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Genetic algorithm-based Ku-band microstrip patch antennas optimization to avoid jamming attacks

Otimização de antenas *patch* pelo método de algoritmo genético na banda Ku para evitar ataques eletrônicos

Anderson Silva Soares[1,*], Luis Alberto Rabanal Ramirez[2], Marcelo da Silva Matias[1]

1. Centro de Guerra Acústica e Eletrônica da Marinha – Rio de Janeiro (RJ), Brazil.

2. Centro Universitário Gama e Souza– Rio de Janeiro (RJ), Brazil.

Correspondence author: eng-soares@hotmail.com

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ABSTRACT

This paper reflects on the design and optimization of patch antennas. Two different methods were conducted. First, optimization was carried out over the whole antenna extension. Second, half antenna was optimized, and the final design was obtaining by reflection. The optimization process was conducted using genetic algorithm, return loss was obtained with full wave finite-differences time-domain, and the initial configuration (design) was obtained with line transmission and cavite method. All methods implemented in-house software. The antennas were designed to operate in Ku band with the center frequency at 16 GHz. Antenna with return greater than 22 dB and bandwidth between 2-5 GHz were obtained. The effectiveness of the proposed designs was confirmed through proper simulation results. Such optimization would aim to make a communication system more robust to electronic warfare attacks.

KEYWORDS: Genetic algorithms, Jamming attacks, Microstrip antenna, Satellite communications.

RESUMO

Este trabalho aborda o *design* e a otimização de antenas *patch*. Dois métodos diferentes foram utilizados. Em primeiro lugar, a otimização foi realizada em toda a extensão da antena. Em um segundo momento, apenas a metade da antena foi otimizada. O processo ocorreu pelo algoritmo genético, em que a perda de retorno foi obtida mediante a implementação do método do domínio de tempo de diferenças finitas, aliada ao método de cavidade ressonante. Todos as simulações foram implementadas em *software* livre. As antenas foram projetadas para operar na banda Ku, com frequência central em 16 GHz. Como resultados, foram obtidas perda de retorno superior a 22 dB e largura de banda entre 2 e 5 GHz. A eficácia dos projetos propostos é confirmada por meio dos resultados apresentados, que visa tornar um sistema de comunicação satelital mais robusto a ataques eletrônicos.

PALAVRAS-CHAVE: Algoritmo genético, Ataques eletrônicos, Antena *microstrip*, Comunicações satelitais.

INTRODUCTION

The rapid advancement in the satellite communication field in the past few decades has led to the development of small, low profile and efficient antenna design. Antenna is an important structure in any satellite communication system. Services such as satellite internet access, spacecraft telemetry, command, and tracking communications[1] have boosted research in this field, and efficient antenna definitely improves the overall performance of the system.

However, electronic warfare (EW) attacks on ground stations are a growing threat to government, military, and commercial satellite communications. In these attacks, adversaries use electromagnetic energy to disrupt or deny friendly access to radio frequency (RF) communications. The forms of electronic warfare are deployed to disrupt and impede operations by interfering with the transmission of RF signals between satellites and ground stations[2-4]. Reducing the antenna's side lobe is always an important goal to prevent attacks in satellite communications[5-7].

This work investigated microstrip antennas to reduce the side lobe satellite communication systems, due to its advantages compared to other antennas, such as large single-dish[8]. Various schemes are being used to minimize the drawbacks of this type of antennas, but it is a difficult task. In this work, the antenna was designed to operate in Ku band with the center frequency at 16 GHz, the frequency band (15.25-17.25 GHz). This work used the genetic algorithms to overcome these disadvantages, based on references[9-11]. Specifically, the numerical method FDTD-3D was combined with the genetic algorithm (GA) for bandwidth and return loss optimization. The initial design was obtained used the resonant cavity/transmission line methods[12]. All methods implemented in-house software.

Antenna design using FDTD-3D is described in the next section. Afterwards, the aspect related with GA used in this work is presented. Then, it is shown the present numerical results. Finally, the last section brings the conclusions and the achieve some goals. The effectiveness of the proposed designs was confirmed through proper simulation results.

FDTD-3D METHOD

The FDTD-3D method[13,14], with the uniaxial perfect matched layer (UPML)[15], was used.

