Compact Antenna based on Fractal for IoT Sub-GHz Wireless Communications

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***Abstract*— This work presents the design of a compact antenna using microstrip patch based on a fractal model for use in Internet-of-Things (IoT) wireless communication in sub-GHz bands. The proposed antenna was implemented on a low cost FR-4 substrate and work in the 433 MHz and 915 MHz or 868 MHz frequencies that are ISM bands used in the IoT networks. The suggested antenna has been manufactured and experimentally characterized, showing a good agreement with the expected simulated results.**

Keywords*— *Antenna, microstrip, multiband, IoT, Internet-of-Things, LPWAN, LoRaWAN, LoRa.

I. Introduction

With the advancement of Internet-of-Things (IoT) emerged the concept of a network architecture where the end-devices relay messages with a gateway connected with a central network server in the backend (see Figure 1) [1]. This communication between end-devices and gateway is usually wireless communication using ISM bands in frequencies below of 1 GHz (sub-GHz) and this is due to the fact that the date rates is variable between 0.3 kbps and 50 kbps to maximize both battery life of the end-devices and overall network capacity [2] [3]. An example of this type of network is the LoRaWAN [4] that is a Low Power Wide Area Network (LPWAN) to use in the IoT networks. The frequency bands used in IoT networks how the LoRaWAN varies slightly from region to region based on the different regional spectrum allocations and regulatory requirements, but typically use ISM bands in sub-GHz frequencies [5].

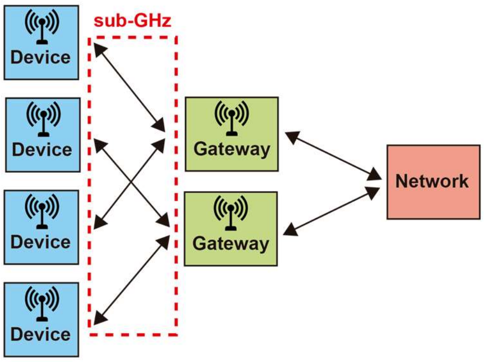

Fig. 1. Example of a network architecture to IoT

This article proposes a compact antenna with dimensions of 95 mm x 75 mm x 1.6 mm using FR-4 substrate for operate in frequencies of 433 MHz and 915 MHz or 868 MHz (ISM bands). To achieve the objective of this project, which is the design of a compact antenna for use in multiband, a microstrip patch antenna with miniaturization techniques including the use of fractal geometry was adopted. The simulations were performed by using ANSYS HFSS software [6].

II. Antenna Design

The antenna adopted as the starting point was a rectangular microstrip patch antenna which is a type of antenna widely used due its characteristics of low weight and profile, low production cost, ease of production and integration (Fig. 2).

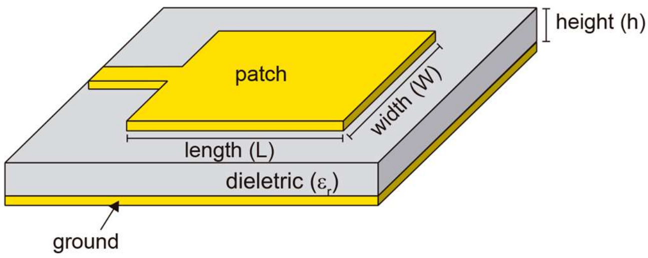

Fig. 2. Microstrip patch antenna

The substrate chosen was FR-4 because is a low cost material and is the most widely used. In time, FR-4 does not specify specific material, only a grade of material, as defined by NEMA in 1968 [7].

The dimensions of the rectangular microstrip patch antenna can be calculated by well-known Transmission-Line model [8]. Using $\varepsilon_r = 4.4$ that is the dielectric constant of the FR-4 substrate and h = 1.6 mm that is height of substrate, the dimensions of the rectangular patch antenna to 433 MHz are W = 210.8 mm and L = 162.2 mm and to 915 MHz the dimensions are W = 99.7 mm and L = 73.3 mm.

