Journal of Microwaves, Optoelectronics and Electromagnetic Applications, Vol. 18, No. 3, September 2019 399
DOI: http://dx.doi.org/10.1590/2179-10742019v18i31672

Study of Patch Antennas with Koch Curve Form Slots

Daniel Fonseca, Feliphe Pereira, Ulysses R. C. Vitor
Universidade Federal de Juiz de Fora, Juiz de Fora, Minas Gerais, Brasil
daniel.fonseca@engenharia.ufjf.br, feliphe.pereira@engenharia.ufjf.br, ulyssesvitor02@gmail.com

***Abstract*— This work proposes the study of patch antennas with fractal slots. Initially, a 2.4 GHz microstrip antenna is designed. Then, the slots in the Koch fractals format are inserted with the iteration 0, 1 and 2. Similarly, it is expected that the antenna can be subjected to various functions in other applications. Simulations using CST STUDIO SUITE *Student* Edition software are shown, in addition to antenna measurements using the Network Analyzer.**

***Index Terms*—** Microstrip Antennas, Wireless Communication, CST and Koch Fractals.

I. INTRODUCTION

Antennas are key elements in a wireless communication system. The antenna can be defined as a device that transmits and receives electromagnetic waves efficiently [1]. There are several types of antennas, such as: filamentary, log-periodic parabolic, aperture and microstrip [2].

A patch antenna is a type of antenna in the radio frequency band that is built on a flat surface. It consists of a flat rectangular, circular or triangular metal sheet, arranged on a larger metal sheet, called ground plane. This sheet metal and ground plane are separated by a dielectric sheet substrate. There are any substrates that can be used for the design of microstrip antennas, and their relative dielectric constants are generally in the range of $2.2 \leq \varepsilon_r \leq 12$ [3]. Many works in the literature that carry out modifications in the planar antenna structure to achieve the increase in bandwidth and more resonance frequencies. These modifications may be stacked patches [4], [5] and the introduction of holes or cracks in the antennas [6], [8]. The holes are called Slit, external holes, or Slot, internal holes, in the planar antenna, for example. It is possible with slots to achieve an increase in the bandwidth of the patch, as discussed in the works [9], [10]. In addition to increasing the impedance width of the antenna, it is possible to produce more resonant frequencies and thus make the multiband antenna [11]. This can be done either with internal slots [9], [10], but also with external slits [7], [8]. In this way, in a reduce space; it is possible to achieve an antenna of greater bandwidth and multiband. Combination of internal and external cracks have also been used in some works [6], [12]-[13]. These combinations allow greater versatility in the design of new antennas.

In this work, the authors produced a new antenna, which can be used in X Band, military applications. Notice the original resonance frequency is maintained with small variation. Therefore, this technique produces a multiband antenna keeping its dimensions.

Brazilian Microwave and Optoelectronics Society-SBMO *received 12 Apr 2019; for review 18 Apr 2019; accepted 5 Aug 2019*
Brazilian Society of Electromagnetism-SBMag *ISSN 2179-1074*

DOI: http://dx.doi.org/10.1590/2179-10742019v18i31672

II. THEORY

A. Antenna Design

The design procedure assumes that the specifications include the relative dielectric constant of the substrate, ε_r, the resonance frequency, f_r, and the thickness of the substrate, h. [3]. In Fig. 1 the dimensions are illustrated.

