Fractal Monopole Antenna based on Tree Fractal for Future Bands 5G

EDGAR ALEJANDRO ANDRADE-GONZALEZ[1], MARIO REYES-AYALA[1],
JOSÉ IGNACIO VEGA LUNA[1], HILARIO TERRES-PEÑA[2], RENÉ RODRÍGUEZ RIVERA[2],
SANDRA CHÁVEZ SÁNCHEZ[2]
[1]Department of Electronics,
Metropolitan Autonomous University,
MEXICO

[2]Department of Energy,
Metropolitan Autonomous University,
MEXICO

Abstract: - This article shows the design and simulation of a broadband antenna based on a circular microstrip monopole using a Duroid substrate with a dielectric permittivity of 2.2 and a thickness of 1.27 mm. The simulations of this article were carried out using Ansys High Frequency Structure Simulator (HFSS). The antenna geometry presents replicas of the monopole following the tree fractal distribution. The S_{11} scattering, current distribution, and the radiation pattern were carried out. The antenna presented shows bandwidth for the new 5G FR2 band operation.

Key-Words: - 5G antenna, Duroid substrate, monopole antenna, tree fractal, UWB, WPAN.

Received: May 17, 2024. Revised: November 8, 2024. Accepted: December 11, 2024. Published: March 18, 2025.

1 Introduction

Wireless personal area networks (WPAN) focus their attention on low-coverage communication with individual needs. These types of networks are found in “wearable” systems with the military, sports, and everyday use applications, in automobiles, home automation systems, and in medicine. Antennas for this type of system have high-frequency handling (60 GHz) with wide bandwidth and beamforming management for different applications, [1], [2].

These systems are characterized by being of low complexity, optimizing the resources of the System that allows them to have low cost, as well as high electromagnetic compatibility with other radio communication systems.

The standards that govern WPAN Communications with low coverage, low costs, and low power consumption are included in the 802.15.X standards. These standards handle various transmission speeds using the 2.4 GHz and 5 GHz frequencies, [3]. Due to the aforementioned, the antennas that support these transmission bands, low profile and small size have been developed for various applications, [4], [5], [6], [7].

Similarly, WiGig systems (802.11ad) provide high transmission rates for short-range systems, although using unlicensed frequencies around 60 GHz. With low complexity in their devices and low power consumption, in addition to antennas with great bandwidth using various techniques such as slotting and directivity management for medical and localization applications using parasitic elements, [8].

Due to the aforementioned, the development of technology in portable devices that operate in bands such as 2.4 GHz, 5 GHz, and 60 GHz is of great importance, [9]. The design of broadband antennas presents characteristics in its structure, as well as construction materials such as its geometry, number of elements, and type of dielectric, among others in order to comply with operating frequencies and bandwidths of various communications systems (specifically WPAN systems), [10], [11], [12].

Antennas have been developed for WIFI-compatible Bluetooth systems and devices that operate in frequency bands with Internet of Things (IoT) applications, [13].

Ultra Wideband (UWB) systems work from 3.1GHz to 10.6 GHz with applications in medical, military, location display systems, among others Ultra Wideband (UWB) systems work from 3.1GHz to 10.6 GHz with applications in medical, military, location display systems, among others, [14], [15],

[16], [17]; and its antennas have a low profile and cost, [18], [19]. Nowadays, for WiGig systems, ultra-compact antennas have been achieved, which can be developed on low permittivity substrates showing a small size and operation around 60 GHz, [1], [20].

Among the antennas used in UWB systems [15] and WPAN [21], those antennas that use fractal geometry are ideal, because of their wide bandwidth, in addition to having a low profile, low cost, compactness, and a wide radiation pattern, [22], [23], [24], [25] [26], [27], [28], [29], [30].

In cellular systems nowadays, 5G bands are used from 450 MHz to 6 GHz (FR1) but there is another frequency range from 24.5 GHz to 52.6 GHz (FR2). In this letter, a compact wideband antenna for 5G FR2 bandwidth applications is presented, this fractal antenna is simulated using HFSS software.

2 Antenna Design

A monopole antenna with fractal behavior is presented, using the tree fractal as a base. As shown in Figure 1.

