# INVESTIGATION OF EFFECTIVE PERMITTIVITY AND PERMEABILITY FOR A NOVEL V-SHAPED METAMATERIAL USING SIMULATED S-PARAMETERS

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## ABSTRACT

**In this paper, it is demonstrated that a structure which consists of V-shaped anti-parallel conducting strips over both faces of a substrate can be used as a magnetic resonator to achieve effective negative permeability. The simulations for this metamaterial have been done using Ansoft HFSS software to obtain the transmission characteristics and the location of the resonant frequency. Furthermore, material parameters such as effective permeability (μ) and effective permittivity (ε) have been extracted from simulated S-parameters.**

## I. INTRODUCTION

In 1968, Veselago proposed that materials with negative permittivity ($\varepsilon<0$) and permeability ($\mu<0$) had some different properties as compared to ordinary materials with positive permittivity and permeability, such as negative refractive index, negative group velocity, and negative Vavilov–Cerenkov effect [1]. After a long time, in 2000, Pendry suggested that left-handed material lenses might offer sub-wavelength resolution and perfect lens phenomena could be achievable [2]. After 2000, studies on left-handed materials became popular and in 2001 Shelby *et al.* demonstrated negative refraction at microwave frequencies using a volume distribution of a composite medium with split ring resonators (SRRs) and wires [3, 4]. They used periodic arrays of SRRs to achieve negative permeability and periodic arrays of wires to achieve negative permittivity [5, 6].

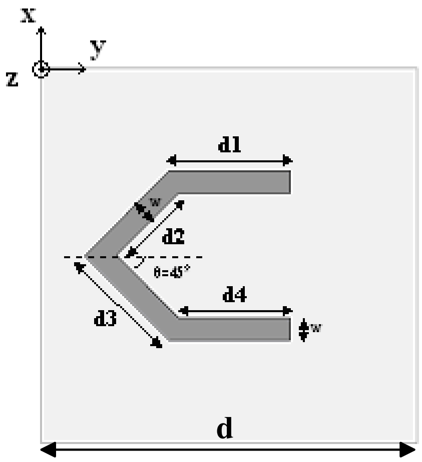
In this study, a novel V-shaped magnetic resonator structure consisting of conducting strips over both faces of a substrate has been proposed. Ansoft's HFSS software, which uses finite integration technique, has been used for S-parameter simulations. By applying time varying electromagnetic field, the S-parameters of the unit cell of this structure and the location of the resulting resonant frequency have been determined. By using simulated S-parameters, complex permittivity and complex permeability of the unit cell has been extracted over the excitation frequency band [7]. The results are all in good agreement with our expectations of obtaining negative effective permeability and thus we can propose that, this V-Shaped structure may be an alternative to the SRR structure.

## II. DESIGN AND SIMULATION

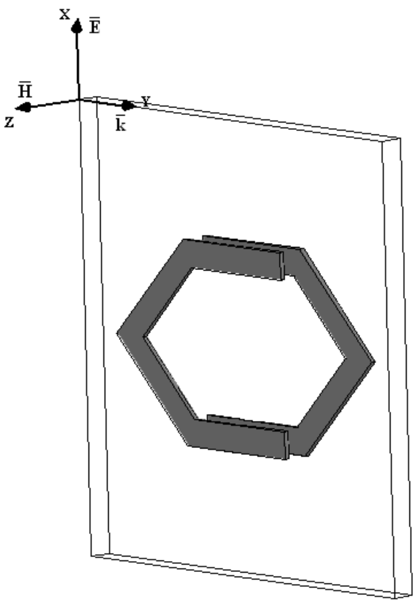
The structure proposed in this study is shown in Figure 1. It is constructed of anti-parallel V-shaped copper strips over both faces of a dielectric substrate with $\varepsilon_r$=3.84 and $\tan\delta_\varepsilon$=0.018. The thickness of the dielectric substrate is 0.25 mm. The top view and the dimensions of the unit cell are given in Figure 1(a). Also, in Figure 1(b) the side view of the unit cell is shown for better understanding. The total dimension of the conducting strips along the x direction is 2.26274 mm, and along the y direction is 3.84852 mm. Substrate dimensions are 5 mm × 5 mm × 2.5 mm.

