ON BASE FREQUENCY OF THE SYMMETRICAL SIX-TOOTH-SHAPED MICROSTRIP ANTENNA

Angelina Markina
Kazan Federal University
Dmitrii Tumakov
Kazan Federal University
Nikolai Pleshchinskii
Kazan Federal University

Abstract. A symmetrical microstrip six-tooth-shaped antenna is considered. The influence of the main geometric parameters of the antenna on the base frequency is investigated. The main geometric parameters of the antenna include length and width of the radiator, depth of the rectangular cutouts on its radiator, thickness of the substrate, length of the ground and width of the feedline. Regression analysis is carried out and several mathematical models are constructed. The first model describes a relationship of the base frequency with depth of the rectangular cutouts, the radiator length and width. The second model describes a relationship between the wavelength at the base frequency and the geometry of the radiator. The root-mean-square error and the relative error of these models are calculated. For the base frequency and wavelength, graphs of dependencies on the geometric parameters of the antenna are plotted. We establish that a decrease in values of the base frequency and an increase in the wavelength is associated with an increase in the depth of cutouts and the radiator length. We show that a slight influence on the base frequency is caused by changes in width of the feedline, thickness of the substrate and length of the ground. The proposed formulas, describing relationships of the base frequency as well as the wavelength at this frequency with the geometric parameters of the antenna, can be used to design a six-tooth-shaped antenna in a wide frequency range.

Keywords: base frequency, wavelength, six-tooth-shaped microstrip antenna, regression analysis, antenna parameters**.**

1 Introduction

Microstrip antennas today are among the most widely used types of antennas in wireless communication systems [1]. These antennas have become popular, first of all, due to their small size and weight. As a result, a large number of publications on various modifications of the antennas have appeared in the literature.

The most researched antennas are microstrip patch antennas with radiators of a simple geometry. For example, a patch antenna with a rectangular radiator represents a well-studied object [1, 2]. One of the approaches to improving the antenna's properties is related to adding cutouts on the sides of the radiator or adding various slots on the radiator itself. By doing this, one can achieve a compact antenna size [3-5], tune or change the resonance frequencies [6-8], increase the bandwidth [9-11], etc.

For example, in [12], a comb-shaped microstrip antenna is considered, and the influence of various parameters of comb-shaped cutouts on the antenna operation is investigated. In [13], compactness of a design of microstrip antennas is achieved by a step-by-step approach to the formation of radiating elements. For wireless systems, the study [14] presents a simple comb-shaped microstrip antenna with seven operating ranges.

However, it is noteworthy that the process of designing any well-matched antenna is quite a long and time-consuming process. In [15, 16], the influence of the antenna geometry on its electrical characteristics is studied and mathematical models describing these relationships are constructed. Using these dependencies, one can predetermine the shape of the antenna for a given frequency range. This approach simplifies the antenna designing process and allows obtaining a well-matched antenna at a quicker time.

The structure of microstrip antennas with a symmetrical tooth-shaped radiator is derived from an antenna with a rectangular radiator by adding rectangular cutouts on the sides. This type of microstrip antennas is studied in [11, 17, 18], where the positive effect of cutouts on the main electrical characteristics of the antenna is also established.

In this paper, we consider an antenna with symmetrical six-tooth-shaped radiator. The influence of the radiator geometry on the base frequency as well as on the wavelength at this frequency is shown. Two regression models are constructed. The first model describes a relationship between the antenna base frequency and the radiator geometric parameters. The second model describes a dependence of the wavelength on the same geometric parameters of the radiator. Graphs of dependences of the base frequency as well as of the wavelength on the cutout depth are given. Below, the investigation of dependences of the base frequency on other antenna parameters is presented.

2 Problem Statement

Let us consider a microstrip antenna with a symmetrical six-tooth-shaped radiator (see Fig. 1). On the front side of the substrate of size mm by with dielectric constant , material density ρ = 1000 kg/m^3 and dielectric loss tangent , a radiator of the size by with a straight feedline is placed. The width and the length of the feedline are 1 mm and 15 mm, respectively. On the back side of the substrate, there is a metal plate called the ground plane of length equal to and width occupying the entire substrate. We assume that . The thickness of the substrate is 1 mm.

