A Novel Dual-band Bandpass Metamaterial Filter using Ground Plane Demetallization Technology for Wireless Communications Applications

Berka Mohammed [1, 3, *], Umut Özkaya[2], Youcef Islam Djilani Kobibi[1], Abdelhak Zouggaret[1] and Mourad Hebali [1]

[1]*Department of Electrotechnic, University Mustapha Stambouli of Mascara, Algeria*
[2]*Konya Technical University, Turkey*
[3]*Department of Electronic/ EPO Laboratory, University Djillali Liabes of Sidi Bel Abbès, Algeria*

[*]*(m.barka@univ-mascara.dz) Email of the corresponding author*

***Abstract* –** The purpose of this article is the analysis and design of a new bandpass metamaterial filter structure, the analysis of this filter is made by applying the concept of ground plane demetallization. The resonator used for the demetallization is a spiral-shaped split ring metamaterial resonator, this resonator which represents a negative permeability (μ<0), has a magnetic resonance. It allows a qualitative control of the bandwidth of the global filter; it also increases the level of electromagnetic coupling with the microstrip lines. The feed lines used at the input and output of the microwave filter have coplanar access adapted to 50 Ω. Numerical calculations are carried out based on the High Frequency Structure Simulator (HFSS) for the finite element method (FEM). The obtained results show a dual-band band-pass DBBPF behavior for two central frequencies located at the C- and X- bands, which nominates the filter to be a potential candidate for wireless communications applications.

Keywords – Coplanaire, DGS, Filtre, HFSS, Perméabilité, Résonateur.

I. Introduction

As modern telecommunications systems move towards “all wireless”, microwave circuits can react to improve the performance of these systems. The operation of filtering is one of the most emphasized circuits in this context, especially band-pass filtering.

Passive microwave filters are electronic circuits containing localized, distributed or both elements contained in the same circuit which are Monolithic Microwave Integrated Circuit (MMIC) [1]. Recent research on microwave filters shows the importance of the choice of materials constituting these filters. A study of the physical properties of this type of material is therefore essential to improve the performance of such a filter [2−5].

Today, a new class of physical material is used when materializing filters, these structures are called "metamaterials". Metamaterials are artificial pseudo-homogeneous structures possessing electromagnetic properties not available in nature; an analysis of this kind of structure was originally made by the Russian physicist Victor Veselago [6]. The physical properties of metamaterials are represented by simultaneously negative permittivity ε and permeability μ [7, 8]. The DGS (Defected Ground Structure) technology was first proposed by Pak et al [9], based on the PBG (Photonic Bandgap Structure) technique to design planar microwave filters. Generally, the global structure of the filtering is obtained by etching a given shape in the ground plane. The position of the printed rings has a remarkable influence on the characteristics of the overall filter [10].

To show the influence of metamaterials on the quality of microwave filters, we propose in this article a new structure which includes a microwave filter using metamaterial resonators in split rings printed on the lower face of the filter, therefore a perfect application. of DGS technology for the design of our overall structure will be verified along this work.

II. Methodology

A. *Presentation of Complementary resonator*

The Complementary Split Ring Resonator (CSRR) is an element derived from the ordinary split ring resonator (SRR). The CSRR has a very small dimensions compared to the wavelength [11. Depending on the chosen geometric shape, several types of CSRR can be obtained. From the physical point of view, the CSRR is the complement of the SRR, i.e. all that is in conductive tracks in the SRR becomes slots in the CSRR and vice versa. We propose in our work a spiral shape which can justify the difference between the CSRR and the SRR. This form is represented by the Fig. 1.