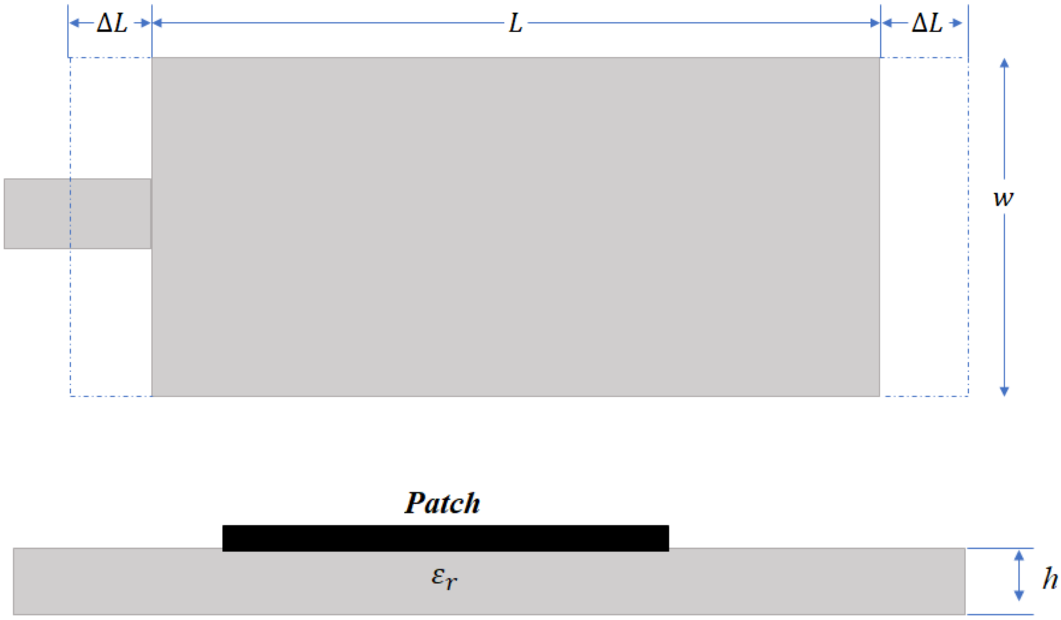


Fig. 1. Rectangular microstrip patch.

In this way, it is specifying the patch width, w, and length, L, that produces a good radiation efficiency [3], [11], [17] for desired f_r.

The microstrip width, w_o, is defined to obtain $Z_{in} = 50\ \Omega$. Now, it is necessary matching impedance with patch antenna, for this to add a gap with width y_0. As shown in Fig. 2.

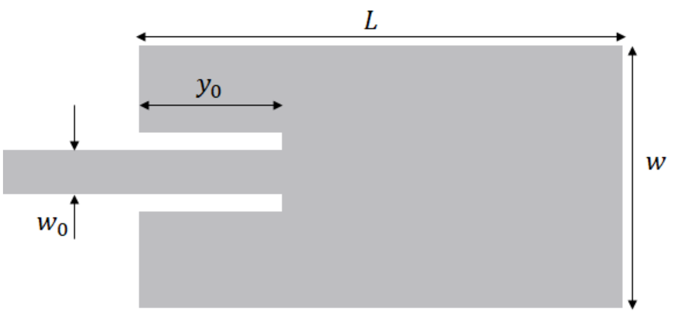


Fig. 2. Microstrip patch feed.

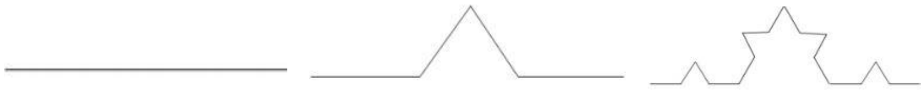
It is possible designed a planar microstrip antenna to operate at a certain frequency of interest, f_r.

ISSN 2179-1074

DOI: http://dx.doi.org/10.1590/2179-10742019v18i31672

B. Fractal geometry

Fractals are geometric figures, in which a part resembles the form as a whole; this property is self-similarity [25]. Or rather, a part of the fractal structure is a miniature of the complete structure. A fractal geometry widely used in antennas is the Koch geometry, which is one of the first structures used in telecommunications antennas to construct Yagi – Uda and Dipole antennas [3], [18]. In Koch's fractal, a segment is replaced by a polygonal segment formed by four segments of 1/3 size of the original. The process is applied indefinitely in each of the segments. In step *n*, it will have a polygonal line with *4n* segments of size *(1/3)n*. The Koch rows with iteration 0, iteration 1 and iteration 2 [19], [20] are shown in Fig. 3.



(a) (b) (c)

Fig. 3. Koch fractals: (a) Iteration 0 - (b) Iteration 1 - (c) Iteration 2.

III. Proposed Antennas

Many papers use slot and slit to increase the bandwidth and to make a multiband antenna [6]-[12]. On the other hand, there are works that modify the antenna in the fractal form and achieve the same goal [21]-[25]. In the following works, changes were made in its structure, however, without modifying the dimensions that made it operates in its frequency.

In this paper, the use of slots in the Koch form curve in a patch antenna is proposed. For this, a patch antenna was initially built to operate in 2.4 GHz. The design of this antenna followed the route described in the previous section, based on [3], [11], [17].

