ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 08, Issue, 12, pp.24718-24722, December, 2018

ORIGINAL RESEARCH ARTICLE OPEN ACCESS

DESIGN OF A CIRCULAR FRACTAL ANTENNA FOR SATELLITES APPLICATIONS

[1]Cícero M. S. Lacerda, [2]Antônio Freitas, [1]David Nadler Prata and *[1]Humberto Xavier de Araujo

[1]Faculdade de Engenharia Elétrica, Universidade Federal do Tocantins (UFT), Palmas, Brazil
[2]Departamento de Telecomunicações e Mecatrônica, Universidade Federal de São João Del Rei (UFSJ), Ouro Branco, Brazil

ARTICLE INFO

Article History:
Received 22nd September, 2018
Received in revised form
14th October, 2018
Accepted 17th November, 2018
Published online 31st December, 2018

Key Words:
Circular Antenna.
Fractal Antenna.
Satellites.

ABSTRACT

Communication systems demand satellite services due its global coverage and capacity to stand all-time communications. Since newer applications need high data rates, higher frequencies are often chosen while considering financial costs. In particular, recent papers show the usage for K and Ka bands. In order to fulfill these requirements, this work shows a modified circular patch antenna with fractal technology applied, which guarantees multiband operation and size reduction – an effect desired to satellite communication. Results obtained from simulation by return loss and radiation patterns assure, according to Anatel's catalog (Brazil's regulatory agency), that the bands are compatible with satellite communications. That is to say, the fractal antenna can operate in applications within the satellite communication context, with low cost transmutation with no need to adjust the dimensions of the reference antenna.

Citation: Cícero M. S. Lacerda, Antônio Freitas, David Nadler Prata and Humberto Xavier de Araujo. 2018. "Design of a circular fractal antenna for satellites applications", *International Journal of Development Research*, 8, (12), 24718-24722.

INTRODUCTION

In recent years, communication systems are requiring satellites services to perform their tasks, such as information sharing, due to its global coverage and capacity to stand all-time communications (MENGMENG, 2017). Since the newer applications are for mobile or vehicular purposes, the antennas must be low-profile (HAN, 2015). Also, it is desirable to design antennas which cover bands that are close to each other (MOK, 2013). To accomplish communications with higher data rates transmission, it is necessary to use higher frequencies. In special, K and Ka bands are used in this context (WANG, 2016). K-band ranges from 18 to 26.5 GHz [5], while Ka-band covers the frequency range of 26.5-40 GHz (NORSAT INTERNATIONAL INC). In order to fulfill the requirements above patch antennas, among other things, the need to be easiness to fabricate and to modify parameters with low fabrication cost and lightness. These features are commonly used in mobile communications (DAS, 2017). In addition, it is important to stand out that these antennas need to be easy to integrate with active devices (SHARMA, 2016).

***Corresponding author:* Cícero M. S. Lacerda**
Faculdade de Engenharia Elétrica, Universidade Federal do Tocantins (UFT), Palmas, Brazil

When it comes to apply patch antennas in satellite communication, it is worth to say that defense and aerospace applications require wideband and compact antennas available to multiband operation (DARIMIREDDY, 2018). In addition, directive antennas are preferred because the same link performance can be achieved with less power (NASCETTI, 2015). However, these antennas have some disadvantages such as narrow bandwidth, low efficiency and power (LIMBERGER, 2017). These characteristics can be avoided by modifying the geometry or inserting new elements in the antenna (GUELBER, 2014). In this work, the changes were made in the radiating element by applying fractal technology. Fractal structures have parts of the entire object with same format, but smaller (PUENTE-BALIARD, 1998). Fractals, when applied in antennas produce two effects, according to (SADIKU, 2010), they reduce the antenna size and make possible to operate it in many frequencies. The format and repetitive geometry of the antenna can be created by using a process called Interactive Function System (IFS) (MALLICK, 2017). In this paper, the fractal technology will be applied in order to use its benefits for satellites applications.

