A novel miniature coplanar band-pass filter for ISM applications

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Article Info	ABSTRACT			
Article history:	This paper presents a novel approach to design a compact miniature coplanar			
Received Oct 3, 2018 Revised Jan 7, 2019 Accepted Jul 22, 2019	band-pass filter by using rectangular split ring resonator. This propose circuit is designed for the Industrial, Scientific and, Medical (ISM) frequence band applications at 2.4 GHz. At the first stage, a metamaterial resonat is designed and simulated in a TEM waveguide to verifiy its electromagner proprieties around the desired frequency bands. At the second stag			
Keywords:	a band pass filter is designed using the proposed metamaterial resonator Many parametric studies are realized to investigate the effect and influence			
Coplanar Filter ISM Metamaterial Split ring resonator	of some resonator parameters on the proposed BPF performances. ADS Agilent and CST-MWS solvers are used in order to verify the simulated results. The circuit frequency responses show an excellent insertion loss and good return loss in the passband.			
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1. INTRODUCTION

The modern wireless communication systems and technologies, in particular, GSM, ISM and WiMAX have recently attracted an important attention of many researchers and developers with a view to improve the transmission and/or reception signal quality and, also to propose new compact and miniature devices can be implemented in these systems and used for these technologies [1-4]. Due to its irreplaceable role in the transmission-reception chain, The microwave filters have widely studied in order to achieve a miniature circuit size [5-8], excellent attenuation in rejected bands and low insertion loss in the desired range of frequencies [9-12], which led to create novel approaches and new resonators can be implemented in filter structures for achieving these characteristics simultaneously. Because these requirements are hard to achieve by the classical and conventional techniques [13-16].

Newly, the unusual electromagnetic proprieties of metamaterial resonators are opening new possibilities to obtain small microwave components such as antennas, power dividers and, filters. Moreover, good studies and uses of metamaterials give us new circuits with excellent electrical performances [17-19]. Generally, the natural materials have positive effective medium parameters. On the other hand, the split ring resonator metamaterial have the capability to exhibit negative effective permeability around their resonance frequencies as it is presented by Pendry in 1999 [20], and the complementary SRRs characterized by negative effective permittivity. Besides, the artificial left-handed metamaterials have negativepermeability, permitivity and, refractive indice, which do not exist in natural materials [21-25]. This letter describes a novel coplanar bandpass filter based on SRR metamaterial

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which is operating in the ISM band that is corresponding to the 2.4 GHz frequency. A brief study is presented in order to investigate the resonator resonant frequency and its electromagnetic proprieties. The proposed circuit is characterized by a good bandwidth matching and an excellent rejection in both attenuated bands.

2. METAMATERIAL STRUCTURE AND ITS CHARACTERISTICS

Among the resonators that have a positive effect on the miniaturization of the microwave circuit and which have a magnetic response, we find the rectangular-SRR. This type of resonator is generally formed by two concentric enclosed rectangular rings with two slits in opposite sides. Its resonant frequency is given by (1). This frequency can be controlled by the resonator parameters. Whereas the global capacity C_{R-SRR} is due to the two splits and space between rectangular rings, and the global inductance L_{R-SRR} is resulting from width and length of the rings. The geometrical configuration parameters of the resonator which will be used in our proposed design are presented in Figure 1. Its dimensions are chosen to obtain a resonant frequency in the desired frequency range.

$$f = \frac{1}{2\pi\sqrt{L_{R-SRR}C_{R-SRR}}} \tag{1}$$







Figure 1. (a) Metamaterial resonator, (b) Its simulation results

The existence of the special electromagnetic proprieties can verified and carried outusing (4) and (5). Figure 2 illustrates the extracted real and imaginary parts of the permeability of the metamaterial resonator.

