Design of a Novel Chiral Fractal Resonator

Zinelabiddine Mezache[1], Chemseddine Zara[2], Fatiha Benabdelaziz[2]

Abstract: In this paper, we presented a compact resonator using a planar chiral fractal tree structure, where the chirality and the fractal form can combine several features at once. The chiral properties of this resonator, which are discussed based on their optical activity, circular dichroism, and the effect of the number of the iteration. Our chiral fractal structure is of major interest in scientific research, their characteristics have given rise to interesting new applications. Numerical results are given and discussed to confirm.

Keywords: Chiral media, Fractal form, Finite element method simulation.

1 Introduction

Chiral media are of major interest in scientific research [1 – 3]. Their characteristics have given birth to new amazing applications [4 – 6]. In our research, we are interested in the effects of chirality in transmission; and the properties specific to the latter, such as its circular dichroism. Chiral fractal structures are now of interest to researchers, for the control of electromagnetic waves with artificial structures in the microwave. Our work was aimed at the simulation study of a chiral resonator with a fractal shape, which will be intended for use in the field of a microwave.

The objective of this work is to develop a new class of microwave devices by showing the polarization of the electromagnetic wave by chiral fractal structures. The proposed approach is based on the development of strategies for the design of new chiral fractal forms. Consequently, the chirality of the transmission media, by the coupling of the TE (transverse electric) and TM (transverse magnetic) modes, allows the propagation of an elliptical polarization in these structures. This interest is focused not only on these new fundamental aspects but also on the potential applications of chirality in fractal structures.

The definition of transmission and reflection at the interface between two environments is achieved by solving the Fresnel equations, or by the S parameters. We will simulate a chiral fractal structure, representing both the

---

[1]Institute of Optics and fine mechanics, University of Ferhat Abbas Setif 1, 19000 Setif, Algeria;
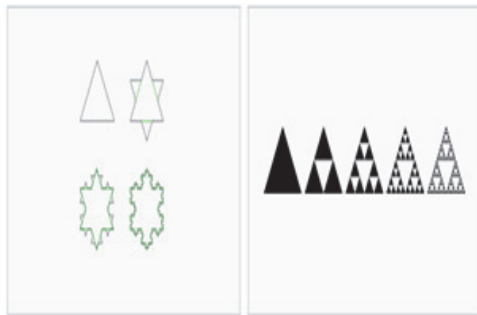 E-mail: zinemezaache@yahoo.fr
[2]Department of Electronic, University of Brothers Mentouri Constantine 1, 25000 Constantine, Algeria;
 E-mails: chemseddine.zara@gmail.com; benabdelaziz2003@yahoo.fr

properties of fractal structures and chirality, from the determination of S parameters, which are not identical for the chiral medium due to the existence of the circular polarization of the left and right wave (LCP and RCP). To illustrate the variation of the absorption, and the circular dichroism of chiral fractal structure, we use the commercial finite element method software (HFSS). We have studied a novel chiral fractal resonator that exhibits larger circular dichroism. The design principles defined in this article, which combine the concepts of the fractal geometry with the chirality (optical activity, circular dichroism, and absorption), represent a model for simulation of the properties of a more complex chiral for multifunctional.

2   Design and simulation

A fractal figure is a mathematical object, such as a curve or a surface, whose structure is invariant by scaling [7 – 10]. The fractal geometry is supported by its two properties i.e. self-similarity and space-filling (Fig. 1) [11].

(a)

(b)

Fig. 1– (a) *fractal shape in mathematics* (b) *Fractal shape in nature.*

Here we present the results of numerically simulated reflection spectra of a chiral fractal resonator (Fig. 2). This resonator using a planar fractal tree with four iteration (Fig. 3), is printed FR4 dielectric substrate with $\varepsilon_r = 2.2$, with an acceptable thickness of 1.53 mm, and with loss tangent of 0.0197. Also, the loading impedance of this microstrip line is 50 Ω. Numerical simulations were performed using the commercial finite element method software (HFSS). The reflection magnitude (S_{11}) for the resonator was carried out in the $1 - 10$ GHz band. Figs. $3 - 6$ show the variation of the reflection magnitude as a function of frequency with $d = 10$ mm to illustrate the proposed multi-band behavior for the fractal resonator.
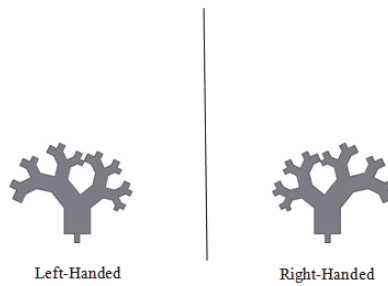
Left-Handed   Right-Handed

