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Band-pass filter based on complementary split ring resonator

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ABSTRACT

This letter presents a new circuit of the band-pass filter designed by using microstrip technology. Based on complementary split ring resonator and various series of optimization technic and a specific design method, a miniature band-pass filter with excellent electrical performances is achieved. First of all, the metamaterial unit cell is studied to obtain a desired resonant frequency and it is implemented in the ground plan in order to increase the characteristics of the bandpass behavior and decrease its operating frequencies. This proposed circuit is designed on an FR-4 substrate having a relative permittivity of 4.4 tangential losses of 0.025 and thickness of 1.6 mm. This filter is developed by using CST Microwave. The obtained features allow this filter to be used in diverse wireless applications such as IMT-E and WiMax.

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1. INTRODUCTION

In recent years, the use of telecommunications and mobile systems is growing rapidly worldwide. These systems have already been widely applied for industrial, commercial, residential and military purposes. However, improving their performances, reducing complexities, and cost of design and manufacturing represent mainly key elements as part of an industrial process for equipment supporting radiofrequency devices [1-5]. Which presupposes the use and implementation of techniques to optimize, miniaturize and improve the microwave circuits constituting these systems to ensure excellent and precise transmission and/or reception [6-11].

The rapid development and widespread use of wireless communication systems places ever more stringent requirements on microwave filters. Miniature size, high performance, very low cost and ease of integration with other radio frequency circuits are all simultaneously required when proposing new approaches to designing new filter structures. Among the most used methods for designing new planar filters that meet these requirements, we find the implementation of defects in the ground plane (defected ground structure), fractal geometry and metamaterials [12-18].

In this context, this paper is devoted to the conception of a new band-pass filter using planar technology. This proposed structure is characterized by small and miniature size, a reduced production cost, and selective frequency responses. These criteria are achieved by taking advantage of the unusual characteristics of the metamaterial resonator which is studied, analyzed, used and implemented in the designed circuit.

2. METAMATERIAL RESONATOR

Dielectric permittivity ε and magnetic permeability μ are two parameters used to characterize the electrical and magnetic properties of materials [19-21]. Recently, Ziolkowski has classified materials according to their constituent parameters. Principally, materials in nature have a positive permittivity and permeability. Therefore, they are termed as double-positive materials. On the other hand, if these two quantities are negative, these materials are described as double negative materials and/or left-handed materials. Finally, materials with only one negative parameter are named single-negative and they are classified into two subcategories namely, ε-negative materials or μ-negative materials [22].

The medium with negative effective permittivity was first discovered in 1998 by J. Pendry. Which used an array of parallel oriented metal wires. After this discovery and more precisely in 2004, Falcone et al have proposed another type of resonator that generates a negative permittivity in a frequency band and has an electrical response. This resonator is a complementary split ring resonator. Planar metamaterials that are composed of complementary structures like CSRR have been widely used in the design of microwave components to achieve compact and small antennas, miniature filters, power dividers, and other radiofrequency devices [19-26].

Basically, the characterization techniques of metamaterial structures are based primarily on resonator S-parameters. Various technics are discovered and developed to characterize metamaterials. In this part, Nicolson-Ross-Weir method is used because of its accuracy of the calculation. This technique is based on the below formulas:

$$V_1 = S_{21} + S_{11} \tag{1}$$

$$V_2 = S_{21} - S_{11} \tag{2}$$

$$\mu_{eff} = \frac{2}{jK_0 d}\frac{1-V_2}{1+V_2} \tag{3}$$

$$\varepsilon_{eff} = \frac{2}{jK_0 d}\frac{1-V_1}{1+V_1} \tag{4}$$

the structure is placed in a radiation box in order to extract the values of its effective parameters from the two reflection and transmission coefficients. The boundary conditions are respected. Figure 1 presents metamaterial resonator. Where Lr = 12 mm, Wr = 10 mm and g = 2 mm. Figure 2 shows the CSRR effective permittivity which has a negative value from 2.5 GHz to 4 GHz.

