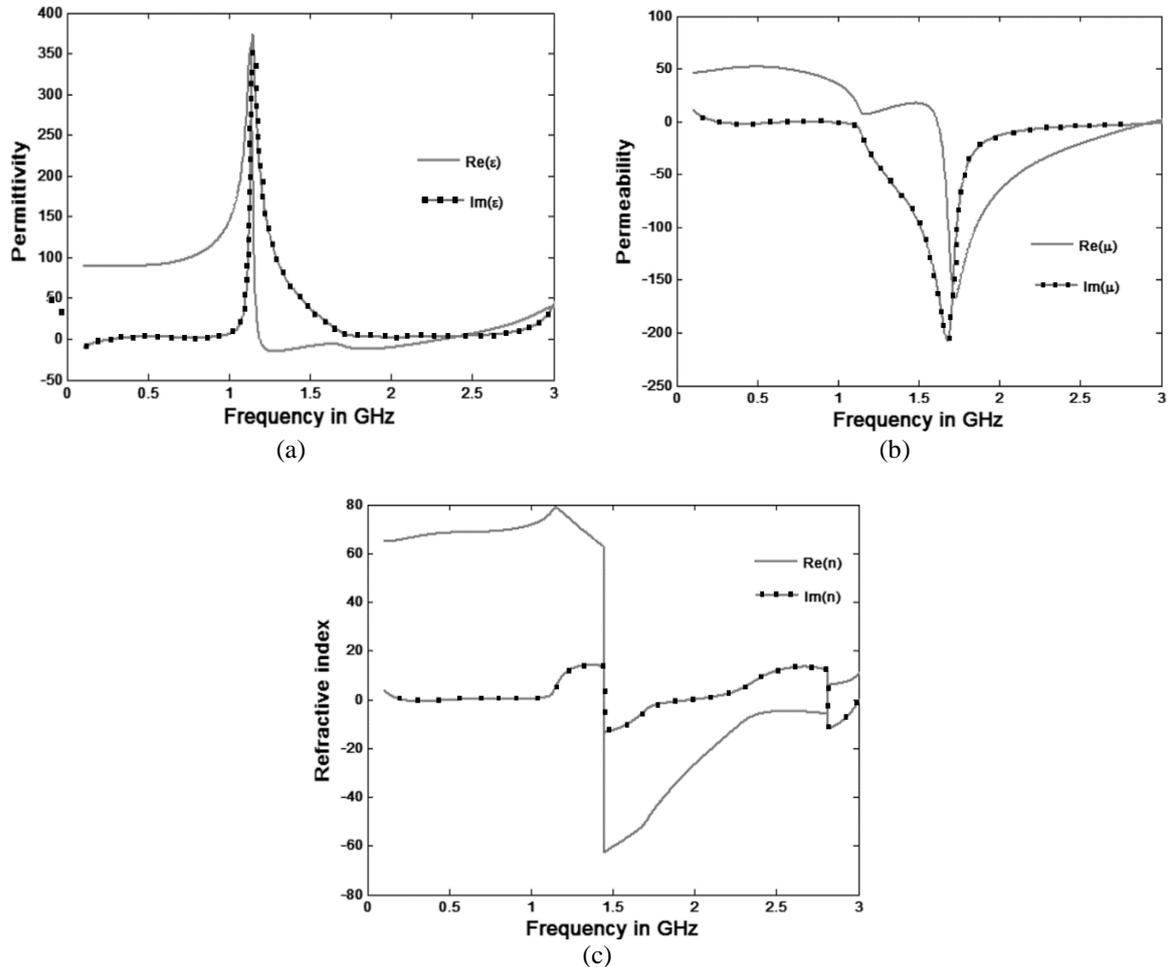


Figure 3. The effective medium parameters (a) permittivity, (b) permeability, and (c) refractive index