Fig. 2 – *The Chiral Fractal Tree.*

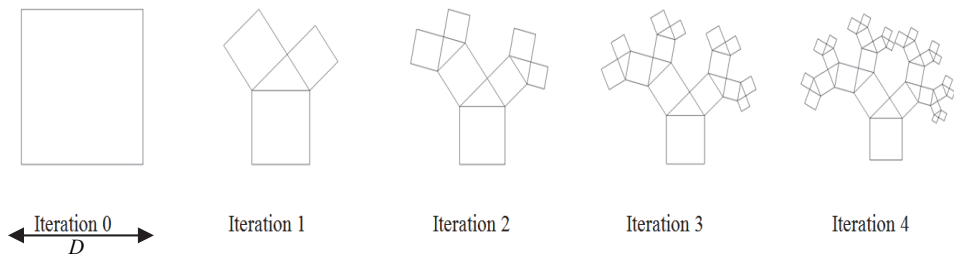Iteration 0   Iteration 1   Iteration 2   Iteration 3   Iteration 4
D

Fig. 3 – *The four first iterations of the Chiral Tree Fractal.*

2.1 Iterations of the Chiral Tree Fractal influence

The reflection Vs frequency plots for 1st, 2nd, 3rd and 4th iterations of proposed Chiral Tree Fractal are shown in Figs. $4 - 7$ respectively.

As shown in Figs. $4 - 7$, the Chiral Tree Fractal configuration operates at resonance frequencies (**Table 1**).

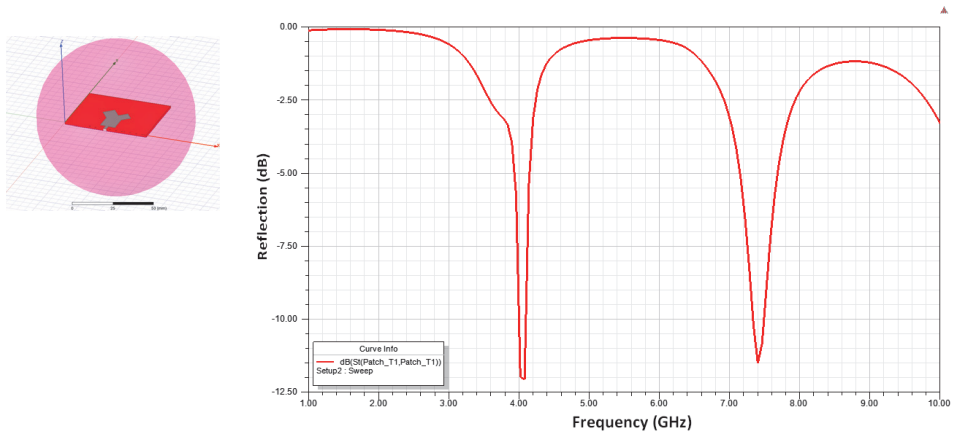According to **Table 1**, we can conclude that the multi-band behavior for our fractal resonator shown.

