Progress In Electromagnetics Research Letters, Vol. 6, 61–66, 2009

UWB FILTER USING DEFECTED GROUND STRUCTURE OF VON KOCH FRACTAL SHAPE SLOT

J. An, G.-M. Wang, W.-D. Zeng, and L.-X. Ma

Missile Institute
Air Force Engineering University
Sanyuan 713800, China

Abstract—A coupled defected ground structure (CDGS) is presented which is synthesized by etching Von Koch fractal shape slot in the ground plane and series capacitive gap in the conductor strip. Unlike the structures loaded with complementary split ring resonators (CSRRs), the proposed structure can operate at very wide band. A UWB filter using the above structure is fabricated and tested. The relative bandwidth of the −10 dB return loss is 128% and the insertion loss is better than 1.5 dB except at high frequencies. The equivalent circuit model of the proposed structure is presented and the electrical parameters are also extracted. The circuit model results are compared with the simulated and measured results which verify that the equivalent circuit model is reasonable.

1. INTRODUCTION

Since the Federal Communications Committee (FCC) authorized the frequency band from 3.1 GHz to 10.6 GHz to be used for short-range wireless communications in 2002 [1], the ultra-wideband (UWB) technology has been a research hotpot in the field of wireless communications. As an important part of UWB wireless communication system, UWB filters have been widely researched by many researchers [2–5]. Presently, UWB filters are designed mainly based on two types of structures, double-layer coupled spurline and microstrip. The structure of double-layer coupled surpline is compact, but is complex and not easy to be modeled accurately, at the same, and needs fine fabrication techniques. The microstrip filter is generally of simple structure, however, of large dimensions.

Corresponding author: J. An (ajz982137@126.com).

CSRRs have been proposed as new constitutive elements for the synthesis of negative permittivity [8–10]. In microstrip technology, it has been demonstrated that one-dimensional LH metamaterials transmission line may be synthesized by etching CSRRs in the ground plane and series capacitive gaps in the conductor strip [9]. These structures have been improved (by introducing additional elements) and they have been applied to the design of compact planar filters with high performance and controllable characteristics [11, 12]. However the bandwidth is not enough for UWB applications. By etching ring slot in the ground, the wider bandwidth is achieved [7].

Fractal technologies are often used to reduce the sizes of the antenna and the component [13, 14]. In this paper, a coupled CDGS is presented which is synthesized by etching Von Koch fractal shape slot in the ground plane and series capacitive gap in the conductor strip. The proposed structure can operate at very wide band and is used to design an ultra-wideband (UWB) filter. The equivalent circuit model of the proposed structure is provided here for insight into the operation mechanism of it. The planar circuit simulation software Designer is used in the design process and the circuit simulation software Serenade is adopted during the electrical parameter extraction process.

2. PROPOSED STRUCTURE AND EQUIVALENT CIRCUIT MODEL

The proposed structure is shown in Fig. 1(a). The black area denotes conductor strip and the grey area denotes the ground plane. It can be seen that the proposed structure is a CDGS. When signal is input the slot line transmission model will be exited. It is well known that the slot line is a type of broadband transmission line, which is suitable for broadband application. On the other hand, if fractal technology is used for the slot line, the whole dimensions of the component can be reduced. Here, the Von Koch fractal curve is adopted. The Von Koch fractal shape slot is the result of the second iteration of the Von Koch curve [13]. The original curve is equilateral triangle with the side length of a. All the iterations are circumscribed inside a circumference of radius $r = \sqrt{3a}/3$. On the other hand, the perimeter increases at each new iteration. The overall perimeter for iteration is given by

$$l_k = 3a\left(\frac{4}{3}\right)^k \tag{1}$$

The circuit model of the proposed structure is displayed in Fig. 1(b). In this model, C_s is accounting for the slot capacitance under the conductor strip, L_s is the line inductance, C_g is the gap capacitance and C is the coupling capacitance between the line and the part surrounded by the Von Koch fractal shape slot. The Von Koch fractal shape slot resonator is described by means of a tandem tank, L_p and C_p being the reactive elements and R accounting for losses. Two sections of microstrip line are used to compensate the phase response in the proposed structure.

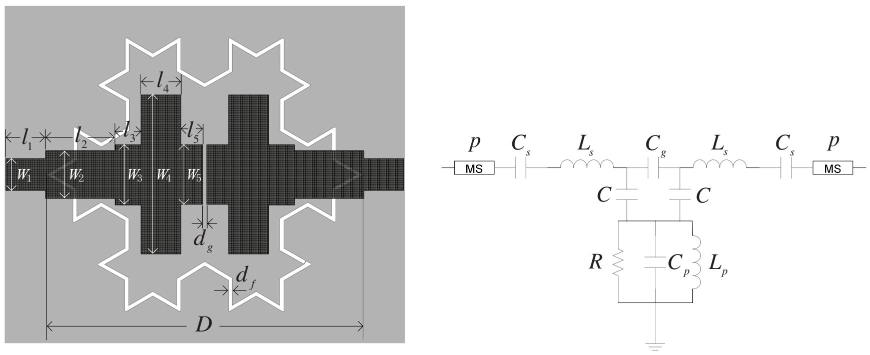

Figure 1. (a) Topology and (b) equivalent circuit model of the proposed structure.

