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New Design Approach for the Dual-Band Bandpass Microwave Filter (DBBPF) Inspired by Square Symmetrical Metamaterial Resonators (SSRRs) for X- and Ku-Band Applications

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In many modern telecommunication systems, band-pass filters represent main devices for multi-band applications. In this paper, a new design approach of the dual-band bandpass microwave filter (DBBPF) is provided for X- and Ku-band applications. The proposed filter is inspired by two symmetrical split ring metamaterial resonators (SSRRs) of the same square shape and different sizes. These resonators which have negative permittivity ($\mu < 0$) are interlinked by a metallic line and etched on the upper face of a Rogers's substrate (RO4003) with physical characteristics $\varepsilon_r = 3.55$ and tg$\delta = 0.0027$. The two SSRRs are connected to two microstrip feed lines adapted to 50 Ω impedance. To obtain the frequency responses of this complicated microwave structure, simulations based on the HFSS are launched. The proposed DBBPF which has the dimensions 26.86 mm × 19.60 mm × 0.8 mm provides good electrical qualities for two bandwidths of 380 MHz and 710 MHz covering X- and Ku- bands, respectively.

Keywords: Bandpass filter, Metamaterial, Permeability, Resonator, Transmission.

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1. INTRODUCTION

Microwave filters have proven day after day their importance and their influence on modern telecommunication systems. For multi-band applications, the microwave bandpass filter becomes a main component [1-4] because of the electrical qualities offered by this filter. The operation on several frequency bands for a single operator requires several circuits in the same system, which makes it voluminous with considerable interference, so the use of a multiband filter becomes a necessity to solve this problem. In this context, several types of dual-band [5] and triple-band [6] bandpass filters have been proposed for microwave systems. Today the choice of a new class of design materials has proven its effectiveness in the filtering world; this class is called «Metamaterials».

The concept of metamaterial started for the first time with the suggestion of the Russian physicist Victor Veselago in 1967 [7]. In his studies, Veselago presented the general properties of the propagation of electromagnetic waves in this type of medium. He showed the unusual properties of metamaterials that are not found in nature. Later, Smith and his research group suggested a new type of metamaterial that offers both negative permittivity and permeability [8]. Several theoretical and experimental works have been realized by researchers interested in this field [9-13]. The common objective of most of this research is to obtain resonators with magnetic activity capable of providing negative permeability; this is the main achievement of the famous Sir John Pendry [14]. The platform dedicated by Pendry to this field has made it possible to define a new type of resonator called today split ring resonator abbreviated as SRR.

In this work, we propose a new design approach to obtain a dual-band bandpass microwave filter (DBBPF). This filter is inspired by two symmetrical split ring metamaterial resonators (SSRRs) of the same square shape which are interlinked. Different dimensions of these SSRRs are chosen to have two different bandwidths to avoid undesirable interference. The frequency response of our filter is based on the electromagnetic coupling between the two proposed SSRRs and the two microstrip feed lines with characteristic impedances matched to 50 Ω.

2. DESIGN APPROACH

2.1 Description of the Square SSRR

The square symmetric split ring resonator (SSRR) is a metamaterial resonator formed by two square shaped rings; the outer one has the arm of side a and the inner one has the arm of side b. The period of the proposed SSRR is P, the two rings spaced by s have the same width d and the same interruption gaps g ($g = d = s$). The SSRR works correctly when the magnetic field $\vec{H}$ is perpendicular to the plane of the two rings. Our square SSRR is shown in Fig. 1.

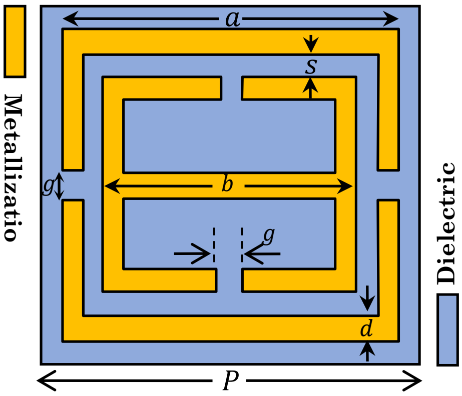

Fig. 1 – Representation of the square SSRR

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For the design of the global filter, we will use two SSRRs for different periods (different sizes of the arms *a* and *b*). The proposed dimensions are shown in Table 1.