Antenna Analysis

To analyze an antenna, some parameters are worth to notice. The first one is the return loss, also called S11 parameter. It is calculated by impedance mismatch between the transmission line and the antenna. According to (POZAR, 2012), if the antenna has an impedance of Z_1 and the transmission line has Z_0, the reflection coefficient is:

$$\Gamma = \frac{Z_1 - Z_0}{Z_1 + Z_0} \quad \text{.........................(1)}$$

And then, the return loss given by [16] is:

$$RL = 20\log|\Gamma| \quad \text{..........................(2)}$$

The next parameters are given by analyzing the far field region of the antenna. In this region, located far enough from the antenna, the radiation pattern is uniform (BALANIS, 2005). There, it is possible to define the directivity function, which means how an antenna can concentrate radiation in some direction (BALANIS, 2005).

$$D(\theta,\Phi) = \frac{4\pi U(\theta,\Phi)}{P_{rad}(\theta,\Phi)} \quad \text{..........................(3)}$$

Where U is the radiation intensity and P_{rad} is the radiated power. Another useful measure is the gain, closely related to directivity. However, it also takes in to count the antenna efficiency (BALANIS, 2005).

$$G(\theta,\Phi) = \frac{4\pi U(\theta,\Phi)}{Pin} = \eta D(\theta,\Phi) \quad \text{.........................(4)}$$

Where η is the antenna efficiency and P_{in} is the input power. It is also common to show directivity and gain in decibels (POZAR, 2012).

$$K_{dB} = 10\log K \quad \text{..........................(5)}$$

Where K represents gain or directivity.

Transmission Antenna Design

In terms of composition, the Patch antennas can be divided into one radiating element (Patch), one dielectric substrate, and one ground plane. Where, the foremost and the last components are made of metallic material (LIMBERGER, 2017). The analyses were made using a circle of radius **a** [cm] as a base geometry for the Patch. The value of **a** is given by (BALANIS, 2005).

$$a = \frac{F}{\sqrt{1+\frac{2h}{\pi\epsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]}} \quad \text{.....................(6)}$$

$$F = \frac{8.791*10^9}{fr\sqrt{\epsilon_r}} \quad \text{.....................(7)}$$

Where ε_r is the substrate's relative permittivity, h [cm] is the *substrate's height and f_r [Hz] is the frequency desired to the* antenna. The feed line width, called W [cm], is calculated as proposed in [18]:

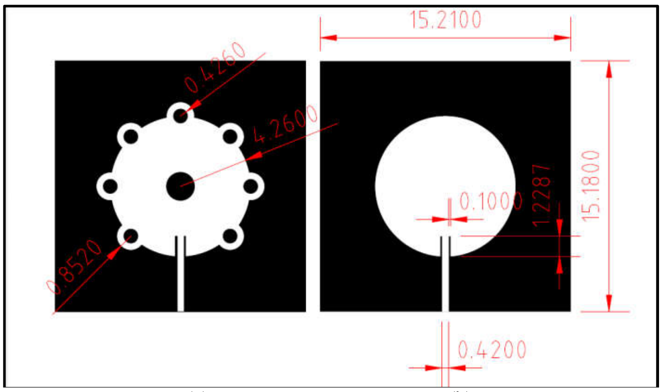
$$\frac{W}{h} = \begin{cases} \frac{30\pi}{\sqrt{\epsilon_r}\,Z_0} - 0.441 & if\ \sqrt{\epsilon_r}\,Z_0 < 120 \\ 0.85 - \sqrt{0.6 - \left(\frac{30\pi}{\sqrt{\epsilon_r}\,Z_0} - 0.441\right)} & if\ \sqrt{\epsilon_r}\,Z_0 > 120 \end{cases} \quad \text{......(8)}$$

Being $\mathbf{Z_0}$ [cm] the line impedance, previously calculated or established. Lastly, the remaining dimensions and the fractal format were adjusted, according to (SHARMA, 2016). The design of the antenna uses the substrate Rogers RT5880, with thickness of 0.508 [mm] and $\varepsilon_r = 2.2$. The frequency of interest was established in 13 [GHz], and the impedance fixed in 50 [Ω], (6), (7) and (8) were used to get the dimensions of the antenna, presented in Table I.

