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FRACTAL-BASED COMPOSITE RIGHT/LEFT-HANDED TRANSMISSION LINE AND ITS APPLICATIONS IN MINIATURIZED NEGATIVE-ORDER RESONANT ANTENNAS

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Abstract—In this article, a fractal-based composite right/left-handed transmission line (TL) is proposed, and its applications in miniaturized negative-order resonant (NOR) antennas are investigated. The TL unit-cell is constructed by etching a Hilbert-fractal slot on the surface of a substrate integrated waveguide structure. The dispersion analysis shows that the proposed TL can be used to design miniaturized NOR antennas. Then, two fractal-based NOR antennas are designed and fabricated. According to the measured results, the electrical sizes of the fabricated open-ended and short-ended antennas are 75.8% and 74.6% smaller than those of the reported counterparts, respectively. In addition, compared with the microstrip patch antennas, the fabricated antennas exhibit similar gain level and radiation patterns, but have a much smaller electrical size.

1. INTRODUCTION

In recent years, researches on metamaterials for microwave applications have grown rapidly with the verification of left-handed metamaterials [1, 2]. Especially, the transmission line approach of left-handed metamaterials has led to the realization of the composite right/left-handed (CRLH) transmission line (TL) which includes left-handed and right-handed attributes [3]. A large number of CRLH microwave components have been developed, including many radiated-wave devices [4, 5]. The rich dispersion relation of the CRLH TL provides these antennas with some unique features. For instance, the CRLH leaky-wave antennas developed with various techniques exhibit a full-space

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beam steering capability [6–8]. Because of their infinite wavelength operation, the CRLH zeroth-order resonant antennas are more compact than conventional half-wavelength antennas. However, these antennas are developed based on the microstrip techniques and suffer from low radiation efficiency and gain [9–11]. In [12, 13], a family of CRLH negative-order resonant (NOR) antennas is proposed. Compared with the existing CRLH zeroth-order resonant antennas [9–11], these NOR antennas provide relatively high radiation efficiency and gain.

In this paper, a fractal-based CRLH TL is presented, and its applications in NOR antennas are investigated. The dispersion analysis shows that the proposed TL can be used to design miniaturized NOR antennas. Then, two fractal-based NOR antennas are designed and fabricated. Compared with the reported NOR antennas, the fabricated NOR antennas provide a similar gain level but exhibit a much smaller electrical size [12, 13].

2. FRACTAL-BASED CRLH TL REALIZATION AND DISPERSION ANALYSIS

Figure 1(a) shows the geometry of the proposed CRLH TL unit-cell. The top layer and ground layer are connected by periodic via arrays forming a substrate integrated waveguide structure. The Hilbert-fractal slot is etched on the top surface of the waveguide. The unit-cell is synthesized on the substrate of F4BM-2 with a thickness of 1.5 mm and a relative permittivity of 2.2. For fabrication convenience, all the metallic via holes are chosen to have a diameter of 0.6 mm and a center-

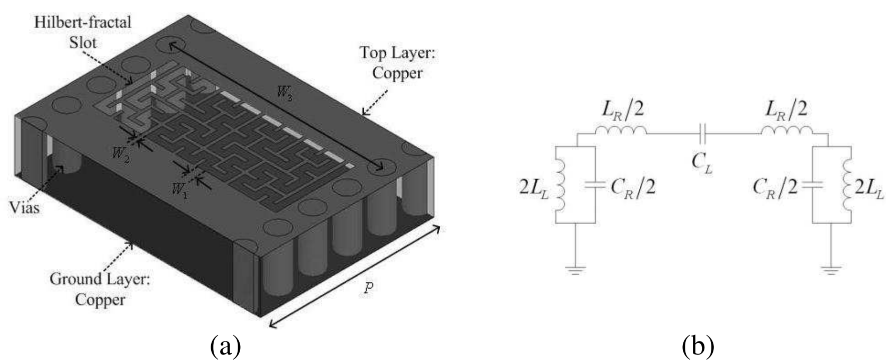

Figure 1. (a) Configuration of the fractal-based CRLH TL unit-cell. Unit-cell dimensions: $W_1 = 0.2$ mm, $W_2 = 0.1$ mm, $W_3 = 6.1$ mm, $p = 5$ mm. (b) Its equivalent circuit model.

to-center spacing around 1 mm. They are employed to form the side walls of the waveguide to prevent the wave leakage [14].

For the unit-cell shown in Figure 1(a), the equivalent circuit is shown in Figure 1(b). The metal surface and the ground can be modeled as a two-wire TL with the distributed series inductance L_R and distributed shunt capacitance C_R which are associated with the permeability and permittivity of the structure. The vias of the substrate integrated waveguide provide a shunt inductance L_L, and the series capacitance C_L is realized by the Hilbert-fractal slot etching on the top surface of the waveguide.