The source

The Morlet wavelet function was used. Input signal is given by the Eq. 1:

$$E_z(t)E_0e^{-2\pi f_b(t-t_0)^2}\cos(2\pi f_c(t-t_0)) \qquad (1)$$

in which: E_0 = 22 V/m = the signal amplitude; t_0 = 5.02 ns = the time at which the pulse reaches its maximum value; f_c = 16 GHz = the central frequency; f_b = 2 GHz; t between [0, 8000Δt] = the propagation time signal with Δt = 0.0342 ns, representing the value of the time step.

Figure 1 shows the time domain signal and its frequency domain equivalent.

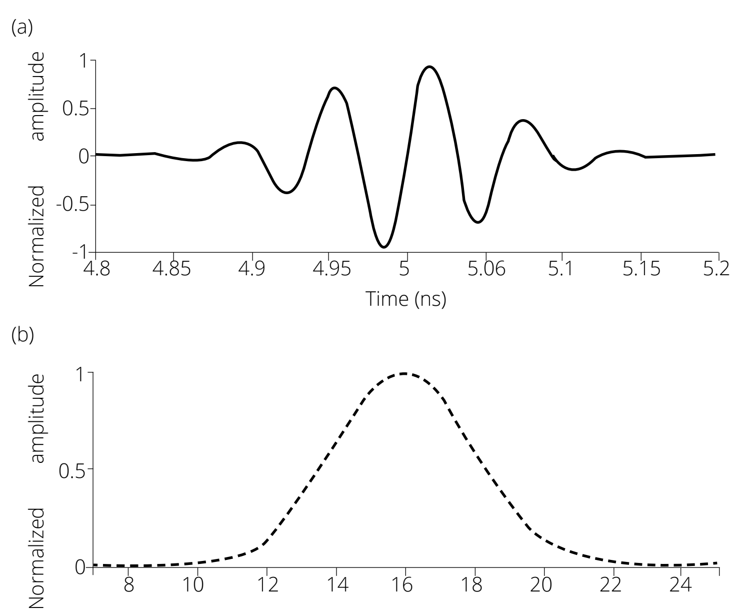

Figure 1: Wavelet function for excitation: (A) time domain and (B) frequency spectrum.

Scattering parameter

Microstrip patch antenna is a one-port circuit. Its scattering matrix has only one element, that is, S11, or the reflection coefficient. The electromagnetic field at any time obtained using FDTD is the superposition from incident and reflected signals. In order to compute the input signal, the network is simulated first without the presence of the patch. Since there is no reflection at the port position, the recorder signal corresponds to the input signal.

In this work, the traditional procedure has been implemented, with changes in the application related to the evolution process. Whereas it is generated a different patch at each genetic generation, the line-feed does not suffer any modification. The first step in the calculation of return loss is the same for all antenna configurations. It is performed only once, and the results are used in other generations.

GENETIC ALGORITHMS

The GA[16] begins by considering the rectangular microstrip antenna with inset geometrically designed using the transmission line method and resonant cavity[12] (Fig. 2).

Afterwards, the patch is modified using GA, for which were considered two schemes: the total area of the patch; and the left half of the patch, symmetrically mirrored to the right.

The patch was divided into a binary matrix of 17 × 17 sub-patches, as shown in Fig. 3. The sub-patch in this representation is an intrinsic representation of problem. It indicates presence (set as 1) or absence (set as 0 – not printed) of copper sub-patches in candidate solution (chromosome).

For the first antenna, in which the total area of the patch was used, the patch parameters values (Fig. 2) were: W = 11.68 mm; L = 8.87 mm; W f = 1.40 mm; g = 0.70 mm; Y 0 = 0.88 mm; substrate dielectric constant = 2.2; substrate height = 0.45 mm; substrate width = 16.58 mm; substrate length = 23.70 mm. The height of ground plane, height of the patch and height of line feed were taken as one delta mesh in the z direction.

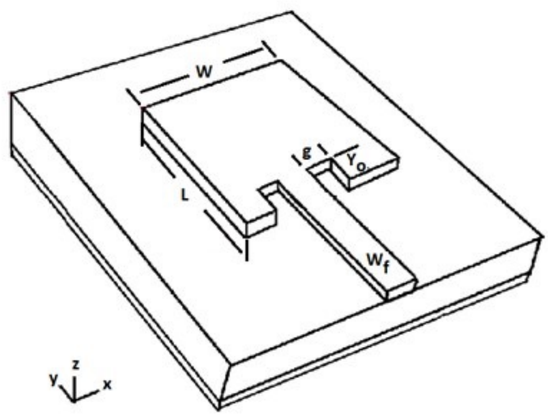

Figure 2: Initial microstrip antenna design.