In the simulation setup, the unit cell is surrounded with an air medium and excited with a time varying electromagnetic field. Directions of the vector fields are given in Figure 1(b) such that the electric field intensity vector is directed along the x axis, the magnetic field intensity vector is directed along the z axis, and the propagation vector is along the y axis. Perfect electric conductor (PEC) boundary conditions are applied along the boundaries perpendicular to z axis and perfect magnetic conductor (PMC) boundary conditions are applied along the boundaries perpendicular to the x axis. Open boundary conditions are applied to the remaining two boundaries [8]. Simulation is performed over the frequency band from 4 to 11.5 GHz with 0.05 GHz incremental steps.

Effective medium parameters, permittivity and permeability, can be extracted from S-parameters following the procedure summarized below [7].




(a)




(b)

Figure 1: V-shaped magnetic resonator. (a) Top view. Unit cell dimensions: d=5 mm, d1=1.6 mm, d2=1.17573 mm, d3=1.6 mm, d4=1.47574 mm, w=0.3 mm and θ=45°. (b) Side view with transparent substrate.

$$S_{11} = \frac{\Gamma(1-T^2)}{1-\Gamma^2 T^2} \quad (1)$$

$$S_{21} = \frac{T(1-\Gamma^2)}{1-\Gamma^2 T^2} \quad (2)$$

where

$$\Gamma = \frac{(Z_{sn}-1)}{(Z_{sn}+1)} \quad (3)$$

$$T = e^{-\gamma d} \quad (4)$$

In (3) and (4), $d$ is the total length of the unit cell along the propagation direction, $Z_{sn}$ and $\gamma$ are the normalized characteristic impedance and the propagation constant of the sample under test, respectively. They can be related to $\mu^*$ and $\varepsilon^*$ as follows:

$$\gamma = \gamma_0 \sqrt{\varepsilon^* \mu^*} \quad (5)$$

$$Z_{sn} = \sqrt{\frac{\mu^*}{\varepsilon^*}} \quad (6)$$

where $\gamma_0 = (j2\pi/\lambda_0)$ is the propagation constant of the free space, $\lambda_0$ is the free-space wavelength, and the symbol " * " denotes the complex conjugate. With the help of (1) and (2), $\Gamma$ and $T$ can be represented in terms of S parameters as follows:

$$\Gamma = K \pm \sqrt{K^2 - 1} \quad (7)$$

where

$$K = \frac{S_{11}^2 - S_{21}^2 + 1}{2S_{11}} \quad (8)$$

$$T = \left(\frac{S_{11} + S_{21} - \Gamma}{1-(S_{11}+S_{21})\Gamma}\right) \quad (9)$$

In (7), there is an ambiguity with the plus or minus sign. The sign is chosen such that $|\Gamma| < 1$. From (4), we can extract the complex propagation constant as

$$\gamma = [\ln(1/T)]/d \quad (10)$$

From (3) and (6)

$$\sqrt{\frac{\mu^*}{\varepsilon^*}} = \left(\frac{1+\Gamma}{1-\Gamma}\right) \quad (11)$$

From (5) and (11), we obtain

$$\varepsilon^* = \frac{\gamma}{\gamma_0}\left(\frac{1-\Gamma}{1+\Gamma}\right) \quad (12)$$

$$\mu^* = \frac{\gamma}{\gamma_0}\left(\frac{1+\Gamma}{1-\Gamma}\right) \tag{13}$$

As the parameter $T$ in (10) is a complex number, $\gamma$ may assume multiple values. If we define $T$ as

