Abnormal Radiation Pattern of Metamaterial Waveguide

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Abstract — The idea to inverse the radiation pattern of the microwave antenna due to application of the isotropic metamaterial screen with negative refractive index in S band is demonstrated at the first time in this investigation. The electromagnetic simulation of waveguide antenna patterns by moment’s methods demonstrates an agreement modeling antenna patterns with measured antenna diagrams for values of metamaterial effective parameters (permittivity and permeability) extracted from measured S-parameters of metamaterial sheet sample.

1. INTRODUCTION

The prediction of left handed materials (LHM) by V. G. Veselago in 1967 [1] can be considered as a new stage in the development of electromagnetics of continuous media. Recently a lot of papers [2, 3] related to the artificial magnetoelectric media with anomalous electromagnetic properties have been appeared. Among these papers there are ones on 2-D, 3-D media with the negative permittivity and permeability [4, 5] and, hence, negative refractive index. The abnormal antenna patterns of a rectangular open waveguide loaded by a rectangular cross-section magnetoelectric tube made of the metamaterial with the negative refractive index in S frequency band for different thicknesses of tube are demonstrated at first in this paper.

2. SCHEME OF WAVEGUIDE RADIATOR

The geometry of open waveguide loaded by the metamaterial screen having a shape of a rectangular cross-section tube (modified open waveguide radiator) is shown in Figs. 1–2. A standard coaxial-waveguide adapter of the S-band with the waveguide window of 50×25 mm in sizes is used in the measurements of antenna patterns of modified waveguide radiator.

The metamaterial under investigation is an isotropic 2D lattice made of nichrome spiral wires (helixes) positioned randomly on the polyurethane substrate with 0.2 mm in thickness. To exclude chiral properties of the metamaterial sample is used an identical combination of left- and right handed helixes. The helixes were wound of the 0.4 mm nichrome wire with the number of turns 3 and coil pitch 1 mm. The helix external diameter is 5 mm. In the experiments an isotropic metamaterial sheet sample named as LR-5I (see Fig. 3 — 1/3 part of helixes set is positioned along rectangular coordinate axes of x, y and z respectively) with 5.2 mm in thickness is used.
A peculiarity of the spiral elements of the metamaterial under investigation consists in revealing of the 3D-isotropic electric and magnetic properties in one and the same frequency band [4]. A helix with the non-zero coil pitch is magnetic and electric dipole simultaneously effectively excited both by the electric and magnetic fields under the coincidence of their polarization with the helix axis.

Figure 3: A view of the metamaterial planar sample LR-5I.

The experimental dependence of the phase of metamaterial transmission coefficient in the dependence of frequency with the area of negative values of phase in the vicinity of frequency of 3 GHz corresponding to the negative refractive index is demonstrated in Fig. 4. Extracting values of effective material parameters of the metamaterial sheet sample recalculated by the Fresnel’s formulae from the S-parameters values (complex reflection and transmission coefficients) are presented in Fig. 5. The measurements of metamaterial S-parameters are performed on R&S Vector Network Analyzer ZVA-24 with the time domain option and special calibration procedure and using wide-band horn antenna.

Figure 5: The effective permittivity and permeability of metamaterial LR-5I in dependence on frequency.

3. THE ANTENNA PATTERNS OF WAVEGUIDE RADIATOR LOADED BY METAMATERIAL

Based upon the numerical estimations of antenna patterns by the Method of moments (thin red lines) and experimental antenna patterns (thick black lines) for the waveguide radiator obtained in the anechoic chamber are presented in Figs. 6–11. The antenna diagrams are performed at the
frequencies closed to the metamaterial resonance frequency which is equal to 3 GHz. An opportunity of obtaining a reversed antenna patterns for waveguide antenna structure loaded by the metamaterial tube had been shown at these diagrams (in Figs. 6–11 normalized antenna patterns is represented).

Figure 6: The antenna patterns of a waveguide radiator at the frequency 3.1 GHz.

Figure 7: The antenna patterns of a waveguide radiator loaded by the metamaterial tube (d = 5 mm) at the frequency 3.1 GHz.

Figure 8: The antenna patterns of a waveguide radiator loaded by the metamaterial tube (d = 10 mm) at the frequency 3.1 GHz.

Figure 9: The antenna patterns of a waveguide radiator loaded by the metamaterial tube (d = 20 mm) at the frequency 3.1 GHz.

For a waveguide radiator loaded by the LR-5I metamaterial tube with the wall thickness d = 5 mm and length L = 150 mm there is a growing of the backside antenna lobe in comparison with the main antenna lobe. The difference between levels of the main and back directional lobes is approximately equal to 2 dB.

With the increasing of the tube wall thickness d, there is an abnormal antenna pattern diagram when the backside directional lobe exceeds the main one more than by 20 dB. In this case the waveguide structure radiates mainly in the backside direction of “180 deg”. This effect is observed only in the case when the metamaterial reveals negative refractive index of

\[ n = \sqrt{(\varepsilon' + i\varepsilon'')(\mu' + i\mu'')} \]

To prove this fact in Fig. 11 an antenna pattern of the waveguide structure with the metamaterial
tube screen at the frequency of 4 GHz is presented. At this frequency refractive index of metamaterial is $n > 0$. The antenna pattern at this frequency has an ordinary form of diagram where the main directional lobe exceeds the backside lobe and the radiation occurs mainly in the front direction “0 deg”. The physical nature of this effect may be explained by the refraction of the electromagnetic waves at the boundary (air/metamaterial tube) inside waveguide structure. At this boundary the surface waves are excited and propagated in an opposite direction towards the spatial wave propagation in the waveguide structure.

Figure 10: The antenna patterns of a waveguide radiator loaded by the metamaterial tube ($d = 30$ mm) at the frequency 3.1 GHz.

Figure 11: The antenna patterns of a waveguide radiator loaded by the metamaterial tube ($d = 20$ mm) at the frequency 4 GHz.

4. CONCLUSIONS

Therefore, at the frequencies, at which a metamaterial possess negative refractive index $n < 0$, and the metamaterial tube thickness exceed 5 mm, and abnormal antenna pattern diagram of waveguide structure with the maximal radiation in the backside direction (<<backside radiation>>) are observed. At the frequencies, at which $n > 0$, the antenna patterns present ordinary diagrams with the maximal radiation in the front direction for any metamaterial tube thickness.

REFERENCES