Fractal Etched Bow-tie Antenna Loading Zero-index Metamaterials

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Abstract— Characterized by its wide impedance bandwidth and relatively stable radiation pattern, the bow-tie antenna has been widely utilized in the microwave as a suitable radiator. However, the comparatively limited radiation gain will constrain this type of antenna from more extensive applications when higher gain is required. In this paper, a bow-tie antenna etched with modified Sierpinski fractal patterns is proposed, which can enlarge the current path for radiation thus minimize the overall dimensions of the radiator to further increase its impedance bandwidth. Moreover, for the sake of gain-enhancement, an artificial structure consisting of zero-index metamaterials (ZIM) unit is carefully designed and adopted in the fractal pattern etched antenna.

1. INTRODUCTION

Bow-tie antenna is featured by its wide impedance bandwidth in the microwave band, thus can be versatile for various needs as an ideal radiator. Such type of antenna, which has been extensively used in the UWB system, is the planarization of bi-conical antenna. In consideration of the commercial aspects, the antenna should be compact, low-cost and easy to fabricate.

Miniature of antenna is always a hot-spot issue in modern antenna design. So as to further minimize the antenna dimension, Sierpinski fractal pattern has been adopted in bow-tie antenna [6, 7]. However, such fractal pattern will give rise to the current discontinuity thus inevitably narrow the impedance bandwidth.

Metamaterials are artificial composite materials that exhibit exotic electromagnetic properties, which will not be found in natural materials. With the development of metamaterials, a novel method is suitable for gain enhancement with the use of zero-index metamaterials (ZIM) [1]. Zero-index metamaterials are such unique artificial structure that one component of its permittivity or permeability tensor approaches to zero, which leads to a near zero refraction index [2, 3].

In this paper, a modified Sierpinski fractal pattern etched on the surface of bow-tie antenna structure is proposed. Our design will improve the current continuity to enlarge the electric current path floating across the two wings of the antenna compared with the previous work. Thus this pattern will have a wider working frequency band with a lower end. Furthermore, a ZIM structure is carefully designed and implemented with the antenna. The simulated results show that the use of ZIM will achieve a higher gain performance.

2. DESIGN OF BOW-TIE ANTENNA AND FRACTAL PATTERN

The bow-tie antenna is fed by a microstrip line, which transforms from a coaxial cable via a coaxial connector. The bow-tie antenna is a double-sided balanced antenna, so a balum [4, 5] is introduced as a transition between the balanced antenna and the unbalanced microstrip line.

The dielectric substrate is chosen as FR-4 with the permittivity of 4.3 and the loss tangent is 0.025. The length of the antenna (L_b) is 53 mm, and the angle of the wing of the antenna is 60°, as illustrated in Fig. 1(a). The balum structure shown in Fig. 1(b) provides a smooth transition from the microstrip line and the coplanar stripline (CPS).

Fractal pattern is a self-similarity pattern, which means the part of the structure is similar to the whole body. The fractal pattern usually used in the bow-tie antenna is the 3rd Sierpinski pattern [6, 7], which is easy to fabricate. The 2nd Sierpinski pattern is shown in Fig. 2(a).

The fractal pattern etched antenna is illustrated in Fig. 3(a). As can be seen, the fractal pattern slightly differs from the 2nd Sierpinski pattern, which is more similar to the picture exhibited in Fig. 2(b), with a little yellow triangle in the center of 2nd Sierpinski pattern. The current path is enlarged by the insertion of the triangle patch. Furthermore, we have modified the size of the 1st and 22nd triangles cutting from the original big triangle to form the fractal pattern shown in Fig. 3(b), which exhibits more continuity with respect to the pattern shown in Fig. 2(b).

From Fig. 4, the −10 dB return loss bandwidth ranges from 5.7 to 7.3 GHz for the original bow-tie antenna and from 4.5 GHz to 6.8 GHz for the fractal etched antenna, respectively. As can be seen, with the modified Sierpinski fractal pattern, the whole working frequency band extends towards the lower frequency end. Thus a wider frequency band is obtained (from 24% of the original model to 41% of the model with fractal pattern).

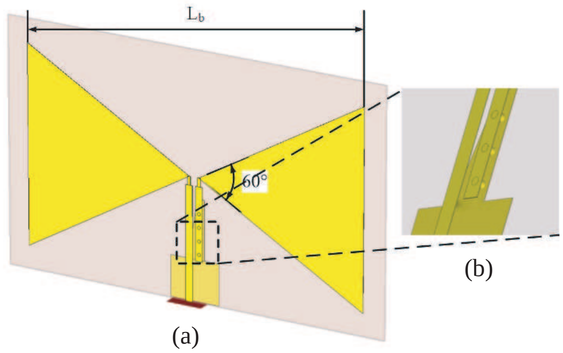

Figure 1: The original bow-tie antenna fed by a microstrip line with a balum as a transition.