Fig. 4 – *Simulated reflection for* 1st *iteration of the Chiral Tree Fractal with d = 10 mm.*
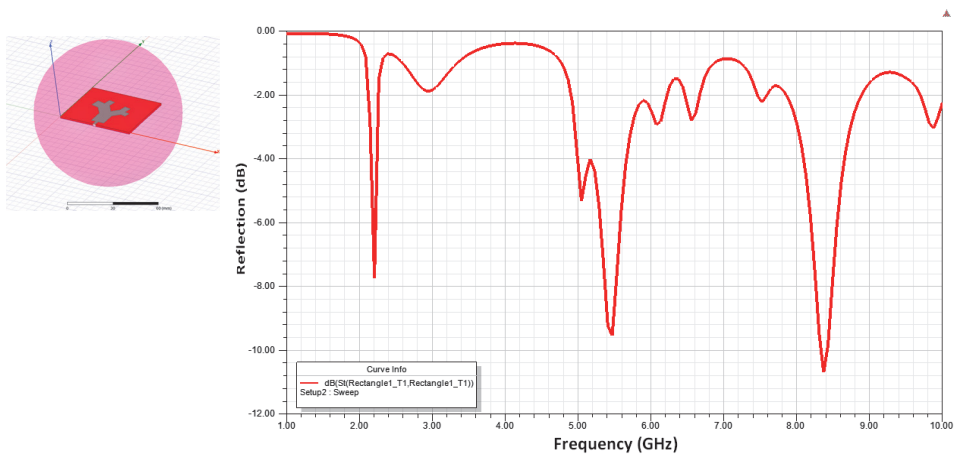

Fig. 5 – *Simulated reflection* for 2nd iteration *of the Chiral Tree Fractal with d* = 10 mm.

Table 1
Resonances frequencies.

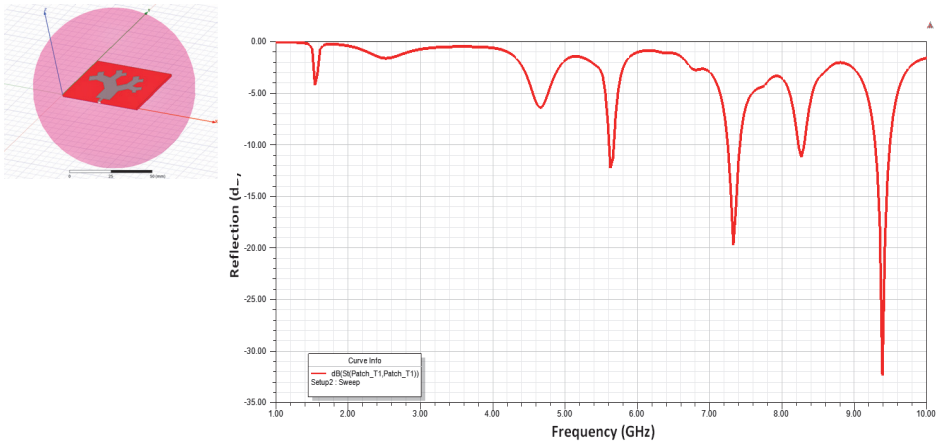| Patch configuration	Frequency bands (GHz)	Number of Frequency bands
1st iteration	4.1 / 7.4	02
2nd iteration	5.4 / 8.4	02
3rd iteration	5.6/7.4 /8.2 /9.4	04
4th iteration	2.6 /5.0/ 6.2 / 7.1/ 8.5	05

Fig. 6 – *Simulated reflection for* 3rd *iteration*
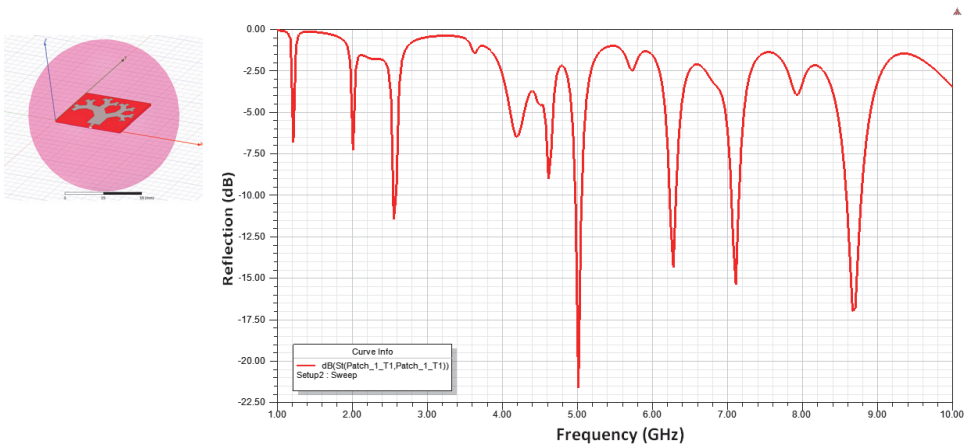*of the Chiral Tree Fractal with d = 10 mm.*

Fig. 7 – *Simulated reflection for* 4th *iteration*
of the Chiral Tree Fractal with d = 10 mm.