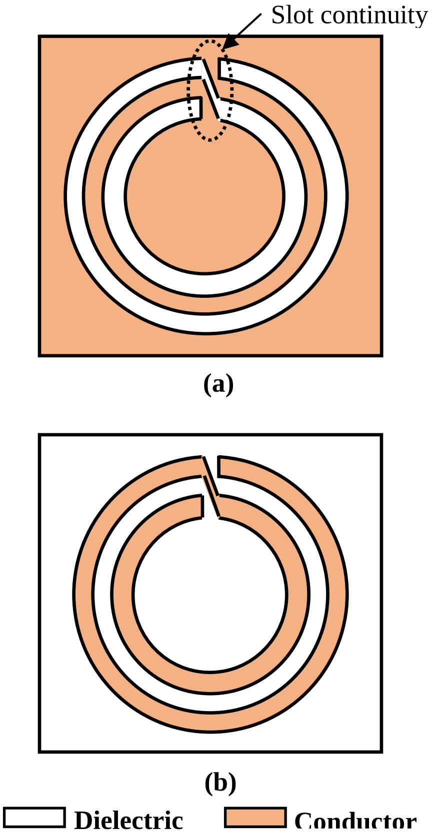


Fig. 1 Comparison between (a) CSRR, (b) SRR circular spiral shape

The complementary resonators are polarized but this polarization is done by respecting the condition (axial field $\boldsymbol{E}$) [11]. Fig. 2 shows the orientation of the trihedron $(\boldsymbol{E}, \boldsymbol{H}, \boldsymbol{k})$ for a cell of CSRR and its equivalent electrical circuit.

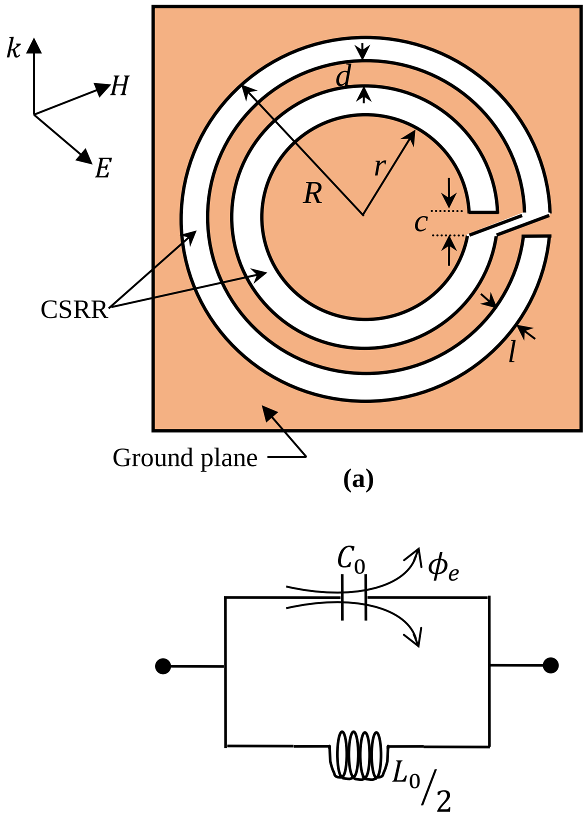


Fig. 2 Presentation of CSRR (a) Polarization, (b) equivalent electrical circuit

B. *DBBPF design*

The design of our filter is achieved by combining coplanar access lines with the CSRR spiral-shape. The coplanar lines are placed on the upper face of the chosen substrate, while the complementary spiral resonator is printed on the lower face of the same substrate. The etching of our ring is done using the same dielectric which is Alumina 96% for physical characteristics (ε_r =9.4, a loss factor $tan\delta$ =0.0004, a thickness h = 0.635mm).

III. Results and Discussion

A. *Magnetic Resonance of the SRR*

The study of the split ring resonator SRR of spiral circular shape is based on the determination of its magnetic resonance. The HFSS simulator allows us to consider this resonance, but the boundary conditions for such a structure must be respected. Another factor can intervene during our study; it is the sign of the magnetic permeability of our resonator. We have chosen dimensions of the resonator for C- and X-band resonance (r =1.3mm, $c = d = l$ =0.15mm, R =1.75mm). It is noted that the SRR is printed with copper for thicknesses of the order of 35μm). The radiation box is of volume of $4.2 \times 4.2 \times 4.2$ mm^3.

The Fig. 3 represents the basic cell for the circular spiral SRR where the polarization is not like the complementary resonator CSRR.

