On the Orientation of Complementary Split-Ring Resonators in Left-Handed Microstrip Lines

Vasa Radonić[1], Vesna Crnojević-Benigin[1] and Branka Jokanović[2]

Abstract – **Split ring resonators (SRR) and complementary split ring resonators (CSRR) are used in left-handed media to obtain negative values of permeability and permittivity, respectively. It is well known that the orientation of SRR positioned next to the microstrip transmission line, significantly influences its performances. However, it is generally accepted that such dependence does not exist in the case of CSRR. In this paper, influence of the orientation of CSRR is analyzed in detail, especially for the case of multiple CSRR geometries. To validate simulation results, left-handed microstrip lines with multiple CSRR are designed, fabricated and measured.**

Keywords – **Metamaterials, Left-handed lines, Complementary split ring resonators.**

I. Introduction

Metamaterials have recently attracted considerable attention because of their unusual magnetic and electric properties, generally not found in nature. Metamaterials are artificial structures designed using unit cells with sub-wavelength dimensions, called particles, that exhibit extreme values of effective permittivity and permeability. A special sub-class of metamaterials are so celled left-handed (LH) metamaterials, that simultaneously exhibit negative values of effective constitutive parameters.

The first particle that exhibits negative permittivity by decreasing the plasmon frequency into microwave range was proposed in mid nineties, [1]. Shortly afterwards, a particle called split-ring resonator (SRR) was introduced, that provides negative permeability at microwave frequencies, [2]. By combining these two structures, the existence of LH metamaterials was experimentally proved in 2001, [3]. In the years to follow, the configurations using SRRs have attracted a lot of attention, [4], [5].

In the microstrip technology, SRRs can only be etched on the upper substrate side, next to the transmission line. Such structure is a single-negative material, that exhibits only negative effective permeability. Using the Babinet principle, a complementary structure was proposed in [6], namely the complementary split-ring resonator (CSRR). CSRRs are etched in the ground plane, beneath the microstrip, thus contributing to the negative effective dielectric permittivity of the structure. In order to obtain LH behavior, effective negative permeability has to be introduced to the structure. This is achieved by periodically etching capacitive gaps in the microstip line.

One of the goals in the development of metamateraials is further miniaturization of the unit cells. With this aim, multiple CSRRs have recently been introduced in [7]. However, it has been noticed that in the case of multiple CSRRs, the orientation of the particles plays an important role. In this paper, influence of the orientation of CSRR is analyzed in detail for the case of multiple CSRR geometries. Three different orientations of CSRR are analyzed. To validate simulation results, LH microstrip lines with multiple CSRR are designed, fabricated and measured.

II. Configuration

In this paper, square CSRRs are used, shown in Fig. 1, where a, d, w and g denote dimensions of its segments. The outer dimensions of a CSRR are equal to 5x5mm, i.e. $\lambda/16x\lambda/16$ on a given substrate. To reduce resonant frequency of the particle, all dimensions are chosen to be the minimal available in standard PCB technology, i.e. $w=g=d=$ 100μm.

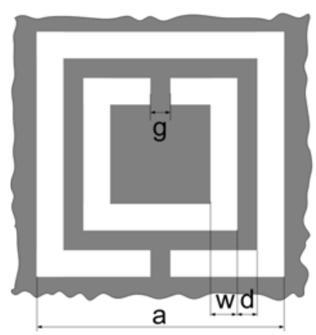

Fig 1. Configuration of the CSRR (gray colour depicts metal)

In order to achieve high magnetic coupling between the line and the ring at resonance, CSRR are etched in the ground layer under the gaps. In Fig 2. LH microstrip line with three unit cells is shown, with CSRRs that have slots positioned along the microstirp. The line is realized on a 1.27mm Taconic CER-10 substrate, having εr=9.8 and dielectric loss tangent equal to 0.0025. Conductor losses are modelled using bulk conductivity for copper. The proposed line can be characterized as a narrow band pass filter.

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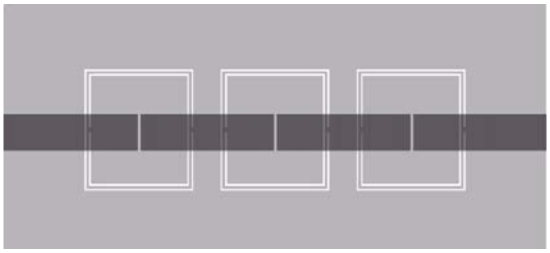
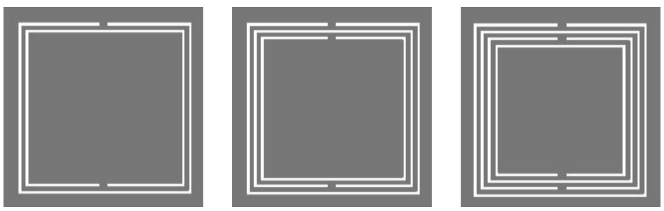


Fig 2. LH line with three unit cells: top (dark grey) and bottom (light grey) conductive layers are shown.