This chiral fractal resonator was simulated using HFSS and CST Microwave Studio Software.

The simulated results obtained from HFSS result are in close agreement with the simulated results obtained from CST MWS software as shown in Fig.8. There is a slight deviation between the two simulated results. This is because both the software are based on different Numerical techniques.
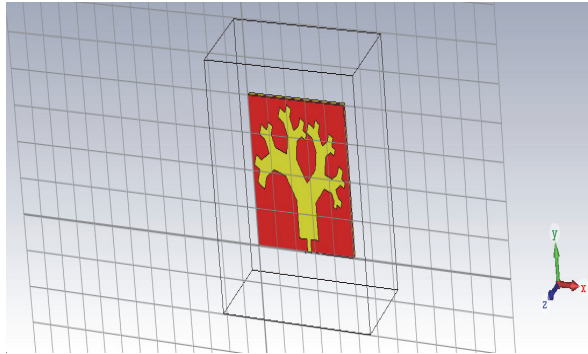
Fig. 8 – *Simulated reflection for* 4th *iteration with CST Microwave Studio software of the Chiral Tree Fractal with d = 10 mm.*
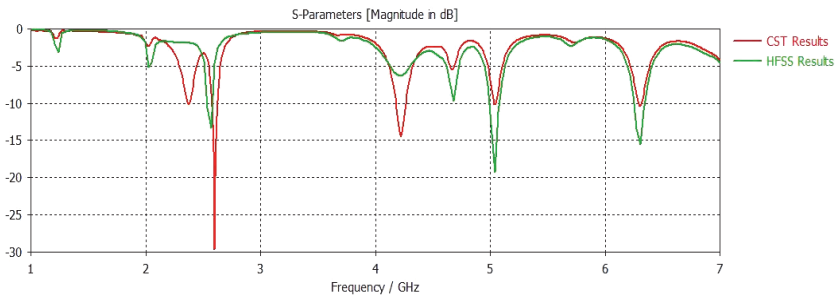

Fig. 9 – *The chiral fractal resonator simulated using HFSS and CST Microwave Studio software.*

A performance comparison between the proposed antenna and other designed antenna in literature in terms of antenna size, operating bands and antenna purpose with antennas reported in [13 − 15] is shown in **Table 2**.

Table 2
Comparison between the proposed antenna and some existing antenna.

Ref	Antenna size (mm^2)	Total area (mm^2)	Frequency bands (GHz)	Number of Frequency bands
[12]	75×75	5625	2.4/5.2	Dual-band
[13]	75×75	5625	2.4/5.2	Dual-band
[14]	70×60	4200	2.4/3.3/4.2	Tri-band
Proposed work	48×38	2000	2.6 /5.0/ 6.2 / 7.1/ 8.5	Five-band

2.2 Effects of chirality influence

We will study the reflection of an electromagnetic wave for a chiral fractal structure, calculating the parameter S_{11} for an LCP and RCP wave. In our work, we will use the transmission and reflection coefficients represented by the S parameters as follows:

S_{11}: Reflection coefficient at the input, when the output is adapted.

S_{21}: Direct transmission coefficient, when the output is adapted.

The definition of circular dichroism is as follows:

$$CD = |A_R - A_L| = \left| |S_{21R}|^2 - |S_{21L}|^2 \right|, \tag{1}$$

$$A_R = 1 - |S_{11R}|^2 - |S_{21R}|^2 \text{ and } A_L = 1 - |S_{11L}|^2 - |S_{21L}|^2,$$

A_R, A_L : Respectively are the absorption right and left.