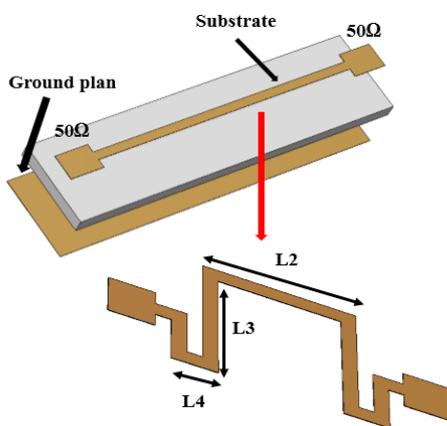


Figure 4. Design steps of BSF

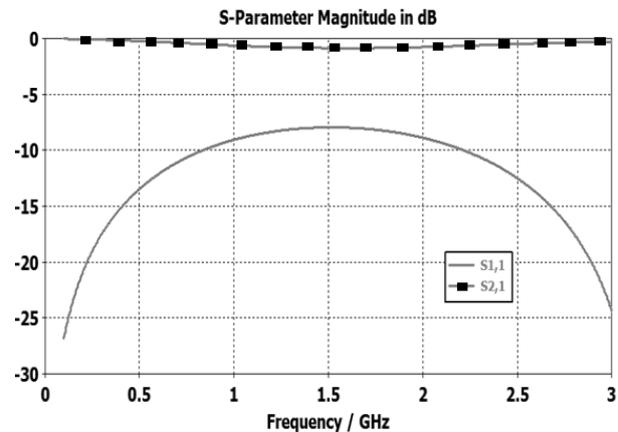


Figure 5. Simulated results without a metamaterial resonator

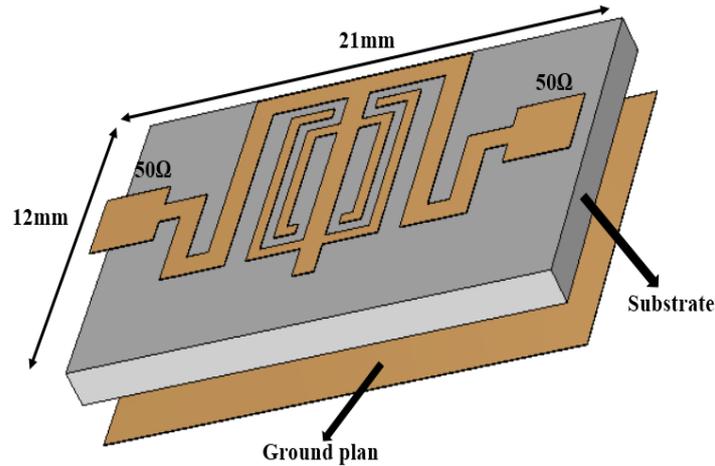


Figure 6. Proposed band stop filter

3. RESULTS AND DISCUSSION

Figure 7 illustrates the S-parameters results of the final designed microstrip band stop filter based on metamaterial unit cell. From these results, the circuit has rejected band characterized by center frequency of 2 GHz and it extended from 1.5 to 2.3 GHz. The insertion loss is less than 0.1 dB in two desired bands. Moreover, a good return loss is remarked. This confirms good transmission performances in the passbands. Besides, a power rejection capability higher than 25 dB is obtained and a fractional bandwidth $FBW=40$ is noticed. To verify the simulated results achieved by CST microwave studio, another simulation is carried out by using accelerator driven system (ADS) electromagnetic solver. The computed results show a good agreement between both solvers.

$$FBW = \frac{f_1 - f_2}{f_0} \% \quad (5)$$

Figure 8 displays the simulated surface current at (a) 1 GHz and (b) 2 GHz. This analysis is done to investigating the BSF performances in the passband and stopband. The obtained surface current results at the first chosen frequency prove that there is a transmission and a displacement of the radiofrequency power between the two ports. The second chosen frequency shows that there is no current close to the output port and it is very weak in the rest of the structure, which signifies that there is no signal propagation in the designed structure. The proposed BSF circuit performances are compared with previously published filters in terms of size and rejected-band properties. It is easy to see from Table 1, that this circuit has good features that make it acceptable for many radio frequencies applications and systems.