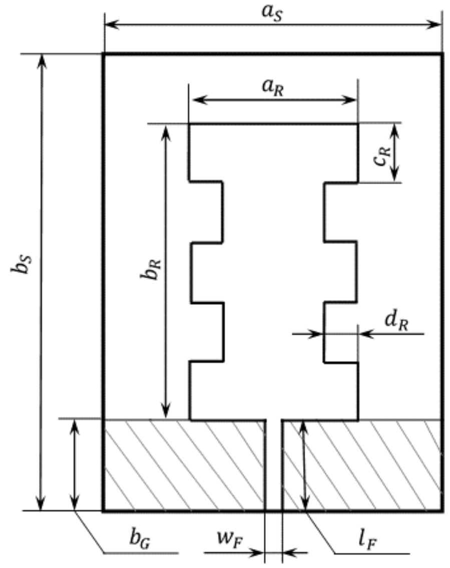

Figure 1. The structure of a symmetrical six-tooth-shaped microstrip antenna

Symmetrical rectangular cutouts of the size are made on the two sides of the radiator (left and right); the width of the radiator comb is calculated by the formula .

Let us investigate the influence of the radiator geometric parameters on the base frequency *f* and on the wavelength *λ* corresponding to this frequency.

We perform numerical experiments in the FEKO program. In the experiments, values of the radiator length are varied from 24 to 41 mm, values of the radiator width are varied from10 to 24 mm, and values of the cutouts depth are changed from 0.4 to 11.9 mm (depending on the width of the radiator).

At the next step, we perform regression analysis and construct the mathematical dependences of the base frequency as well as of the wavelength at this frequency on the length , width of the radiator and depth of the rectangular cutouts .

3 Dependence Of The Base Frequency On The Radiator Geometry

We present the dependence of the base frequency *f* of the microstrip antenna on the size of rectangular cutouts at the fixed radiator length mm in Fig. 2 and at the fixed radiator width mm in Fig. 3.

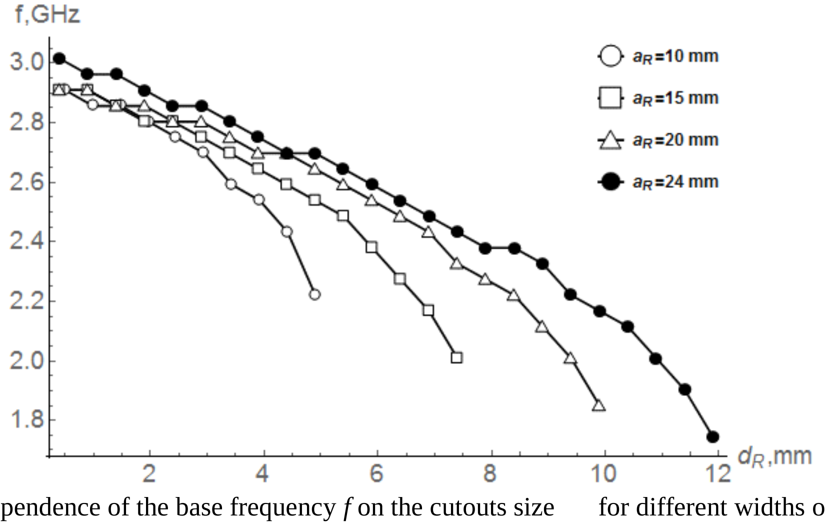

Figure 2. The dependence of the base frequency *f* on the cutouts size for different widths of the radiator at mm

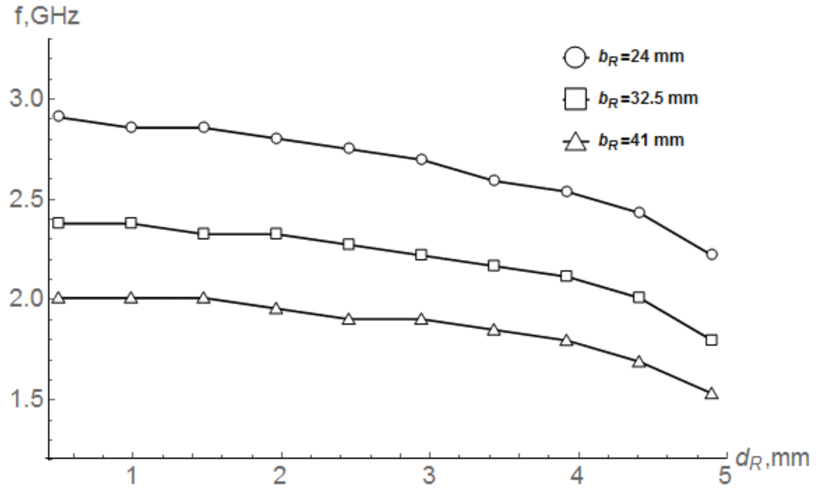

Figure 3. The dependence of the base frequency *f* on the cutouts size for different lengths of the radiator at mm

