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Transmission measurements of a new metamaterial sample with negative refraction index

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ABSTRACT

We presented the microwave experiments with a new metamaterial composed of triangular split ring resonators (TSRRs) and wire strip at microwave regime. The transmission measurements were performed in free space for two LHM samples which have different number of TSRRs and wire strips. The experimental results show that the left-handed transmission peak stands in the frequency band where both the permittivity and permeability are negative. It is also observed that left-handed transmission band can be shifted if the number of TSRRs and wire strips are changed.
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1. Introduction

Metamaterials with negative refractive index were firstly introduced by Veselago in 1967 and their electromagnetic properties and unexpected phenomena were discussed in his study [1]. After that, Pendry and coworkers presented a thin-wire-array to obtain negative permittivity and another array composed of split ring resonators to obtain negative permeability over a band of frequencies [2,3]. In 2001, Smith et al. demonstrated a microwave experiment to observe the negative refraction using a composite medium with split ring resonators and wires [4]. The first experiment showing negative refraction was performed using a metamaterial consisting of a two-dimensional array of repeated unit cells of copper strips and split ring resonators in 2001 by Shelby et al. [5]. Later on, many researchers have extensively used various resonators and wires combinations to design and achieve original metamaterials [6–13]. In addition, the design of novel metamaterials with negative refraction index based on shape and geometry is a very interesting work among the others [14–23]. In this sense, novel metamaterials with negative refraction index were designed and manufactured using the combination of triangular split ring resonators (TSRRs) and wire strips by Sabah in 2008 [24]. Additionally, the unit cell of this combination is studied by Sabah and Uckun using simulated *S* parameters and retrieved effective material parameters [25]. In the last two studies, it is shown that the designed new metamaterials exhibit double negative properties in the frequency region of interest and it can be applicable to various potential applications. Thus, we manufactured metamaterial samples with the use of TSRRs and wire strip inclusions on FR4 substrate and performed transmission experiments with the manufactured sample at Bilkent University. Basically, this paper deals with this experimental work and its results. The experimental work covers the transmission spectra of the metamaterial samples in free space to observe the characteristic properties of this new structure. It is found that the left-handed peak for the transmission measurement stands in the frequency region where the manufactured metamaterial shows a negative refraction property. The results obtained are in good agreement with our expectations and in good accord with Refs. [24,25]. Thus, we can suggest that the proposed new metamaterial may become an alternative of the other types of metamaterials and they can be used in several RF devices.

2. Transmission experiments

The transmission spectra of the manufactured novel metamaterial samples are performed in free space by using an Agilent Technology N5230A network analyzer. The schematic representation of the first sample is given in Fig. 1. This structure has 16 copper TSRRs located on one face of FR4 substrate and a copper wire strip situated on the opposite face of the substrate. The sample is designed and simulated using the commercial software package, ANSOFT's High Frequency Structure Simulator (HFSS), to investigate the left-handed characteristics of the structure. The thicknesses of the FR4 substrate and copper inclusions are 1.0 and

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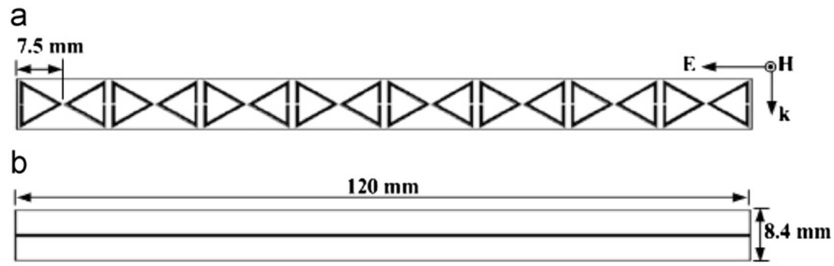

Fig. 1. Schematic drawing of the new metamaterial: (a) front view, (b) back view.

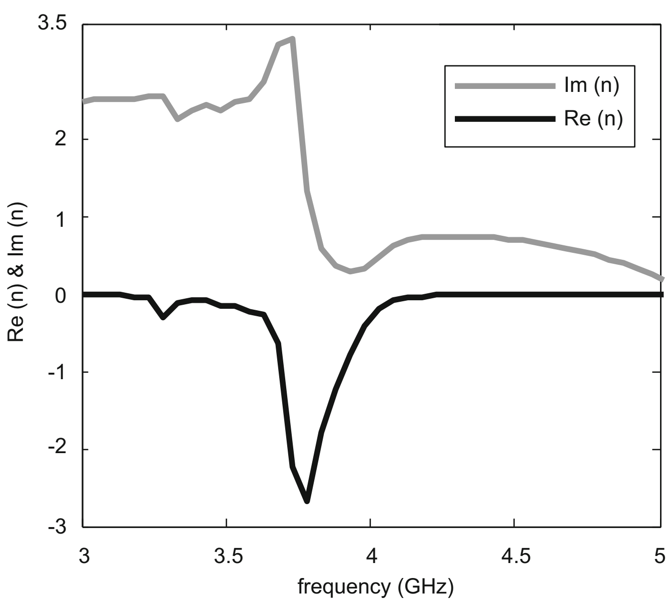

Fig. 2. Simulated refractive index of the metamaterial sample comprising 16 resonators and a wire strip.