Table 1. Dimensions Used

Name	Value [mm]
Patch Radius	4.26
Feed line Width	0.42
Antenna Width	15.21
Antennas Height	15.18
Feed line inset cut Width	0.01
Feed line inset cut Height	1.23

For comparison, two antennas were made, as can be seen in Fig. 1. Fig. 1 (a) has the modifications in the Patch with the insertion of fractal technology. While Fig. 1 (b) shows de reference antenna, that is, without changes. The circles removed from the center of the patch and the external ones have the radius equal to one-fifth of the patch's radius, presented at Table I. Lastly, the minor circles removed from the center of the external ones are one-tenth of the main radius. The simulations were made in the CST Microwave Studio 2016 Software, from 10 GHz to 50 GHz, providing a wide spectrum. Fig. 1 shows the layout of both antennas, dimensions were coted in millimeters.



(a) (b)

Figure 1. Antennas Layout. Left: fractal; Right: Reference

RESULTS AND DISCUSSIONS

It is known that an antenna operates at a given frequency when its return loss value is inferior to -10 dB [9][20]. In particular, tune band is defined as being a continuous interval which is below S11 = -10 dB line. From Table II, it is possible to observe the tune bands for each antenna, with the respective minimum values for each band.

Table 2. Simulation Results

Antenna	Tune Band (GHz)	Width (GHz)	Minimum S_{11} (dB)	Frequency of Minimum S11 (GHz)
Reference	13.16-13.48	0.32	-13.58	13.30
	21.84-22.12	0.24	-10.55	22.00
	31.00-31.64	0.64	-17.17	31.30
	45.32-46.20	1.16	-11.37	45.70
Fractal	12.08-12.28	0.20	-11.36	12.10
	19.76-20.16	0.40	-15.30	20.00
	27.28-27.76	0.48	-15.50	27.50
	30.68-31.12	0.40	-12.70	30.90

According to Anatel's catalog (Brazil's regulatory agency) [21], the bands listed in Table III can be used to satellite communications.

Table 3. Satellite Communications Bands

Band (GHz)	Width (GHz)
19.70 – 20.01	0.31
27.00 – 27.50	0.50
30.00 – 31.00	1.00

The figures below show the return loss for both antennas in intervals that incorporates the bands listed in Table III, and the band from 12 to 14 GHz, which includes the frequency used to design the antennas. Therefore, the Fig. 2 shows from 12 to 14 GHz; the Fig. 3 exposes from 17.5 to 22.5 GHz; Fig. 4, from 25.5 to 29.5 GHz and Fig. 5 exhibits from 28.5 to 33.5 GHz.

