Stop-Band Filter using A New Metamaterial Complementary Split Triangle Resonators (CSTRs)

M. A. Abaga Abessolo, Y. Diallo, A. Jaoujal, A. El Moussaoui, and N. Aknin

Information and Telecommunication Systems Laboratory (LaSIT)
Faculty of Sciences, Abdelmalek Essaadi University, Tetuan, Morocco
Michelabaga1@yahoo.fr, aknin@ieee.org

Abstract **—** In this paper, a compact stop-band microstrip filter based on a new complementary split triangle resonator (CSTRs) is presented. We first describe the structure of the resonator and present its characteristics, which are essentially a simultaneous negative-ε and negative-μ. Then, we apply the complementary of this structure on a microstrip device. The result gives stop-band filter with high rejection band around the resonance frequency of the CSTRs (3.2GHz). The substrate used is the FR4.

Index Terms **—** Metamaterial, split triangle resonators, and stop-band filter.

I. INTRODUCTION

Recently, there has been an extensive research effort within the electromagnetic community to develop and use novel metamaterials. Among these materials electromagnetic bandgap (EBG) structures, a simultaneous negative μ and ε with left-handed (LH) media have received much attention in the microwave and millimeter wave community [1-6]. Split ring resonators (SRRs) proposed by Pendry et al. [1] attracted much attention as a canonical metamaterial structure that gives rise to an effective magnetic response without the need for magnetic materials. SRRs have been successfully applied to the fabrication of LHM. Since then, there have been large numbers of experimental investigations on the observation of this phenomenon. However, there are still some drawbacks such as high losses and limited bandwidth and anisotropic property preventing its further development. These issues prompted researchers to explore new designs such as omega pattern [2-4], S-type [5] or triangular split ring resonator and wire strip [6].

It is well known that the complementary of a planar metallic structure is obtained by replacing the metal parts of the original structure with apertures, and the apertures with metal plates [7]. Due to symmetry considerations, it can be demonstrated that if the thickness of the metal plate is zero, and its conductivity is infinity (perfect electric conductor), then the apertures behave as perfect magnetic conductors. In that case the original structure and its complementary are effectively dual and if the field $F = (E, H)$ is a solution for the original structure, its dual F' defined by,

$$F' = \left(E', H'\right) = \left(-\sqrt{\frac{\mu}{\varepsilon}}.H, \sqrt{\frac{\varepsilon}{\mu}}.E\right) \tag{1}$$

is the solution for the complementary structure (rigorously speaking is the solution on one side of the plane, and on the other side, due to the lack of magnetic charges in the apertures) [8]. Many researchers proposed microwave structures based on split ring resonator and complementary split ring resonator with metamaterial properties [9-12].

In this paper, a microstrip filter based on a new metamaterial particle named split triangle resonator (STR) with simultaneous negative permittivity and permeability, which are essentials characteristics of metamaterial structures [13]. Then, we use complementary split triangle resonator (CSTRs) to design a band-stop filter in microstrip technology. The CSTRs will be implemented in microstrip technology by etching the triangle particles in the ground plane, just underneath the conductor strip. This position of CSTR is properly excited, this time by an electric field polarized in the axial direction of the triangle particle. In contrast to the usual $\lambda_g / 2$ transmission line resonators, CSTRs are sub-lambda structures,

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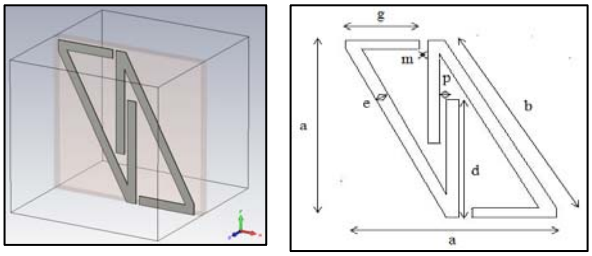
i.e., their dimensions are electrically small at the resonant frequency (typically one tenth of the guided wavelength or less). Therefore, high level of miniaturization is expected by using these particles.

II. RESONATOR DESIGN AND SIMULATION STUDY

The split triangle resonator (STRs) is formed by two coupled conducting triangles printed on a dielectric slab. Assuming a particle size much smaller than the free space wavelength, the STR's essentially behaves as a quasistatic RLC circuit fed by the external magnetic flux linked by the particle. Figure 1 (a) shows the cubic unit cell of the proposed structure, composed by a 0.5 mm thick substrate of FR4 (ε_r = 4.4, loss tangent of 0.02) and a copper STR positioned on the top side of the substrate. The cubic cell dimension is a = 15.4 mm. Figure 1 (b) presents the planar view of the top side of the unit with dimensions a = 15.4 mm, b = 16 mm, g = 6 mm, d = 10 mm, e = 0.4 mm, P = 0.6 mm, and m = 1 mm. S-parameters were determined via full-wave simulations. Effective medium parameters (ε, μ) were determined using the standard transfer matrix method [14, 15].