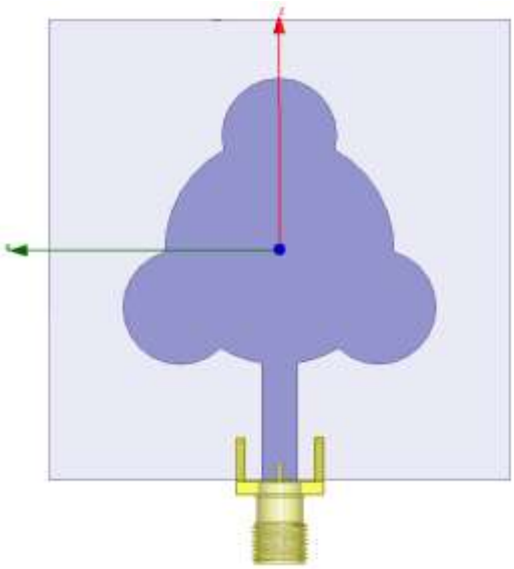

Fig. 1: Monopole fractal antenna

The geometry of the antenna begins from a circular monopole antenna (Figure 2), in which its geometry is modified, taking as the center of the circular element, the center of the tree fractal.

In [31] the study of the circular monopole achieves a minimum bandwidth of 3.1 GHz to 10.6 GHz (UWB frequency range), where they also introduce a slot in the ground plane and in the same patch with a rejection function band from 5 Ghz. to 6 GHz. However, the use and study of new frequency bands are present in the development of 5G and 6G cellular systems.

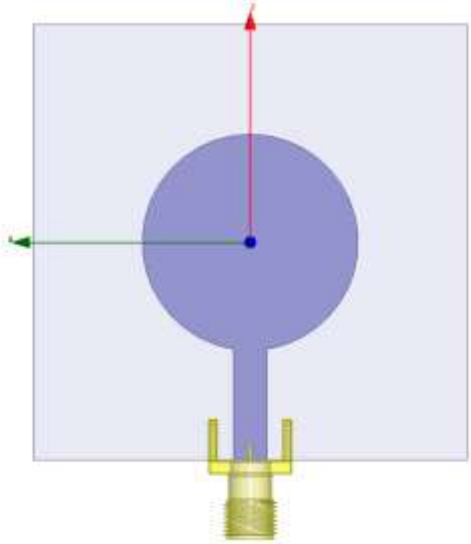

Fig. 2: Circular monopole antenna

The fractal of the tree begins with 3 segments of the same size as shown in Figure 3, where n=0, here the 2 upper branches are separated by an angle, in particular, we use 120 degrees of angle.

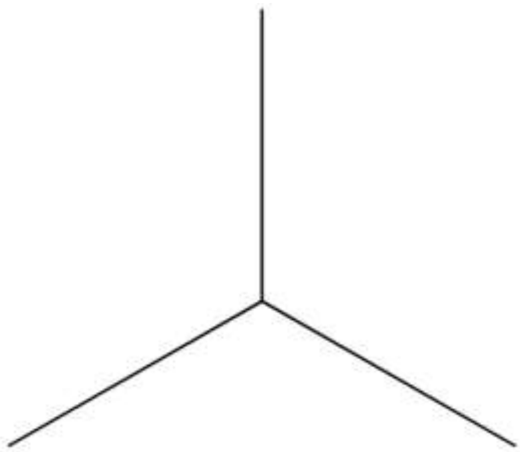

Fig. 3: Tree fractal with n=0

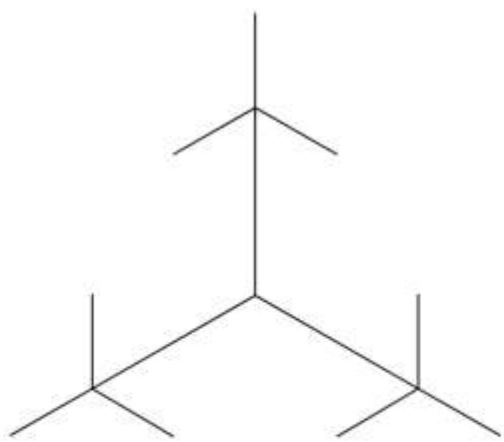

Fig. 4: Tree fractal with n=1

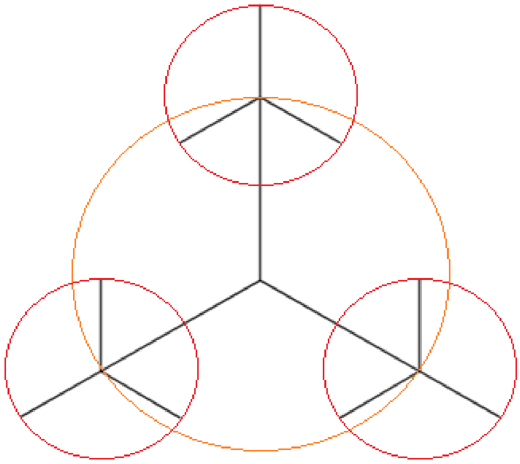

Fig. 5: Monopole-Tree fractal with n=1

For the value of n=1, 3 derivations of the line are made again at each end of the connected lines, following the same original configuration with new lengths equal to half the value of the previous lines (Figure 4).