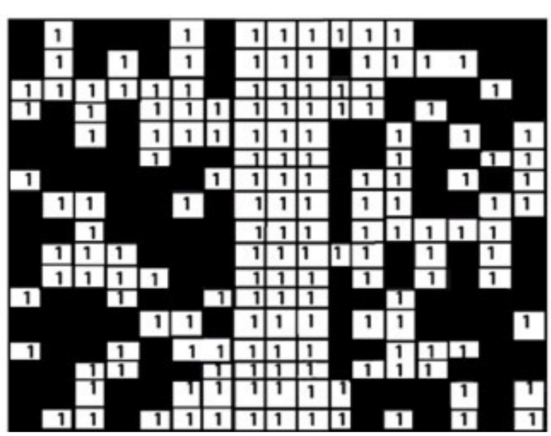

Figure 3: Modificated patch antenna.

The size of the population was set to 70 chromosomes. For the chromosome, various sizes were tested, but a digital individual of 289 elements (connect rows of the matrix) was chosen. The fitness function, related to the bandwidth and the return loss, is presented in Eq. 2.

$$fit = \alpha fit_{BW} + (1 - \alpha) fit_{RL} \tag{2}$$

Two optimization objectives were used. In Eq. 2, α is a weighting factor in the range [0, 1], which allows the choice of the emphasis or preference of a parameter with respect to each other. The fitness function related to bandwidth (fit_{BW}) is set with minimum bandwidth 2 GHz, and the related to return loss (fit_{RL}) demands further loss of 25 dB.

After the initialization of population and definition of the fitness function, the cyclic or evaluative process begins (cycle and generation are effectively interchangeable terms in this work). In the cycle process, a roulette-wheel technique was used. Shuffle crossover with swapping probability was set equal to 0.5. The mutation probability was fixed to 0.001 and bit-flip[11] (Fig. 4).

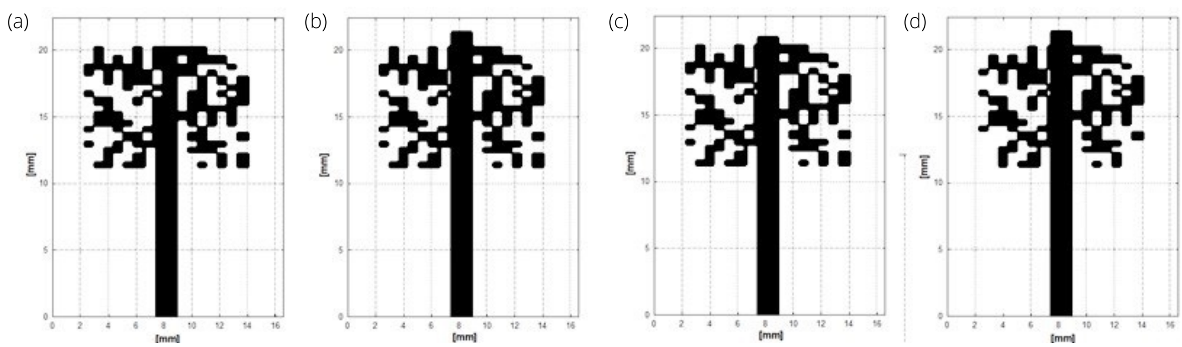

Figure 4: Changes in the antenna (4) in the evolutive process.

The return loss comparison of partial results of the optimization process is present (Fig. 5). For the second and third antennas (Figs. 6 and 7), the left half of the patch and the symmetrically mirrored right were considered. The dimension of the second and third antennas (Figs. 6 and 7) are: W = 12.81 mm; L = 14.23 mm; Wf = 1.42 mm; material substrate value = 2.2; height substrate = 0.45 mm; width substrate = 23.48 mm; length substrate = 28.23 mm. The height of ground plane, the height patch and the height of line feed were taken as one delta mesh in the z direction.

NUMERICAL RESULTS

For the three rectangular microstrip antennas (4, 6, 7), the first one was built with an inset and the other one without it. To work in the Ku band, the initial dimensions were obtained by the resonant cavity and transmission line methods. The calculation of return losses was obtained with the FDTD-3D method. In the optimization process, in order to provide higher bandwidth (compared to the original antenna), genetic algorithm was used.