The circuit parameters can be extracted as follows: Firstly, The S parameters of the fractal-based CRLH TL unit-cell can be obtained by the Ansoft's HFSS. Secondly, based on the obtained S parameters and the equivalent circuit shown in Figure 1(b), the circuit parameters can be extracted by the Optimization Dialog Box in Serenade. The extracted values are: $L_R = 0.76\,\text{nH}$, $C_R = 2.83\,\text{pF}$, $L_L = 0.09\,\text{nH}$ and $C_L = 0.49\,\text{pF}$. Figure 2 shows the dispersion diagrams obtained from the proposed CRLH TL unit-cell by full-wave simulation with Ansoft's HFSS package and the equivalent circuit shown in Figure 1(b) with all the extracted values. The equivalent circuit with all the extracted values describes the dispersion relation of the proposed unit-cell very well. Since a longer and thinner Hilbert-fractal slot with more corners provides a larger series capacitance, the proposed unit-cell has a much smaller physical size even with the same left-handed band (below 8.2 GHz) by comparing with the unit-cell reported in [12, 13]. Therefore, the fractal-based CRLH TL can be used to design miniaturized NOR antennas.

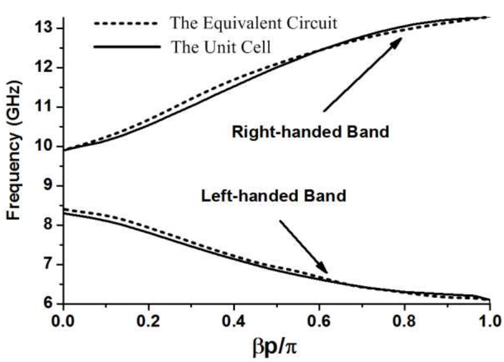

Figure 2. Dispersion diagrams for the unit-cell shown in Figure 1(a) and the corresponding equivalent circuit shown in Figure 1(b).

3. NOR ANTENNAS DESIGN

The fractal-based NOR antennas are shown in Figure 3. The antennas can be classified into two categories: the open-ended type and the short-ended type. Both of them are excited by a piece of 50-Ohm microstrip line. The simulated return losses of these two antennas are shown in Figure 4. It is observed that the open-ended antenna has a lower simulated NOR frequency compared with the short-ended one.

Figure 5 shows the fabricated prototypes of the fractal-based NOR antennas. The measured return losses of the fabricated antennas are shown in Figure 6. It is observed that the measured results are agree with the simulated ones. Table 1 draws a performance comparison

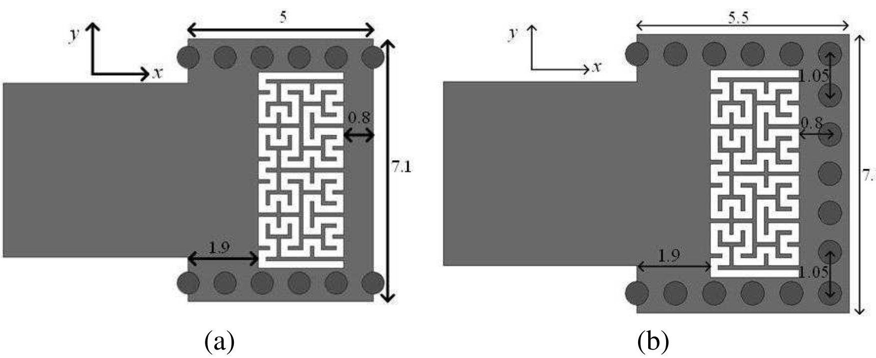

Figure 3. Configurations of the fractal-based NOR antennas with dimensions in mm. (a) The open-ended type. (b) The short-ended type.

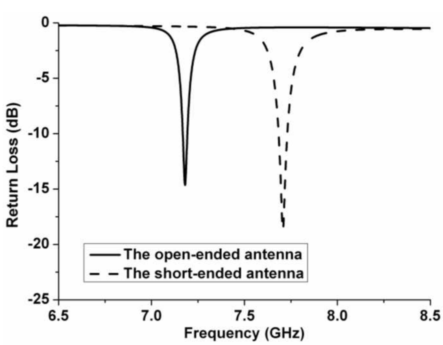

Figure 4. Simulated return losses of the fractal-based NOR antennas.

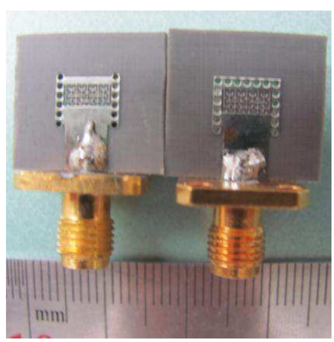

Figure 5. The fabricated prototypes of the fractal-based NOR antennas.