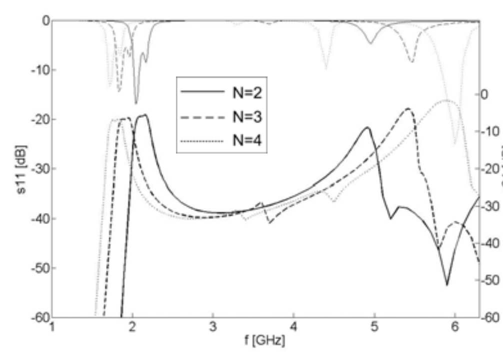
In order to reduce resonant frequency of the particle, i.e. decrease size of the unit cell, multiple CSRR configurations with two, three and four concentric rings can be used, shown in Fig. 3.



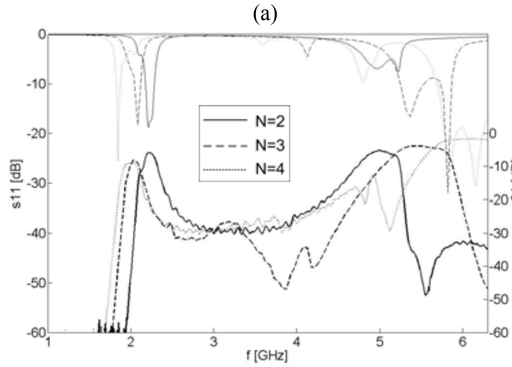
(a) (b) (c)

Fig 3. Multiple CSRR geometries with: (a) two rings, (b) three rings, (c) four rings

Simulation and measurement results for LH lines that use multiple CSRRs with splits positioned along the microstrip are shown in Fig. 4, reprinted from [7].



(a)



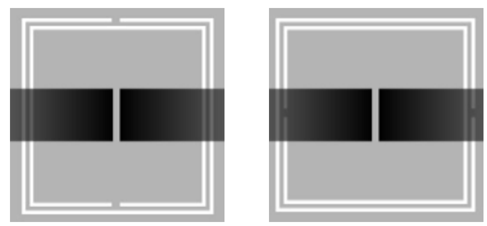
(b)

Fig 4. (a) Simulation and (b) measurement results for LH lines that use multiple CSRRs with splits positioned along the microstrip, where *N* denotes number of concentric rings.

It can be seen that the frequency corresponding to the maximum of the transmission coefficient differs from the value corresponding to the minimum of the reflection coefficient, especially in the case of higher values of *N*. This is even more visible in the measured data. Additional simulations have shown that this discrepancy can not be explained by inaccuracy of the fabrication process, where the top and the bottom conductive layers were not ideally aligned. Moreover, LH lines of this type show great robustness to such misalignments.

III. RESULTS

In this paper, two different orientations of CSRR in respect to the microstrip are analyzed: Orientation 1, where splits are positioned in the direction perpendicular to the host microstrip line, and Orientation 2 where splits are positioned along the microstrip, depicted in Fig 5.



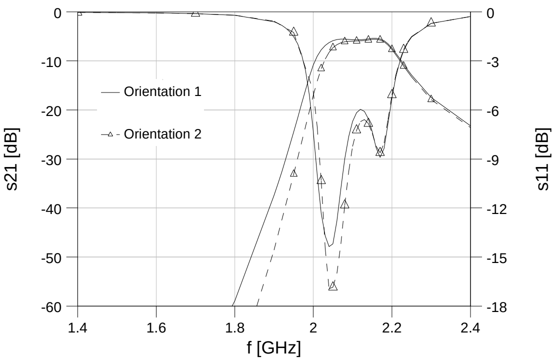
(a) (b)

Fig 5. Different orientations of CSRRs:
(a) Orientation 1, (b) Orientation 2.

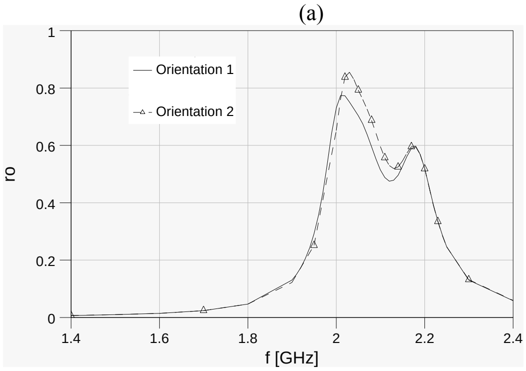
Performances of all structures were determined using EMSight, EM simulator in Microwave Office. Responses of the proposed LH lines with two different orientations of multiple CSRRs, are shown in Fig. 6. to 8, for different number of concentric rings *N*. In the same figures, radiation is depicted as well, defined as:

