4E2-5

Design of Planar Left-Handed Metamaterials Transmission Lines Based on Defected Ground Structures and SRRs

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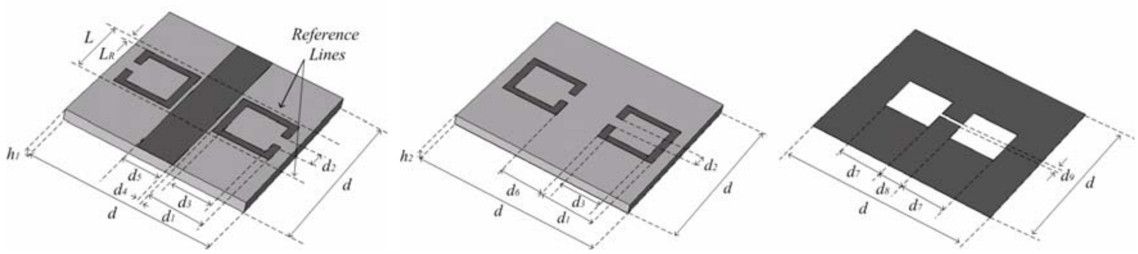
1. Introduction

Experimentally, the first effective Left-Handed Metamaterial (LHM) was fabricated by Smith *et al.* in microwave regime [1]. The original artificial medium was constructed with a bulky combination of metal wires and Split Ring Resonators (SRRs), which were employed to synthesize the negative permittivity and permeability respectively, and, indeed, successfully demonstrated negative refraction [2]. In this paper, defected ground structure (DGS) is considered to replace the wires to produce effective negative permittivity. DGS denotes a specific pattern etched on the ground plane of a microstrip line; usually behaves as an electromagnetic band-gap structure to improve the performance of various kinds of filters [3]. DGS can play as counterpart of wires to produce shunt inductance at some frequency bands, while DGS can be exited in a planar style, which leads to a more compact configuration than wires/SRRs.

2. The LH Microstrip Line Based on DGS/SRRs

Fabrication

Figure 1 demonstrates the physical configuration of the DGS/SRRs LH microstrip. It consists of three parts, the microstrip line at the top of the first substrate, the DGS at the bottom of the second substrate and the double-layer SRRs. The first and second layer SRRs are located at the top of the first and second layer dielectric substrate respectively. Double-layer SRRs consist of two layers concentric square split rings, whose splits are oriented opposite to each other. Then two SRRs are symmetrically placed at both sides of the microstrip line. In the case when the quasi-TEM mode propagates along the microstrip line, the magnetic field is circled around the strip conductor and can penetrate the SRRs; hence the SRRs nearby the strip conductor can produce series capacitance and generate an effective negative permeability. As for the negative permittivity, it is generated by the DGS at the bottom of the second substrate. The pattern of DGS is square and directly etched on the ground plane by photolithographic techniques.



(a) (b) (c)

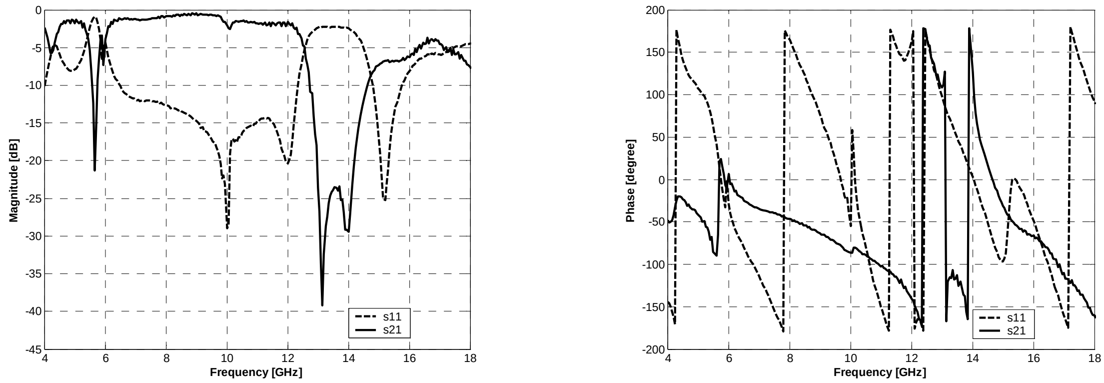
Figure 1: Physical configuration of one unit cell of the DGS/SRRs Left-Handed microstrip line. (a) The first layer SRRs. (b) The second layer SRRs. (c) The DGS located at the bottom of the second substrate.