As shown in graphs of Fig. 2 and 3, we can see that values of the base frequency decrease with the size of the rectangular cutouts. The increasing of the radiator length also reduces the base frequency. This relationship can be explained by the fact that the current along the side walls of the radiator travels a greater distance. It follows that the radiators with the largest perimeter correspond to lower values of the base frequency.

At the next step, we consider the dependence of the wavelength at the base frequency on the size of the cutouts. We show dependences of the wavelength λ on at the fixed radiator length mm in Fig. 4 and at the fixed radiator width mm in Fig. 5

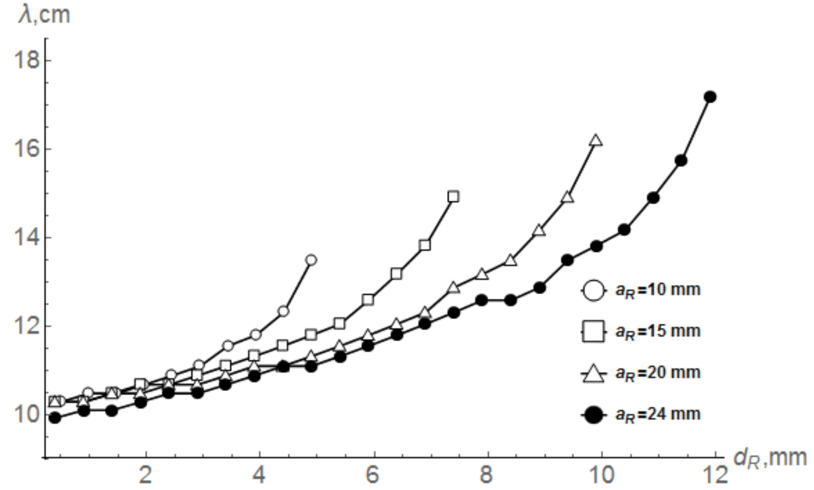

Figure 4. The dependence of the wavelength λ at the base frequency of the cutouts size for different widths of the radiator at mm

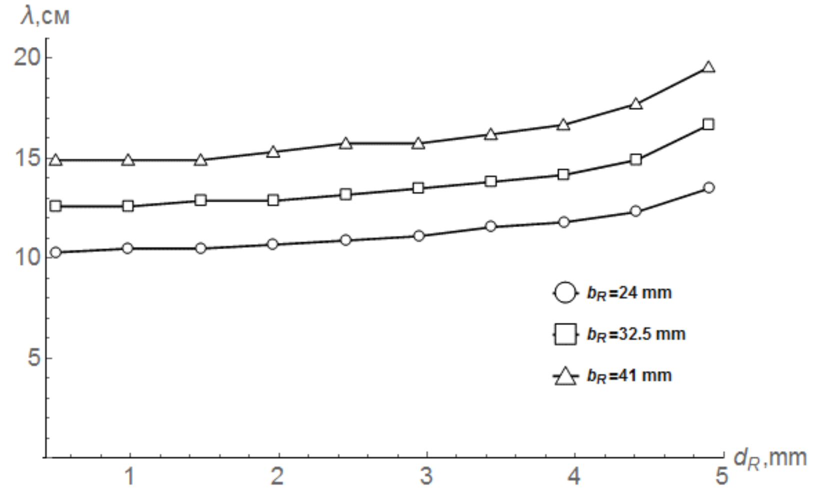

Figure 5. The dependence of the wavelength λ at the base frequency of the cutouts size for different lengths of the radiator at mm

We know that the value of the frequency is inversely proportional to the wavelength; therefore, in graphs of Fig. 4 and 5 we have an increase in values of the wavelength λ at the base frequency with an increase of cutout depth . A similar change in the wavelength occurs with an increase in length of the radiator .