Subsequently, and from each new tree branch, a circular monopole is generated with a radius equal to half of the previous circular monopole and whose center coincides with the union of the branches of the new iteration, as shown in Figure 5.

3 Results

In comparison with the circular monopole antenna where a bandwidth of 2.5 GHz to 10.5 GHz is obtained [32], it should be taken into account that the Kraus fractal technique and bevel technique were used in order to enhance the coupling antenna and increase your bandwidth. On the other hand, an antenna based on the circular monopole shows operating frequencies for the GPS system, [33]. For the proposed antenna, the same techniques are used in the ground plane, however, by adding the fractal variation of the tree with that of the monopole, as seen in Figure 6, a coupling of the antenna is obtained from 21.05 GHz to 30.51 GHz. operating within the FR2 bandwidth of 5G systems, a bandwidth of 1 GHz (from 8.7 GHz to 9.9 GHz) within the UWB bandwidth, and a bandwidth of 2.2 GHz (from 12.25 GHz to 14.42 GHz), as shown by the dispersion parameter S_{11} (return losses) in Figure 7.

Fractal geometry reduces the size of antennas by displaying wide bandwidths or multiple operating frequencies by increasing the number of iterations; however, hybrid fractal structures are mixed in order to modify their radiation pattern and other properties. Examples of fractal antennas that present various bandwidths for UWB and SWB applications are found in [32] where bandwidths from 2.7 GHz to 18.8 GHz (UWB) are achieved, some applications with multiband response (from 1.5 to 2.7 GHz and 5.1 to 5.8 GHz) and wide bandwidths in SWB systems (from 35 GHz to 85 GHz), [34].

Figure 8 shows the radiation pattern and Figure 9 shows the distribution of currents in the antenna, where a uniform distribution is observed.

The radiation pattern and distribution of currents show a behavior suitable for short and medium-range communications, so in future work we will seek to present a regular or quasi-omnidirectional pattern.

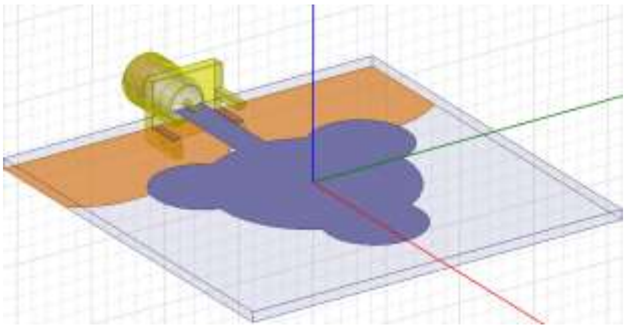

Fig. 6: Antenna model in HFSS

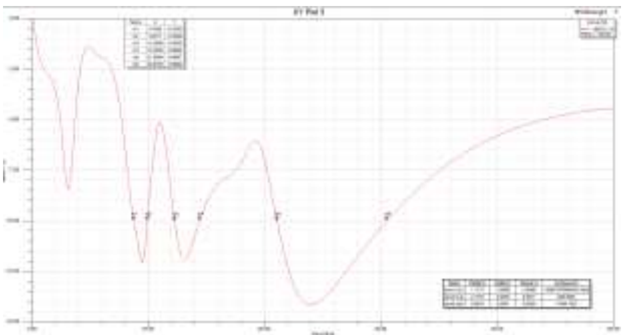

Fig. 7: Return Losses (S_{11} Parameter)