Figure 4 shows several steps in the evolutionary process of the first antenna, chosen in order to leave evidence of some important characteristic in the optimization process. In Figs. 4b, 4c, and 4d, for instance, the line feed has been extended beyond the top edge of the patch, at different multiples of Δy, and the current flows from the line to the sub-patches (it forms a resonant structure). On the other hand, the subpatches that did not pair directly became parasitic sub-folders. In common antennas, it is known that these elements improve its bandwidth. The return loss for the partial stages of the first antenna is presented in Fig. 5. The antenna in Fig. 4a, represented by a discontinuous line in the figure, has a bandwidth of 2.83 GHz and a return loss of 34.85 dB. The antenna in Fig. 4b has a bandwidth of 4.80 GHz with a return loss of 23.45 dB, represented by a continuous line.

The antenna in Fig. 4c has a bandwidth of 3.84 GHz and the return loss is of 25.05 dB, represented by a continuous line with x. The antenna in Fig. 4 has 4.80 GHz of bandwidth and a return loss of 39.42 dB, represented with a continuous line with *o*. The antenna in Fig. 4d is the final stage of the optimization process.

The antenna in Fig. 4b presents the worst return loss if compared with the antenna in Fig. 4a, but it presents wider bandwidth, 4.80 GHz. These changes are due to the mutation process, particularly in the extension beyond the upper edge of the patch (feeding line, in 4 sub-patches).

Comparisons between Figs. 4c and 4d show that the bandwidth of the antenna in Fig. 4d is larger than that of the antenna in Fig. 4c, and the antenna in Fig. 4d shows a better return loss.

In Fig. 5, it is also possible to relate the performance of the antenna with the size of the notch. These small changes are characteristics of the mutation process. It should be emphasized that, for the antenna in Fig. 4d, the bandwidth has been increased by approximately 2 GHz and the return loss by 5 dB if compared to the antenna of Fig 4d, after the optimization process.

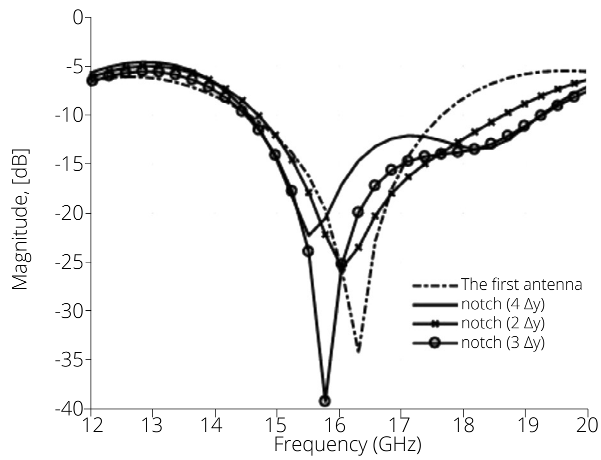

Figure 5: Return loss comparison of partial results of the optimization process.

The antennas in Figs. 6 and 7 were obtained by mirroring the left half of the patch in order to obtain a symmetrical structure and to observe the effects of this symmetry. The return loss presented in Fig. 8 corresponds to these symmetric antennas. Figure 8 presents the final result of the optimization process for both antennas. In the antenna of Fig. 6, the feed line has an extension beyond the upper edge of the patch. The presence of this discontinuity allows the band and the return loss to increase. The extension beyond the upper edge of the patch produces negligible changes in the parameters to be optimized. The bandwidth of the antenna of Fig. 6 is 4.97 GHz with return loss of 27.12 dB. In the antenna of Fig. 7, the feed line presents an extension between 12.81 and 16.37 mm. The antenna bandwidth is 5 GHz, and its return loss is 27.20 dB. Figure 9 presents the radiation patterns of the antenna of Fig. 7 for 15.25, 16 and 17.25 GHz.

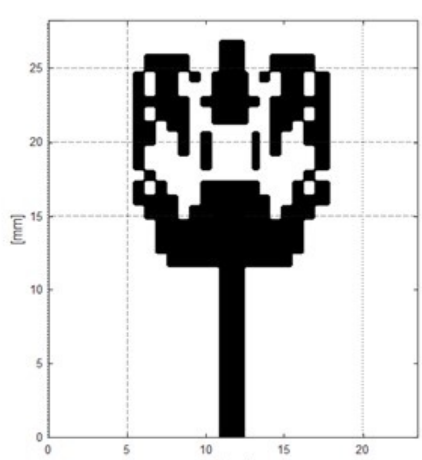

Figure 6: First symmetric antennas.