From the rectangular microstrip patch antenna, a miniaturization technique based on a fractal geometry was adopted, where it is possible to have a large electric length in a small physical volume [9] [10]. The fractal geometry adopted was based on Minkowski fractal curve that can have infinite interactions (Fig. 3) [11] [12], however, in this paper just one iteration was used as a trade-off between size and antenna parameters, since the first iteration provides a good area reduction while for each additional iteration there is a degradation in the antenna parameters [13] [14] [15]. Furthermore, from the second interaction Minkowski fractal the geometrical characteristics become more complex and difficult to implement with simple pcb manufacturing techniques.

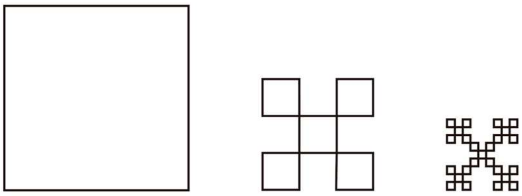

Fig. 3. Iterations of the microstrip patch antenna based on a variant of fractal Minkowski curve.

The final modifications on the antenna include the chamfers in the radiating element to improve the antenna impedance matching over frequencies [16]. The slot in the ground neutralizes the capacitive to get nearly pure resistive input impedance [17] [18] and obtain a better impedance matching. The chamfers and slot dimensions were determined through a parametric choice in simulation software.

The Fig. 4 shows the final antenna structure. It is possible to modify the frequency of 915 MHz to 868 MHz (ISM band in Europe) with few changes in dimensions. The Table I show the dimensions to 433 MHz and 915 MHz or 433 MHz and 868 MHz.

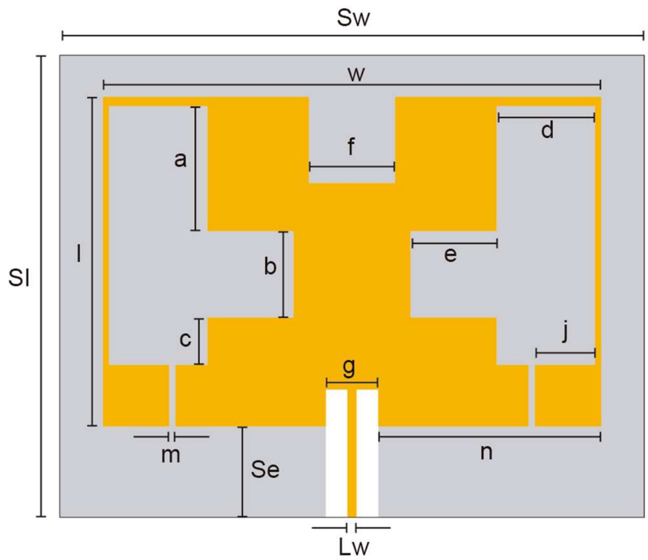

Fig. 4. The proposed antenna with dimensions.

TABLE I. DIMENSIONS

Dimensions (Fig. 4)	915 MHz and 433 MHz (mm)	868 MHz and 433 MHz (mm)
a	19.8	20.3
b	14.0	14.0
c	8.2	7.7
d	17.0	19.3
e	14.0	14.0
f	14.0	14.0
g	8.5	8.5
j	9.0	8.5
l	53.5	53.5
m	1.0	1.0
n	36.2	36.2
w	81.0	81.0
Se	14.7	14.7
Lw	1.5	1.5
Sl	75.0	75.0
Sw	95.0	95.0

Therefore, using size reduction techniques based on fractal geometry, it was possible to reduce the initially calculated dimensions from 210.8 mm x 162.2 mm to 95 mm x 75 mm, but there were degradations in some antenna parameters, mainly the gain for the low frequency operating (433 MHz).

The simulation of the antenna was performed by using the full wave simulator Ansoft HFSS and the Fig. 5 shows the simulated 3D total directivity to 433 MHz, 915 MHz and 868 MHz. The Fig. 6 shows the simulated radiation pattern also to 433 MHz, 915 MHz and 868 MHz. The simulated peak gains are -14.8 dBi for 433 MHz, 3.2 dBi for 915 MHz and 2.1 dBi for 868 MHz.