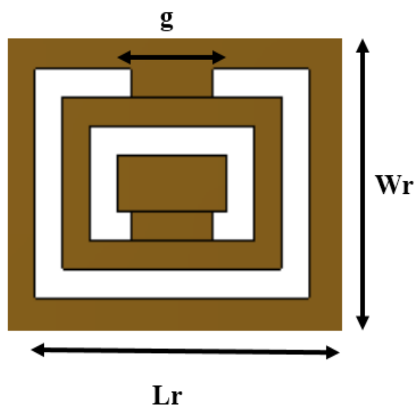


Figure 1. CSRR

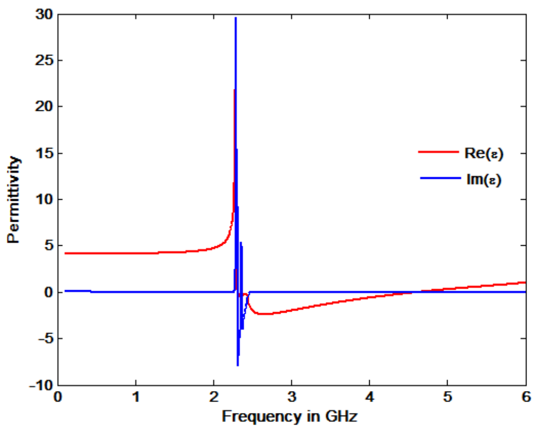
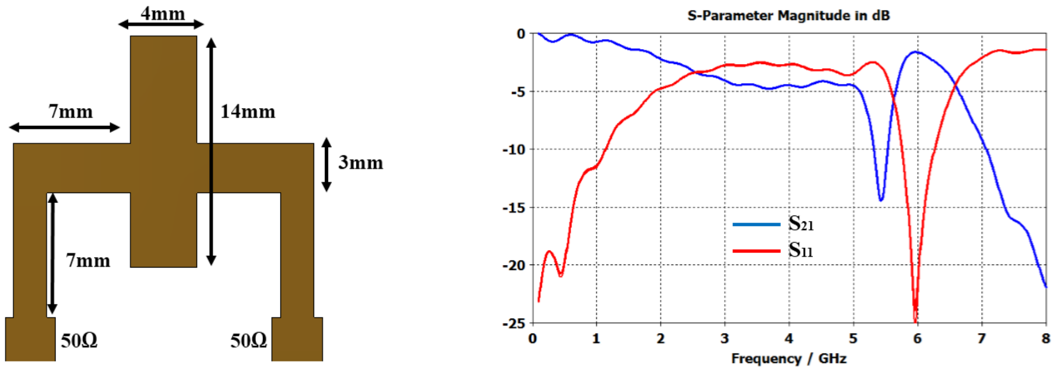


Figure 2. CSRR permittivity

3. PROPOSED BANDPASS FILTER

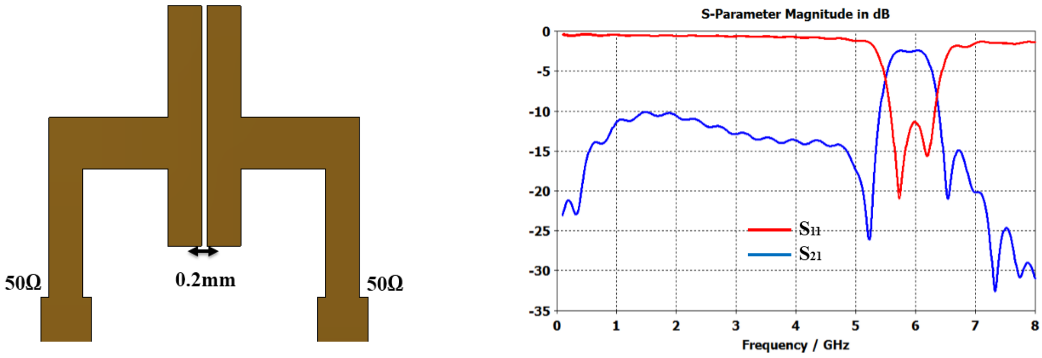
The design steps of the band-pass circuit are divided into three parts. The first one consists to develop a simple and miniature microstrip structure compound of one low-impedance section line separated by a tow short sections lines which are connected to both modified vertical 50 feed line as shown in Figure 3 (a). Secondly, so as to produce a bandpass behavior, the coupling technique is applied by etching a gap of 0.2 mm on the circuit top layer, more precisely in low impedance as shown in the Figure 4 (a). For the purpose of investigating the effect of the gap, the starting structure, the designed circuit with gap and their simulation results are presented respectively in Figures 3 and 4.

It is plain to see from Figure 4 (b) that the simulation results of the transmission and reflection coefficients show a band-pass behavior from 5.6 GHz to 6.4 GHz. This result confirms the gap influence. However, the pass-band characterized by a high insertion loss which decrease the transmission quality. With reference to its operating frequencies, we can not say that this structure has a small size. For all these reasons, the metamaterial unit cell will be etched in the ground plan of this circuit.