(a) (b)

Fig. 1. Split triangle resonators (STRs), (a) perspective view of the unit cell and (b) planar view of the unit cell.

Figure 2 presents the amplitude of the calculated S-parameters for the metamaterial structure, it can be seen that S_{11} is equal to S_{22}, and S_{12} is equal to S_{21}, since the structure is symmetric and indeed roughly matched at 3.5 GHz. Accordingly, using the standard retrieval method [14], the results for an effective refractive index, effective permittivity, and permeability are presented.

As shown in Fig. 3, the range of the simultaneous negative permittivity and permeability starts from 3.2 GHz to 3.75 GHz. Moreover, Fig. 4 confirms the negative index of the split triangle resonator.

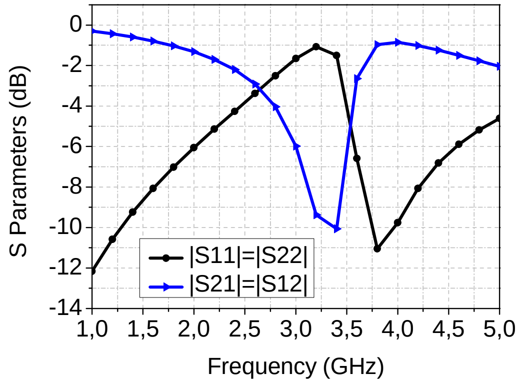


Fig. 2. S-parameters.

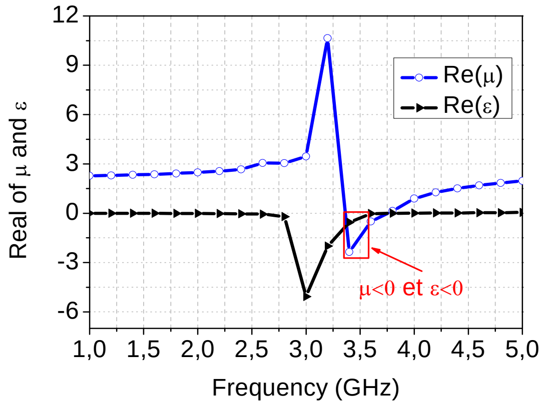


Fig. 3. Real permeability and permittivity.

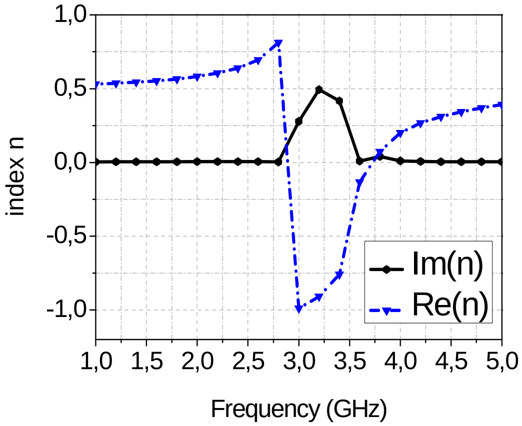


Fig. 4. Index of unit split triangle resonator.

III. STOP-BAND MICROSTRIP FILTER DESIGN BY ETCHING CSTRs ON THE GROUND PLANE

A. Filter description

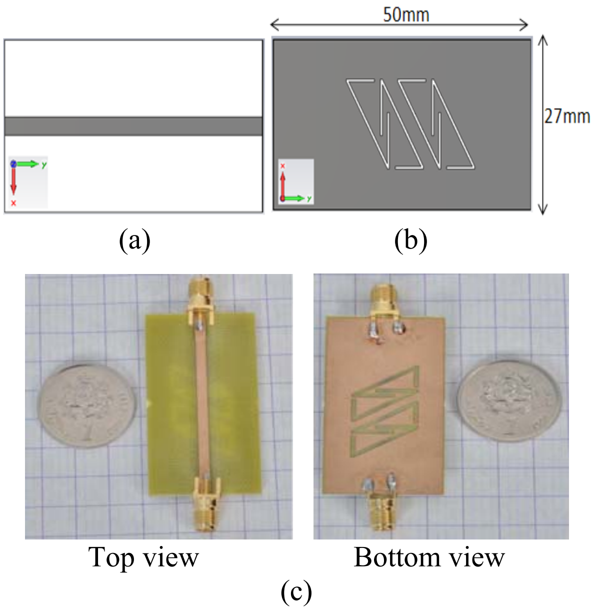
Usually, in the microstrip technology, complementary split ring resonators are achieved by periodically etching capacitive gaps in the ground plane underneath the 50 Ω microstrip line [16-19]. Since ours CSTRs are excited by the electric field, they produce negative effective permittivity $\mathrm{Re}(\varepsilon_{\mathrm{eff}}) < 0$ and negative effective permeability $\mathrm{Re}(\mu_{\mathrm{eff}}) < 0$.