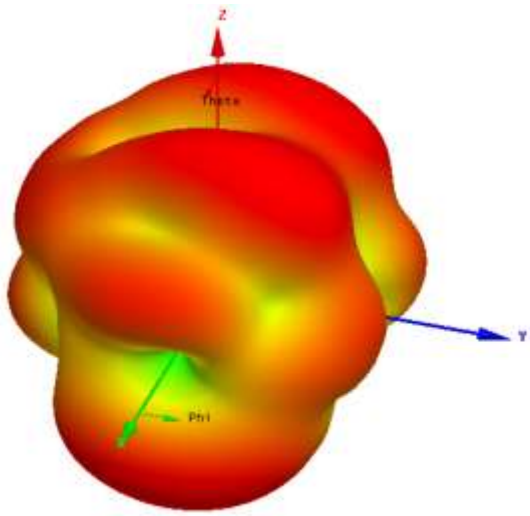

Fig. 8: Radiation pattern of the fractal antenna

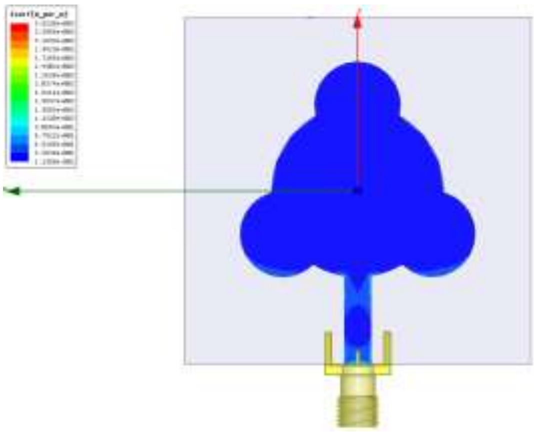

Fig. 9: Current distribution in the fractal antenna

4 Conclusion

The proposed antenna shows coupling for the new FR2 band of 5G systems. In the future, the aim is to reduce decoupling in 11 GHz and 19 GHz in order to increase the bandwidth of the proposed antenna.

In future work, the aim is to implement modern algebraic methods in the distribution of the fractal geometry of the antennas.

Acknowledgment:
This work was supported by the research project “Diseño, Desarrollo y evaluación de antenas de banda ultra ancha (UWB) para aplicaciones en la banda de 3.1 GHz a 10.6 GHz.” (EL002-20). From Metropolitan Autonomous University – Azcapotzalco.

References:

[1] M. Imbert, A. Papió, F. De Flaviis, L. Jofre and J. Romeu, “Design and Performance Evaluation of a Switched-Beam Antenna Array for 60 GHz WPAN Applications,” *9th European Conference on Antennas and Propagation (EuCAP)*, Portugal, 2015.

[2] Z. Dong, Z. Jiang, M. Leach, Z. Wang, J. Wang, W. Zhang and R. Pei, “A Compact Versatile Multi-band Antenna for WPAN Applications,” *2024 IEEE International Symposium on Antennas and Propagation and INC/USNC-URSI Radio Science Meeting (AP-S/INC-USNC-URSI)*, pp. 629-630, Italy, 2024, DOI: 10.1109/AP-S/INC-USNC-URSI52054.2024.10685858.

[3] D. Coppens, A. Shahid, S. Lemey, B. Van Herbruggen, Ch. Marshall and E. De Poorter, “An Overview of UWB Standards and Organizations (IEEE 802.15.4, FiRa, Apple): Interoperability Aspects and Future Research Directions,” Vol. 10, pp. 70219-70241, 2022.

[4] J. Gnanathickam, G. Thanusha and N. Moses, “Design and Development of Microstrip Patch Antenna for 5G Application,” *2023 International Conference on Computer Communication and Informatics (ICCCI),* pp. 1-4, India, 2023, DOI: 10.1109/ICCCI56745.2023.10128505.

[5] L. Pazin and Y. Leviatan, “A Compact 60-GHz Tapered Slot Antenna Printed on LCP Substrate for WPAN Applications,” *IEEE Antennas and Wireless Propagation Letters,* Vol. 9, pp. 272-275, 2010, DOI: 10.1109/LAWP.2010.2046612.

[6] A. Artemenko, A. Maltsev, A. Mozharovskiy, A. Sevastyanov, V. Ssorin and R. Maslennikov, “Millimeter-Wave Electronically Steerable Integrated Lens Antennas for WLAN/WPAN Applications,” *IEEE Transactions on Antennas and Propagation,* Vol. 61, No. 4, pp. 1665-1671, 2013, DOI: 10.1109/LAWP.2017.2690440.

[7] M. Garbaruk, “Radiation of Planar Stripline Ultrawideband Antenna for WPAN Systems,” *6th International Conference on Antenna Theory and Techniques,* pp. 274-275, Ukraine, 2007, DOI: 10.1109/ICATT.2007.4425182.

[8] M. S. Ibrahim, “Low-Cost, Circularly Polarized, and Wideband U-Slot Microstrip Patch Antenna with Parasitic Elements for WiGig and WPAN Applications,” *13th European Conference on Antennas and Propagation (EuCAP)*, pp. 1-4, Poland, 2019.