Table 1 – Various dimensions of the proposed SSRR

Parameter		*g*	*a*	*b*	*P*
Value (mm)	$SSRR_1$	0.2	4.6	3.8	5
	$SSRR_2$	0.2	6.6	5.8	7

2.2 Proposed DBBPF

Our proposed global filter consists of two SSRRs of a square shape and dimensions indicated in Table 1. The two SSRRs are linked by a metallic line of length *l* and width d_1. All the components are fed by two microstrip lines adapted to 50 Ω impedance, these lines have the same length ($l_{in} = l_{out} = 12.57$ mm) for a width *W* identical to that of the metallic line ($W = d_1$). The spacing between the metallic line connecting the two SSRRs and the two microstrip lines is *e*. The elements constituting the global filter are etched ($t = 15$ μm) on the upper surface of the RO4003 substrate of thickness $h = 0.8$ mm and have a ground plane on the lower face ($w/h = 1.2$). The geometrical parameters of our proposed DBBPF are summarized in Table 2.

The DBBPF of section $m \times n$ mm^2 with $m = 26.86$ mm and $n = 19.6$ mm is shown in Fig. 2.

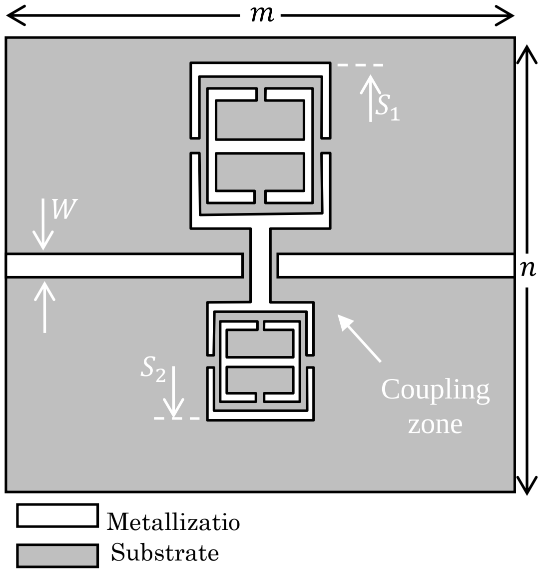
3. RESULTS AND DISCUSSION

3.1 Electromagnetic Characteristics of SSRRs

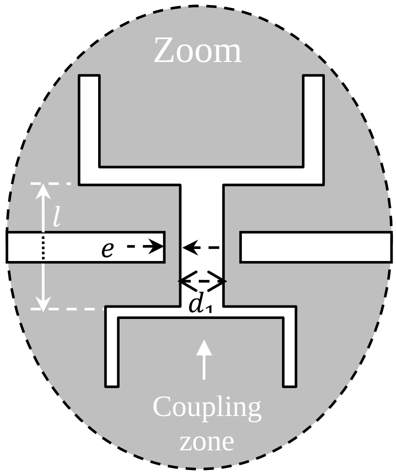
From the dimensions shown in Table 1, we will simulate the two SSRRs constituting our global DBBPF to obtain its electromagnetic characteristics. On the 3D modeler of the HFSS simulator, the largest period resonator $SSRR_2$ with P = 7 mm is shown in Fig. 3.