The first modification occurred with the implementation of two normal slots, vertically and symmetrically. As the study revolves around Koch's fractal geometries, it can be said that this first crack is a Koch fractal of iteration 0. An important point within the design of the slots is that they must have the same dimension. Both the thickness and its height and position in the antenna would influence the results. As there are numerous possible values for these variables, the chosen values were the ones that previously maintained the antenna with acceptable reflection coefficients and radiation diagrams. In fact, a study around these dimensions could generate an optimization of the project, but this work aims to analyze the influence of Koch's geometry on the slots, without necessarily looking for an optimum result.

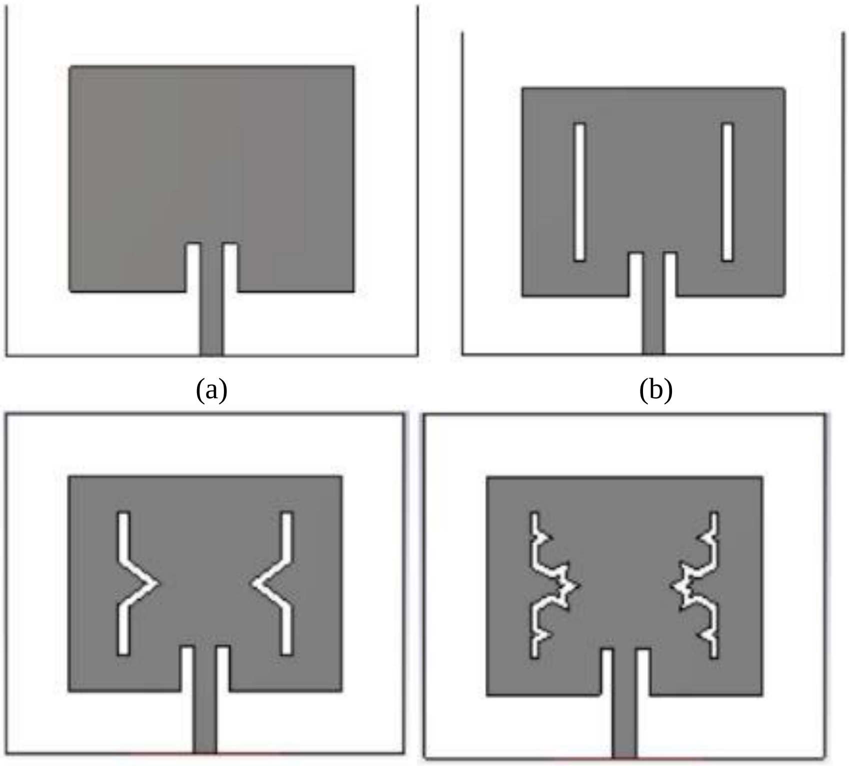
The Evolution of the internal cracks was in the fractal geometry of Koch producing fractures of iteration 0, 1 and 2. The choice of the direction in which they would be possible could only be made after an initial analysis of some results. Therefore, it was seen that the best results are with the fractals facing the internal area of the planar antenna.

Figure 4 shows the complete evolution within the patch antenna. Fig. 4 (a) The patch antenna with dimensions designed to radiate at 2.4GHz, Fig. 4 (b) shows the antenna with two slots at the ends, which

  ISSN 2179-1074

DOI: http://dx.doi.org/10.1590/2179-10742019v18i31672

correspond to the Koch Fractals of Iteration 0 (zero). Finally, in Fig. 4 (c) and (d), the slots evolve to Koch's fractions of iteration 1 (one) and iteration 2 (two).



(a) (b) (c) (d)

Fig. 4. Patch antennas and their derivations.