Thus, a time varying electric field having a strong component in the axial direction gives rise to ε and μ effective medium. Considering this fact in mind, the working mechanism of the CSTRs based stop-band filter can be explained as follows: a microstrip transmission line induces electric field lines that originate from the central strip and terminate perpendicularly on the ground plane. Due to the presence of dielectric substrate, field lines are tightly concentrated just beneath the central conductor and the electric flux density reaches its strongest value in the vicinity of this region. Therefore, if CSTRs is etched on the ground plane aligned with the strip, a strong electric coupling with the desired polarization is expected.

Figure 5 (a) (top view) and Fig. 5 (b) (bottom view) show the geometry of the CSTRs loaded microstrip on an FR4 substrate of $\varepsilon_r = 4.4$, $\tan\delta = 0.02$, and thickness = 1.5 mm. All dimensions of the CSTRs have been selected identical to their STR counterparts (Fig. 1 (b)) so that the operating frequency of the filter is also around 3.25 GHz. Figure 5 (c) presents photograph of the fabricated prototype using Protomat S100.

B. Simulation and experimental results

The proposed filter has been simulated and measured. Figures 6 (a), 6 (b), and 6 (c) show the simulated frequency response (S_{11} and S_{21}) of the proposed filter with various numbers of CSTRs. In all cases, a deep rejection band is obtained around the design frequency. It is oblivious that the rejection characteristic depends on the number of SRRs used. The best rejection is found using two CSTRs.

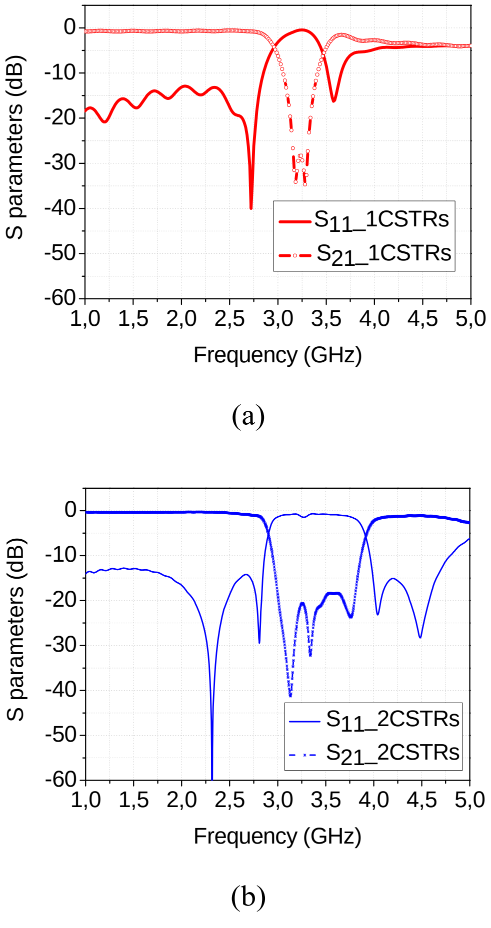


(a) (b)

Top view Bottom view

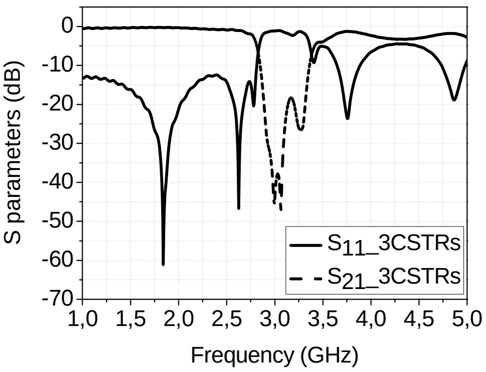
(c)

Fig. 5. (a) Top view of microstrip stop-band filter with CSTRs etched into the ground plane, (b) bottom view of proposed filter, and (c) photograph of the fabricated prototype.



(a)

(b)



(c)

Fig. 6. Results of the stop-band filter with CSTRs on the ground plane, (a) S_{11} and S_{21} of the proposed microstrip filter with 1 CSTRs, (b) S_{11} and S_{21} of the proposed microstrip filter with 2 CSTRs, and (c) S_{11} and S_{21} of the proposed microstrip filter with 3 CSTRs.