Table 2 – Dimensions of the proposed DBBPF

Parameter	*w*	d_1	*l*	*e*	S_1	S_2
Value (mm)	0.96	0.96	3.4	0.2	1.5	3.5



a



b

Fig. 2 – Proposed DBBPF: (a) top view, (b) zoom of the coupling zone

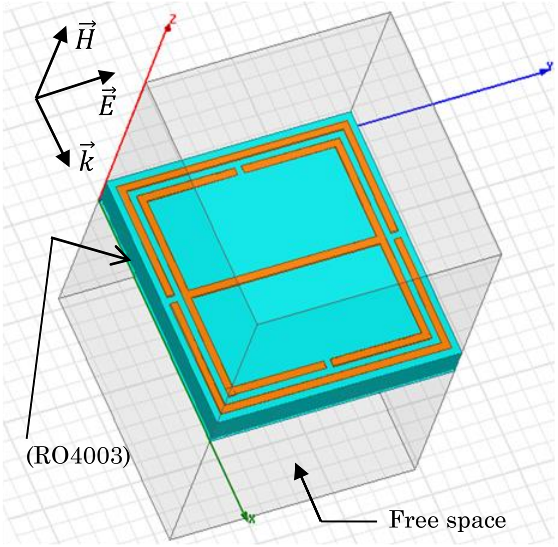
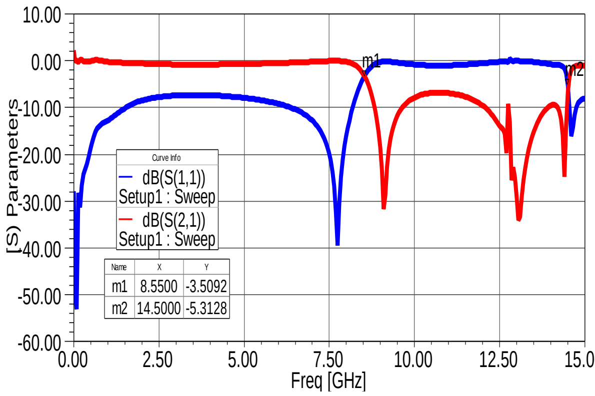


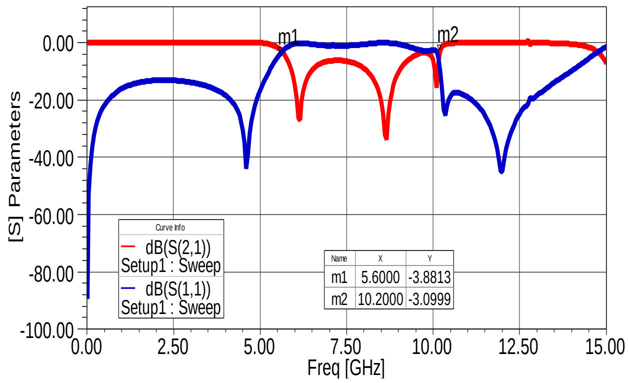
Fig. 3 – Square $SSRR_2$ polarized according to $\overrightarrow{OY}$

After applying the boundary conditions to our structure (in the HFSS simulator), the coefficients of reflection and transmission of both square SSRRs are represented in Fig. 4.

To show the difference between the two SSRRs, Fig. 5 shows the two transmissions of the two SSRRs.



a



b

Fig. 4 – Reflection and transmission of SSRRs: (a) SSRR₁ and (b) SSRR₂

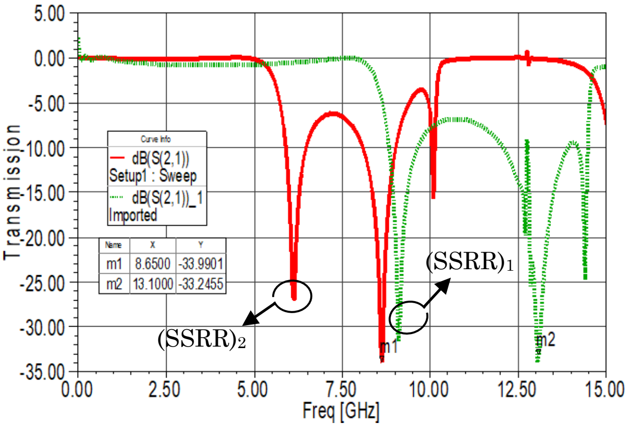


Fig. 5 – Transmission of both SSRRs

Fig. 4 represents the reflection and transmission of each SSRR, for the two representations it is noted that the behavior of each SSRR is stop-band. In Fig. 5 we notice that the transmission of each SSRR contains three peaks for different magnetic resonances. For SSRR₁, the central resonance is around 13.1 GHz for a gain of around 33.24 dB, while for SSRR₂, the central resonance is around 8.65 GHz for a gain of the order of 33.99 dB. The comparison between two transmissions allows us to say that the more the period (therefore the arms of the inner and outer rings), the more the magnetic resonance decreases.

To characterize the effective permeability of each square SSRR, we will apply the extraction procedure based on the two reflection and transmission coefficients of each resonator. The two parts, real and imaginary of each SSRR, are given by [15]:

$$\mu_{eff} = \mu'_{eff} - j\mu''_{eff} = j\left(\frac{A-1}{A+1}\right) \tag{1}$$

with

$$A = S_{21} - S_{11} . \tag{2}$$

Fig. 6 shows the two parts, real and imaginary, of the effective permeability of SSRR₂.