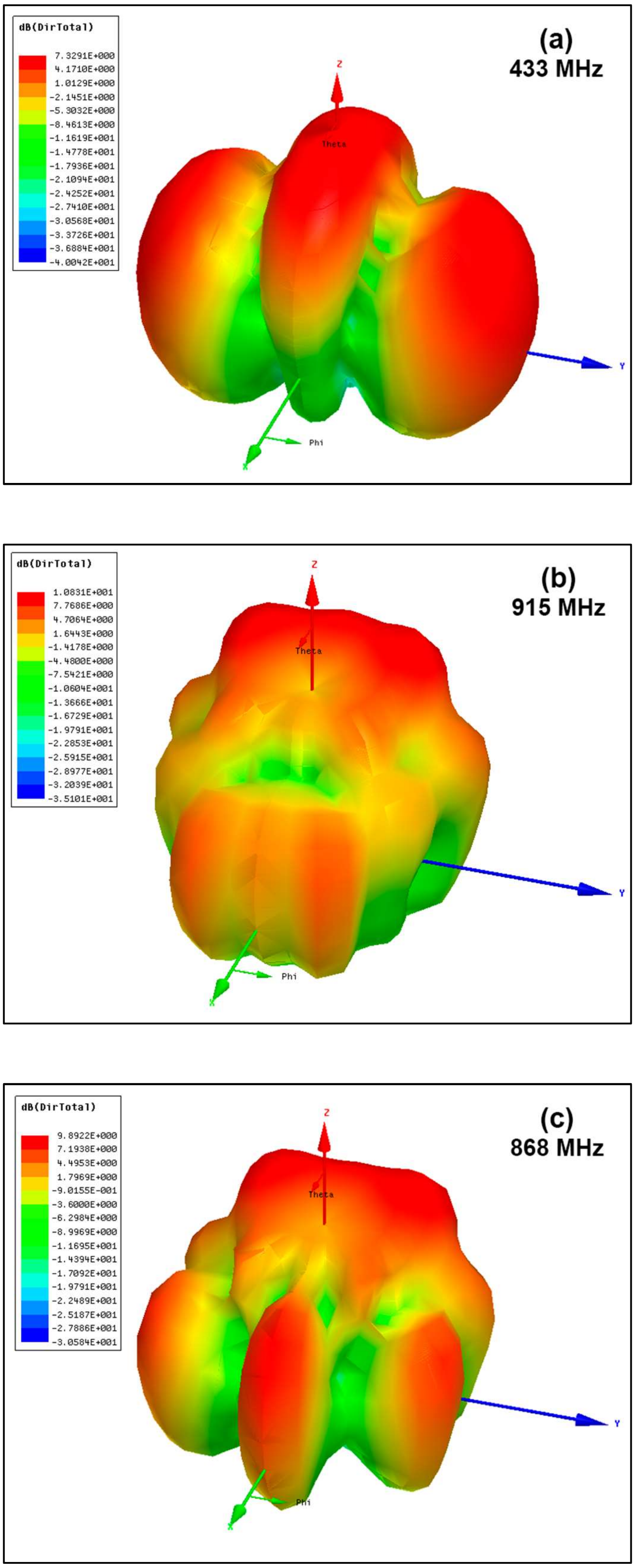

Fig. 5. Simulated 3D total directivity for (a) 433 MHz, (b) 915 MHz and (c) 868 MHz