Analyzing the behavior of the obtained dependences, we see that these dependences can be approximated by a certain curve. For the case of dependences of the base frequency and of the wavelength at the fixed radiator length, the corresponding curves in Fig. 2 and 4 are characterized by a high rate of change in values at the ends of the curves (rapid decrease and rapid increase, respectively). It is noteworthy that such relationships can be approximated by an exponential function. For the case of dependences of the base frequency and of the wavelength at the fixed radiator width, the corresponding curves in Fig. 3 and 5 are best approximated by a quadratic function.

In [17], we obtained that the approximate functional dependence of the base frequency on the length of a rectangular radiator has the following form:

, 1)

where f is measured in GHz, and is measured in cm.

Let us get down to the construction of a functional dependence of the base frequency on the radiator parameters , and for an antenna with a symmetrical six-tooth-shaped radiator. We seek a regression model for the base frequency in the same form as it was for a symmetrical four-tooth-shaped antenna in the study [18]:

, 2)

where f is measured in GHz; the radiator length , the radiator width and the depth of cutouts are measured in mm; the coefficients are assumed unknown.

By using the least squares method, we determine the unknown parameters in (2); the final form of the desired functional dependence for the base frequency is following:

. 3)

We calculate the root-mean-square error (RMSE) by using the formula:

4)

and the relative error by using the formulas of [19]:

5)

The regression model (3) for the base frequency has RMSE = 0.082 GHz, δ = 3.05%. Moreover, we note that we obtained the regression model for a six-tooth-shaped antenna with almost identical high accuracy as in [18] for a four-tooth-shaped antenna (RMSE = 0.0876 GHz, δ = 3.16%).

Now we construct the functional dependence of the wavelength λ at the base frequency on the radiator geometric parameters. We seek a regression model in the same form as for a symmetrical four-tooth-shaped antenna in [18]:

6)

where λ, the radiator length , the radiator width and the depth of cutouts are measured in mm; the coefficients are assumed unknown.

Similarly, using the method of least squares, we determine the unknown parameters in (6) and the final form of the desired functional dependence for the wavelength at the base frequency is following:

7)

The resulting regression formula (7) for a six-tooth-shaped antenna has errors RMSE = 3.59 mm and δ = 1.63%. It should be noted that the model (6) for the four-tooth-shaped antenna in [18] gives errors RMSE = 3.61 mm and δ = 1.69%. Moreover, if one makes a judgment by using the relative error, then the functional dependence (7) for the wavelength at the base frequency appears more accurate than (3) for the base frequency. In addition, the radiator (Fig. 1) takes a rectangular shape at = 0; for this scenario the following relationship

$$\frac{}{} =$$

8)

describing a relationship of the wavelength at the base frequency with the length of the rectangular radiator holds true, where *C* is some constant. In our case, i.e. at , from expression (6) we obtain a formula different from (8), but more accurate, at the same time. We can exclude the first term in the representation (6). Then the modified formula (7) has an error of about 4.5%, and this particular case coincides with the expression (8).

4 Influence Of The Main Antenna Parameters On Base Frequency

Let us investigate the influence on the base frequency of other geometric parameters of a six-tooth-shaped antenna such as the ground length , the radiator dimension (RD), the substrate thickness (TS), the feedline width (see Fig. 1). We choose the radiator with dimensions 10 by 24 mm and with sizes of cutouts 0.5 and 2.5 mm for analysis.

First, we consider the influence of the ground size on the base frequency *f* in Fig. 6. The size of the ground will be changed by varying its height .

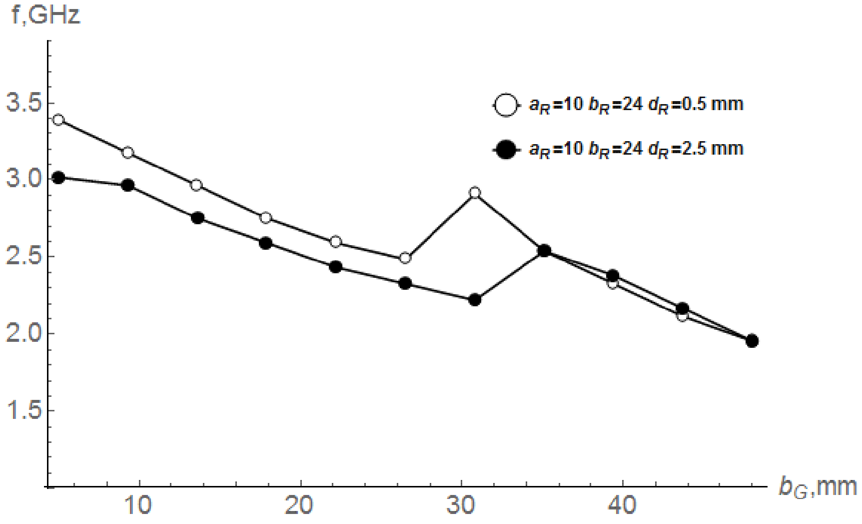

Figure 6. The dependence of the base frequency *f* on the ground length at different depths of cutouts