In Fig. 6, we notice that the imaginary part of the effective permeability of SSRR₂ is positive in the simulation range, while the real part changes its sign from − 46.13 to 36.05 around the first resonance, which justifies the magnetic activity of SSRR₂ in a narrow band of frequency 4.95-5 GHz, which is not justified for any other type of resonator.

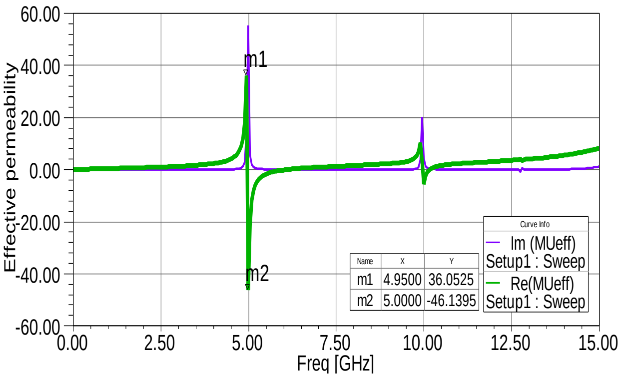


Fig. 6 – Effective permeability of SSRR₂

3.2 Electrical Qualities of the Proposed DBBPF

The use of the two SSRRs studied previously makes it possible to represent the global filter under the 3D modeler of the HFSS in Fig. 7.

The frequency response of our DBBPF is represented in Fig. 8.

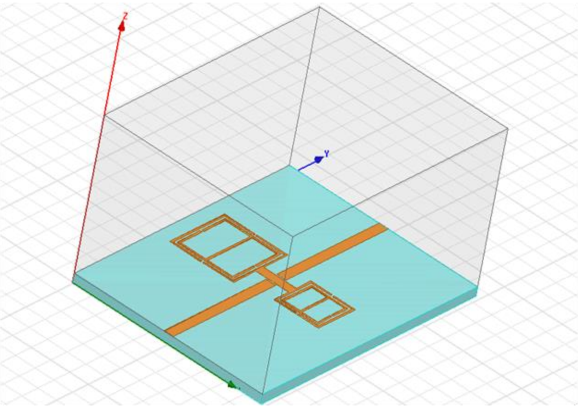


Fig. 7 – Perspective view of the proposed DBBPF

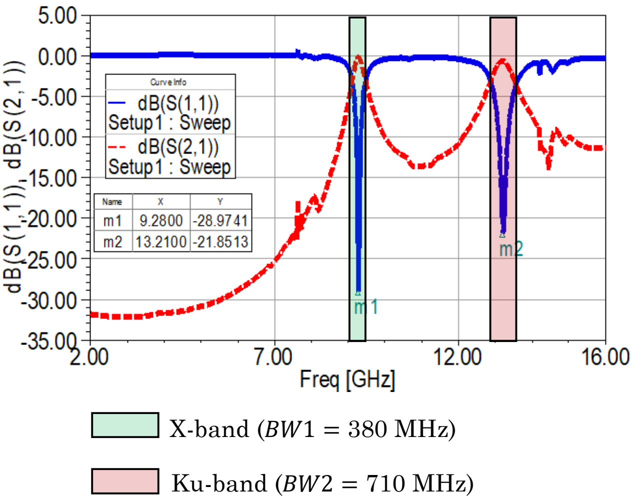


Fig. 8 – Frequency response of the proposed DBBPF

Fig. 8 represents the reflection and transmission coefficients of our DBBPF. We notice that our filter has two different bandwidths for two center frequencies f_{r1} = 9.28 GHz and f_{r2} = 13.21 GHz for two reflections of 28.97 dB and 21.85 dB, respectively. Insertion losses (IL) in the filter are low at center frequencies; 0.27 and 0.71 dB. We also note that the two bandwidths are estimated by 380 and 710 MHz for X- and Ku- bands.