3. ILLUSTRATIVE RESULTS

The Rogers5880 substrate board with thickness 0.508 mm and relative dielectric constant 2.2 is used in the whole design process. In order to obtain good transmission flatness performance, the stepped transmission line is used and the dimensions are as follows: $l_1 = 2$ mm, $w_1 = 1.6$ mm, $l_2 = 3.5$ mm, $w_2 = 2.4$ mm, $l_3 = 1.3$ mm, $w_3 = 3$ mm, $l_4 = 2$ mm, $w_4 = 8$ mm, $l_5 = 1.1$ mm, $w_5 = 3$ mm. Both gap separation dg and fractal shape slot width df are 0.2 mm and the diameter D of the circumference which circumscribes the Von Koch fractal shape slot is 16 mm. To demonstrate the viability of the equivalent circuit model of the proposed structure, we have applied it in circuit simulation software *Serenade* to the determination of the electrical parameters shown in Fig. 1(b). By matching the S parameters of the circuit model to the simulation ones of the proposed structure in *Designer*, the ethe electrical parameters of the equivalent circuit model are extracted as follows: $L_s = 1.11$ nH, $C_s = 6.76$ pF, $C_g = 2.06$ pF, $C = 0.14$ pF, $L_p = 0.04$ nH, $C_p = 2.88$ pF, $R = 1.19$ kΩ, $p = 11.5$ mm. And the length of each microstrip line section is 12.5 mm. For convenient measurement, a microstrip line section is added to each port of the proposed stricture, which can be seen in the fabricated prototype in Fig. 2. The simulated, circuit model and measured S parameters are compared and displayed in Fig. 3. It can be seen that the measured and simulated results agree well with each other except at attenuation poles and at about 13.2 GHz. The circuit model results agree well with the measured and simulated results except at low frequencies. It is possible that the proposed structure operates at different manners in such wide bandwidth and the circuit model is not always accurate. But the circuit model still provides for us the main operation principle of the proposed structure. By measurement results, the -10 dB return loss bandwidth is from 2.5 GHz to 11.4 GHz with relative bandwidth 128%. In this frequency bandwidth, the insertion loss is better than -1.5 dB except at high frequencies. The relative large insertion loss is mainly attributed to radiation loss. Since the proposed structure is extended in the fabrication process, the measurement phase is needed to be de-embedded in order to compare with the simulated and circuit model results. Fig. 4 plots the simulated, circuit model and measured (de-embedded) phases. It is observed that the *designer* simulation, circuit model and measurement results are consistent with each other except at low and high frequencies for circuit model. The possible reason for the discrepancy is mentioned above. The measured group delay is shown in Fig. 5. It can be seen that the group delay fluctuation is less than 0.1 ns in the bandwidth of interest, which is beneficial to narrow pulse applications.

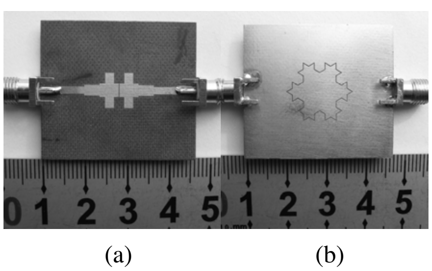

Figure 2. The prototype of the proposed structure. (a) Front side, (b) Back side.

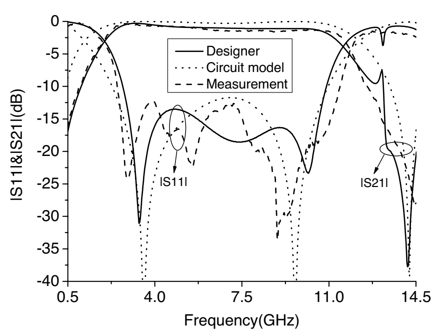

Figure 3. The simulated, circuit model and measured S parameters of the proposed structure.

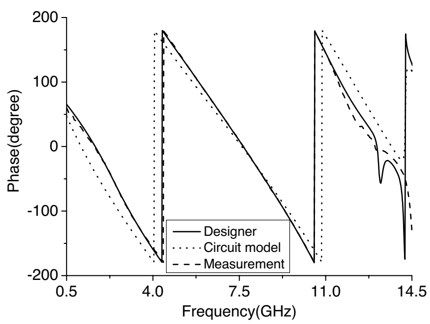

Figure 4. The simulated, circuit model and measured phases of the proposed structure.