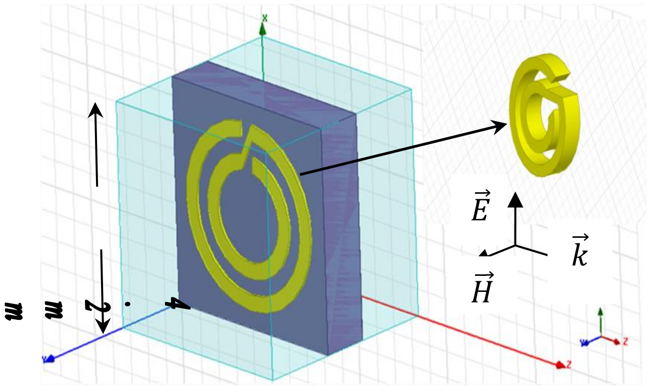


Fig. 3 Polarization of the SRR along $\boldsymbol{OX}$.

After applying the boundary conditions, the HFSS simulator represents the two coefficients of transmission and reflection and the variation of the permeability as follows.

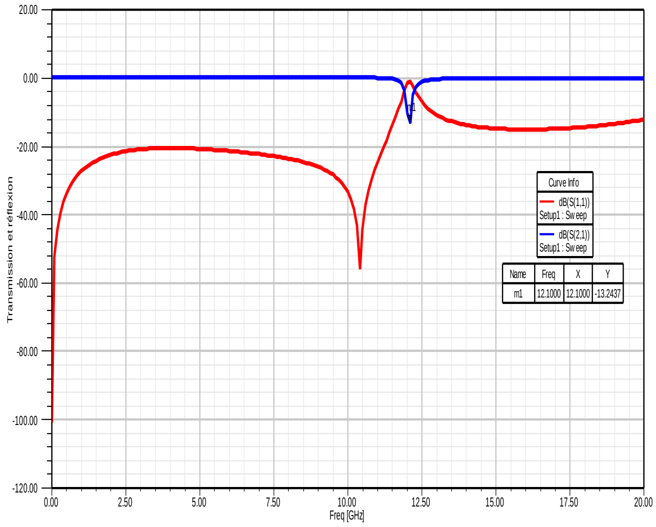


Fig. 4 Transmission and reflection SRR

Fig. 4 shows the variation of the two coefficients of transmission and reflection in the frequency range [0−20] GHz, we observe a band-stop behavior for a single resonance along the indicated range. The resonance frequency is f_r =12.1 GHz for a transmission of the order of −13.24 dB.

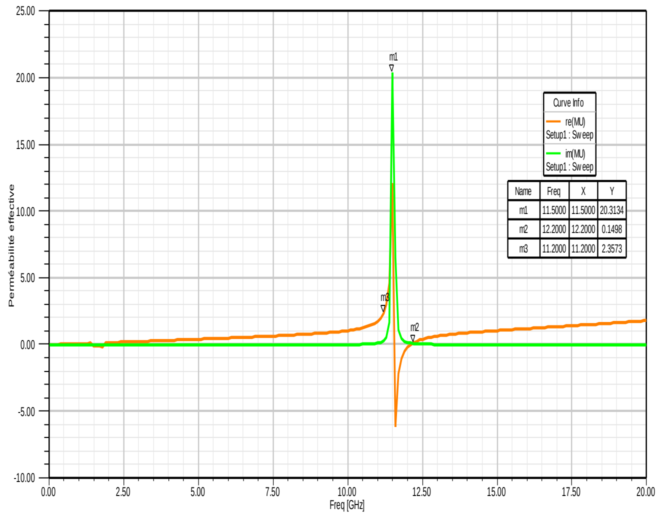
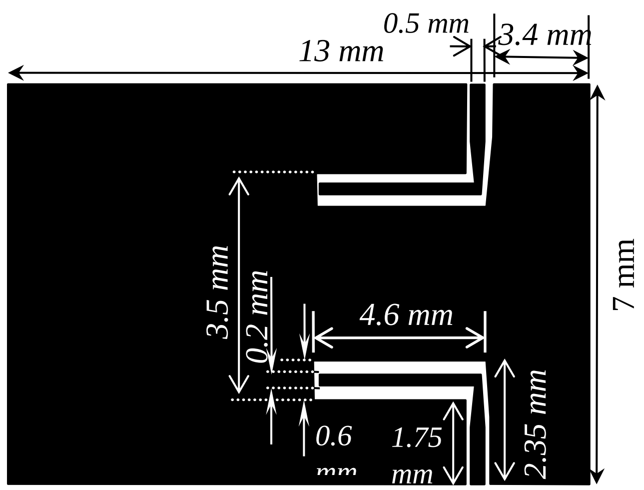


Fig. 5 Variation of the effective permeability of the SRR

Fig. 5 shows a positive value of the imaginary part of the effective permeability along the frequency range [0 – 20] GHz. The real part of this permeability is also represented, it is positive on the same frequency range, except in a narrow band around the magnetic resonance [11.5 – 12.2] GHz. Outside this band, the real part of the permeability is varied from 0 to 2.35.