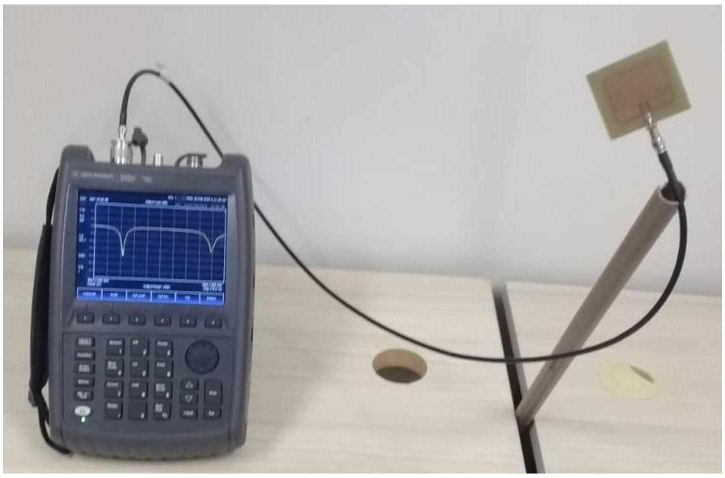
IV. RESULTS

As quoted in the previous section, the project had an initial resonance frequency of 2.4 GHz, due to its applications. However, after assembly and testing, a frequency shift was observed in relation to those simulated by the CST, even with all confirmed dimensions. The only parameter that could be causing this variation was the substrate material. Small variations in the value of the electrical permittivity of the fiberglass (FR4) showed that it displaced the S11 graph without significantly altering its curve. This fact led to the belief that the substrate caused such lags together with the lack of a reliable specification of the material and with the observation of the phenomenon in all the other antennas.

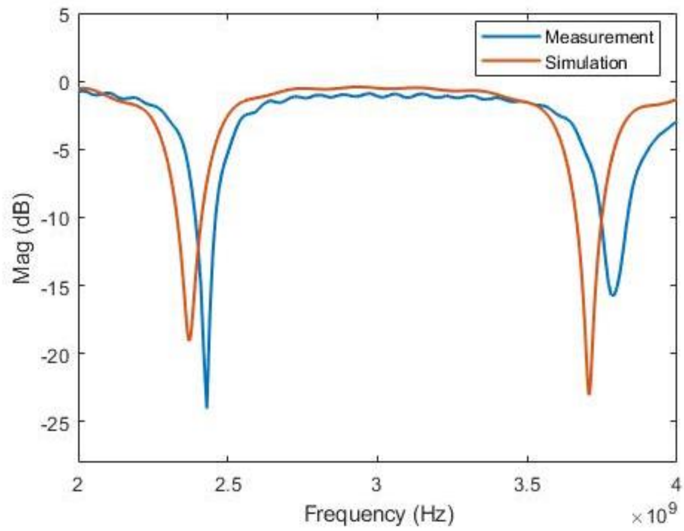
Fig. 5 (a) shows the Patch Antenna measurement that was constructed and the measurement with the Agilent FieldFox RF Analyzer N9912a 4GHz network analyzer. Fig. 5 (b) shows the side-by-side curves and Fig. 5 (c) show the polar diagram. There is a good agreement between the measured and simulated values, but we can notice in both a frequency shift and a variation in amplitude. This may include some factors, such as imprecision of the permissiveness value of the substrate (not exactly 4.3, as simulated) and the inclusion of the connector, which is also not present in the simulation.

Brazilian Microwave and Optoelectronics Society-SBMO received 12 Apr 2019; for review 18 Apr 2019; accepted 5 Aug 2019
Brazilian Society of Electromagnetism-SBMag ISSN 2179-1074

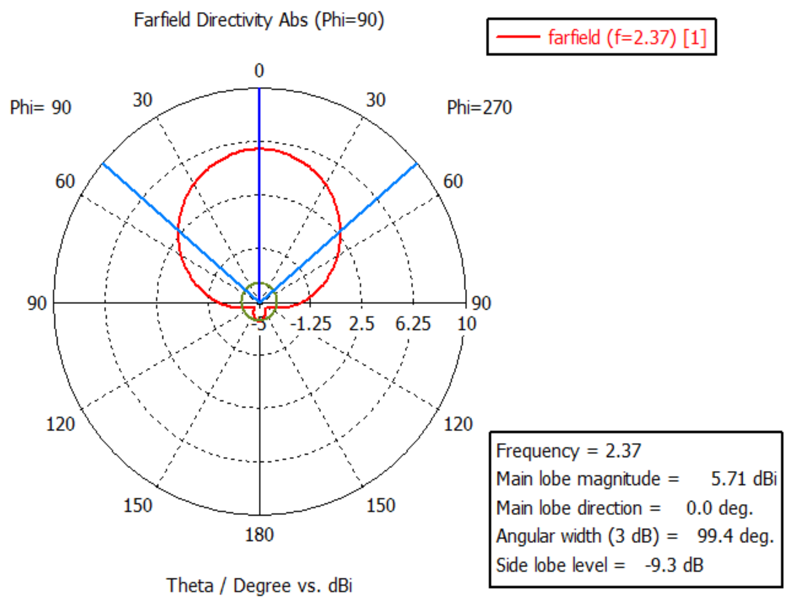
DOI: http://dx.doi.org/10.1590/2179-10742019v18i31672