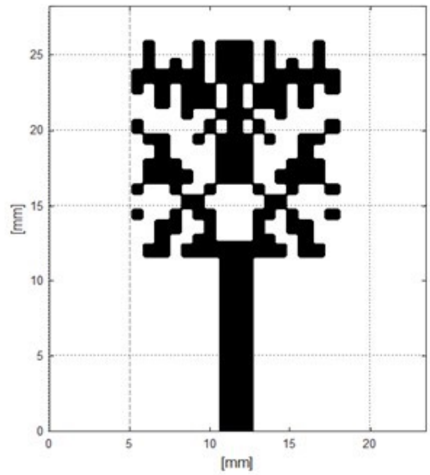

Figure 7: Second symmetric antenna.

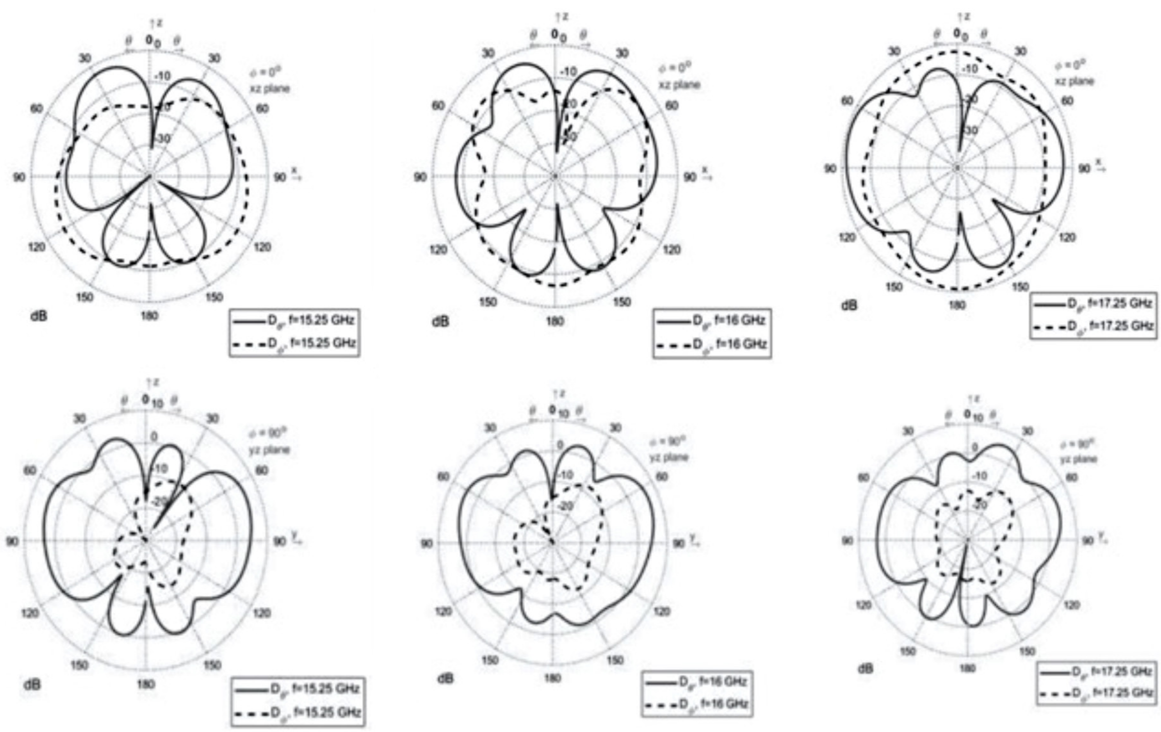

Figure 8: Radiation patterns of the antenna of Fig. 7 for 15.25, 16 and 17.25 GHz. Planes xy and xz.

CONCLUSION

Evaluation of the article was made. The objective of the article was to investigate the optimization of an antenna design through the minimization of the side lobe. Such optimization would aim to make a communication system more robust to electronic warfare attacks. Since a satellite communication link is easily exposed to a jammer or a signal interceptor, it must be protected to overcome the hostile attacks.