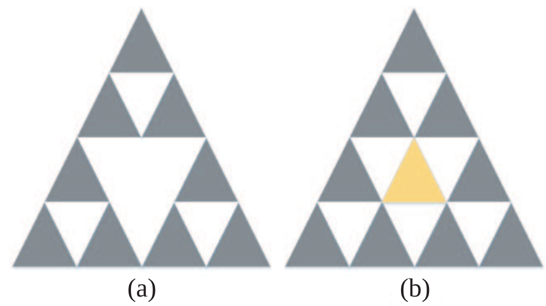

Figure 2: (a) The 2nd Sierpinski fractal pattern. (b) The 2nd Sierpinski fractal pattern with a 2nd triangle in center.

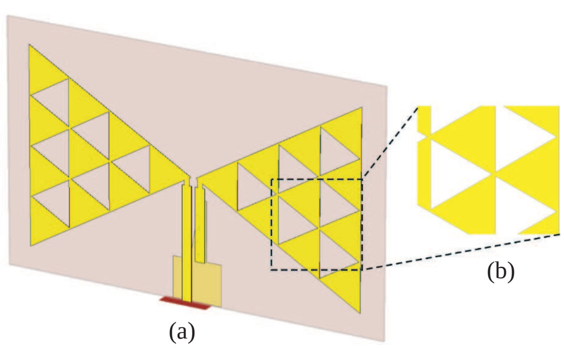

Figure 3: (a) The 2nd Sierpinski fractal etched bow-tie antenna. (b) The 2nd Sierpinski fractal pattern with a 2nd triangle in center.

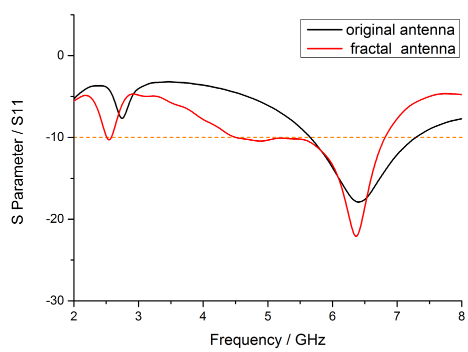

Figure 4: The S parameter of the original antenna and the fractal antenna around their working frequency.

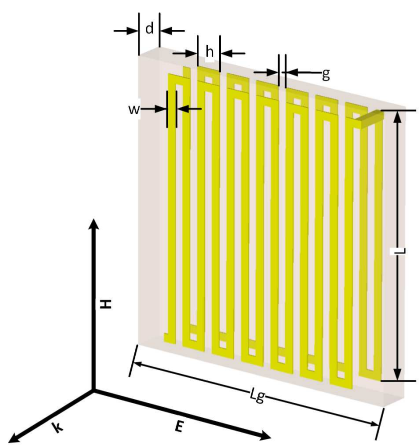

Figure 5: The designed ZIM unit cell structure is made of two meander lines which are on the front and back surface of the dielectric substrate. The parameters of the structure are: $L_g = 7\,\text{mm}$, $L = 6.5\,\text{mm}$, $w = 0.2\,\text{mm}$, $d = 0.8\,\text{mm}$, $h = 0.6\,\text{mm}$, $g = 0.2\,\text{mm}$. The substrate is chosen as Rogers RO4003 with the permittivity of 3.55 and the loss tangent is 0.0027.

3. DESIGN AND FABRICATION OF ZIM STRUCTURE

The zero-index metamaterials (ZIM) are such kinds of metamaterials whose value of permittivity or permeability approximates to zero. With such a unique property, ZIM can be used for gain enhancement of antennas [8, 9]. As illustrated in the Fig. 5, the ZIM unit cell is a two-layer structure with meander lines etched on both sides of the dielectric substrate. Each tail of the two meander lines is connected by a metallic stick through the substrate, which enlarges the current loop thus minimizes the overall dimension of the unit cell.

The ZIM structure is carefully designed at the frequency of 5 gigahertz, with the unit length (denoted by L_g) of about 7 mm. The unit cell is designed and simulated via the commercial microwave software CST MICROWAVE STUDIO.

As exhibited in the Fig. 6, the refractive index around 5 GHz is about 0.15 and enough for ZIM design [10]. We arrange the ZIM structure in front of the fractal etched antenna, as illustrated in

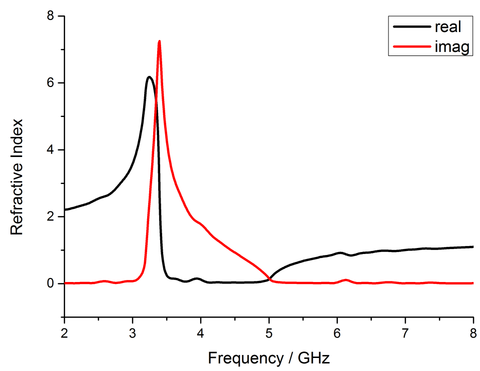

Figure 6: The real and imaginary part of refractive index of the ZIM structure, ranging from 2 to 8 GHz.