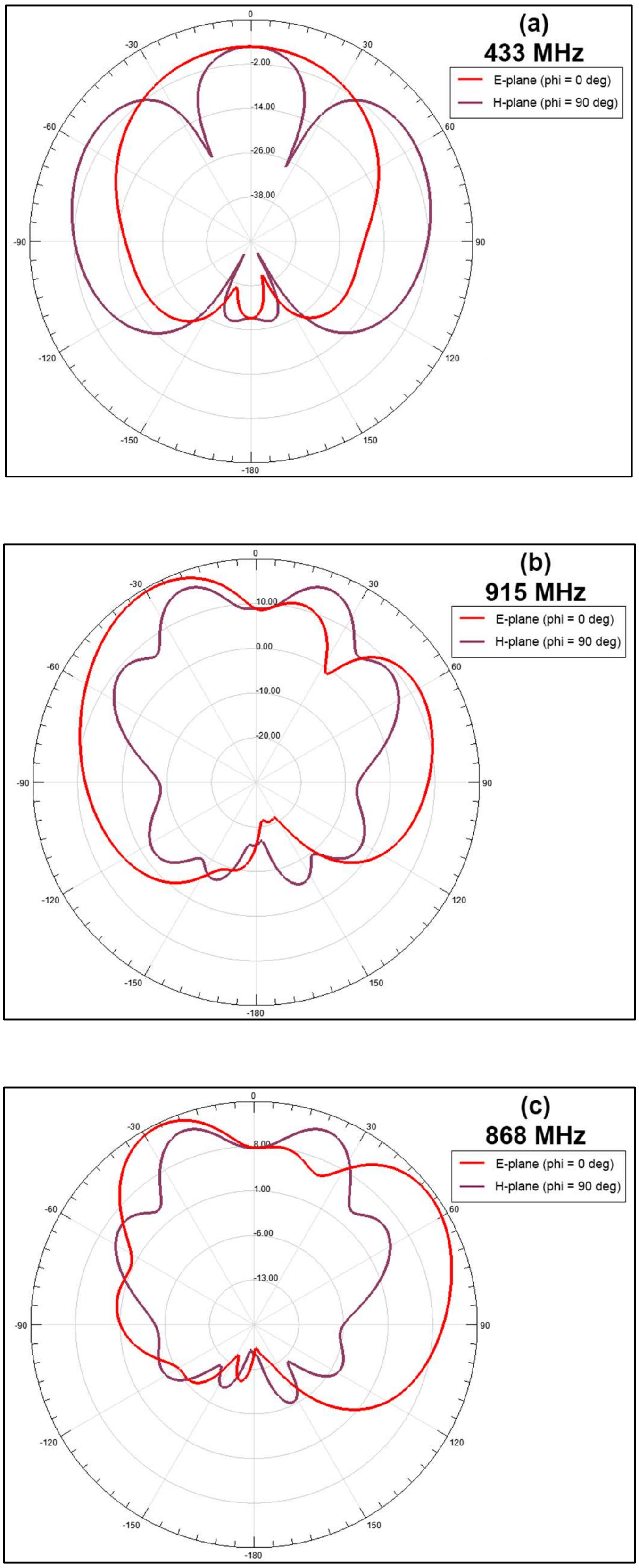

Fig. 6. Simulated radiation pattern for (a) 433 MHz, (b) 915 MHz and (c) 868 MHz

The surface current distributions at center frequencies of the three bands are given in Fig. 7.