(a)



(b)



(c)

Fig. 5. (a) FieldFox measuring; (b) S11 parameter; (c) Polar diagram.

received 12 Apr 2019; for review 18 Apr 2019; accepted 5 Aug 2019

ISSN 2179-1074

DOI: http://dx.doi.org/10.1590/2179-10742019v18i31672

The antennas fabricated, following Section 3, seen in Fig. 6, were perfectly constructed using an LPKF prototyping machine, maintaining all measurements with good precision in relation to the simulated ones. These measures can be seen in Table I. The choice of slots in the vertical position was made after several tests, where it was observed that for the horizontal position the characteristics of the antennas for the initial resonance frequency (2.4 GHz) underwent major changes, causing the antenna not to behave as Dual-Band within expected frequency range. In Fig. 7 (a), (b) and (c) are shown comparing the simulations and return loss measurement of the antennas, S11, again maintaining a good harmony between experimental simulation and measurement. The size and location of the slots are very important factors as well, because in each value for both the final answers vary. In this way, the values were adjusted so that the slots had length equal to 2/3 of the patch and width of 1.2 mm, maintaining the width and length of the ground with 53 mm and 46 mm, respectively. Its position was 9 mm away from the center of the patch. It was used a substrate with thickness of 1.5mm.

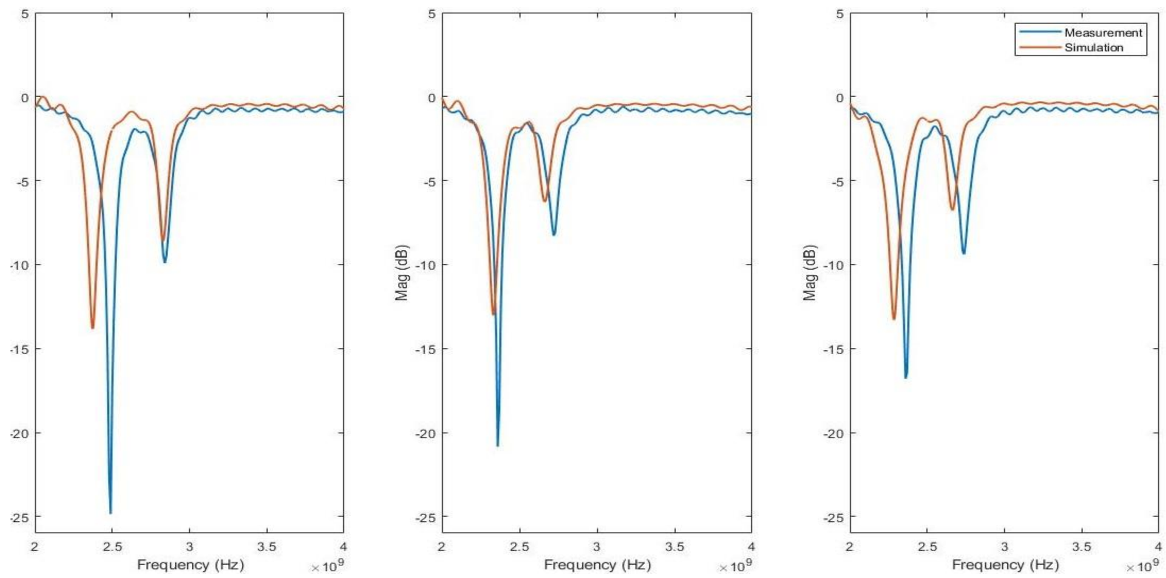
Fig. 6. Evolution of the iteration in the patch antennas.

TABLE I. TYPE SIZES AND APPEARANCE

Type	Value (mm)
Width	37.29
Length	29.06
Substrate thickness	1.5
Feed width	3
Slot width	1.74

Brazilian Microwave and Optoelectronics Society-SBMO received 12 Apr 2019; for review 18 Apr 2019; accepted 5 Aug 2019
Brazilian Society of Electromagnetism-SBMag ISSN 2179-1074

DOI: http://dx.doi.org/10.1590/2179-10742019v18i31672



(a) (b) (c)

Fig. 7. S11 parameter for (a) iteration 0, (b) iteration 1, (c) iteration 2.