B. Characterization of the global filter in DGS technology

The geometric parameters of the global filter are determined relative to the dimensions of the circular spiral SRR previously studied to have a good electromagnetic coupling. The coplanar lines of the two ports are determined to have a 50 Ω matching. The portions of the top face of our structure are as follows.



(a)

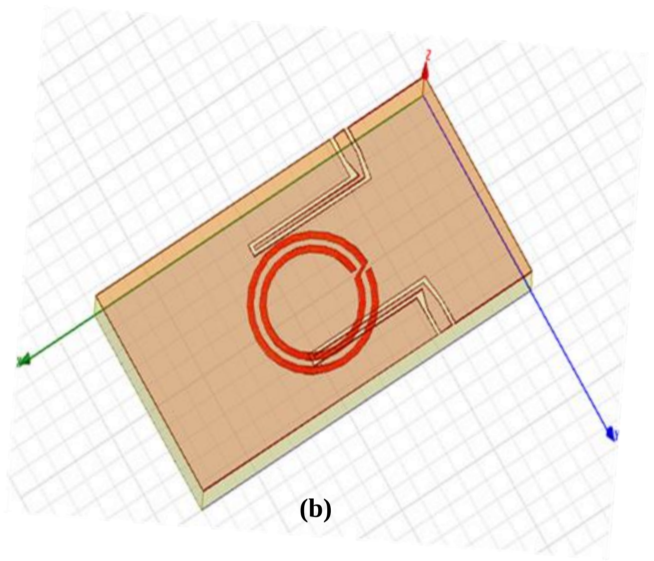


Fig.6 Overall filter (a) portions (b) top view

The simulation of this structure under HFSS for which all the conditions are applied allows us to obtain the following two transmission and reflection coefficients.

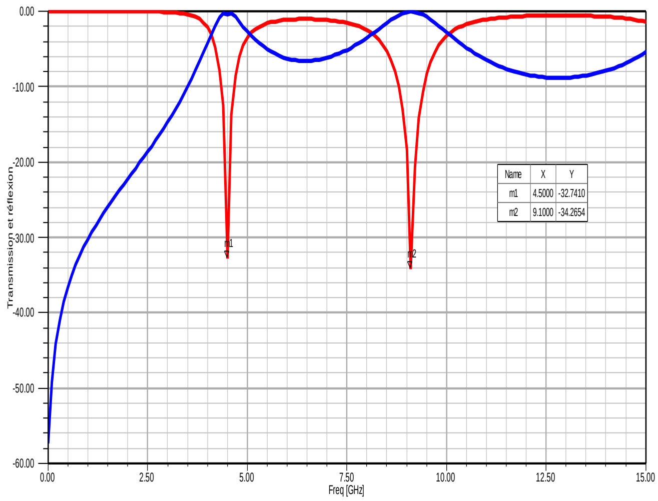


Fig. 7 Transmission and reflection of the proposed DBBPF.

Fig. 7 shows in the range [0-15] GHz a band-pass behavior of our filter. The filter resonates at 4.5 and 9.1 GHz, these resonances due to electromagnetic coupling which justifies the effect of our complementary spiral resonator engraved in the ground plane. We notice that the central frequencies of our filter are modest, which justifies the advantage of miniaturizations offered by the metamaterial resonator.

IV. CONCLUSION

A new band-pass filter structure is proposed in this work. The DGS technology has allowed us to improve the qualities of the proposed filter. A new band-pass filter structure is proposed in this work, the use of “DGS” technology has allowed us to improve the qualities of the filter to be studied. Our bandpass behavior filter is achieved by etching a spiral metamaterial resonator in the ground plane, so we designed slotted-transmission lines using lower plane demetallization, which allows us to control an electromagnetic coupling between two different planes of the substrate. The obtained results show that the proposed DBBPF is a good candidate for wireless communication applications.

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