We note that the increase in the ground length leads to a small increase in frequency at values of about 27-36 mm. This can be explained by the fact that to the ground, there also corresponds a certain resonant frequency, the value of which decreases with an increase in the ground length, since the current on the ground is to travel a greater and greater distance. At small values of , the frequency of the ground has large values. However, as the ground increases, this frequency decreases and becomes the base frequency starting from a certain value of . This fact can help to control two frequencies, one of which corresponds to the radiator, whereas the other one corresponds to the ground.

Let us consider in Fig. 7. the influence of the radiator dimension (RD) on the base frequency.

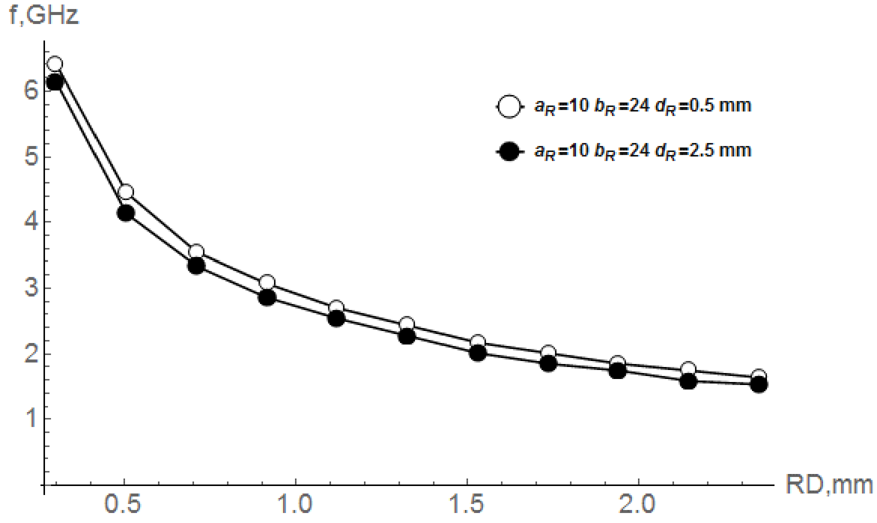

Figure 7. The dependence of the base frequency *f* on the radiator dimension (RD) at different depths of cutouts

The graph shows that for a small dimension of the radiator RD ≤ 0.4, we have large values of the fundamental frequency; in addition, values of *f* vary significantly for RD ranging from 0.1 to 1.25 mm, and then we can see a smoother decrease in the base frequency.

At the next step, we consider the influence of the thickness of the substrate (TS) on the base frequency in Fig. 8. We note that increasing the substrate thickness from 0.6 mm to 5 mm leads in a monotonically small decrease in the base frequency. Moreover, values of the base frequency, corresponding to different sizes of rectangular cutouts have a very similar behavior.

