Losses dependence of wave transmission in the single negative metamaterials

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Abstract

The losses-dependent properties of wave transmission in the single-negative (SNG) materials are experimentally investigated. Results show that the transmittance of the lossy SNG materials can be enhanced by increasing dissipation coefficient. The lossy ENG material is physically fabricated by using CRLH transmission lines grafted with radiation unit cell.

1. Introduction

To improve transmission properties of lossy metamaterials (MMS), various approaches have been proposed for compensating or reducing these losses. For example, in Ref [1], the authors compensate optical loss with the assistance of the gain medium. Compensate losses by optical parametric amplification [2]. Reduce losses by reducing the scale of the lossy SNG materials [3]. In addition, there are other unusual approaches to enhance the transmission of the lossy metamaterials. Recently some authors theoretically investigate the loss effect on the wave propagation properties in the lossy SNG monolayer and the lossy ENG-MNG bilayer [4-6]. In lossy SNG material, the reflection is shown to monotonically decrease as dissipation coefficient or the thickness of the lossy SNG material increases. This decreasing behavior in reflection will give rise to the unusual transmission properties. In particular, the transmission of the lossy SNG can be enhanced even when the dissipation coefficient or the thickness increases. But no corresponding experiment has been made to prove above theoretical results.

In this paper, we report the experimental investigation of the transmission enhancement of the lossy SNG material with the loss factor, and the roles played by their thicknesses are also numerically simulated. The lossy SNG materials were physically fabricated by using the radiation lossy CRLH TL. The properties of the transmission are simulated by software CST microwave studio and measured by means of an Agilent N5222A PNA Microwave Network Analyzer. It is found that the experimental results are in good agreement with numerical simulations.

2. Simulations and experiment

The applicable approach to implement the single negative materials is the transmission line loaded with series capacitor (C) and shunt inductor (L), known as CRLH TL [7]. For the sake of simplicity, the CRLH TL possessing ENG (MNG) in a certain range of frequencies are termed as ENG (MNG) units. In the present experiments, ENG and MNG units have been fabricated on a FR-4 substrate (with relative permittivity of 4.75, thickness of 1.6 mm). The parameters of ENG and MNG units are the same as in Ref. [8]: $d_{ENG} = 7.2mm$, $L_{ENG} = 5.6nH$, $C_{ENG} = 5.1pF$, and $d_{MNG} = 8mm$, $L_{ENG} = 10nH$, $C_{ENG} = 1pF$, respectively. In the previous work, the lossy ENG materials were constituted by grafting

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microstrip lines (parallel opened stub) along the ENG transmission line periodically. In Fig.1(a), the CRLH TL structure constituted of a host transmission line medium with the distributed parameters L_R and C_R, the discrete loading lumped element series capacitors (C_L) and shunt inductors (L_L). When the lattice constant d is much smaller than the guided wavelength λ_g, $d < \lambda_g/4$, it can be effectively homogeneous in the certain range of frequencies. The schematic of the radiation lossy CRLH TL composed of finite parallel open-stub grafted periodically along a SNG waveguide line is shown in Fig. 1(c). The parameter d, z_0, w, and z denotes the lattice spacing, impedance parameter of the SNG waveguide line, the width of the parallel microstrip line and the impedance parameter of the parallel open-stub, respectively. In terms of the two-port transmission line theory, the parallel opened stub is similar to the admittance parameter (Y), as follows:

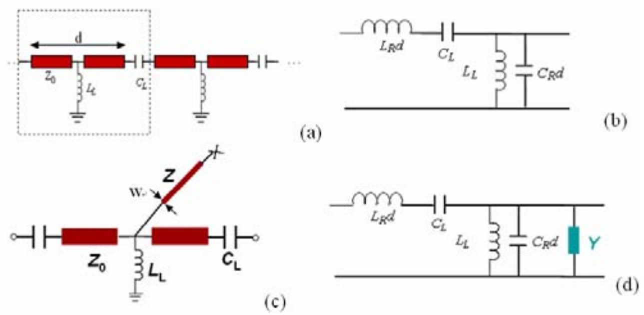

Fig.1 the unit cell of the ideal CRLH TL and the lossy CRLH TL

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$$\begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\mathrm{j}\dfrac{1}{Z}\tan(\theta)+\dfrac{\alpha}{Z} & 1 \end{bmatrix} \tag{1}$$

where θ is the electric length, α is the proportionality factor of the admittance parameter linked with the characteristic impedance of the parallel opened stub. Then, it can be effectively homogeneous in the certain range of frequencies with effective relative parameters $\varepsilon(f)$ and $\mu(f)$ of the lossy ENG TL.

