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A Compact Square Split-Ring Resonators Band-pass Filter for X Band Applications

Mohammed Bendaoued[1,*], Anouar Es-saleh[2], Badr Nasiri[3], Soufian Lakrit[4],
Sudipta Das[5], Rachid Mandry[1], Ahmed Faize[4]

[1] *LMIET FST of Settat, University of Hassan 1st, Morocco*
[2] *Mathematics and Information Systems Laboratory, FP of Nador, Mohammed First University, Oujda, Morocco*
[3] *Laboratory of Optic of Information Processing, Mechanic, Energetic and Electronics, Faculty of Science, University Moulay Ismail, Meknes, Morocco*
[4] *Mathematics and Information Systems Laboratory, EST of Nador, Mohammed First University, Oujda, Morocco*
[5] *Electronics and Communication Engineering, IMPS College of Engineering & Technology, Malda, West Bengal, India*

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In this paper, the design of a bandpass filter is discussed. There has been a rising trend in recent years towards the design and development of new microwave circuits based on metamaterials to best meet the advanced requirements of modern wireless communication systems. The implementation and use of metamaterial resonators is among the most widely used technical solutions to improve the electrical performance, and reduce the size of microwave devices and circuits such as antennas, couplers and filters. The proposed filter is based on the use of split-ring coupled square resonators; the realized circuit has been optimized in simulation using the electromagnetic solver HFSS. This filter is suitable for X-band applications with a bandwidth of 1200 MHz [10.5 GHz-13.4 GHz] with a total area of 24.54 × 4.84 mm^2. The final circuit is mounted on a low cost FR4 substrate with a dielectric permittivity of 4.4 and a thickness of 1.6 mm. The originality of this filter is its selectivity in terms of bandwidth, having a wide band rejection and its easy integration with passive and active devices. Due to its straightforward construction, the suggested filter shows promising characteristics, for usage in wireless technologies for communications to offer an excellent performance.

Keywords: Microstrip, Filter, SRR: Split-Ring resonators, X band.

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1. INDRODUCTION

The need for microwave devices with high performances has increased in recent years due to the development of wireless communication and wireless power transfer technologies. Microwave filters are one of the most important parts of these devices. In communication technology, microstrip filters are crucial passive components for attenuating undesired signals and noise [1, 2]. Modern communication systems are paying increasing attention to the development of small, inexpensive microstrip filters with out-of-band rejection capabilities. Several filtering architectures have thus been investigated in order to meet these requirements [3]. Defected ground structure (DGS) studies for microstrip applications have also been the subject of numerous reports throughout the years. The distributed capacitance and inductance of the transmission are changed in order to implement the DGS by adding a defective resonator to the ground plane. [4, 5].

There are a significant number of technologies which each have their advantages and their disadvantages. The technology of a microwave filter is chosen according to electrical performance, size and manufacturing cost. The order of importance of these criteria depends on the environment of the telecommunications system. So it is necessary to make a compromise between these three criteria to best meet the application.

Planar technologies consist of one or more dielectric substrates comprising metallized stripes and ground planes. The propagation modes are TEM or quasi-TEM modes. The flexibility of the designs and the ease of interconnections between the make these technologies the most used in filtering microwave. Planar technologies can be divided into several processes of realization (microstrip, coplanar, etc.). These technologies are mainly used at high frequencies, for reasons of compactness, manufacturing cost and reproducibility. The topology of open loop resonator filters has been discussed and reported by many researchers [6-11]. This topology has a significant number of degrees of freedom at the level of the resonators. Indeed, the shape of the resonators can evolve to increase its compactness or improve the out-of-band response. It is also possible to choose the type of coupling between the resonators. Among these resonators we find the Square SRR.

2. SPLIT RING RESONATOR THEORY

The applications of metamaterial structures are enormous in design and development of electronic devices and components. The general field of application of metamaterials is that of the design of planar structures with specific uses for antennas and filtering. In fact, planar metamaterials which are made up of complementary structures like CSRR have been used in the design of microwave components like antennas, filters, power dividers, and phase shift devices [7].