$$ro = 1 - s_{11}^2 - s_{21}^2 \quad (1)$$

It can be seen that the orientation of the slots influences the transmission coefficients in the terms of the pass band bandwidth, while the central frequency of the pass band remains almost unchanged. However, the more significant influence is observed in the reflection coefficients, and hence in the radiation curves. LH lines that use CSRRs with splits positioned in direction perpendicular to the transmission line (Orientation 1) exhibit no (or smaller) shift in frequency between the maximum of the transmission coefficient and the minimum of the reflection coefficient. Therefore, radiation in the case of LH lines with Orientation 1 is decreased. LH lines that use CSRRs with Orientation 2 (splits along the microstrip) suffer from increased radiation, due to the fact that they are non symmetrical structures.

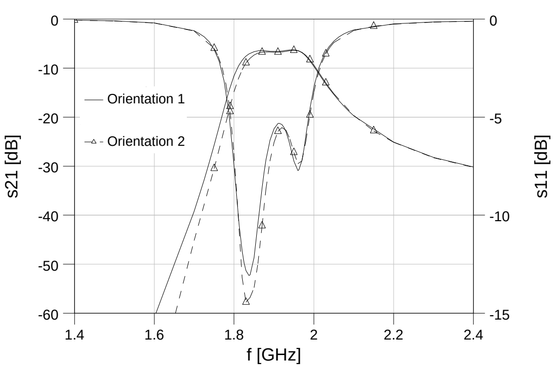


(a)



(b)

Fig 6. Simulation results for LH lines that use CSRR with *N*=2 concentric rings, for different orientations of splits: (a) s_{11} and s_{21} coefficients, (b) radiation.



(a)

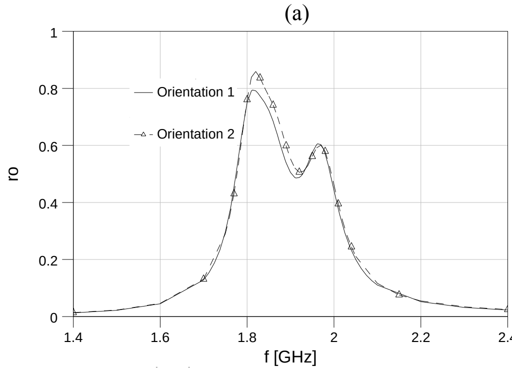


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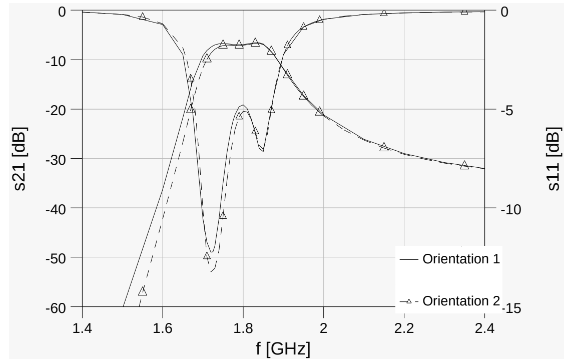
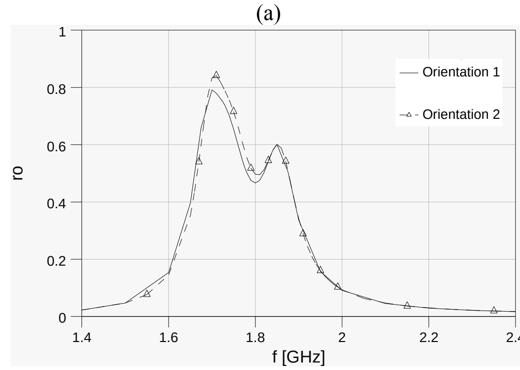
Fig 7. Simulation results for LH lines that use CSRR with *N*=3 concentric rings, for different orientations of splits: (a) s_{11} and s_{21} coefficients, (b) radiation.



(a)



(b)

Fig 8. Simulation results for LH lines that use CSRR with *N*=4 concentric rings, for different orientations of splits: (a) s_{11} and s_{21} coefficients, (b) radiation.

IV. CONCLUSION

It is well known that the orientation of SRR positioned next to the microstrip transmission line, significantly influences its performances. However, it is generally accepted in the scientific community that such dependence does not exist in the case of CSRR. In this paper, influence of the orientation of CSRR was analyzed in detail, especially for the case of multiple CSRR geometries. It has been shown that a significant influence of the orientation of the splits in the CSRRs does exist. In the case of splits positioned along the microstirp, the whole structure becomes unsymmetrical, and therefore exhibits a frequency shift between the maximum of the transmission coefficient and the minimum of the reflection coefficient, which results in the increased unwanted radiation. Therefore, in the design of resonant-type LH microstrip lines, CSRRs with splits positioned in the direction perpendicular to the host transmission line should always be used.

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