(a) (b)

Figure 3. (a) Initial microstrip structure, (b) S-parameters of initial microstrip structure



(a) (b)

Figure 4. (a) Microstrip structure with gap, (b) S-parameters of microstrip structure with gap

The last stage of the design procedures is the implementation of the complementary split ring resonator in the structure bottom layer in order to increase the transmission and rejection quality. Moreover, to achieve pass-band on the lower frequencies. The Figures 5 and 6 show respectively the bottom layer of the final designed microstrip bandpass filter and its simulation results. The general structure of this filter is very simple, which reduces the fabrication errors. Furthermore, the final simulation results show a good pass band from 2.8 GHz to 5.3 GHz with fractional bandwidth is equal to 62% and it has an excellent return loss and insertion loss which ensures a very high transmission quality in this frequency range. On the other hand, an excellent rejection level is reached in the first and second stop band.

All these obtained features in term of size and electrical performances allow us to say that this filter is a good choice for many applications such as IMT-E and WiMax.

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

f0: Center pass-band frequency.
f1: Low pass-band frequency.
f2: High pass-band frequency.

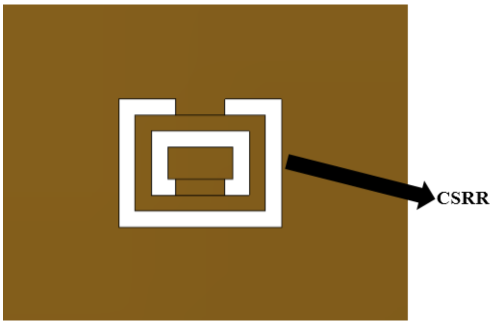


Figure 5. Bottom layer of the final BPF

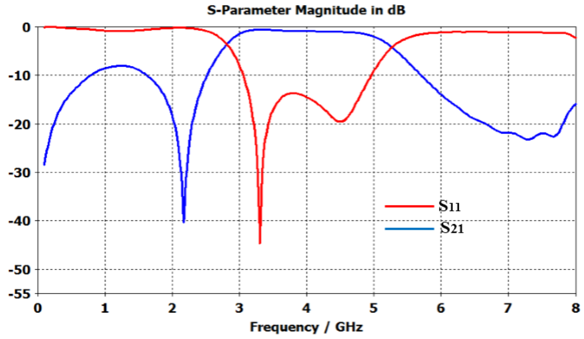
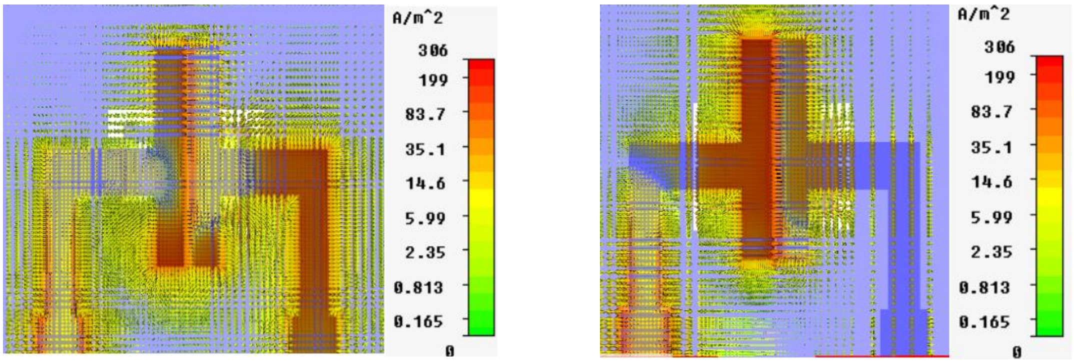


Figure 6. S-parameters of the proposed BPF

This investigation is performed so as to verify the circuit electrical performances in the rejected band and desired frequency range. As might be seen from Figure 7 (a), the band-pass filter allows the transmission of the radiofrequency power from the input-port to the output-port. But in the Figure 7 (b), we observe that this power is blocked in the middle of the proposed circuit which means there is no transmission of the radiofrequency power.



(a) (b)

Figure 7. (a) Simulated surface current in the pass band, (b) Simulated surface current in the stop band

4. CONCLUSION

This work presents an application of a metamaterial unit cell to achieve a compact band-pass structure with high electrical performances. From the achieved results, the proposed filter offers an important improvement of the pass-band behavior in terms of insertion loss, the attenuation level and size reduction compared with the conventional approach used to design band-pass filters. This filter is characterized by a wide passband with a fractional bandwidth FBW = 60% and gives a high transmission and reception in desired frequencies.

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