Artificial magnetism is the fabrication of magnetic metamaterials in the microwave range using wholly

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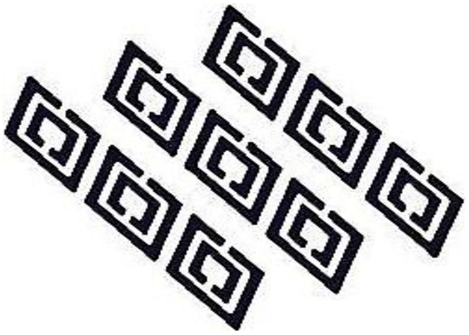
[*] mohammed.bendoued@gmail.com

non-magnetic structured metallic elements that act as magnetic "molecules". Pembry [12] was the first researcher to introduce metamaterials with negative permeability by proposing a new structure called "SRR" split ring resonators (Fig. 1) in several geometric forms (square, circular, triangular) in 1999.



1.

Fig. 1 – SRRs proposed by Pendry to have a medium with negative permeability

When a magnetic field is supplied parallel to the rings' axis, according to the two equations (1) and (2), The resonators are then supplied a current, and magnetic activity starts to manifest. [7, 12]:

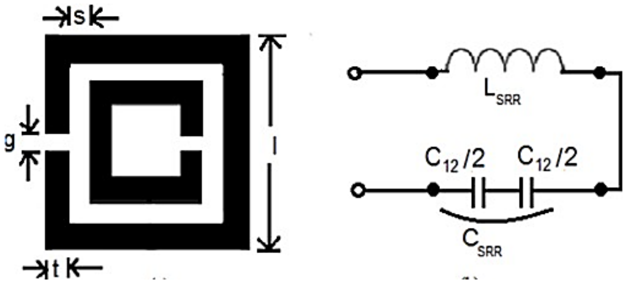
$$B = \mu_{eff} \cdot \mu_0 \cdot H \quad (1)$$

$$D = \varepsilon_{eff} \cdot \varepsilon_0 \cdot E \quad (2)$$

The expression of the effective permeability is therefore given by [13]:

$$\mu_{eff} = 1 - \frac{\omega_{0m}^2 - \omega_m^2}{\omega(\omega + j\Gamma) - \omega_m^2} \quad (3)$$

where Γ presents the metallic losses of SRRs, ω_m and ω_{pm} are respectively the magnetic resonant frequency and the frequency magnetic of plasma. SRR can be modeled as demonstrated in [14] by the following electrical circuit.

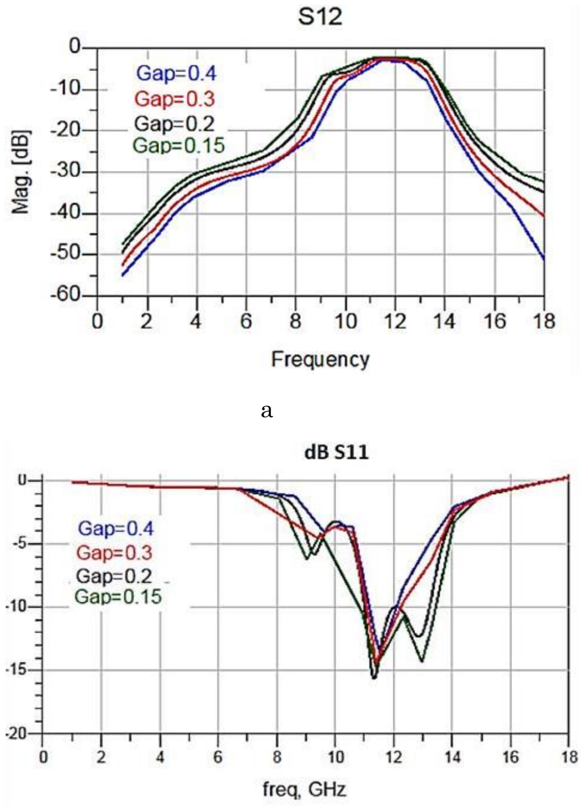


a b

Fig. 2 – Electrical model of Square SRR [15]

This circuit model's inductance, LSRR, is determined by assuming uniform current across the loop. The capacitances associated with each set of neighboring loops are believed to have a parallel counterpart in the CSRR. The resonant frequency is given by [14]:

$$f_r = \frac{1}{2\pi\sqrt{L_{SRR} C_{SRR}}} \quad (4)$$



a

b

Fig. 3 – (a) The insertion versus frequency (b) The reflection coefficient versus frequency

3. SQUARE SRR BAND-PASS FILLTER

To design such filter based on square SRR, firstly we have started this study by associating periodic coupling square SRR. The optimization is conducted on SRR dimensions and the gap between SRR elements. After many series of optimizations by using parametric studies, we have validated the proposed Band-pass filter. The filter is mounted on FR4 substrate, with a high mesh density at 18 GHz, which is taken as a maximum frequency in simulation. Fig. 3 presents the variation of S parameters versus frequency which is a parametric study. As it can be seen, the validated gap is 0.15 mm which permits to obtain the best insertion loss, a good matching of input impedance and enlarge the bandwidth which make it suitable for X band applications.