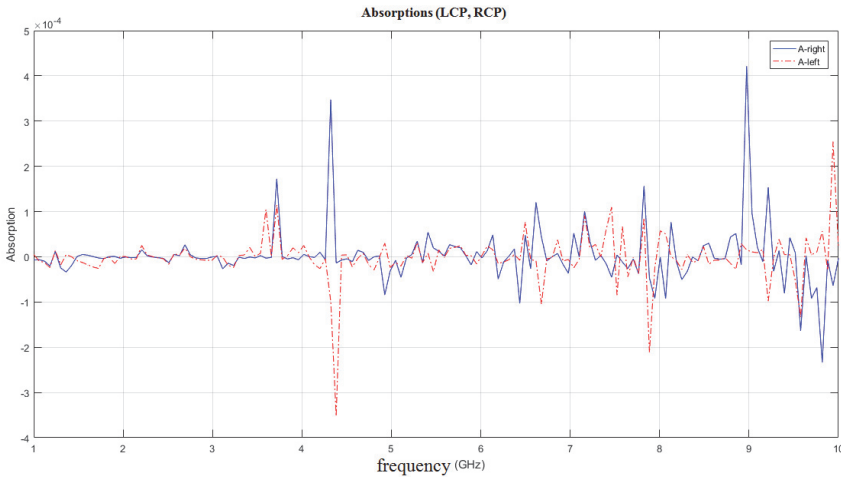S_{11R}, S_{11L} : Respectively are the reflection coefficients of RCP and LCP.

Fig. 10 – *Absorptions (LCP, RCP) variation for 4$^{\text{th}}$ iteration of the Chiral Tree Fractal with d = 10 mm.*

The results obtained from the numerical calculation demonstrate the absorption and the circular dichroism curves (Figs. 10 and 11), to highlight the effect of the chirality of the structure considered, which remains in perfect harmony with the law (1).

One can observe from Fig. 8 the absorption spectra of chiral fractal resonator differ considerably for left A_L and right-circularly A_R polarized components.
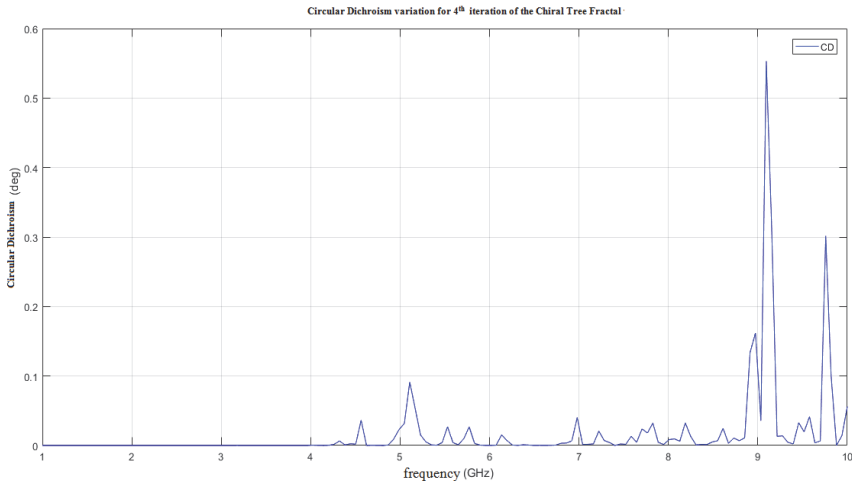
Fig. 11 – *Circular Dichroism variation for* 4th *iteration of the Chiral Tree Fractal with d = 10 mm.*

Fig. 9 shows the variation of circular dichroism as a function of frequency for the chiral fractal structure with $d = 10$mm:

– for the 5 GHz resonance frequency, the circular dichroism is of the order of 0.097 deg;

– for the 9.2 GHz resonance frequency, the circular dichroism is of the order of 0.56 deg;

– for the 9.7 GHz resonance frequency, the circular dichroism is of the order of 0.3.deg.

Therefore, the maximum value of the degree of circular dichroism is observed around 9.2 GHz. The CD spectrum has typically both positive and negative bands. These results led to the realization of novel circularly polarized devices in microwave.