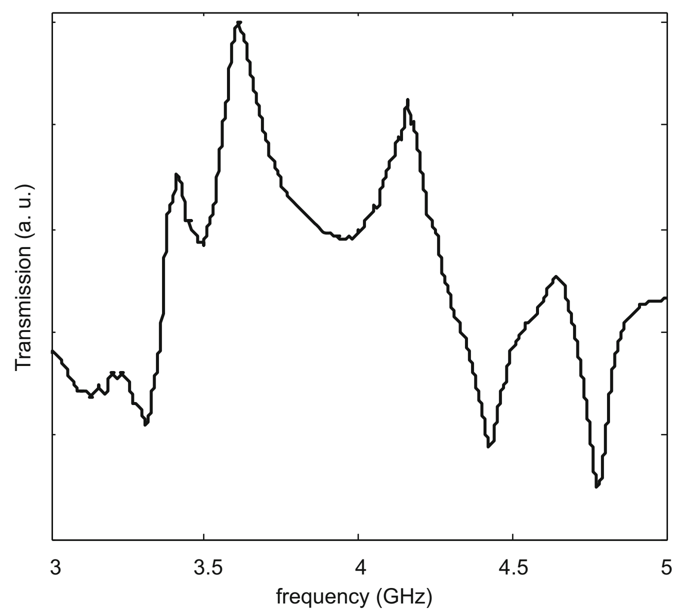

Fig. 3. Measured transmission spectrum of the metamaterial sample with 16 resonators and a wire strip.

0.125 mm, respectively. The widths of the wire and the gap in resonators are 0.5 and 0.3 mm [24]. Fig. 2 presents simulation result for the refractive index (n) of the sample. In this figure, the black and gray lines represent the real and imaginary parts of the refractive index, Re(n) and Im(n), respectively. As it is seen, Re(n) is negative between 3.14 and 4.30 GHz, and Im(n) ≥ 0 in all frequencies. Thus, it can be said that this sample displays left-handed properties in the frequency band of 3.14–4.30 GHz. In the experiments, two monopole antennas were used to transmit and detect the electromagnetic waves through the metamaterial samples. Monopole antennas had been constructed by removing the shield around one end of a microwave coaxial cable. The length of antennas is arranged to work at a frequency range covering resonance frequencies. The monopole antennas were then connected to the network analyzer to measure the transmission characteristics of the metamaterial structure. The first transmission measurement of a metamaterial sample is displayed in Fig. 3. The frequency response of the transmission has a non-fixed characteristic due to the frequency dependent effective permittivity and permeability. As it is seen from the figure, the measured left-handed transmission peak is at 3.614 GHz which stands in the frequency band where the refractive index of the structure is negative. In addition, high transmission peak was achieved in the mentioned frequency region as it was expected. It can be concluded that the experimented novel metamaterial was well designed, successfully worked around the operation frequency and can be used in various devices for several potential applications.

In the second experiment, the transmission spectrum of a metamaterial sample comprising 32 TSRRs (at the front) and two wire strips (at the back) is measured. The front view of this sample is shown in Fig. 4. The result of this measurement is illustrated in Fig. 5. The transmission band is relatively wide (approximately 1 GHz). The left-handed transmission peak is measured at 3.796 GHz. This peak stands in the frequency region where the manufactured metamaterial exhibits as a LHM. It means that the left-handed peak is observed at the frequency band where both the dielectric permittivity and magnetic permeability are simultaneously negative. In addition to the last two figures, Fig. 6 shows the transmission spectra for a LHM sample comprised of 16 TSRRs with a wire strip and 32 TSRRs with two wire strips, in the same plot, for the comparison purpose. Gray line corresponds to 16 TSRRs with a wire strip and black line corresponds to 32 TSRRs with two wire strips. As it is clearly observed from the figure, the measured transmission peak shifts to the right from 3.614 to 3.796 GHz when a LHM sample has 32 TSRRs. It means that it is possible to change the left-handed region of the LHMs. Furthermore, the transmission band of the left-handed region is wider in the metamaterial sample with 32 TSRRs.

