Focusing and negative refraction in anisotropic indefinite permittivity media

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ABSTRACT

Materials that exhibit negative refraction demonstrate physical phenomena that may be used for novel applications. This work serves to evaluate the possibility of hyperbolic focusing due to an indefinite anisotropic permittivity tensor. Two single-loop antennas were used to approximately achieve a transverse magnetic (TM) point source and detector. Using an Agilent 8510C Vector Network Analyzer (VNA), the frequency spectrum was scanned between 7 and 9 GHz. Relative gain or loss measurements were taken at equal spatial steps around the center of the sample. A scanning robot allowed for the automatic scanning of the space behind the sample in the x, y, and z directions, to establish the focusing patterns, and to compare the signal amplitudes in the presence and absence of the sample. The robot was controlled using LabVIEW, which also collected the data from the VNA and passed it to Matlab for processing. A soft focusing spot was observed when the antennas were placed in a symmetric configuration with respect to the sample. These results suggest a method of focusing electromagnetic waves using negative refraction in indefinite materials.
Keywords: electromagnetic waves, negative refraction, hyperbolic focusing, indefinite media

1. INTRODUCTION

Negative-index materials have intrigued researchers since their discovery in 1999[1]. Current understanding of their capabilities has improved near to the point of direct applications. Earlier work into their use as a flat, gradient lens, showed focusing of close to +7 dB over incident power[2], demonstrating that negative-index materials could be used to focus microwave signals without the need for convex lenses.

With a wire spacing d and a self-inductance L, the overall dielectric constant of the composite can be described in terms of the plasmon frequency[3, 4]:

$$\kappa = \frac{\varepsilon_{overall}}{\varepsilon_0} = k - \frac{f_p^2}{f^2} \tag{1}$$

for

$$f_p = \frac{\omega_p}{2\pi} \tag{2}$$

where

$$\omega_p^2 = \frac{1}{d^2 L \varepsilon_0} \tag{3}$$

and

$$L = \frac{\mu_0}{4\pi}\left(\ln\left(\frac{d^2}{\pi r^2}\right) - 1\right) \tag{4}$$

A graph showing the relationship between the frequency and the dielectric constant κ is shown in Figure 1. Here, k is the dielectric constant of the base composite.

The purpose of this study was to demonstrate that negative refraction can be used to focus signals via an indefinite anisotropic permittivity tensor.

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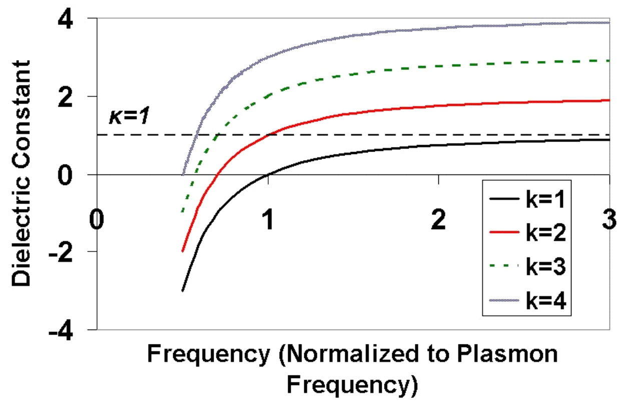

Figure 1: Graph of the relationship between dielectric constant and frequency for various values of k.

2. METHODOLOGY

2.1 Sample

The sample for this series of experiments was constructed out of Styrofoam and 12-gauge brass wires. Two square panels of Plexiglas with large circular holes were placed on either side of the Styrofoam for support and secured with threaded nylon rods, as shown in Figure 2.

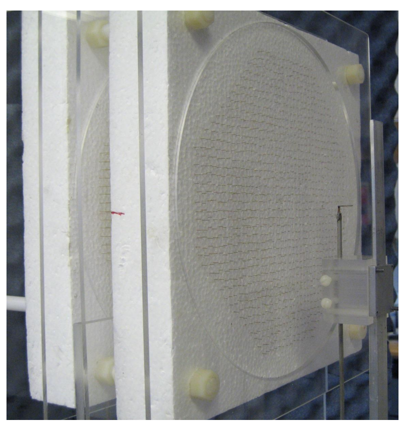

Figure 2: Styrofoam sample

2.2 Test Setup

For each test, two single-loop antennas were placed around the sample to transmit and receive signals. The transmitter antenna sent signals from a stationary position. The receiver antenna scanned the sample in the x, y, and z directions while receiving signals. The scanning was carried out by an XYZ automated scanning robot and controlled using LabVIEW. Each antenna was connected to the Agilent 8510C Vector Network Analyzer (VNA), where the signals originated and returned. Figure 3 shows the test setup.