[9] Y. Xia, Y. Li, W. Xue, L. Zhao, E. Sinkevich and V. Mordachev, “A Passive Component Incorporated Miniaturization Super-Wideband Antenna for EMC Measurement,” *2024 IEEE International Symposium on Antennas and Propagation and INC/USNC-URSI Radio Science Meeting*, pp. 2073-2074, Italy, 2024, DOI: 10.1109/AP-S/INC-USNC-URSI52054.2024.10686153.

[10] M. S. Ibrahim, “Design of Low-Cost, Circularly Polarized, and Wideband U-Slot Microstrip Patch Antenna with Parasitic Elements for WiGig and WPAN Applications,” *Applied Computational Electromagnetics Society Journal,* Vol. 34, No. 9, pp. 1453-1456, 2019.

[11] L. R. Tan, Ch. Yanhuan, W. Duan and Z. Li, “Coplanar Waveguide Fed Roof-Shaped Multiband Antenna for WPAN Applications,” *5th International Conference on Circuits,*

Systems and Simulation (ICCSS), pp. 146-150, China, 2022, DOI: 10.1109/ICCSS55260.2022.9802137.

[12] M. Klemm, I. Z. Kovcs, G. F. Pedersen and G. Tröster, "Novel Small-Size Directional Antenna for UWB WBAN/WPAN Applications," *IEEE Transactions on Antennas and Propagation,* Vol. 53, No. 12, pp. 3884-3896, 2005, DOI: 10.1109/TAP.2005.859906.

[13] A. Firoz, K. Hasnat, Abu M. T. I. Abu Zafor, "An Ultra-Wideband Patch Antenna for Future Internet of Things Applications," *Journal of Science and Arts,* Vol. 23, No. 4, pp. 1067-1080, 2023, DOI: 10.46939/J.Sci.Arts-23.4-c01.

[14] W. A. Alamro, B. C. Seet, L. Wang and P. Parthiban, "Compact Super-Wideband Antenna for Medical Imaging Applications," *2021 IEEE Conference on Antenna Measurements & Applications (CAMA)*, pp. 505-508, France, 2021, DOI: 10.1109/CAMA49227.2021.9703550.

[15] Federal Communications Commission, First Report and Order, Revision of Part 15 of the Commission's Rules Regarding Ultra WideBand Transmission Systems, February 2002, [Online]. https://www.fcc.gov/document/revision-part-15-commissions-rules-regarding-ultra-wideband-7 (Accessed Date: October 15, 2024).

[16] Y. Han, Ch. Zhang, M. Ma and X. Liao, "Ultra-wideband Vivaldi antenna for applications in microwave medical imaging," *IEEE 7th International Conference on Electronic Information and Communication Technology (ICEICT)*, pp. 344-347, China, 2024, DOI: 10.1109/ICEICT61637.2024.10671030.

[17] Y. Rahayu, R. Ngah and T. A. Rahman, "Various Slotted UWB Antenna Design," *6th International Conference on Wireless and Mobile Communications,* Spain, 2010, DOI: 10.1109/ICWMC.2010.96.

[18] M. Afzaal Khan, A. Abdur Rahim and W. Tariq Sethi, "Design of Low Profile Broadband Wearable Antenna for On Body WBAN Applications," *18th IEEE Int. Conf. on Emerging Technologies, FAST-NUCES,* Pakistan, 2023.

[19] A. Yadav, D. Sethi and R. K. Khanna, "Slot loaded UWB antenna Dual band notched characteristics," *International Journal of Electronics and Communications (AEÜ),* vol. 70, No. 3, pp. 331-335, 2015, DOI: 10.1016/j.aeue.2015.12.014.

[20] S. Kundu and A. Chatterjee, "A compact super wideband antenna with stable and improved radiation using super wideband frequency selective surface," *International Journal of Electronics and Communications,* Vol. 150, pp. 2022, DOI: 10.1016/j.aeue.2022.154200.

[21] B. Lee and Y. Yoon, "Low-Profile, Low-Cost, Broadband Millimeter-Wave Antenna Array for High-Data-Rate WPAN Systems," *IEEE Antennas and Wireless Propagation Letters,* Vol. 16, pp. 1957-1960, 2017, DOI: 10.1109/LAWP.2017.2690440.

[22] G. Kalkhambkar, R. Khanai and P. Chindhi , "A Novel Snail Shell Inspired Wideband Fractal Antenna for Internet of Things Applications," *Arabian Journal for Science and Engineering,* Vol. 48, pp. 15463-15474, 2023, DOI: 10.1007/s13369-023-08079-y.