This paper presented the design of compact and efficient microstrip patch Ku-band antennas to avoid jamming attacks. Return loss greater than 30 dB with a bandwidth up to 5 GHz was obtained. When compared to the rectangular patch antenna, return loss was increased by 14.2% and bandwidth by 85%, which can decrease its side lobe and then make the hostile site difficult to interfere or intercept.

After the optimization process, non-restricted configurations were obtained. This process can potentially generate a variety of structures that cannot be conceived by conventional design approaches. The advantages of the proposes antenna are lower complexity and easy implementation, that could be used to provide further protection from jamming.

AUTHORS' CONTRIBUTION

Conceptualization: Soares A, Ramirez LAR and Matias MS; **Software:** Ramirez LAR; **Supervision:** Matias MS; **Validation:** Soares A, Ramirez LAR and Matias MS; **Writing – Original Draft Preparation:** Soares A, Ramirez LAR and Matias MS; **Writing – Review & Editing:** Soares A, Ramirez LAR and Matias MS.

DATA AVAILABILITY STATEMENT

Not applicable.

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REFERENCES

1. Bagri DS. Pros and cons of using arrays of small antennas versus large single-dish antennas for the deep space network. IPN Progress Rep. 2008;10:42-174.

2. Rao GK, Rao RSH. Status study on sustainability of satellite communication systems under hostile jamming environment. Annual IEEE India Conf. 2011;1-7. https://doi.org/10.1109/INDCON.2011.6139448

3. Mountin SM. The legality and implications of intentional interference with commercial communication satellite signals [PhD thesis]. United States: U.S. Naval War College; 2014;90.

4. G. K. Rao and R. S. H. Rao, "Status study on sustainability of satellite communication systems under hostile jamming environment," Annual IEEE India Conference,, pp. 1–7, 2011.

5. Kim K, Lee M, Lim J. Spreading technique of satellite beacon to avoid jamming attacks. International Conference on Advanced Communication Technology, 14., 2012;778-81.

6. Hou S, Wang H, Jiang X, Huang Y. Efficient digital channelized jamming analysis method for anti-jamming satellite navigation system. IEEE Int Workshop Electromagn. 2016;1-3. https://doi.org/10.1109/iWEM.2016.7505051

7. Hautcoeur J, Panther G. Anti-jamming GNSS antenna for timing applications. International Symposium on Antenna Technology and Applied Electromagnetics. 2018;1-3. https://doi.org/10.1109/ANTEM.2018.8572916

8. van de Burgwal M. Interfacing networks-on-chip: hardware meeting software [PhD thesis]. Enschede: University of Twente; 2010.

9. Griffiths L, Furse C. Broadband and multiband antenna design using the genetic algorithm to create amorphous shapes using ellipses. IEEE Trans Antennas Propagation. 2006;54(10):2776-82. https://doi.org/10.1109/TAP.2006.882154

10. Choo H, Hutani A, Trintinalia L, Ling H. Shape optimization of broadband microstrip antennas using genetic algorithm. Electr Letters. 2000;36(25):2057-8. http://dx.doi.org/10.1049/el:20001452

11. Rahmat-Shamii Y, Kovitz JM, Rajagopalan H. Nature-inspired optimization techniques in communication antenna design. Proceeding of the IEEE. 2012;100(7):2132-44. https://doi.org/10.1109/JPROC.2012.2188489

12. Balanis CA. Antenna theory analysis and design. 3rd ed. New York: John Wiley & Sons; 2005. v. 1.

13. Ramirez L, Santos J. Design, simulation, and optimization of an irregularly shaped microstrip patch antenna for air-to-ground communications. Int J Antennas Propagation. 2017;2017:5156263. https://doi.org/10.1155/2017/5156263

14. Ramirez L. Aplicação do método das diferenças finitas no domínio do tempo na análise de cobertura em ambientes interiores [PhD thesis]. Rio de Janeiro: Pontifícia Universidade Católica do Rio de Janeiro; 2008.

15. Gedney SD. An anisotropic perfectly matched layer absorbing medium for the truncation of FDTD lattices. IEEE Trans Antennas Propagation. 1996;44:1630-9. https://doi.org/10.1109/8.546249

16. Jayasinghe JW, Anguera J, Uduwawala D. On the behavior of several fitness functions for genetically optimized microstrip antennas. Int J Adv Sci Res. 2015;3:53-8.