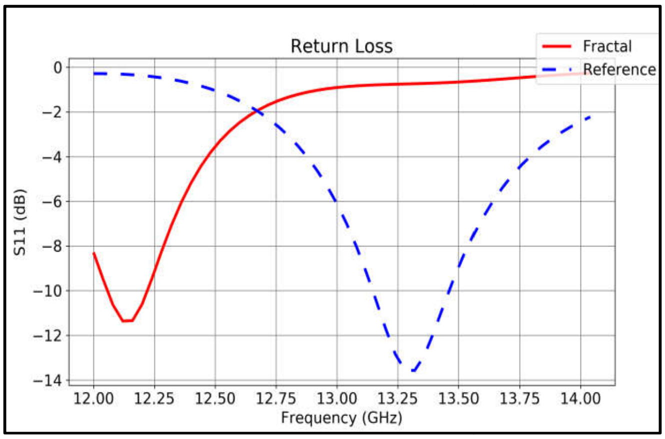


Fig. 2. Return loss from 12 to 14 GHz

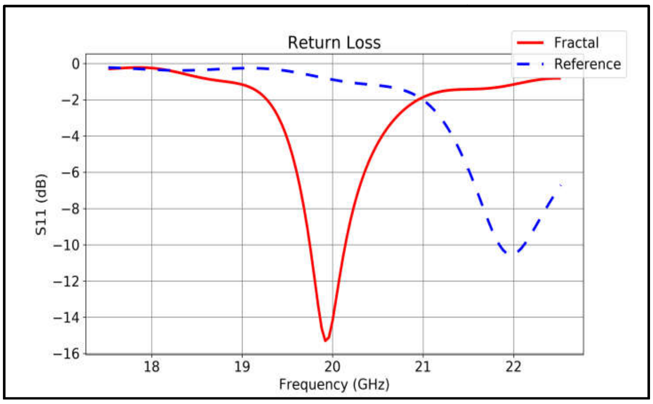


Fig. 3. Return loss from 17.5 to 22.5 GHz

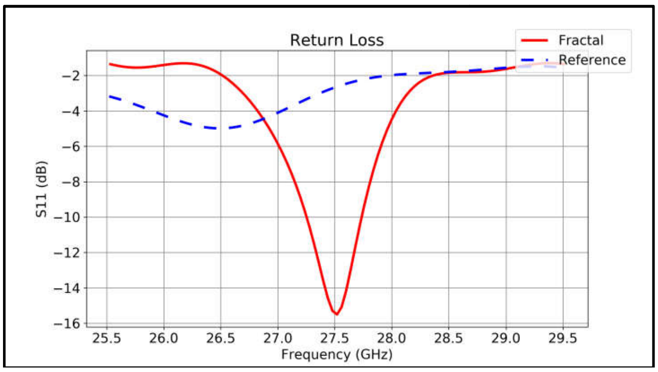


Fig. 4. Return loss from 25.5 to 29.5 GHz

The figures above show the tune bands of each antenna. It can be noted that the fractal curve is slightly displaced to the left and the tune bands within the ranges became narrower. In addition, the modifications added a new band, as can be seen in Fig. 4.

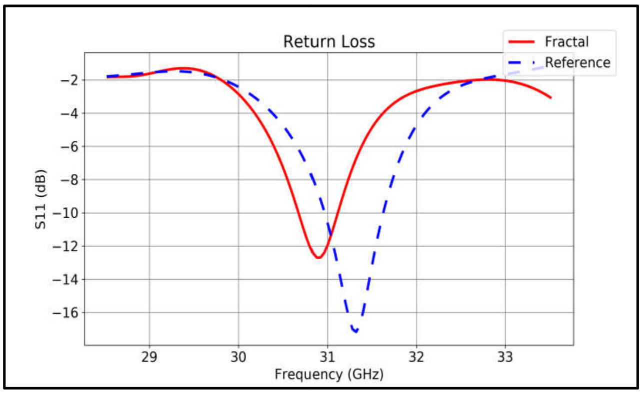


Fig. 5. Return loss from 28.5 to 33.5 GHz

The figures Fig. 6, Fig. 7, Fig. 8 and Fig. 9 show the radiation pattern of the fractal antenna with Φ = 90º, presenting the directivity and gain to the frequencies of minimum S11, according to Table II.