A smaller metamaterial resonator is responsible for generating the upper band. The width of each band is controllable by varying the length of the metal line connecting the two SSRRs. The value of the center frequency of each band is adjusted according to the dimensions (periods) of each SSRR: a high frequency for a short period and vice versa. The distribution of the electric field on the DBBPF for the two center frequencies is shown in Fig. 9.

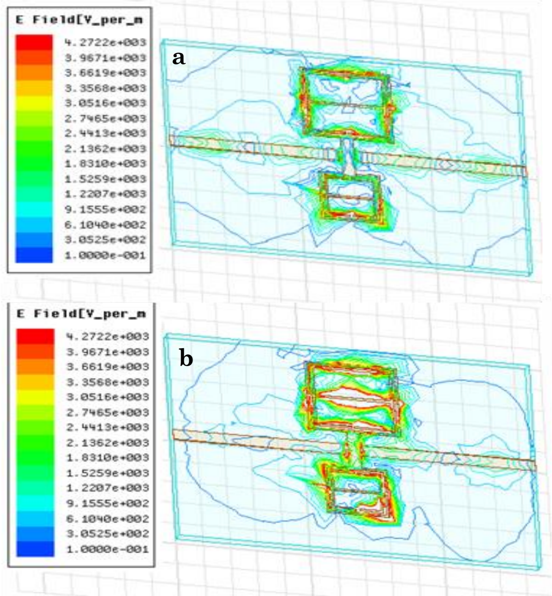


Fig. 9 – Electric field mapping on DBBPF at: (a) 9.28 GHz and (b) 13.21 GHz

Fig. 9 represents the mapping of the electric field on the DBBPF. At the first resonance of 9.28 GHz, we notice a considerable coupling between the two SSRRs constituting the filter, this means that the electric field and the electromagnetic power are important. At the second resonance of 13.21 GHz, we can notice that the electric field decreases in the filter which justifies the transfer of power from one resonator to the other (in the sense of density, which is determined from the Poynting instantaneous vector expressed as a function of the electric and magnetic fields).

4. CONCLUSIONS

In the presented paper, we have concerned ourselves with the proposition of a new approach for the design of a dual-band bandpass filter. We exploited the electromagnetic characteristics of two symmetrical split ring metamaterial resonators (SSRRs) to constitute our global filter. The used SSRRs have the same square shape for two different sizes in order to obtain two different bandwidths. All the components are fed by two microstrip lines with a characteristic impedance of 50 Ω. The electrical qualities of our filter are based on the electromagnetic coupling between the two SSRRs, and the two microstrip lines show the band pass effect for two different bandwidths of 380 and 710 MHz with an overall miniaturized size and low insertion loss (0.27 and 0.71 dB, better than 1 dB), which justifies the impact of metamaterial resonators on the band-pass microwave filters often used for X- and Ku-band applications.

ACKNOWLEDGEMENTS

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Новий підхід до проектування дводіапазонного смугового мікрохвильового фільтра (DBBPF) на основі квадратних симетричних резонаторів з метаматеріалу (SSRR) для додатків X- та Ku- діапазонів

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У багатьох сучасних телекомунікаційних системах смугові фільтри є основними пристроями для багатодіапазонних застосувань. У статті запропоновано новий підхід до проектування дводіапазонного смугового мікрохвильового фільтра (DBBPF) для застосування в діапазонах X і Ku. Запропонований фільтр заснований на двох симетричних резонаторах з роздільними кільцями (SSRR), виготовлених з метаматеріалу, однакової квадратної форми та різних розмірів. Ці резонатори, які мають негативну діелектричну проникність ($\mu < 0$), з'єднані між собою металевою лінією та вигравірувані на верхній поверхні підкладки Роджерса (RO4003) з фізичними характеристиками $\varepsilon_r = 3.55$ та tg$\delta = 0.0027$. Два SSRR підключені до двох мікросмужкових ліній живлення, адаптованих до опору 50 Ом. Щоб отримати частотні характеристики цієї складної мікрохвильової структури, використовується моделювання на основі HFSS. Запропонований DBBPF, який має розміри 26,86 мм × 19,60 мм × 0,8 мм, забезпечує хороші електричні якості для двох смуг пропускання 380 МГц і 710 МГц, що охоплюють X- і Ku-діапазони відповідно.

Ключові слова: Смуговий фільтр, Метаматеріал, Проникність, Резонатор, Пропускання.