$$T = |T|e^{j\phi} \tag{14}$$

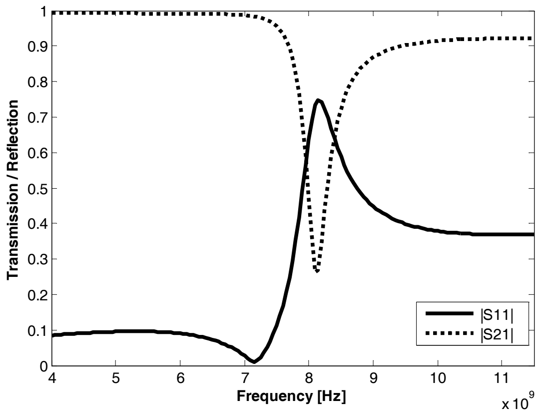
then, $\gamma$ is given by

$$\gamma = \left[\ln(1/|T|)\right]/d + j\left[\frac{2\pi n - \phi}{d}\right]$$

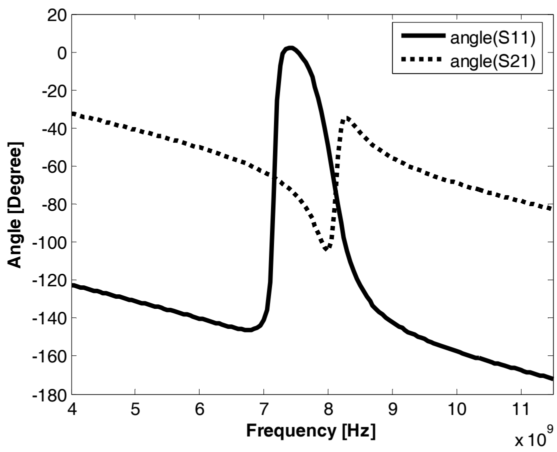
where $n = 0, \pm 1, \pm 2, ...$

## III. RESULTS AND DISCUSSION

Transmission and reflection characteristics of the V-shaped resonator were observed using simulated $S_{21}$ and $S_{11}$ parameters, respectively. These results are given in Figure 2. It can be seen in Figure 2(a) that there is a transmission minimum and a reflection maximum at 8.10 GHz. This also indicates the location of the resonant frequency of the proposed resonator.




(a)




(b)

Figure 2: Simulated S parameters. (a) Magnitude of $S_{11}$ and $S_{21}$. (b) Angle of $S_{11}$ and $S_{21}$

Complex permittivity and permeability of the medium were extracted from S-parameters with the procedure given in part II. Figure 3 shows the real and imaginary parts of the effective permittivity from 4 to 11.5 GHz. We observe that real part of the effective permittivity is always positive within the given frequency band, but there is a fluctuation around the resonant frequency. Figure 4 shows the real and imaginary parts of effective the permeability from 4 to 11.5 GHz. In this case, the real part of the permeability becomes negative over a sub-bandwidth from 8.05 to 8.50 GHz. Imaginary parts of effective permittivity and permeability are related to the loss effect.

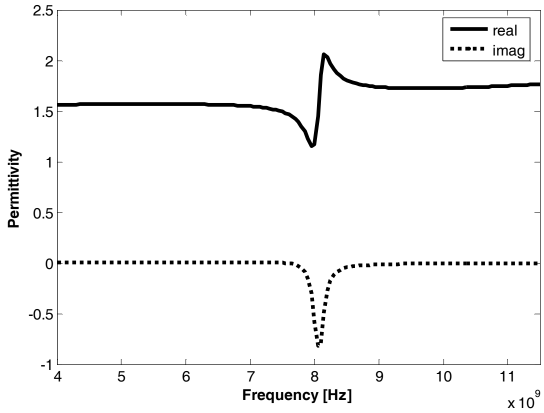



Figure 3: Real and imaginary part of effective permittivity.

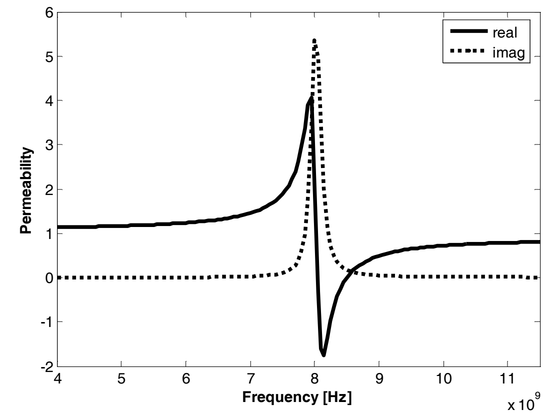



Figure 4: Real and imaginary part of effective permeability

## IV. CONCLUSION

This study shows that the proposed V-shaped magnetic resonator can be used to obtain negative permeability over a frequency band of about 450 MHz. Therefore, if someone construct a composite medium with an array of this V-shaped structure implementing also an array of conducting wires, it will be possible to obtain both negative permittivity and negative permeability over the same frequency band. That means, it will be possible to obtain a left-handed material with this newly proposed V-shaped resonator.

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