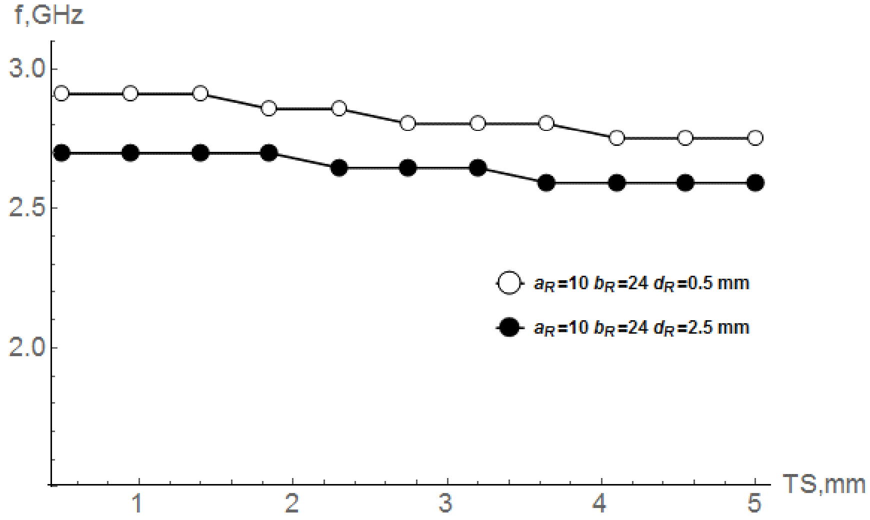

Figure 8. The dependence of the base frequency *f* on the substrate thickness (TS) at different depths of cutouts

We note that the substrate is homogeneous, but by choosing an inhomogeneous filling of the dielectric layer, it is possible to affect the given frequency range. Examples of the influence of the heterogeneity of filling the layer with a dielectric material on the diffraction of electromagnetic waves can be found in [20, 22].

We consider in Fig. 9 the influence of the feedline width on the base frequency.

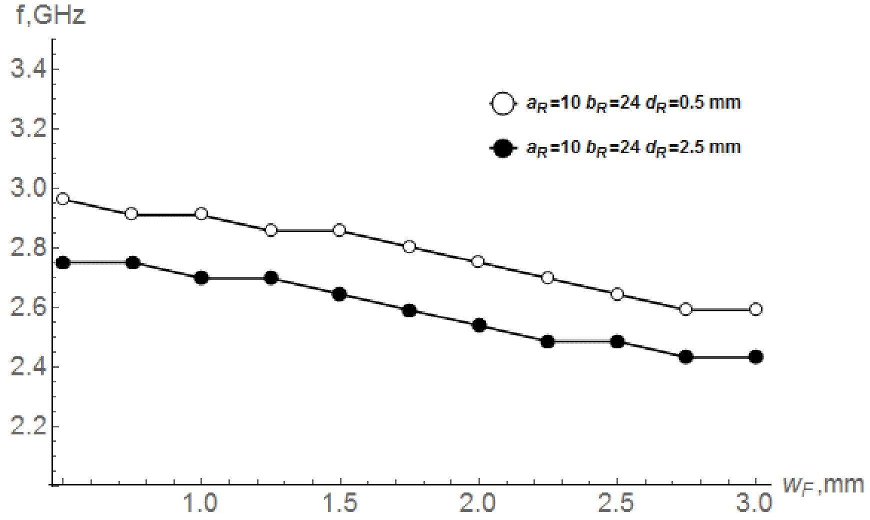

Figure 9. The dependence of the base frequency *f* on the feedline width at different depths of cutouts

Analysis of the graphs shows that values of the base frequency decrease monotonically with increasing the feedline width. Moreover, for antennas with different cutouts, the difference between the frequency values remains approximately the same. This suggests that changing the feedline width can slightly correct the base frequency.

5 Summary

A microstrip antenna with a symmetrical six-tooth-shaped radiator is considered.

We establish that as the depth of the rectangular cutouts is increased, values of the base frequency decrease and the wavelengths at the base frequency increase, while similar changes occur with increasing the radiator length.

We reveal that the increases in the ground length, the substrate thickness and the feedline width lead to insignificant changes in the base frequency in contrast to the increase of the radiator size.

Regression models with high accuracy are constructed for dependences of the base frequency as well as of wavelength at this frequency on the radiator width and length as well as on the depth of the rectangular cutouts. Moreover, the model for the wavelength has a smaller approximation error.

6 Conclusions

Investigated dependences of the base frequency and the wavelength at this frequency on the geometrical parameters of the radiator show a decrease in values of the base frequency and an increase in the wavelength with an increase in size of the rectangular cutouts and radiator length. For a more complete understanding of dependences of the base frequency on the ground length, feedline width, substrate thickness and antenna size, a further regression analysis can also be carried out.

We note that the regression models obtained for the base frequency and for the wavelength at this frequency provide an opportunity to simulate an antenna operating in a given frequency range.

7 Acknowledgements

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

References

1. R. Garg, P. Bhartia, I. Bahl and A. Ittipiboon, *Microstrip antenna design handbook*, London: Artech House, 2001.

2. T. A. Milligan, *Modern Antenna Design*, 2nd ed., New Jersey: John Wiley & Sons, 2005.

3. M. Sarkar, S. Dwari, A. Daniel, “Compact printed monopole antenna for ultra‐ wideband application with dual band‐ notched characteristic*,” Microwave and Optical Technology Letters*, vol. 55(11), pp. 2595-2600, 2013.