Fig. 4 – The 3D geometry of the band-pass filter

The simulated 3D model of the designed metamaterial based bandpass filter is depicted in Fig. 4. The structure of the prescribed filter with geometrical design parameters are shown in Fig. 5.

Table 1 – The bandpass filter's optimal dimensions

Design parameters	Dimensions (mm)
L_{in}	2.339
L_{out}	4.485
L_{feed}	1.2
W_{feed}	3
G_1	0.485
G_2	0.5
W_{in}	0.44
W_{out}	0.562

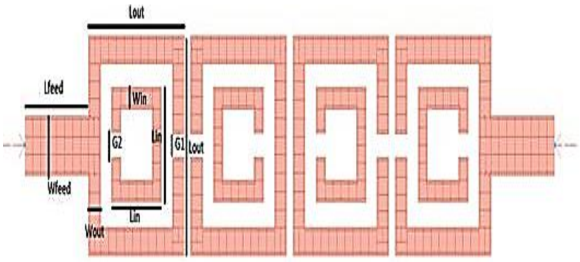
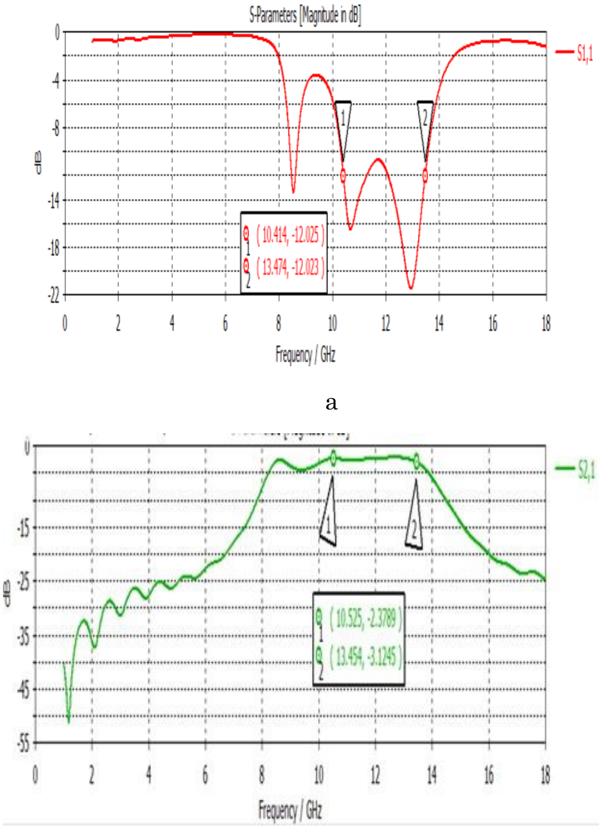


Fig. 5 – The final proposed band-pass filter

Table 1 presents the final dimensions of the prescribed bandpass filter. As illustrated in Fig. 6, the simulated bandpass filter permit to validate the bandpass filter with – 3 dB bandwidth of [10.5 GHz-13.4 GHz] which tend to support X band applications.

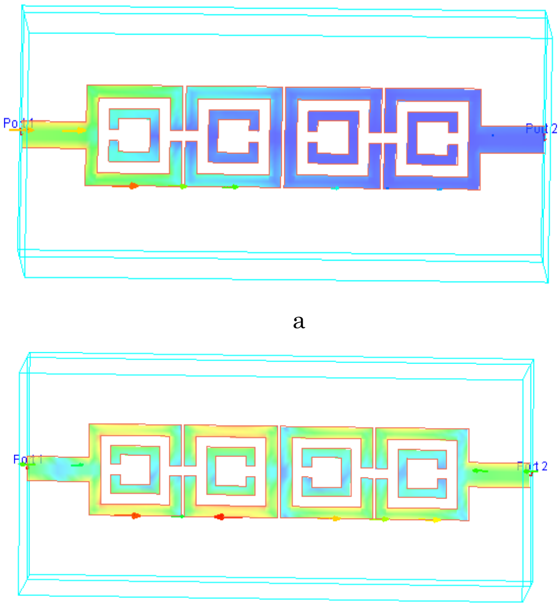


a

b

Fig. 6 – (a) The reflection coefficient (b) The insertion loss versus frequency

In order to study the behavior of this filter, we have launched the simulation of the flow of microwave energy, as depicted in Fig. 7. It can be observed that for a frequency around 3.12 GHz, a high attenuation of the signal is noted which can't reach the port 2 as this is the rejection band but for a frequency inside the passband, we can see a good transmission from port 1 to port 2.



a

b

Fig. 7 – Surface current (a) @ 3.12 GHz (b) @ 12.33 GHz

Table 2 presents comparative analytics of suggested BPF structure with some other filter structures available in the literature. The dimensions of the filter structure equals 24.54 × 4.84 mm^2 with a size reduction of up to 60 %.