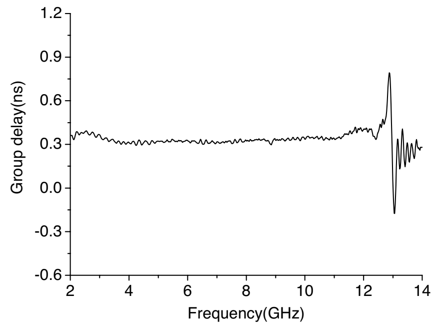

Figure 5. The measured group delay of the proposed structure.

4. CONCLUSIONS

In this paper, we proposed a novel CRLH TL structure which is synthesized by etching Von Koch fractal shape slot in the ground plane and series capacitive gaps in the conductor strip. A UWB filter using the proposed CRLH TL structure is realized. The UWB filter has good performance in group delay, and has comparable dimensions with the UWB filter reported in some literatures but adopt low dielectric constant substrate. How to improve out-off-band performance is under investigation. The equivalent circuit model of the proposed CRLH TL structure is presented and the electrical parameters are also extracted. The circuit model results are compared with the simulated and measured results which verify that the equivalent circuit model is reasonable.

REFERENCES

1. Federal Communications Commission, "Revision of part 15 of the commission's rules regarding ultra-wideband transmission system first report and order," Tech. Rep. ET Docket 98-153, FCC02-48, FCC, Feb. 2002.
2. Menzel, W., M. S. R. Tito, and L. Zhu, "Low-loss ultra-wideband (UWB) filters using suspended stripline," *Asia-Pacific Microwave Proceedings*, 2148–2151, 2005.
3. Sun, S. and L. Zhu, "Capacitive-ended interdigital coupled lines for UWB bandpass filters with improved out-of-band

performances," *IEEE Microw. Wireless Compon. Lett.*, Vol. 16, No. 8, 440–442, Aug. 2006.

4. Hsu, C.-L., F.-C. Hsu, and J.-T. Kuo, "Microstrip bandpass filters for ultra-wideband (UWB) wireless communications," *IEEE, MTT-S Int. Digest*, 679–682, 2005.
5. Hong, J.-S. and H. Shaman, "An optimum ultra-wideband microstrip filter," *Microw. Opt. Technol. Lett.*, Vol. 47, No. 3, 230–233, Nov. 2005.
6. Chen, H. and Y.-X. Zhang, "A novel and compact UWB bandpass filter using microstrip fork-form resonators," *Progress In Electromagnetics Research*, PIER 77, 273–280, 2007.
7. Naghshvarian-Jahromi, M. and M. Tayarani, "Miniature planar UWB bandpass filters with circular slots in ground," *Progress In Electromagnetics Research Letters*, Vol. 3, 87–93, 2008.
8. Falcone, F., T. Lopetegi, J. D. Baena, R. Marqués, F. Martín, and M. Sorolla, "Effective negative-ε stop-band microstrip lines based on complementary split ring resonators," *IEEE Microw. Wireless Compon. Lett.*, Vol. 14, No. 6, 280–282, Jun. 2004.
9. Falcone, F., T. Lopetegi, M. A. G. Laso, J. D. Baena, J. Bonache, R. Marqués, F. Martín, and M. Sorolla, "Babinet principle applied to the design of metasurfaces and metamaterials," *Phys. Rev. Lett.*, Vol. 93, 197401-4, Nov. 2004.
10. Bonache, J., M. Gil, I. Gil, J. García-García, and F. Martín, "On the electrical characteristics of complementary metamaterial resonators," *IEEE Microw. Wireless Compon. Lett.*, Vol. 16, No. 10, 543–545, Oct. 2006.
11. Bonache, J., I. Gil, J. García-García, and F. Martín, "New microstrip filters based on complementary split rings resonators," *IEEE Trans. Microw. Theory Tech.*, Vol. 54, No. 1, 265–271, Jan. 2006.
12. Bonache, J., F. Martín, I. Gil, J. García-García, R. Marqués, and M. Sorolla, "Microstrip bandpass filters with wide bandwidth and compact dimensions," *Microw. Opt. Technol. Lett.*, Vol. 46, 343–346, Aug. 2005.
13. Borja, C. and J. Romeu, "On the behavior of Koch island fractal boundary microstrip patch antenna," *IEEE Trans. Antennas Propag.*, Vol. 51, No. 6, 1281–1291, Jun. 2003.
14. Xiao, J.-K. and Q.-X. Chu, "Novel microstrip triangular resonator bandpass filter with transmission zeros and wide bands using fractal-shaped defection," *Progress In Electromagnetics Research*, PIER 77, 343–356, 2007.