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

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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,

\[
F' = (E', H') = \left( -\frac{\mu}{\varepsilon} H, \sqrt{\frac{\mu}{\varepsilon}} E \right)
\]

(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,
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 ($\varepsilon_r = 4.4$, 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 ($\varepsilon$, $\mu$) were determined using the standard transfer matrix method [14, 15].

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

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 \( \Omega \) microstrip line [16-19]. Since ours CSTRs are excited by the electric field, they produce negative effective permittivity \( \text{Re}(\varepsilon_{\text{eff}}) < 0 \) and negative effective permeability \( \text{Re}(\mu_{\text{eff}}) < 0 \).

Thus, a time varying electric field having a strong component in the axial direction gives rise to \( \varepsilon \) and \( \mu \) 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.
Fig. 7. Simulated S-parameters of the proposed filter ($S_{11}$, $S_{22}$, $S_{21}$, and $S_{12}$).

(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 CSTR, (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. 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-$\varepsilon$ and negative-$\mu$ 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.

REFERENCES


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