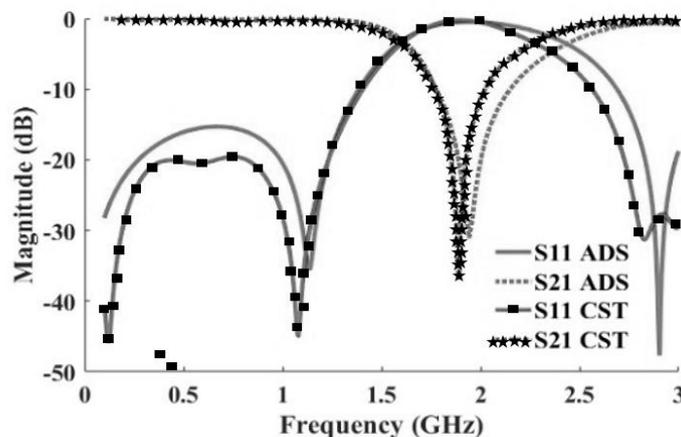


Figure 7. S-parameters results of the final designed microstrip band stop filter

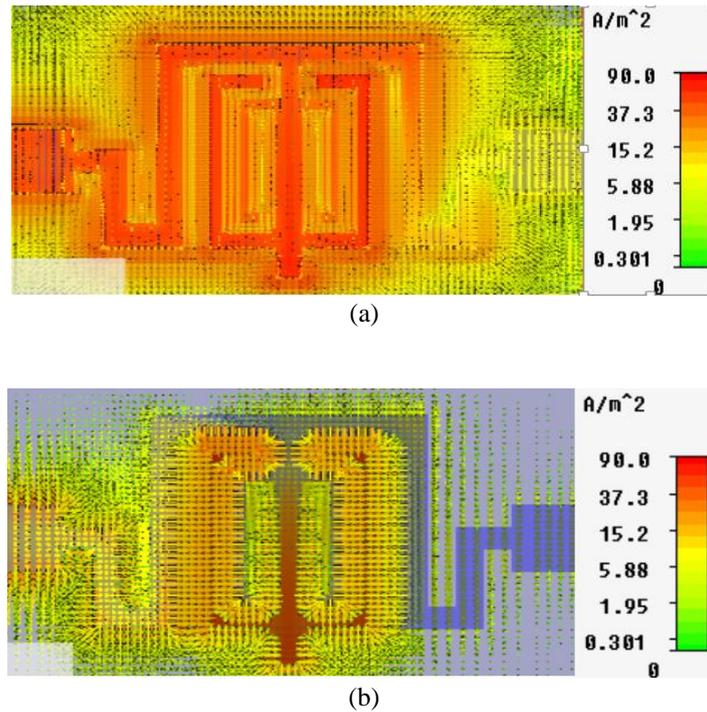


Figure 8. Simulated surface current at (a) 1 GHz and (b) 2 GHz

Table 1. Performance's comparison

Parameters/Ref	Rejected Band (GHz)	FBW	S21 deep	Size (mm ²)
[2]	[0.975, 1.025]	5%	35 dB	6370 \geq
[3]	[1.3, 1.7]	26%	30 dB	1800
[4]	[4.4, 5.4]	20%	25 dB	1041 \geq
[1]	[2.75, 3.35]	20%	25 dB	609
This work	[1.5, 2.3]	40%	30 dB	252

4. CONCLUSION

In this study, a novel compact and miniature band-stop filter based on double negative metamaterial resonator was designed and optimized using CST Microwave and ADS Agilent. The filter is characterized by rejected-band between 1.5 and 2.3 GHz which is achieved by implementing the metamaterial unit cell in the final circuit. This structure has excellent electrical features such as high return loss and insertion loss is less than 0.1 dB. Further, it exhibits a good attenuation level in the stopband with FBW of 40%.

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