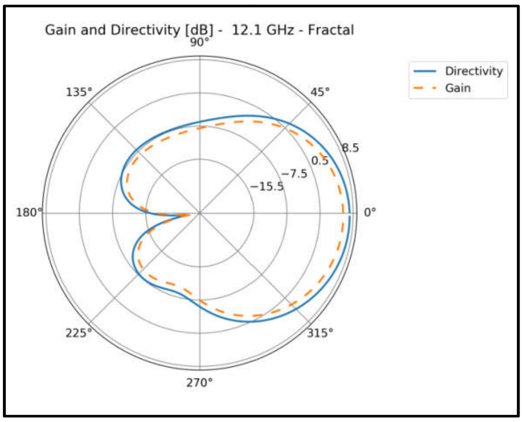


Fig. 6. Radiation pattern for 12.1 GHz

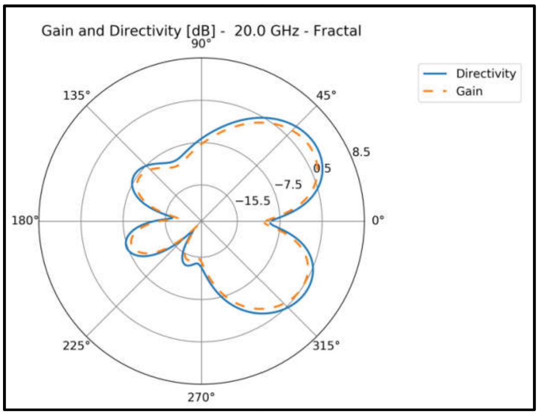


Fig. 7. Radiation pattern for 20 GHz

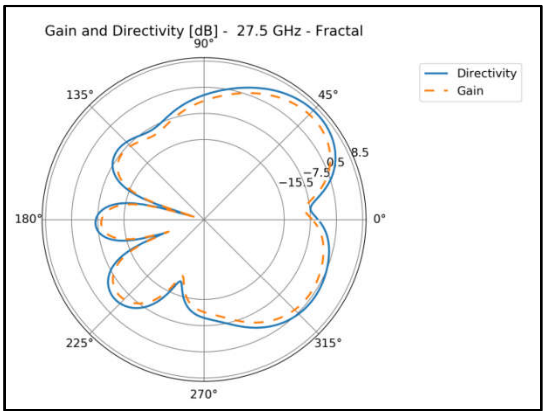


Fig. 8. Radiation pattern for 27.5 GHz

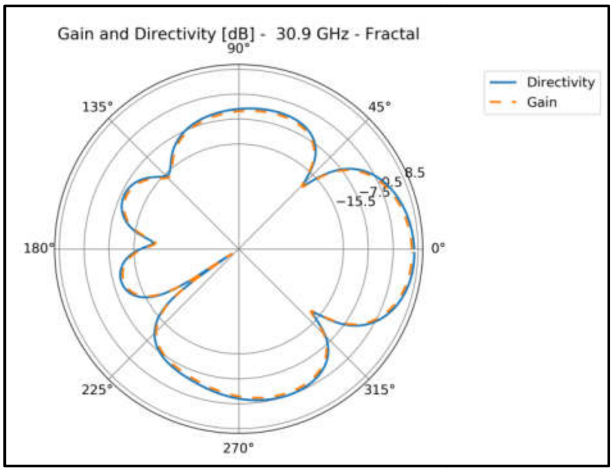


Fig. 9. Radiation pattern to 30.9 GHz

The figures Fig. 10, Fig. 11, Fig.12 and Fig.13 show the tridimensional directivity radiation pattern for 12.1, 20, 27.5 and 30.9 GHz, respectively.