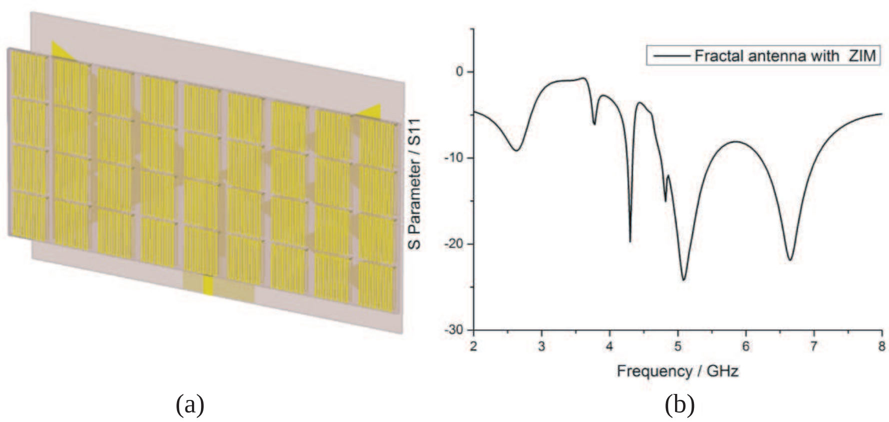

Figure 7: (a) The fractal etched antenna with ZIM structure. (b) The S parameter of the fractal antenna with ZIM.

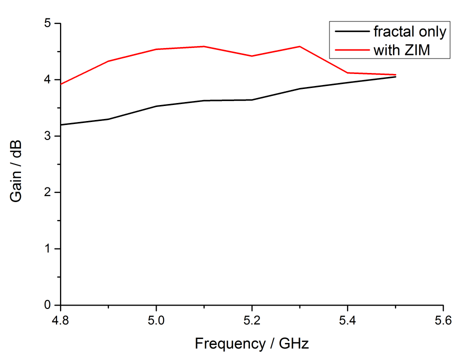

Figure 8: The gain versus frequency of the model with and without ZIM.

the Fig. 7(a).

The ZIM is a narrow band structure, as we can see from Fig. 6. The real part of refractive index increases as the frequency surpasses 5 GHz, which results to deterioration of the ZIM performance. While the frequency reaches to below 5 GHz, the imaginary part of refractive index increases, thus the loss will also degrade the performance. As Fig. 7(b) shows, when the antenna is implemented with the ZIM structure, the −10 dB return loss frequency band splits into two as can be seen from Fig. 4 and Fig. 7. Since the ZIM structure is designed at 5 GHz, the interested radiation gain versus frequency is plotted in Fig. 8. At 5 GHz, the gain of the model with ZIM is 1 dB higher than the model without ZIM.

4. CONCLUSION

In this paper, we proposed a bow-tie antenna etched with the modified Sierpinski fractal pattern. With this pattern, the working frequency bandwidth expands from 24% (5.7∼7.3 GHz) to 41% (4.5∼6.8 GHz) compared with the original model. To improve gain performance, a ZIM structure is implemented with the antenna, and the gain increases by about 1 dB at the interested frequency.

REFERENCES

1. Zhou, B., H. Li, X. Zou, and T.-J. Cui, "Broadband and high-gain planar vivaldi antennas based on inhomogeneous anisotropic zero-index metamaterials," *Progress In Electromagnetics Research*, Vol. 120, 235–247, 2011.
2. Ma, Y. G., et al., "Near-field plane-wave-like beam emitting antenna fabricated by anisotropic metamaterial," *Applied Physics Letters*, Vol. 94, No. 4, 044107, 2009.
3. Cheng, Q., W. X. Jiang, and T. J. Cui, "Radiation of planar electromagnetic waves by a line source in anisotropic metamaterials," *Journal of Physics D: Applied Physics*, Vol. 43, No. 33 335406, 2010.
4. Kim, Y.-G., et al., "Design of bow-tie-type UWB antennas using an ultra-wideband balun," *2007 IEEE Antennas and Propagation Society International Symposium*, 2007.
5. Chiu, C.-W., "Coplanar-waveguide-fed uniplanar antenna using a broadband balun," *Microwave and Optical Technology Letters*, Vol. 40, No. 1, 70–73, 2004.
6. Li, D. and J.-F. Mao, "A Koch-like sided fractal bow-tie dipole antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 60, No. 5, 2242–2251, 2012.
7. Yamini, A. H. and M. Soleimani, "Multiband behavior of wideband sierpinski fractal bow-tie antenna," *The European Conference on Wireless Technology*, Vol. 3, 2005.
8. Lv, Y.-L., et al., "A zero index metamaterial lens for gain enhancement of patch antenna and H-plane horn antenna," *2013 IEEE International Wireless Symposium (IWS)*, 1–4, 2013.
9. Zhou, H., et al., "A novel high-directivity microstrip patch antenna based on zero-index metamaterial," *IEEE Antennas and Wireless Propagation Letters*, Vol. 8, 538–541, 2009.
10. Chung, K. L. and S. Chaimool, "Broadside gain and bandwidth enhancement of microstrip patch antenna using a MNZ-metasurface," *Microwave and Optical Technology Letters*, Vol. 54, No. 2, 529–532, 2012.