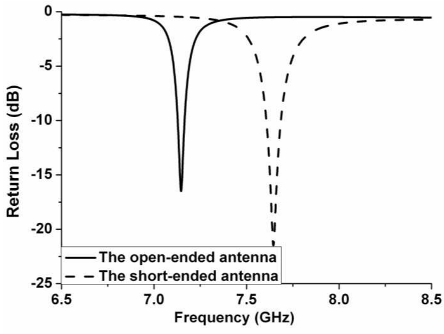

Figure 6. Measured return losses of the fabricated antennas.

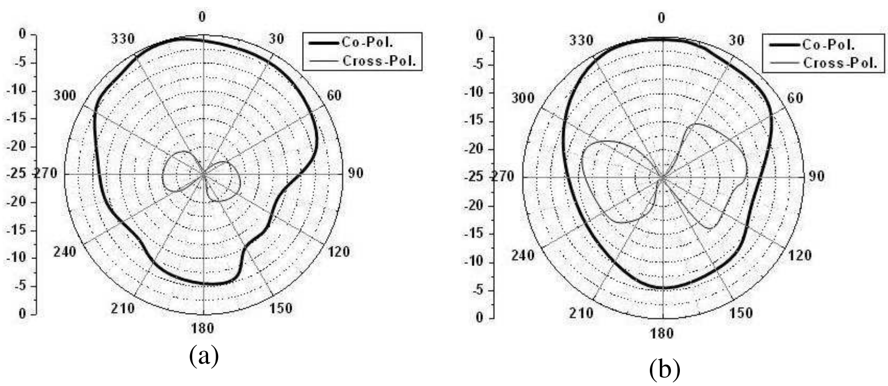

Figure 7. Measured radiation patterns for the fabricated open-ended antenna at 7.12 GHz. (a) x-z plane (E-plane). (b) y-z plane (H-plane).

for the fabricated and reported NOR antennas with the measured NOR frequency, the antenna's electrical size and the measured peak gain [12, 13]. From this Table, the electrical sizes of the fabricated open-ended and short-ended antennas are 75.8% and 74.6% smaller than those of the reported counterparts, respectively.

Figure 7 shows the measured radiation patterns at 7.12 GHz for the fabricated open-ended antenna. They are very similar to the radiation patterns of conventional microstrip patch antennas or slot antennas. The E-plane pattern is not very symmetrical and the backward radiation is stronger than the forward radiation. This can be attributed to the influence of the microstrip feeding and the fact that this antenna is operated on the negative-order resonance. The cross-polarization in both the E-plane and H-plane is less than -13 dB. As shown in Figure 8, the fabricated short-ended antenna also has similar

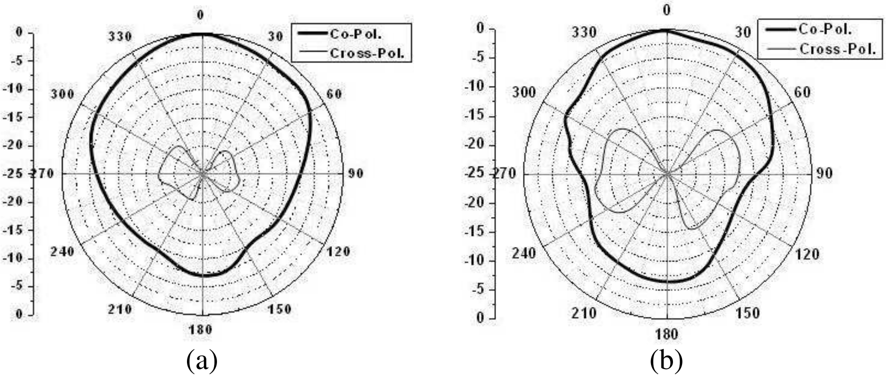

Figure 8. Measured radiation patterns for the fabricated short-ended slot antenna at 7.64 GHz. (a) x-z plane (E-plane). (b) y-z plane (H-plane).

Table 1. A performance comparison for the fabricated antennas and the antennas reported in [12, 13].

	Frequency (GHz)	Size (λ_0)	Gain (dBi)
Fabricated open-ended antenna	7.12	0.17×0.12	3.02
Fabricated short-ended antenna	7.64	0.18×0.14	3.51
Reported open-ended antenna	7.25	0.265×0.318	3.16
Reported short-ended antenna	7.75	0.296×0.335	4.31

radiation patterns to the microstrip patch antennas. Its radiation mainly goes to the broadside, and the level of cross-polarization is much lower than that of the co-polarization.

4. CONCLUSION

In this article, a fractal-based CRLH TL is proposed. Owing to the Hilbert-fractal slot, the proposed TL can be used to design miniaturized NOR antennas. As verification, two fractal-based NOR antennas are designed and fabricated. According to the measured results, the electrical sizes of the fabricated open-ended and short-ended antennas are 75.8% and 74.6% smaller than those of the reported counterparts, respectively. In addition, compared with the microstrip patch antennas, the fabricated antennas have similar gain level and radiation patterns, but exhibit a much smaller electrical size. Consequently, these antennas can be used as substitutes for microstrip patch antennas in compact microwave systems.

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