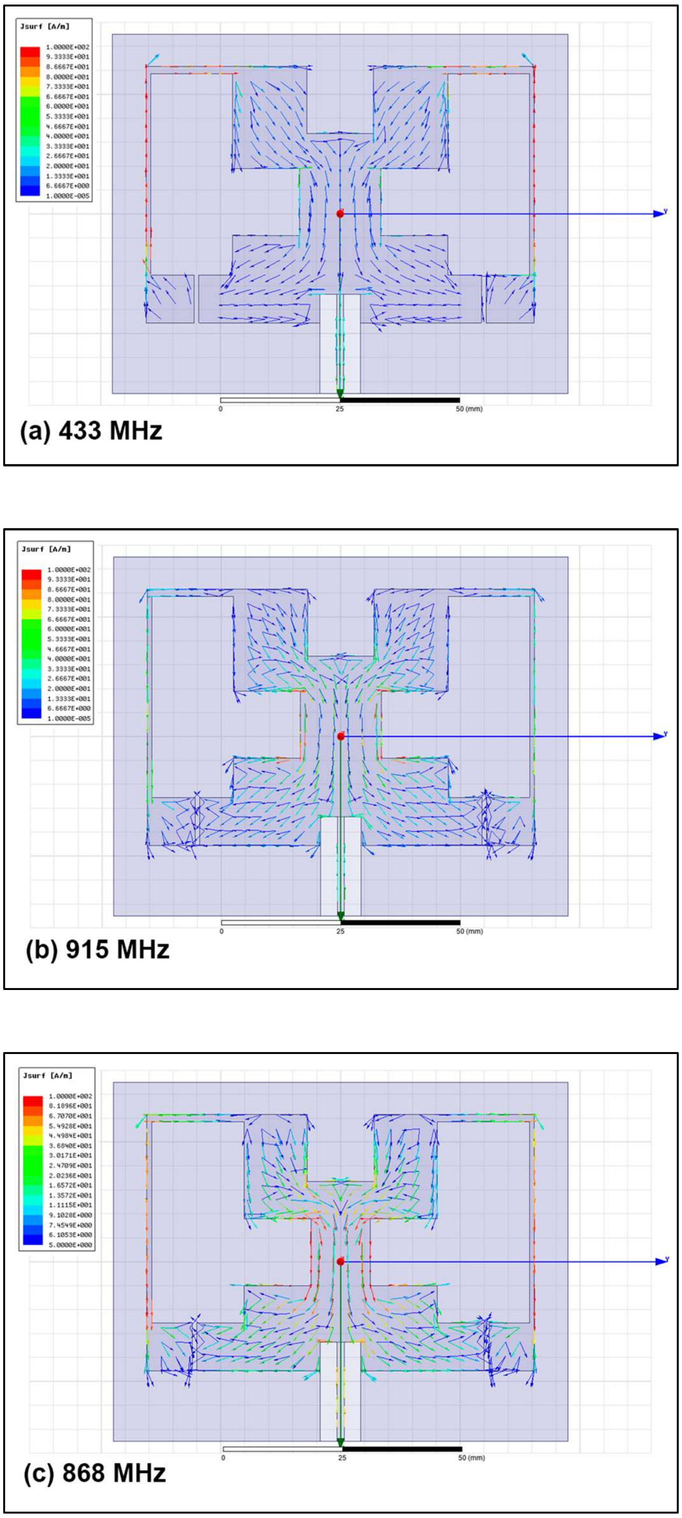

Fig. 7. Simulated J-field vectors of the proposed antenna at (a) 433 MHz, (b) 915 MHz and (c) 868 MHz.

III. Results

An antenna prototype to 433 MHZ and 915 MHZ was constructed using a FR-4 substrate and the Fig. 8 presents top and bottom views of the antenna prototype. The measurement of |S11| parameters were made with HP 8714B vector network analyzer (Fig. 9).

Fig. 8. Antenna prototype (top and bottom views).

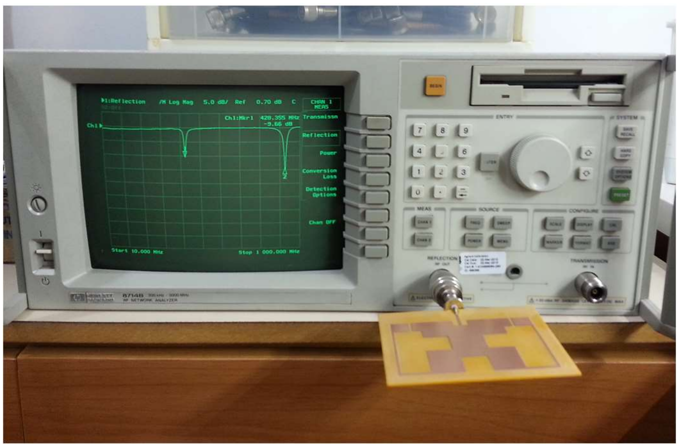

Fig. 9. Measurement with vector network analyzer.

As shown in Fig. 10, the measured |S11| curve of antenna agrees reasonably with the simulated. For |S11| < −10 dB, the measured two operating frequencies are 433.4 MHZ and 900.9 MHz, which means that the desired operating bands are successfully excited.

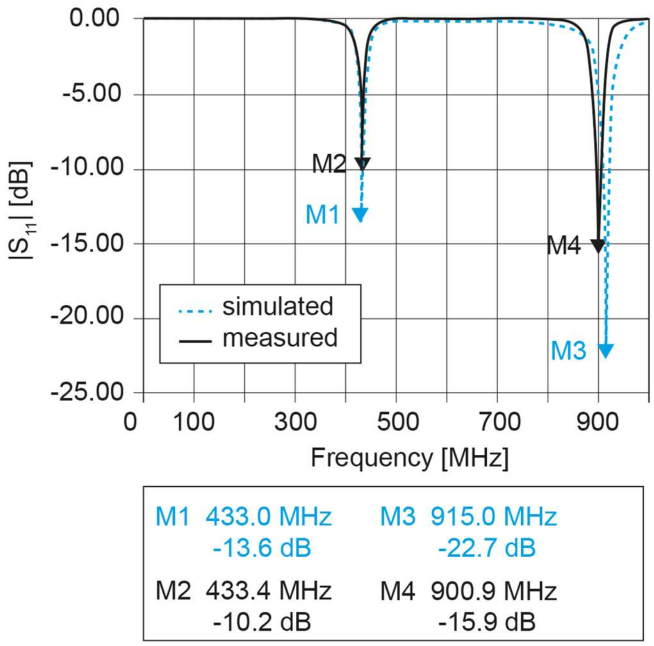

Fig. 10. Simulated and measured |S11| of the proposed antenna.