We present simulation result of all S-parameters in Fig. 7. We observe a symmetric characteristic of the proposed filter. The comparison results are shown in Fig. 8. Very good agreement is obtained between simulated and measured results. The small discrepancies can be attributed to fabrication tolerances and to the dissipative losses not taken into account in the simulation. A deep rejection band is obtained around 3.25 GHz, with sharp cutoffs, maximum rejection of 30 dB, and low return losses.

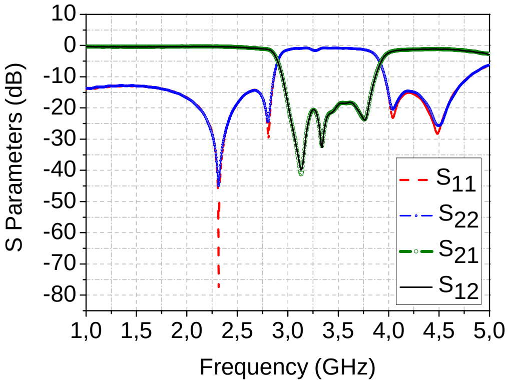


Fig. 7. Simulated S-parameters of the proposed filter (S_{11}, S_{22}, S_{21}, and S_{12}).

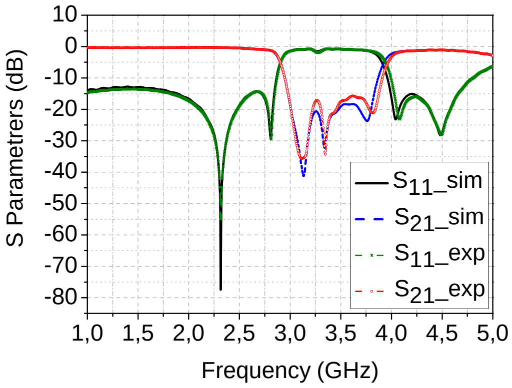


Fig. 8. Comparison of measured and simulated S-parameters (S_{11} and S_{21}) for the proposed stop-band filter in microstrip technology based on complementary STRs.

IV. CONCLUSION

In this paper, a new metamaterial resonator (STRs) with simultaneous negative-ε and negative-μ is presented and applied on microstrip stop-band filter. The compact stop-band microstrip filter based on CSTRs has been proposed and successfully tested. The measured result shows a good agreement with experimental measurement and simulation. We observed that the proposed device is very compact and produces very high rejection band around the resonance frequency of CSTRs.

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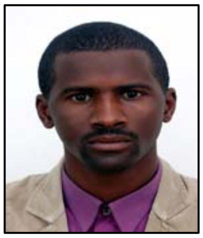
Michel Audrey Abaga Abessolo was born in Oyem, Gabon, in January 1981. He received the License of Sciences in physics and the DESA degree in Information and Telecommunication Systems from the Abdelmalek Essaadi University, Tetuan, Morocco, respectively, in 2005 and 2007. In 2012, he received the PhD degree in Electrical Engineering from Abdelmalek Essaadi University in Tetouan, Morocco. His current interest includes microwave antennas, filters based on enhanced transmission phenomena, and metamaterials. He has been a Professor of physics in Omar Bongo University, Libreville, Gabon since December 2012.



Diallo Yaccoub Mohamed Hamidne was born in Monguel, Mauritania, in 1982. He received B.Sc. degree in Physics-Chemistry from Nouakchott University, Mauritania, and M.Sc. degree in Electronics and Telecommunications from the Abdelmalek Essaadi University, Tetuan, Morocco, respectively in 2007 and 2009. He is currently working toward the Ph.D. degree at the Abdelmalek Essaadi University. His current interest includes electronic engineering for wireless systems.

A. El Moussaoui received the PhD degree in Electronics at the University of Bradford in 1990. In 2007 he received the international Master in E-learning in the Curt Bosh institute in Switzerland. He has been a member of the organizing and the scientific committees of several symposia and conferences dealing with RF, mobile networks and information technologies. He has participated in several projects with France and Spain. His research interests are: electronic engineering, third generation mobile system, radio network planning and optimization. Currently, he is the vice president of Abdelmalek Essaidi University in Tetuan Morocco.

Noura Aknin received the License in Physics and the PhD degree in Electrical Engineering, respectively, in 1988 and 1998 from Abdelmalek Essaadi University in Tetouan, Morocco. She is a Professor of Telecommunications and Computer Engineering in Abdelmalek Essaadi University since 2000. She is the co-founder of the IEEE Morocco Section since November 2004 and she is the Women in Engineering Coordinator. She has been a member of the organizing and the scientific committees of several symposia and conferences dealing with RF, mobile networks, and social web and information technologies. She is a member of the IEEE communications society and computer society. Her research interests focus mainly on Wireless and mobile communication systems, radio network planning and optimization. Moreover, she is the project manager for research and development project related to mobile networks funded by the national telecommunications company “Maroc Telecom”.