The similarity relation between the values simulated and the values measured is remarkable. This, in addition to confirming that the simulation has been successful, can serve as a basis for the simulation to provide a response with reasonable confidence also for higher frequencies, where there are limitations of equipment for the measurement, since the available Network Analyzer has frequency limitation of 4GHz.

For a better comparison, the amplification of the frequency range is recommended. Thus, a simulation of the return loss of the antenna in the frequency band from 2GHz to 10GHz was performed. This simulation is shown in Fig. 8.

There is a threshold at -10dB, frequencies below that can be used to transmit data. In addition, it is shown the simulation comparison between the antenna without slots, Fig. 4 (a), and the antenna with slots in Koch form of iteration 2, Fig. 4 (d).

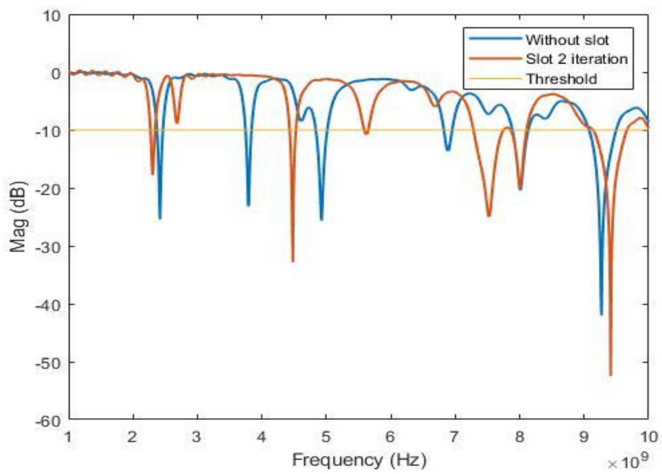
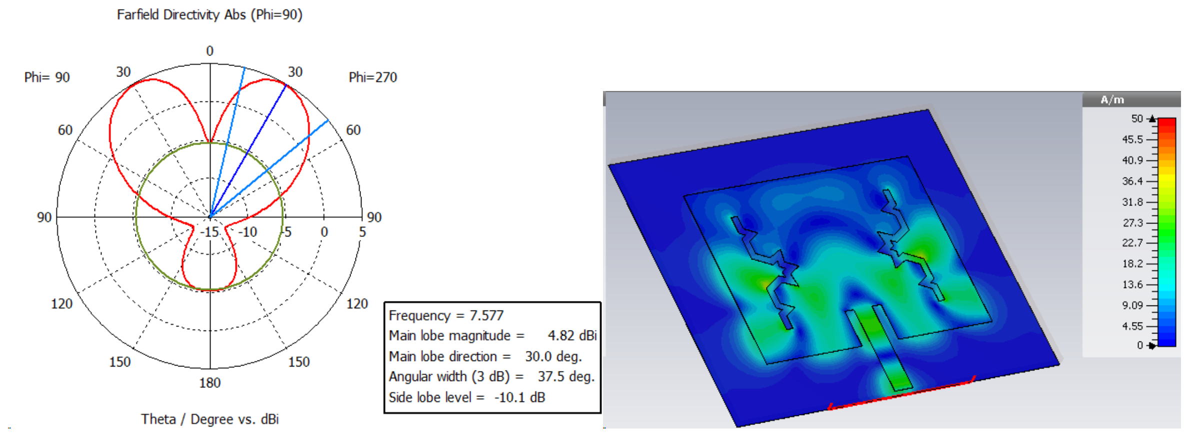


Figure 8. The S11 response of the proposed antenna without slot and with slot of the second iteration.