IV. Conclusions

A compact microstrip patch antenna designed for use in ISM bands in 433 MHz and 915 MHz or 868 MHz was presented. Compact size, easy fabrication and flexibility to operate in various ISM bands make the proposed antenna a suitable candidate for use in Internet-of-Things (IoT) wireless communication in sub-GHz bands.

Thus, a good agreement between the simulations and experiments was obtained. The small discrepancy obtained for this case is probably due the manufacturing tolerances of the antenna with regards to accurate positioning and the flatness of the pcb surface or due the connections.

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References

[1] Internet of Things: Wireless Sensor Networks, IEC-International Electrotechnical Commision.

[2] D. Puccinelli and M. Haenggi, “Wireless Sensor Networks: Applications and Challenges of Ubiquitous Sensing”, IEEE Circuit and Systems Magazine, Vol. 5, Issue 3, pp. 19-31, 2005.

[3] L. Atzori, A. Iera, G. Morabito, "The Internet of Things: A survey", Computer Networks, vol. 54, issue 15, pp. 2787–2805, Oct. 2010.

[4] LoRaWAN. What is it? A technical overview of LoRa® and LoRaWAN™, LoRa Alliance, Nov. 2015.

[5] A. Harney and C. O'Mahony, "Wireless Short-Range Devices: Designing a Global License-Free System for Frequencies <1 GHz", Analogue Dialogue, vol. 40, no. 3, pp. 1–5, Mar. 2006

[6] ANSYS Electronics Desktop: http://www.ansys.com

[7] NEMA National Electrical Manufacturers Association. https://www.nema.org

[8] C. A. Balanis, “Antenna Theory Analysis and Design,” John Wiley & Sons, 3rd edition, pp. 817-820, 2005.

[9] D. H. Werner and S. Ganguly, “An overview of fractal antenna engineering research”, IEEE Antennas and Propagation Magazine, vol. 45, pp. 38–57, Feb. 2003

[10] J. P.Gianvittorio, Y. Rahmat-Samii: "Fractal antennas: a novel antenna miniaturization technique, and applications", IEEE Antennas and Propagation Magazine, 44, pp. 20–36, 2002.

[11] S. Dhar, R. Ghatak, B. Gupta, D. R. Poddar, "A Wideband Minkowski Fractal Dielectric Resonator Antenna", IEEE Transactions on Antennas and Propagation, vol. 61, no. 6, Jun. 2013.

[12] J. K. Ali, “A New Reduced Size Multiband Patch Antenna Structure Based on Minkowski Pre-Fractal Geometry,” Journal of Engineering and Applied Sciences, JEAS, vol. 2, no. 7, pp. 1120-1124, 2007.

[13] D. A. Manjibhai, J. C. Prajapati, D. J. Barasara, "An Overview of Fractal Geometries and Antenna", Research Inventy: International Journal of Engineering and Science, vol. 1, issue 2, pp. 01-04, Sep. 2012.

[14] L. H. Abderrahmane, A. Brahimi, "A New Design of Dual Band Fractal Antenna for LEO Applications", ICSNC 2013: The Eighth International Conference on Systems and Networks Communications, IARIA, 2013

[15] K. Kumari, S. Kaushik, “Analysis of effects of height of substrate on Minkowski based fractal patch antenna", International Journal for Research in Applied Science & Engineering Technology (IJRASET), vol. 3, issue VIII, Aug. 2015

[16] K. Wong, "Compact and Broadband Microstrip Antennas", John Wiley & Sons, 2002

[17] N. M. Awad, M. K. Abdelazeez, "Multislot microstrip antenna for ultra-wide band applications", Journal of King Saud University – Engineering Sciences, 2016

[18] L. Liu, S. W. Cheung, T. I. Yuk, "Bandwidth Improvements Using Ground Slots for Compact UWB Microstrip-fed Antennas", Progress In Electromagnetics Research Symposium Proceedings, Sept. 2011