3   Conclusion

The chiral fractal resonator with intrinsic cleanliness (chirality and fractal form) can combine several features at once. According to the results, the chiral fractal structures present windows on the transmission of the clearly separated structure, for the application in domains of precise frequency ranges. The curves plotted by Matlab illustrating circular dichroism indicate a remarkable variation in the frequency range, which is in perfect agreement with the characteristics of chiral media.

4 References

[1] A. H. Sihvola, I. V. Lindell: Chiral Maxwell Garnett Mixing Formula, Electronics Letters, Vol. 26, No. 2, January 1990, pp. 118 – 119.

[2] A. H. Sihvola, I. V. Lindel: BI-Isotropic Constitutive Relations, Microwave and Optical Technology Letters, Vol. 4, No. 8, July 1991, pp. 295 – 297.

[3] Z. Mezache, F. Benabdelaziz: Rigorous Approach of the Constitutive Relations for Nonlinear Chiral Media, Progress in Electromagnetics Research Letters. Vol. 52, March 2015, pp. 57 – 62.

[4] Z. Mezache, S. Seghaouil, W. Chaibi, F. Benabdelaziz: Optimization of Optical Nanoantenna Based on Structures Chiral Photonic Crystal, American Journal of Nanosciences. Vol. 3, No. 3, August 2017, pp. 47 – 52.

[5] Z. Mezache, F. Benabdelaziz: Nonlinear Effects in Chiral Nihility Metamaterial, Optical and Quantum Electronics, Vol. 50, No. 8, August 2018, pp. 328 – 338.

[6] M. Tarbouch, A. El Amri, H. Terchoune, O. Barrou: Compact PIFA Antenna with H-Tree Fractal for Mobile Handset Applications, Proceedings of the 2nd International Conference on Computing and Wireless Communication Systems, Larache, Morocco, pp. 5.1 – 5.6, November 2017.

[7] M. Tarbouch, A. El Amri, H. Terchoune, O. Barrou: A Compact Microstrip Patch Antenna Based on Fractal Geometry on the Ground Plane, Proceedings of the International Conference on Advanced Communication Technologies and Networking (CommNet), Marrakech, Morocco, April 2018, pp. 1 – 8.

[8] A. Reha, A. El Amri, M. Bouchouirbat: The Behavior of CPW-Fed Sierpinski Curve Fractal Antenna, Journal of Microwaves, Optoelectronics and Electromagnetic Applications, Vol. 17, No. 3, September 2018, pp. 366 – 372.

[9] N. Sharma, G. P. Singh, V. Sharma: Miniaturization of Fractal Antenna Using Novel Giuseppe Peano Geometry for Wireless Applications, Proceedings of the IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), New Delhi, India, July 2016, pp. 1 – 4.

[10] J. S. Sivia, S. S. Bhatia: Design of Fractal Based Microstrip Rectangular Patch Antenna for Multiband Applications, Proceedings of the IEEE International Advance Computing Conference (IACC), Bangalore, India, June 2015, pp. 712 – 715.

[11] R. Kumar, S. Gaikwad: On the Design of Nano-Arm Fractal Antenna for UWB Wireless Applications, Journal of Microwaves, Optoelectronics and Electromagnetic Applications, Vol. 12, No. 1, June 2013, pp. 158 – 171.

[12] H. ‑ M. Hsiao, J. ‑ W. Wu, Y. ‑ D. Wang, J. ‑ H. Lu, S. ‑ H. Chang: Novel Dual ‑ Broadband Rectangular ‑ Slot Antenna for 2.4/5 ‑ GHz Wireless Communication, Microwave and Optical Technology Letters, Vol. 46, No. 3, August 2005, pp. 197 – 201.

[13] J.- W. Wu: 2.4/5 ‑ GHz Dual ‑ Band Triangular Slot Antenna with Compact Operation, Microwave and Optical Technology Letters, Vol. 45, No. 1, April 2005, pp. 81 – 84.

[14] D. El Nabaoui, A. Tajmouati, J. Zbitou, A. Errkik, L. El Abdellaoui, Á. Mediavilla Sánchez: A New Design of a Low Cost Multiband Fractal CPW-Fed Antenna, International Journal of Microwave and Optical Technology, Vol. 13, No. 1, January 2018, pp. 1 – 7.