[23] I. H. Nejdi, S. Bri, M. Marzouk, S. Ahmad, Y. Rhazi, M. Ait Lafkih, Y. Ali Sheikh, A. Ghaffar and M. Hussein, "UWB Circular Fractal Antenna with High Gain for Telecommunication Applications," *Sensors,* 2023.

[24] A. Sabban, "New Fractal Compact Printed Antennas," *2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, pp. 2197-2198, USA, 2017, DOI: 10.1109/APUSNCURSINRSM.2017.8073141

[25] S. Singhal, "CPW fed circular Sierpinski terahertz antenna for super wideband pattern diversity applications," *Optik - International Journal for Light and Electron Optics,* Vol. 243, 2021, DOI: 10.1016/j.ijleo.2021.167430.

[26] M. Susila and T. Rama Rao, "Design of a Novel Microstrip-fed UWB Fractal Antenna for Wireless Personal Area Communications," *2015 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, pp. 1815-1818, India, 2015, DOI: 10.1109/ICACCI.2015.7275879.

[27] A. Dalmiya and O. P. Sharma, "A Novel Design of Multiband Minkowski Fractal Patch Antenna with Square Patch Element for X and Ku Band Applications," *2016 International Conference on Recent Advances and Innovations in Engineering (ICRAIE-2016)*, India, 2016, DOI: 10.1109/ICRAIE.2016.7939567.

[28] N. Cohen, R. Hohlfeld, D. Moschella and P. Salkind, "Fractal Wideband Antennas for

Software Defined Radio, UWB, and Multiple Platform Applications," *Radio and Wireless Conference, 2003. RAWCON '03. Proceedings,* pp. 99-102, United States of America (USA), 2003, DOI: 10.1109/RAWCON.2003.1227902.

[29] K. Inamdar, P. Avhad and U. D. Dalal, "Fractal Metamaterial Inspired MSA for Wearable Devices," *2019 IEEE Indian Conference on Antennas and Propagation (InCAP),* India, 2019, DOI: 10.1109/InCAP47789.2019.9134528.

[30] O. Abbes, "The Study of Sierpinski Fractal Antennas for Detecting Various Object Forms," *WSEAS Transactions on Communications*, Vol. 22, No. 10, pp. 110-116, 2023, https://doi.org/10.37394/23204.2023.22.10.

[31] C.-Y.-D. Sim, W.-T. Chung, and C.-H. Lee, "A circular-disc monopole antenna with band-rejection function for ultrawideband application," *Microwave and Optical Technology Letters*, Vol. 51, No. 6, pp. 1607–1613, 2009, DOI: 10.1002/mop.24379.

[32] J. A. Tirado-Mendez, D. Martinez-Lara, H. Jardon-Aguilar, R. Flores-Leal and E. A. Andrade-Gonzalez "Inscribed Fibonacci Circle Fractal in a Circular Radiator for Ultra-Wideband Antenna Operation and Size Reduction," *International Journal of Antennas and Propagation,* Vol. 2019, DOI: 10.1155/2019/6393401.

[33] I. A. Hidalgo-García, M. Reyes-Ayala, E. A. Andrade-González, S. Chávez-Sánchez, H. Terres-Peña, J. I. Vega-Luna, Rene Rodríguez-Rivera, "Microstrip GPS Circular Antenna for Terrestrial Transportation Systems," *WSEAS Transaction on Communications*, Vol. 23, No. 2, pp. 11-17, 2024, https://doi.org/10.37394/23204.2024.23.2.

[34] K. Anirban, "Fractal antennas and arrays A review and recent developments," *International Journal of Microwave and Wireless Technologies,* Vol. 13, No. 2, pp. 173-197, 2020.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Edgar Alejandro Andrade González carried out the antenna design and obtained the surface currents distribution simulation.
- Mario Reyes did the simulation and analysis of the radiation pattern, also, the supervision and validation.
- Hilario Terres and Sandra Chávez Also carried out the simulation of the S_{11} parameter. Both supervised the methodology.
- José Ignacio Vega Luna described the introduction of the paper and the design of the feeder transmission line.
- René Rodríguez checked spelling and grammar. Also, he wrote, review and edited. Finally, he helped with supervision.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

This work was supported by the research project EL002-20 at the Metropolitan Autonomous University in Mexico City.

Conflict of Interest

The authors have no conflicts of interest to declare.