$$\begin{aligned} \varepsilon_{ENG} = \varepsilon_{ENG}(f) &\approx -j\frac{1}{2\pi f}(j2\pi fC_R - j\frac{1}{2\pi fL_L} + j\frac{\tan\theta}{2\pi fZ} + \frac{\alpha}{Z}) \Big/ (\varepsilon_0 \cdot p) \\ &= (C_R + \frac{\tan\theta}{(2\pi f)^2 Z} - \frac{1}{(2\pi f)^2 L_L}) \Big/ (\varepsilon_0 \cdot p) - j\frac{\alpha}{2\pi fZ} \Big/ (\varepsilon_0 \cdot p) \\ &= \varepsilon_R(f) + i\varepsilon_I(f) \end{aligned} \tag{2}$$

$$\mu_{ENG} \approx p \cdot (L_R - \frac{1}{(2\pi f)^2 C_L d}) \Big/ \mu_0 \tag{3}$$

We change the value of the loss though adjusting the width of the parallel microstrip line. The radiation loss will increase when the width of the parallel opened stub increases. Furthermore, the impedance parameter will decrease, the real and imaginary part of the permittivity will increase, which is in accord with the theoretical calculation in the Ref [4].

Firstly, we study the wave properties for the lossy ENG monolayer. Fig. 2 (a) and (b) show the simulated and measured transmittance and reflectance of the lossy ENG layer. From Fig.2 (a), one can see that in 1.15-2.0GHz, the reflectance is reduced continuously with the width. The transmittance is enhanced as the width increases (loss factor increases). In Fig.2(b), we can see that the experimental transmission/reflection data is basically accorded with the simulated result.

Secondly, we study the wave properties for an ENG-MNG bilayer. In this case, we only change the loss factor of the ENG material through change the width of the parallel opened stub from 0.5mm to 2.5mm. From Fig 2(c) and (d), we can see that the reflectance decreases when the loss factor increase in the frequency range 1.1-1.56GHz. The transmittance increases with the loss factor. The experimental result is basically fitted with the simulated result. Because the ENG-MNG bilayer is longer than ENG monolayer, there is more error in experiment, so the experiment is larger different from the simulation than ENG layer.

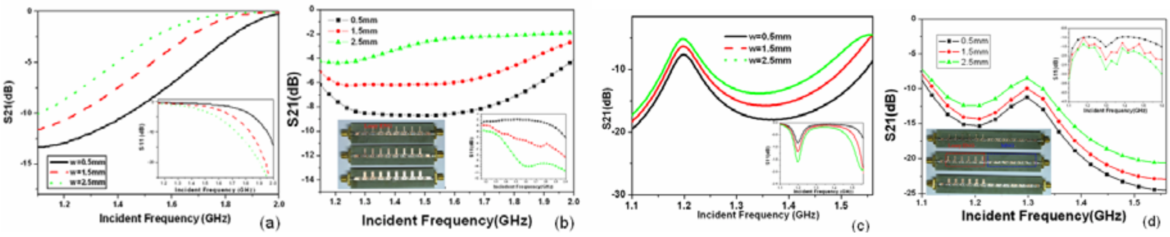

Fig.2 the simulated (a) and measured (b) transmittance and reflectance of the lossy ENG slab, the simulated (c) and measured (d) transmittance and reflectance of the lossy ENG-MNG bilayer

3. Conclusion

Lossy ENG and MNG materials are successfully fabricated by using radiation lossy CRLH TL. We experimentally demonstrate the transmission phenomenon occurring in the lossy ENG slab and lossy ENG-MNG bilayer, and verified that in sharp contrast to lossy right handed and left handed materials, the transmission though the lossy ENG slab and the lossy ENG –MNG bilayer can be enhanced when the radiation loss increases. Generally, we can enhance the transmission of the lossy SNG monolayer and the lossy SNG bilayer by increasing the loss factor of the lossy SNG material. These results may be used to improve transmission properties of artificial structures containing highly lossy metamaterials.

Acknowledgments

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