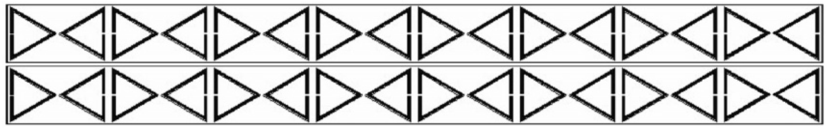

Fig. 4. The front view of the second LHM sample.

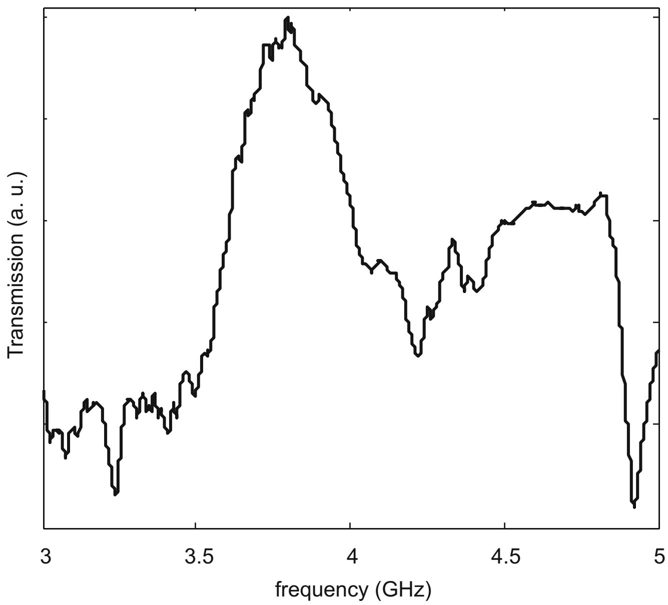

Fig. 5. Measured transmission spectrum of a LHM sample comprising 32 TSRRs and two wire strips.

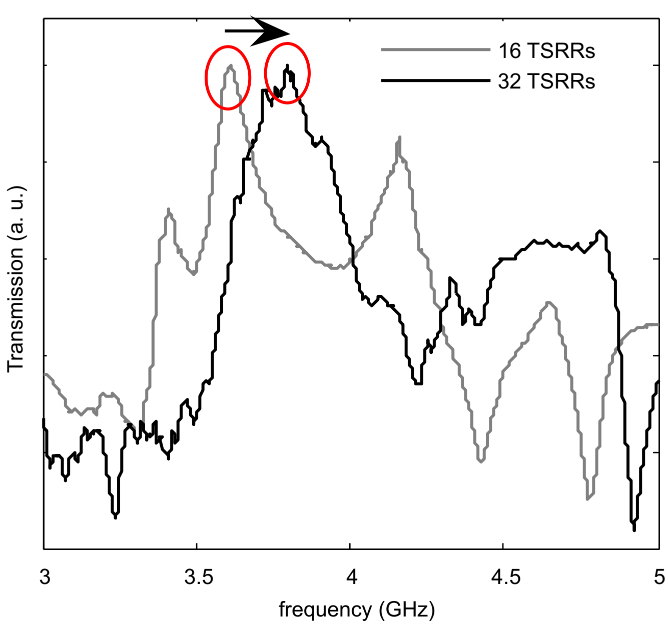

Fig. 6. Measured transmission spectra for a LHM sample comprising 16 TSRRs with a wire strip and 32 TSRRs with two wire strips, respectively. Gray line corresponds to 16 TSRRs with a wire strip and black line corresponds to 32 TSRRs with two wire strips.

3. Summary and conclusion

In summary, this paper has discussed the experimental investigation of the novel LHM consisting of TSRRs and wire strips. Two types of new LHM samples with 16 and 32 TSRRs were experimented in free space by using two monopole antennas and network analyzer. The left-handed transmission peak is clearly observed for these two samples. According to the results obtained in these experiments, the novel metamaterial exhibited left-handed properties in the frequency band of interest. It means that the experimented novel LHMs were well designed and successfully worked around the operation frequency. In the transmission spectra, high transmission peak was achieved in the frequency region where the manufactured metamaterials exhibit as a LHM as it was expected. In addition, the effects of the number of TSRRs and wire strips on the transmission characteristics are also illustrated. Transmission band of the left-handed region becomes wider when the number of TSRRs and wire strips are increased. Therefore, it is shown that the manufactured novel LHM shows left-handed behavior in the frequency region of interest and also it is possible to change left-handed region of the LHMs by changing the number of TSRRs and wire strips. Consequently, this new LHM has many advantages such as ease to fabricate, ease to control the structure geometry to obtain new LHMs for lower and/or higher frequencies, more suitable than the concentric ones, and has a wide negative band than some of its counterparts. As a result, the construction of more efficient LHM structures with TSRRs and wire strips in terms of bandwidth, loss, capabilities, and performance remains a topic for further studies and some of them are now under investigation.

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