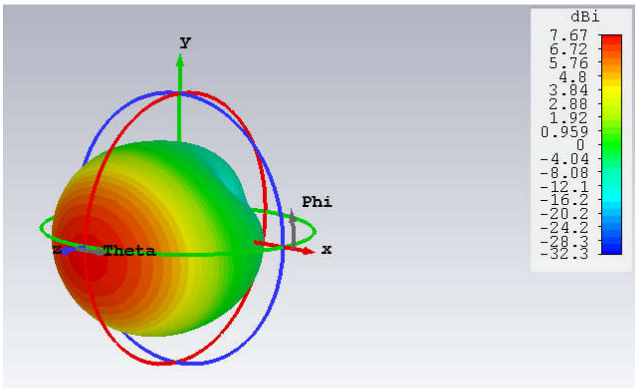


Fig. 10. 3D Radiation Pattern for 12.1 GHz

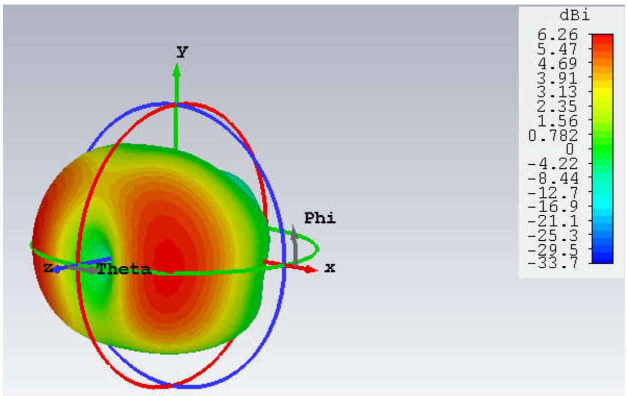


Fig. 11. 3D Radiation Pattern for 20 GHz

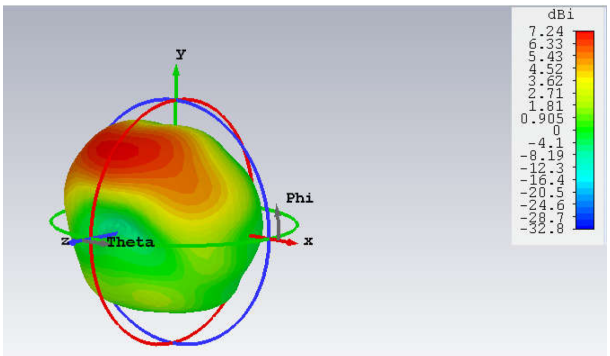


Fig. 12. 3D Radiation Pattern for 27.5 GHz

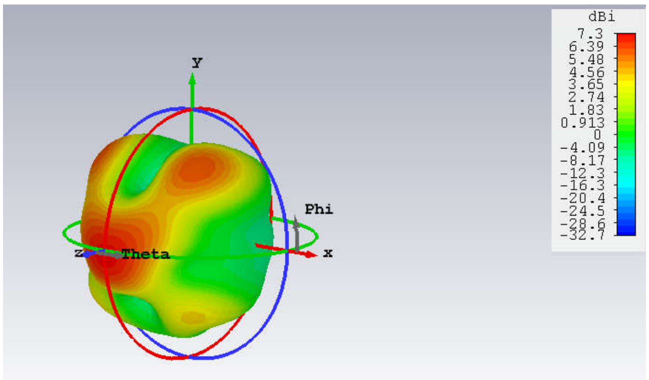


Fig. 13. 3D Radiation Pattern for 30.9 GHz

The eight figures above show a directive radiation pattern, which is recognized by a high directivity. In addition, the values are compatible with some other works, such as [10], [22] and [23]. The Table IV shows the maximum values of gain and directivity, for the fractal antenna, by logarithmic and normal scales, taking as reference the radiation pattern from Fig. 6 to Fig. 9 (2D pattern with $\Phi = 90^o$). The values in normal scale were found by applying the reverse function of (5).

Table 4. Maximum values of directivity and gain for the fractal antenna

Parameter	Frequency			
	12.1 GHz	20 GHz	27.5 GHz	30.9 GHz
Directivity (dBi)	7.68	3.59	7.29	7.33
Directivity (normal scale)	5.86	2.29	5.36	5.41
Gain (dB)	6.13	2.54	5.53	6.56
Gain (normal scale)	4.10	1.79	3.57	4.53

With the values above in normal scale, the antenna efficiency can be calculated by solving (4) for η. The values are shown in Table V.

Table 5. Fractal Antenna Efficiency

Parameter	Frequency			
	12.1 GHz	20 GHz	27.5 GHz	30.9 GHz
Efficiency	69.97%	78.17%	66.60%	83.73%

Conclusions

In this work, the patch's transformation into a fractal element displaced the S11 parameter graphic slightly to the left. This result means a new tune for the antenna, satisfying the requirements to satellite communication besides reducing the bandwidth. However, such alterations, according to Anatel's catalog, provided the antenna with three of the four tune bands compatible to satellite communication. In particular, the last three bands in Table III makes possible the fractal antenna to operate in three different applications within the satellite communication context. Finally, it is important to reiterate that modifications are low cost and do not change de dimensions of the reference antenna.

Acknowledgments

The development of this research was partially supported by the Federal University of Tocantins - Institutional Productivity Research Program (PROPESQ/UFT), and Escola Superior da Magistratura Tocantinense - ESMAT. The authors also would like to thank Rogers Corporation for the samples.

REFERENCES

ANATEL. Consultar Faixas de Frequência. Available in: < https://sistemas.anatel.gov.br/pdff/Consulta/Consulta.asp?SISQSmodulo=1068>.

BALANIS, CONSTANTINE A. Antenna Theory: Analysis and Design. 3. ed. S.l: John Wiley & Sons, Inc., 2005. 1072 p.

DARIMIREDDY, NARESH K.; REDDY, R. RAMANA; PRASAD, A. MALLIKARJUNA. A Miniaturized Hexagonal-Triangular Fractal Antenna for Wide-Band Applications. IEEE Antennas & Propagation Magazine, 7p., 2018.