ISBN: 978-4-88552-223-9 C3055©IEICE

The physical parameters of the DGS pattern and SRRs are as follows: d=10 mm, d_1=3.15 mm, d_2=0.75 mm, d_3=2.35 mm, d_4=0.2 mm, d_5=2 mm, d_6=2.4 mm, d_7=2.5 mm, d_8=1.2 mm, d_9=0.25 mm. The first layer substrate is RT-Duroid substrate: ε_r = 10.2, h_1 = 0.635 mm, metal thickness t_1 = 0.017 mm and loss tangent tan δ_1= 0.0023, and the second layer substrate is Teflon substrate: ε_r = 2.54, h_2 = 0.54 mm, metal thickness t_2 = 0.018 mm and loss tangent tan δ_2 = 0.002. There are two reference lines beyond the SRRs shown in Figure 1(a). They are set with L_R=0.25 mm for the effective parameters extraction, which is proposed in next section.

Measurement

To obtain the scattering parameters, a vector network analyzer Agilent 8510C is used to characterize the experiment data in this paper. Figure 2 demonstrates the magnitude and phase of S parameters of the LH microstrip line, but they can not directly indicate the frequency bands exhibiting Left-Handed properties.



(a) (b)

Figure 2: Experimental S parameters: (a) Magnitude of S_{11} and S_{21} and (b) Phase of S_{11} and S_{21}.

3. The Effective Electromagnetic Parameters Retrieve

To characterize the DGS/SRRs LH microstrip under the dominant quasi-TEM mode excitation, the effective medium theory is used when the dimensions of the DGS/SRRs unit cell are much smaller than the wavelength. The size of DGS/SRRs is 3.15 mm, while the free-space wavelength is 30 mm at about 10 GHz. It means that the combination of DGS/SRRs is about 0.1 wavelengths. Consequently, the DGS/SRRs can be treated as homogeneous medium with effective permittivity ε_{eff} and permeability μ_{eff}.

Effective Parameters Retrieve Approach

To extract the effective permittivity ε_{eff} and permeability μ_{eff} from S parameters, this paper employs the retrieve method proposed in [5] as an extension of the Nicolson-Ross-Weir (NRW) method.

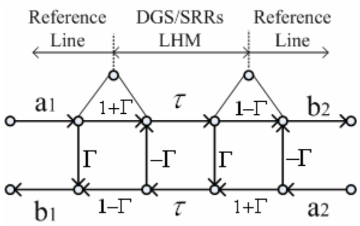


Figure 3: The signal flow graph of Figure 1.

Considering a wave propagates along the microstrip line with the time dependent of $e^{j\omega t}$, the reflection coefficient Γ for a wave passing from the reference line shown in Figure1 (a) into the DGS/SRRs LH unit cell is:

$$\Gamma = \frac{Z_{LH} - Z_{TL}}{Z_{LH} + Z_{TL}} \tag{1}$$

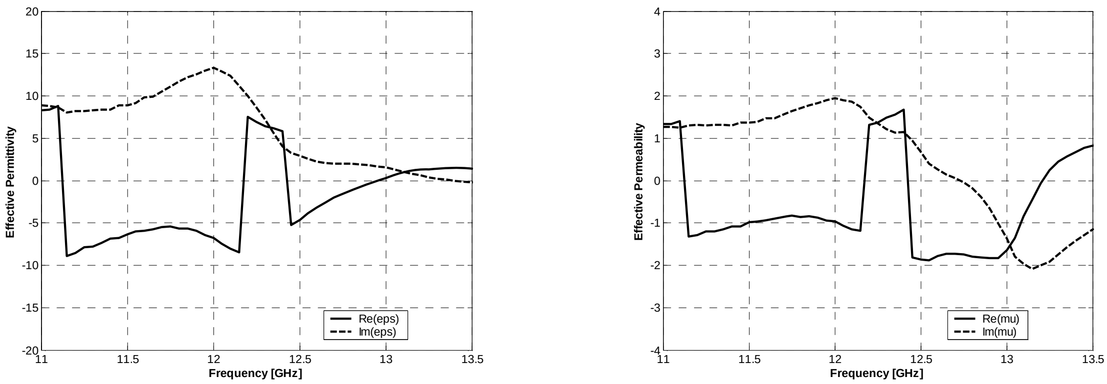
where Z_{LH} and Z_{TL} are the characteristic impedances of the DGS/SRRs and the microstrip line, respectively. Moreover, set the wave propagates through the DGS/SRRs with a complex propagation constant γ, so the propagation factor τ of the DGS/SRRs is $\tau = e^{-\gamma L}$. Here, L represents the physical length of the DGS/SRRs unit cell (L=d_I+2L_R) shown in Figure 1 (a). Additionally, the two ports scattering parameters can be calculated by the signal flow graph shown in Figure 3:

$$S_{11} = \frac{\Gamma(1-\tau^2)}{1-\Gamma^2\tau^2} \quad (2a) \qquad S_{21} = \frac{\tau(1-\Gamma^2)}{1-\Gamma^2\tau^2} \quad (2b)$$

Then we can solve (2a) and (2b) and obtain the effective permittivity and permeability expressions by the approach stated in [5].