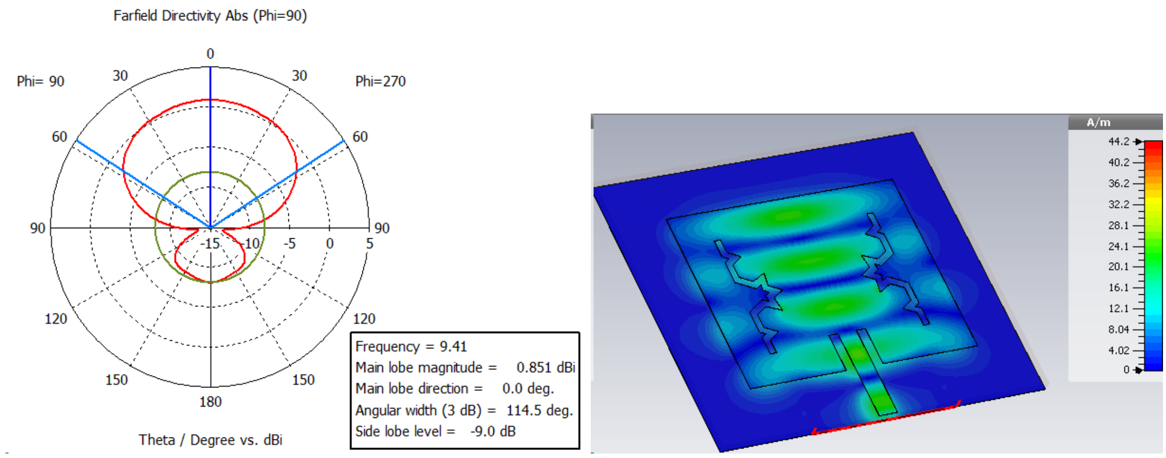
  ISSN 2179-1074

DOI: http://dx.doi.org/10.1590/2179-10742019v18i31672

Although for lower frequencies there is a worsening in the return loss, at higher frequencies the resonance points are better, especially the frequencies of 4.48 GHz, 7.57 GHz and 9.4 GHz. The last two are located in X Band, and they have different military applications. Fig. 9 (a) and 9 (b) show polar diagrams and surface currents for the 7.57 GHz and 9.41 GHz frequencies, respectively.



(a)



(b)

Fig. 9. Polar diagrams and surface current for (a) 7.57GHz, (b) 9.41GHz.

V. CONCLUSION

In this paper, the use of slots was studied in the form of Koch's Fractals in antennas patches. Simulations and experimental measurements results show a good agreement. There was a frequency shift, which is accounted for imprecision in the knowledge of the relative electrical permittivity of the FR4 plate. For the last iteration process, resonance frequencies were obtained in the X Band with low return loss values and very useful radiation patterns.

  ISSN 2179-1074

DOI: http://dx.doi.org/10.1590/2179-10742019v18i31672

REFERENCES

[1] M. N. O. Sadiku, *Elementos de eletromagnetismo*. 3th ed. Porto Alegre, Bookman, 2004.

[2] D. K. Cheng, *Fundamental of Engineering Electromagnetics*. Reading MA, Addison-Wesley: London, 1992 I.S.

[3] C. A. Balanis, *Antenna Theory, Analysis and Design*. Second edition, John Wiley and Sons, New York, 1997.

[4] J. Anguera, C. Puente, and C. Borja, "A Procedure to Design Wide-Band Electromagnetically-Coupled Stacked Microstrip Antennas Based on a Simple Network Model," *IEEE Antennas and Propagation Society International Symposium*, vol. II, pp. 944-947, Orlando, USA July 1999.

[5] J. Anguera, C. Puente, and C. Borja, "Dual Frequency Broadband Microstrip Antenna with a Reactive Loading and Stacked Elements," *Progress in Electromagnetics Research Letters*, vol. 10, pp. 1-10, 2009.

[6] M. K. Idris, B. Sarwar, Y. Rehman and T. Imeci, "Rectangular shaped microstrip patch antenna with multiple slits and slots," *25th Signal Processing and Communications Applications Conference* (SIU), Antalya, pp. 1-4, 2017.

[7] F. Z. Hanin and L. Setti, "Slotted patch antenna loaded with ferrite," *5th International Conference on Multimedia Computing and Systems (ICMCS)*, Marrakech, pp. 487-491, 2016.

[8] H. Saini, A. Kaur, A. Thakur, R. Kumar, and N. Kumar, "A parametric analysis of ground slotted patch antenna for X-band applications," *3rd International Conference on Signal Processing and Integrated Networks (SPIN)*, Noida, pp. 549-552, 2016.

[9] A. Zamani, B. Mudun, E. Kara, G. Dilaver and T. İmeci, "Patch antenna with slits at 8 GHz," *IEEE/ACES International Conference on Wireless Information Technology and Systems (ICWITS) and Applied Computational Electromagnetics (ACES)*, Honolulu, HI, pp. 1-2, 2016.