DAS, S.K., VYSHNAVI; SHANMUGANANTHAM, T. Design of Multiband Microstrip Patch Antenna for IoT Applications. ICCS, 6p., 2017.

EVERYTHING RF. K-Band. Available in: <https://www.everythingrf.com/tech-resources/frequency-bands/k-band>.

GUELBER, ELISE FRAGA. Aplicações da Tecnologia Metamaterial em Dispositivos de Telecomunicações. 2014. 45 f. Trabalho de Conclusão de Curso – Universidade Federal de São João Del-Rei. Ouro Branco, 2014.

HAN, GUODONG; ET AL. A Novel Hybrid Phased Array Antenna for Satellite Communication on-the-Move in Ku-band. IEEE Transactions on Antennas and Propagations, Vol. 63, No. 4, 9p., 2015.

HIGGINS, JAMES ALEX. Microwave Engineering. 2011. 16 p. Notas de Aula. Portland State University.

LIMBERGER, PATRICK SCHWEIG. Projeto De Antenas Multibandas Modificadas Com Metamateriais Para A Futura Quinta Geração De Telefonia Móvel. 2017. 78 f. Trabalho de Conclusão de Curso – Universidade Federal do Tocantins, Palmas, 2017.

MALLICK, MONICA; MOHANTY SWETASWINI. SHEEJA K.L. A Hybrid Fractal Antenna for Wideband Applications. IEEE WiSPNET, 4 p., 2017.

MENGMENG, CUI; WEINA, HAO. A Printed Quadrifilar-Helical Antenna for Ku-Band Mobile Satellite Communication Terminal. 17th IEEE International Conference on Communication Technology, 5p. 2017.

MOK, WING CHI; ET AL. Single-Layer Single-Patch Dual-Band and Triple-Band Patch Antennas. IEEE Transactions on Antennas and Propagations, Vol. 61, No. 8, 4p., 2013.

NASCETTI, AUGUSTO; ET AL. High-Gain S-Band Patch Antenna System for Earth Observation CubeSat Satellites. IEEE Antennas and Wireless Propagation Letters, Vol. 14, 4p., 2015.

NORSAT INTERNATIONAL INC. Ka-Band: The Future of Satellite Technology. Available in: <http://www.norsat.com/ka-band-the-future-of-satellite-technology/>.

POZAR, David M. Microwave Engineering. 4. Ed. S.l: John Wiley & Sons, Inc., 2012. 756 p.

PUENTE-BALIARD, CARLES; ROMEU, J; POUS, R; CARDAMA, A.On The Behavior of the Sierpinski Multiband Fractal Antenna. IEEE Transactions on Antennas and Propagation, 8 p., 1998.

SADIKU, MATTHEW N. O. Elements of Electromagnetics. 5. ed. Oxford University Press, 2010. 800p.

Sahithi, Saraff; Kumar, S. Ashok; Shanmuganantham, T. A U-Slot Microstrip Patch Antenna for Wi-Max Applications. ICCS, 3 p., 2017.

SHARMA, NARINDER; KAUR, AMANDEEP; SHARMA, VIPUL. A Novel Design Of Circular Fractal Antenna…ICPEICES, 4 p., 2016.

SHARMA, NARINDER; KAUR, AMANDEEP; SHARMA, VIPUL.Comparative Analysis of Koch, Sierpinski and Composite Fractal Antennas with Retangular Microstrip Fractal Antenna. ICIIS, 6 p., 2016.

SO, KWOK KAN; ET AL. Miniaturized Circularly Polarized Patch Antenna With Low Back Radiation for GPS Satellite Communications. IEEE Transactions on Antennas and Propagation, Vol. 63, No. 12, 5p., 2015.

TUBBAL, FAISEL EM; RAAD, RAAD; CHIN, KWAN-WU. A Survey and Study of Planar Antennas for Pico-Satellites. IEEE Access, 23p., 2015.

WANG, HUANJU; SUN, HOUJUN; HAN, GUODONG. An Active Receiving Phased Array for Satellite Communication in K Band. IEEE, 3p., 2016.

****