Table 2 – Performance analysis with state of the art

Ref.	Size (mm^2)	Stopband S21 BW (20 dB)	Rejection BW (S11 3 dB)	S11 max (bandpass) (dB)
[15]	12.87 × 7.04 = 90.6	2.55 (8.38-10.93)	4 GHz	– 15
[16]	4.56 × 2.57 = 11.71	2 (9.9-11.9)	4.2 GHz	–10
[17]	17.3 × 5.6 = 96.88	2.6 (9.3-11.9)	5.3 GHz	– 17
[18]	30 × 7 = 210	0.5 (10.6-11.1)	1.18 GHz	– 20
[19]	30 × 20 = 600	0.44 (4.92-5.36)	0.8 GHz	– 15
[this work]	24.54 × 4.84 = 118.77	2.9 (10.5-13.4)	3.12 GHz	– 13.75

4. CONCLUSION

This paper presents a brief study and discussions on the achievement of good characteristics parameters on using a connected periodic square SRR as the basis for a bandpass filter. The proposed filter structure is cost effective as designed using low-cost FR-4 substrate, easy for integration in the same surface with devices due to planar geometry. The major traits of this filter are its dimensions which are miniatured size, a good rejection outside the frequency bandwidth. Also, the bandwidth is selective around the X band applications.

As future perspective, the structure of the BPF can be associated with active devices like varactor diodes for the purpose of increasing bandwidth and also to shift the frequency band making it reconfigurable bandpass filter.

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Компактний квадратний смуговий фільтр резонаторів із розділеним кільцем для застосування в X-діапазоні

Mohammed Bendaoued[1], Anouar Es-saleh[2], Badr Nasiri[3], Soufian Lakrit[4],
Sudipta Das[5], Rachid Mandry[1], Ahmed Faize[4]

[1] *LMIET FST of Settat, University of Hassan 1st, Morocco*
[2] *Mathematics and Information Systems Laboratory, FP of Nador, Mohammed First University, Oujda, Morocco*
[3] *Laboratory of Optic of Information Processing, Mechanic, Energetic and Electronics, Faculty of Science, University Moulay Ismail, Meknes, Morocco*
[4] *Mathematics and Information Systems Laboratory, EST of Nador, Mohammed First University, Oujda, Morocco*
[5] *Electronics and Communication Engineering, IMPS College of Engineering & Technology, Malda, West Bengal, India*

У статті обговорюється конструкція смугового фільтра. В останні роки спостерігається зростання тенденції до проектування та розробки нових мікрохвильових схем на основі метаматеріалів для кращої відповідності передовим вимогам сучасних систем бездротового зв’язку. Реалізація та використання резонаторів із метаматеріалів є одним із найбільш широко використовуваних технічних рішень для покращення електричних характеристик і зменшення розміру мікрохвильових пристроїв і схем, таких як антени, з’єднувачі та фільтри. Пропонований фільтр заснований на використанні квадратних резонаторів, пов'язаних з роздільним кільцем; реалізована схема була оптимізована під час моделювання з використанням електромагнітного вирішувача HFSS. Цей фільтр підходить для застосування в X-діапазоні із смугою пропускання 1200 МГц [10,5 ГГц-13,4 ГГц] із загальною площею 24,54 × 4,84 мм^2. Кінцева схема змонтована на недорогій підкладці FR4 з діелектричною проникністю 4,4 і товщиною 1,6 мм. Оригінальність цього фільтра полягає в його селективності щодо пропускної здатності, наявності широкосмугового відхилення та його легкої інтеграції з пасивними та активними пристроями. Завдяки своїй простій конструкції запропонований фільтр демонструє багатообіцяючі характеристики для використання в бездротових технологіях зв’язку з високою ефективністю.

Ключові слова: Мікросмужка, Фільтр, SRR, Кільцеві резонатори з розділеним кільцем, X-діапазон.