$$n = \frac{1}{k_0} \cos^{-1} \left[\frac{1}{2S_{21}} \left(1 - S_{11}^2 + S_{21}^2 \right) \right]$$
(2)

$$z = \pm \sqrt{\frac{\left(1+S_{11}\right)^2 + S_{21}^2}{\left(1-S_{11}\right)^2 + S_{21}^2}} \tag{3}$$

$$\mathcal{E}_{eff} = \frac{n}{z} \tag{4}$$

$$\mu_{eff} = nz \tag{5}$$

Where; n= medium refractive index z=medium impedance k_0 =wave number equivalent to $2\pi/\lambda 0$ d=thickness of the substrate of R-SRR



Figure 2. Metamaterial effective permeability versus frequency

3. ANALYSIS AND DESIGN PROCEDURE OF THE BAND-PASS FILTER

With a view to meet the requirement of the structure size and transmission or/and reception features, various optimization technics are used by two electromagnetic solvers and several simulated results are carried out and analyzed so as to determine the best one which satisfies the band-pass filter specifications. For the purpose of achieving a pass-band response, the chosen metamaterial resonator is implemented and connected with 50 coplanar feeding lines in order to facilitate its integration with other planar components. The optimized filter is shown in the Figure 3. In orther to investigate the effect of the metamaterial unit cell on the circuit behavior, we changed the length value of the used cells from 6.5mm to 9.5mm and keept all other parameters invariant. As we can see in Figures 3 and 4, as we increase the length of the resonator, the centre frequency of the bandwidth decreases, which allows us to say that the transmission band of this proposed filter can be shifted and controlled by L-resonator.



Figure 3. Proposed coplanar band-pass filter



Figure 4. Effect of cell length on the designed bandpass filter

The centre frequency of the bandwidth of the designed filter can be shifted from 3.4GHz to 2GHz by varying the width of the resonator, which allows us to conclude that the desired frequency band of our bandpass filter can be controlled by changing the parameters of the metamaterial resonator as shown in the Figure 5.



Figure 5. Effect of cell width on the designed bandpass filter

The results of the final circuit in terms of reflection and transmission coefficients are shown in Figure 6. The obtained results show a bandpass behavior with a centre frequency of 2.4 GHz (ISM band). An excellent adaptation and a good level of attenuation are achieved in both rejection bands. In order to verify the CST Microwave simulation results, another simulation is performed via Agilent ADS. From the Figure below, we deduce that there is a good agreement between the two simulations. The slight deviations which we can observe in bandwidth can be explained by the different methods and different numerical resolutions used in Agilent ADS and CST MWS software.

The surface current distribution of the proposed circuit at the central frequency 2.4 GHz of the bandwidth and at 4.5GHz of the second rejected band is illustrated in Figure 7. We can notice that we achieve a maximum transmission of radiofrequency power in the ISM band and a good rejection level in the attenuated bands.







(a)



(b)

Figure 7. Surface current density (a) At the frequency 2.4GHz, (b) At the frequency 4.5GHz

This proposed bandpass filter circuit is compared with other previously published works in the literature. Table 1 shows that our structure has excellent passband characteristics and good attenuated band performances. Most importantly, it has a miniature and compact size compared to its operating frequency range and it is characterized by a fractional bandwidth of FWB=16%.

$$FBW = \frac{f_2 - f_1}{f_0} 100\%$$

Table 1. Comparison among published works and the proposed filter					
Parameters/	Pass-band	EWD	S11	Size	
Reference	(GHz)	FWB	(dB)	(mm^2)	
[9]	[2, 2.2]	9.5%	20dB	795.5	
[12]	[4.6, 4.8]	4.25%	25dB≥	1200≥	
The proposed Filter	[2 2 2 6]	16%	25dB>	480	

4. CONCLUSION

A novel coplanar band-pass filter is designed on an FR-4 substrate and it is achieved by using two metamaterial cells. The proposed circuit is validated by two electromagnetic solvers and good agreement is obtained between both simulated results. the filter is operating in the ISM band, low insertion loss which is less than 0.2dB is obtained in the bandwidth and good power rejection level is attained in two undesired bands. This filter has small and miniature size and high electrical performances whichallow us to say that this circuit is a good choice in modern communication systems.

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