[10] K. Chung, H. Park, J. Choi, "Wideband microstrip-fed monopole antenna with a narrow slit," *Microwave and Optical Technology Letters*, vol. 47, no. 4, pp. 400–402, YEAR.

[11] M. K. Aghwariya, P. Ranjan, P. S. Pandey, G. Rani and R. Sharma, "Miniaturization of L-Band Rectangular Patch Antenna by Using Two Rectangular Slit," *8th International Conference on Computational Intelligence and Communication Networks (CICN)*, Tehri, pp. 222-225, 2016.

[12] A. A. Deshmukh, A. G. Ambekar, A. P. C. Venkata, A. Doshi, and K. P. Ray, "Modified U-slot cut rectangular patch antenna for wideband response," I*EEE Applied Electromagnetics Conference (AEMC)*, Aurangabad, pp. 1-2, 2017.

[13] S. Mathew, M. Ameen, M. P. Jayakrishnan, P. Mohanan, and K. Vasudevan, "Compact dual polarized V slit, stub and slot embedded circular patch antenna for UMTS/WiMAX/WLAN applications," *Electronics Letters*, vol. 52, no. 17, pp. 1425-1426, 2016. doi: 10.1049/el.2016.1996.

[14] J. Eichler, P. Hazdra, M. Capek, T. Korinek, and P. Hamouz, "Design of a Dual-Band Orthogonally Polarized L-Probe-Fed Fractal Patch Antenna Using Modal Methods," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 1389-1392, 2011.

[15] S. Kumar, and D. K. Vishwakarma, "Compact circularly polarized slits- loaded microstrip patch antenna with symmetric-fractal boundary," *IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC)*, Cairns, QLD, pp. 34-37, 2016.

[16] M. A. Oliveira, E. E. C. Oliveira, A. G. Neto, J. J. P. Gonçalves, J. N. Cruz, "Análise paramétrica em uma antena patch retangular de microfita com fendas," *Revista INNOVER*, v. 1, no. 4, pp. 48-61, 2014.

[17] S. R. Spandana and K. P. Jasmine, "Design and performance analysis of Sierpinski diamond fractal antenna for multi-band applications," *Conference on Signal Processing And Communication Engineering Systems (SPACES)*, Vijayawada, pp. 85-89, 2018.

[18] P. Z. Petkov, M. R. Kolev, and B. G. Bonev, "Fractal Yagi antenna," *Conference on Microwave Techniques (COMITE)*, Pardubice, pp. 1-3, 2015.

[19] Z. Yu, J. Yu, C. Zhu, and Z. Yang, "An improved Koch snowflake fractal broadband antenna for wireless applications," *IEEE 5th International Symposium on Electromagnetic Compatibility (EMC-Beijing)*, Beijing, pp. 1-5, 2017.

[20] K. J. Falconer, *Fractal Geometry (Mathematical Foundations and Applications)*. 2nd edition, John Wiley & Sons Ltd., 2003.

[21] N. A. Rahman, and M. F. Jamlos, "A Wideband Log Periodic Antenna with Fractal Koch Geometry and Rectangular Stub," *International Conference on Computer and Communication Engineering (ICCCE)*, Kuala Lumpur, pp. 5-8, 2016.

[22] N. A. Rahman, and M. F. Jamlos, "Miniaturized Log Periodic Fractal Koch Antenna with C-Shaped Stub," *International Conference on Computer and Communication Engineering (ICCCE)*, Kuala Lumpur, pp. 53-56, 2016.

[23] V. Hebelka, J. Velim, and Z. Raida, "Dual band Koch antenna for RF energy harvesting," *10th European Conference on Antennas and Propagation (EuCAP)*, Davos, pp. 1-3, 2016.

[24] J. Anguera, J. P. Daniel, C. Borja, J. Mumbrú, C. Puente, T. Leduc, N. Laeveren, and P. Van Roy, "Metallized Foams for Fractal-Shaped Microstrip Antennas," *IEEE Antennas and Propagation Magazine*, vol.50, no. 6, pp.20-38, 2008.

[25] J. Anguera, C. Puente, C. Borja, and J. Soler, "Fractal-Shaped Antennas: a Review," *Wiley Encyclopedia of RF and Microwave Engineering*, edited by K. Chang, vol.2, pp.1620-1635, 2005.

  ISSN 2179-1074