Retrieval Effective Parameters

The retrieval variations of effective parameters are demonstrated in Figure 4. Figure 4(a) illustrates the real part (solid line) and the image part (dash line) of the ε_{eff}, and Figure 4(b) illustrates the real part (solid line) and the image part (dash line) of the μ_{eff}. It shows that the frequency bands of the negative real part of ε_{eff} are during 11.12-12.18 GHz and 12.42-12.95 GHz, and the bands of the negative real part of μ_{eff} are located at 11.12-12.18 GHz and 12.42-13.22 GHz. Then the real parts of ε_{eff} and μ_{eff} are put together shown in Fig .4(c), it indicates that the DGS/SRRs LH microstrip line can exhibit simultaneously negative permittivity and permeability at 11.12-12.18 GHz and 12.42-12.95 GHz range.



(a) (b)

Figure 4. The retrieval results of effective permittivity and permeability. (a) The effective permittivity. (b) The effective permeability.

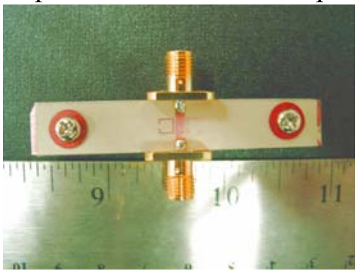
4. Comparison and Discussion

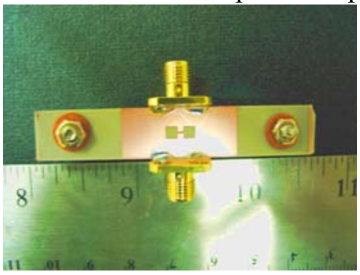
TABLE I: COMPARISON OF TWO COMBINATIONS

Performance	Wires/SRRs [5]	DGS/SRRs
LHM Bands (GHz)	4.47-4.60	11.12-12.18 and 12.42-12.95
Relative BW (%)	2.87	9.10 and 4.18
Configuration	nonplanar	planar
Excitation Style	nonplanar	planar
Synthesis	difficult	easy

Figure 5 shows the pictures of the fabricated DGS/SRRs LH microstrip line depicted in Figure 1. In this prototype, Figure5 (a) shows the SRRs located at the top of the first layer substrate, and Figure 5(b) demonstrates the DGS pattern etched at the bottom of the second layer substrate. The width of the substrates has been enlarged for the pins.

Table I illustrates the comparison between conventional wires/SRRs [5] and the DGS/SRRs LH microstrip lines. Conventional LH microstrip lines need the electric field to be parallel with wires; it means that the wires have to be perpendicularly embedded in the substrate, consequently, both the configuration and the excitation are nonplanar, which makes the process difficult in microstrip technology. While DGS pattern is planar, and can be easily etched at the bottom of the substrate. Moreover, DGS can play counterpart of wires for LH microstrip line, which makes the LH microstrip line convenient to adapt for microwave antennas and circuit components applications.





(a) Top view (b) Bottom view

Figure 5. Prototype of the DGS/SRRs LH microstrip line. (a) Top view. (b) Bottom view.

4. Conclusion

In this paper, the planar distributed LH microstrip line realized by the combinations of the DGS/SRRs has been constructed, characterized and measured, and the microstrip line can exhibit left-handed properties over double frequency bands located at 11.12-12.18 GHz and 12.42-12.95 GHz respectively. Several important characteristics of the DGS/SRRs LH microstrip line are demonstrated compared to the conventional LHMs based on bulky constructed waveguides or the lumped-element microstrip lines. Firstly, both DGS and SRRs can be directly synthesized on the substrates by photolithographic techniques. Secondly, it can also be easily realized at a higher frequency region by scaling the dimensions of DGS and SRRs without any chip inductors and capacitors. Lastly, the synthesis of planar DGS is much more convenient then wires for microwave antennas and circuit components applications.

Acknowledgments

The authors are extremely grateful to Tae-Soon Yun, Hee Nam, Il-Woo Lee, Seung-Hyun Han and Fang Zhang, all of the School of Electronic Engineering, Kwangwoon University, Seoul, Korea, for their kindly help during the fabrication and measurement of DGS/SRRs LH microstrip lines. This work was supported by the Natural Science Foundation of China under Grant 60571026, and the grant from National Key Laboratory of Electromagnetic Environment under Grant 514860303.

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