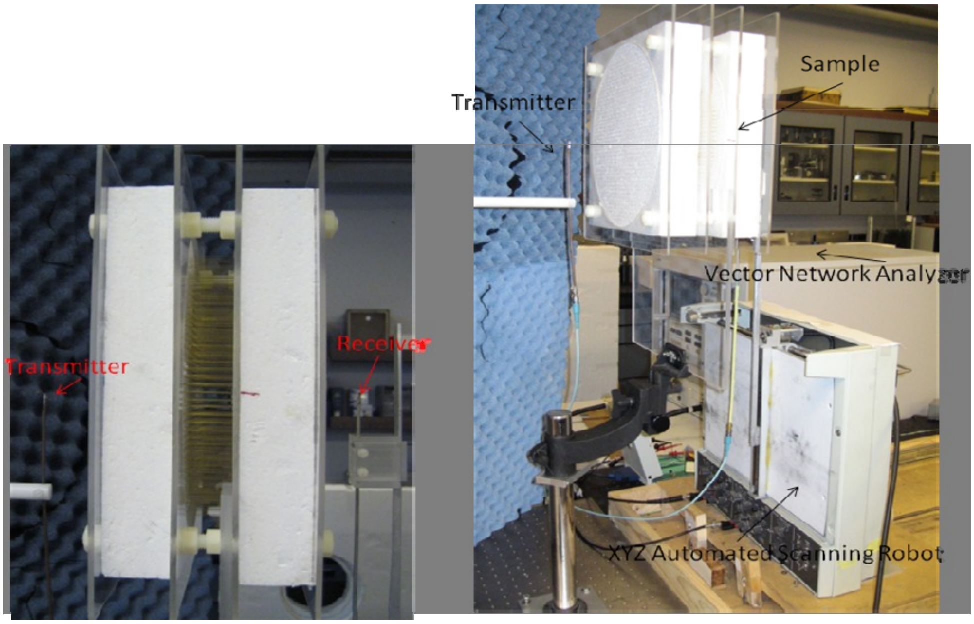

Figure 3: Test setup – computer with LabVIEW not shown

2.3 Calibration

The system was calibrated by aligning the transmitter antenna to the center of the sample. Once this antenna was in place, the robot with the receiver antenna was aligned such that the x and y axes were symmetric around the center of the sample, with 0 being the center point. It was noted that the x, y, and z movements do not correspond exactly with the parameters requested by the program. For example, a 10cm test would see x move 9.7cm, y 9.5cm and z 10.4cm. However, each axis moved consistently.

2.4 Antenna Configuration

The orientation of the transmitter and receiver antennas affects the way in which the signals are transmitted and received. To determine the optimal orientation to use for the experiments, three configurations were tested: both loops facing each other, both loops facing away from each other and both loops facing sideways. Each orientation is depicted in Figure 4.

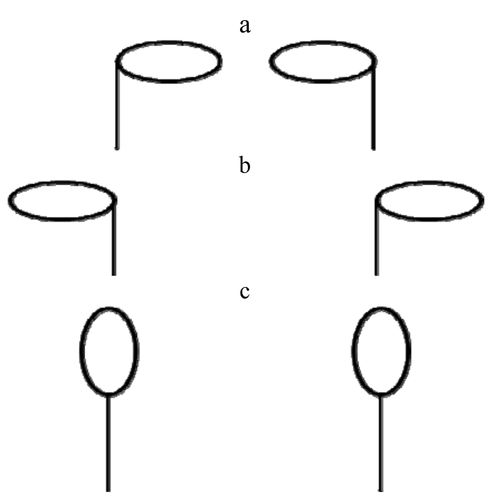

Figure 4: Antenna configurations - a) towards each other, b) away from each other, c) sideways

The tests showed that the second orientation with the loops facing away from each other produced less variation in the power loss without the sample than the other orientations. For this reason, the second orientation was chosen for the experiments.

2.5 Experimental Procedure

Tests were carried out with and without the sample in place. The VNA sent the signals to the transmitter antenna. The VNA then collected the transmitted signal from the receiver antenna and relayed the information to Matlab for processing via a LabVIEW module. This procedure was repeated at each stop of the receiver probe.

3. RESULTS AND CONCLUSIONS

The strongest focusing occurs at 7.6 GHz at a distance of 7.5 cm from the sample surface. A distinction can be made between the data with the sample and without the sample. The results of the experiments show that the sample decreases the amount of signal loss compared to that without the sample in place. Though this difference is small, the sample seems to focus at 7.5cm distance from the surface of the sample at a frequency of 7.6GHz, with softer focusing at other frequencies. Better antenna construction could allow for more signals to be transmitted and received. Also, enclosing the whole system in an absorbing material would reduce ambient reflection and could improve signal reception. Still, these results show that hyperbolic focusing with negative refraction is possible.

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