4. M. Abdollahvand, G. Dadashzadeh, D. Mostafa, “Compact dual band-notched printed monopole antenna for UWB application,” *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 1148-1151, 2010.

5. J.R. Panda, A.S.R. Saladi, R.S. Kshetrimayum, “A compact printed monopole antenna for dual-band RFID and WLAN applications,” *Radioengineering*, vol. 20(2), pp. 464-467, 2011.

6. L. Ma, R.M. Edwards, W.G. Whittow, “A multi-band printed monopole antenna,” *Antennas and Propagation, 2009. EuCAP 2009. 3rd European Conference on*, IEEE, pp. 962-964, 2009.

A. Agarwal et al., “Design of CPW-fed Printed Rectangular Monopole Antenna for Wideband Dual-Frequency Applications,” *International Journal of Innovation and Applied Studies*, vol. 3, no. 3, pp. 758-764, 2013.

7. J. Chen et al., “Design of Tri-band Printed Monopole antenna for WLAN and WIMAX applications,” *Progress In Electromagnetics Research*, vol. 23, pp. 265-275, 2011.

8. S.K. Palaniswamy et al., “Super wideband printed monopole antenna for ultra wideband applications,” *International Journal of Microwave and Wireless Technologies*, vol. 9, no. 1, pp. 133-141, 2017.

9. C.Y. Pan et al., “Dual wideband printed monopole antenna for WLAN/WiMAX applications,” *IEEE Antennas and Wireless Propagation Letters*, vol. 6, pp. 149-151, 2007.

10. A.G. Markina, D.N. Tumakov, N.B. Pleshchinskii, “Bandwidth enhancement of symmetrical fourth-teeth-shaped microstrip antenna,” *Helix*, vol. 8, no. 1, pp. 2275–2283, 2018.

11. C.Y. Pan, J.H. Duan, J.Y. Jan, “Coplanar printed monopole antenna using coaxial feedline for DTV application”, *Progress In Electromagnetics Research*, vol. 34, pp. 21-29, 2012.

A. Boutejdar, A. A. Ibrahim and E. P. Burte, “Novel microstrip antenna aims at UWB applications,” *Microwaves & RF*, pp. 62-66, Oct. 2015.

12. K. Mandal, “Seven-band comb-shaped microstrip antenna for wireless systems,” *PIER Letters*, vol. 59, pp. 15-20, 2016.

13. D.N. Tumakov et. al, “Modeling of the Koch-type wire dipole,” *Applied Mathematical Modelling*, vol. 51, pp. 341–360, 2017.

14. G.V. Abgaryan, A.G. Markina, D.N. Tumakov, “Application of correlation and regression analysis to designing antennas,” *Revista Publicando*, vol. 4, no. 13(2), pp. Pr1–Pr13, 2017.

A. G. Markina, N. B. Pleshchinskii and D. N. Tumakov, “On electrical characteristics of comb-shaped microstrip antennas,” in *Proc. 2017 EIConRus*, pp. 179-183, Febr. 2017.

15. A.G. Markina, D.N. Tumakov, N.B. Pleshchinskii, “On base frequency for the symmetrical four comb-tooth-shaped microstrip antenna,” *Journal of Fundamental and Applied Sciences*, vol. 9, no. 1S, pp. 1534–1547, 2017.

16. Opata, C. E. (2017). An Assessment of Embedded Power Generation in Nigeria (Doctoral dissertation).

A. V. Anufrieva and D. N. Tumakov, “Peculiarities of electromagnetic wave propagation through layers with ridge-shaped refractive index distribution,” in *Proc. MMET 2012*, pp.386-389, 2012.

17. N. B. Pleshchinskii and D. N. Tumakov, “Analysis of electromagnetic wave propagation through a layer with graded-index distribution of refractive index,” in *Proc. MMET 2012*, pp. 425-429, 2012.

18. Pérez, Eudes De Armas, Cristian De Armas Iturriago, and Eudes Rafael De Armas. "Desempleo como violación de los derechos humanos al trabajo en Colombia." Opción 34.86 (2018): 642-666.