SERBIAN JOURNAL OF ELECTRICAL ENGINEERING
Vol. 11, No. 1, February 2014, 85-96

UDC: 621.396.677.5:621.3.011.21 DOI: 10.2298/SJEE131121008S

The Impedance Variation with Feed Position of a Microstrip Line-Fed Patch Antenna

Snežana Lj. Stefanovski[1], Branko M. Kolundžija[2]

Abstract: This paper presents a very precise analysis of the impedance variation with feed position of a microstrip line-fed patch antenna. The influence of the inset length and width has been investigated, taking into account finite size of the substrate, various lengths of the feeding microstrip line, losses and finite thickness of metallization. The obtained numerical results are compared with the previously published ones, showing very good agreement. However, the results of the additional analysis confirmed that the mathematical functions proposed in previously published papers (the cosine-squared function and the cosine to the fourth power function) are not really good approximations of the input impedance behavior for this type of the microstrip patch antenna.

Keywords: Input impedance, Microstrip line feed, Microstrip patch antenna.

1 Introduction

Microstrip antennas have wide implementation in many applications where size, weight, cost, performance and ease of installation are constraints [1]. As low-profile antennas, they represent sustainable solution for demanding applications, such as wireless communications, mobile radio, aircraft and satellite applications, etc. These antennas are simple to fabricate and, depending on the design requirements, they can provide various solutions, in terms of resonant frequency, radiation pattern, polarization, impedance.

In order to meet strict requirements regarding the antenna performance, the analysis and synthesis of the microstrip antenna must be as accurate as possible. Various parameters may affect the antenna operation, thus they have to be taken into account for precise antenna design. Therefore, it is very important to understand the operation of these antennas and the influence of certain parameters on the antenna characteristics, in order to be able to design the antenna accurately and to reduce the time from design to production.

[1]Ph.D. student, School of Electrical Engineering, University of Belgrade, Bulevar kralja Aleksandra 73, 11120 Belgrade, Serbia; E-mail: stefanovskisnezana@gmail.com
[2]School of Electrical Engineering, University of Belgrade, Bulevar kralja Aleksandra 73, 11120 Belgrade, Serbia; E-mail: kol@etf.rs

Microstrip patch antenna consists of thin metal patch which is significantly wider than the usual transmission-line [2]. The patch and the ground plane are separated by a substrate. The feed of the patch antenna can be configured in different ways, and some of the most common models use the coaxial probe, microstrip line, aperture coupling and proximity coupling.

Several methods of analysis for microstrip antennas have been developed so far, but the most commonly used ones are the transmission-line model, cavity model and full wave model [1]. The transmission-line model represents the microstrip antenna as two slots, separated by a low-impedance transmission line. It is simple, but less accurate model, providing analytical formulas for calculation of the antenna parameters. However, these formulas do not always yield exact values of the considered parameters, thus additional analysis is needed for precise antenna design. The cavity model is more accurate, compared with the previous one, it provides good explanation of the antenna operation, but at the expense of complexity. The full wave model is based on the MoM (Method of Moments), it is very accurate, but also the most complex method of analysis.

In general, the patch can be analyzed as a resonant cavity with electric (metal) walls represented by the patch itself, along with the ground plane and magnetic walls around the edges [2]. The edges of the patch are considered as slots whose excitation depends on the fields inside the cavity, and the radiation of the patch stems from the fringing fields around its edges. When a patch resonates as a resonant cavity, the impedance is matched and the antenna operates with maximum efficiency. While the properly matched microstrip lines are not expected to radiate, the radiation is desirable characteristic of the microstrip patch antennas.

In this paper, the rectangular microstrip patch antenna, fed by an inset microstrip line, is considered. This model of the microstrip antenna has simple design, can be simply matched by controlling the inset position and it is easy to fabricate, regarding the feeding method. Namely, the antenna impedance changes by varying the parameters of the inset (the width and the length). Although some authors assume that the resonant input resistance can be analytically qualified as cosine-squared type function ($\cos^2$) of the inset length [1], there can be also found the formulation of the resonant input resistance using cosine to the fourth power function ($\cos^4$) [2]. Actually, there are only a few papers elaborating on this topic for microstrip line-fed patch antenna. Some of the previously published papers investigated the variation of the input resistance with feed position in order to confirm cosine to the fourth power dependency. Thus, they presented results obtained by experimental characterization of the input resistance [3] and results obtained using software based on the FDTD (Finite-Difference Time-Domain) method [4]. However, only a few results have been provided, with no theoretical background, which is not enough to confirm the proposed analytical qualification.

The objective of this paper is to accurately analyze the rectangular microstrip patch antenna, fed by an inset microstrip line, and to investigate the influence of the inset parameters on the antenna impedance. This analysis will be used to validate whether the input resistance is proportional to the proposed fourth power of the cosine function, depending on the inset length.

2 Model of the Microstrip Line-Fed Patch Antenna

The model of the considered microstrip patch antenna, along with the dimensions, is given in Fig. 1. The parameters of this antenna are set to be the same as for the antenna presented in [3], in order to be able to compare the results with those previously published. A copper clad Duroid substrate is used, with a thickness of $h = 1.27$ mm, and it has dielectric properties of $\varepsilon_r = 2.42$ and $\tan\delta = 0.0019$. The antenna is designed to operate at the central frequency of $f_0 = 2.3$ GHz. According to Fig. 1, the antenna has the width of $W = 59.4$ mm and the length of $L = 40.4$ mm. The inset width can be equal to the width of the feeding microstrip line ($s = W_0$), but it will be shown that the variation of this parameter also affects the input impedance. For the antenna modeling and analysis, WIPL-D software [5] is used, as a powerful three dimensional (3D) electromagnetic (EM) solver, capable to perform full-wave simulations.

First, the feeding microstrip line is modeled as a matched 50 Ω - line. For the given frequency, the line width is set to $W_0 = 3.7$ mm and the length L_0 is adjusted to accomplish required matching. The line is excited by an ideal voltage source, connected to the feeding line using conic wire and properly shaped small trapezoidal plate inside the substrate. In this way, smooth transition between the source and the line is accomplished, as shown in Fig. 2a.

Using this model of the feeding line, the model of the antenna is made, according to the dimensions and labels given in Fig. 1. The patch is modeled as a metallic plate with insets of various length and width, on the substrate of finite size. The PEC (Perfect Electric Conductor) plane is placed beneath the antenna. The 3D EM model of the antenna made in WIPL-D software is depicted in Fig. 2b.

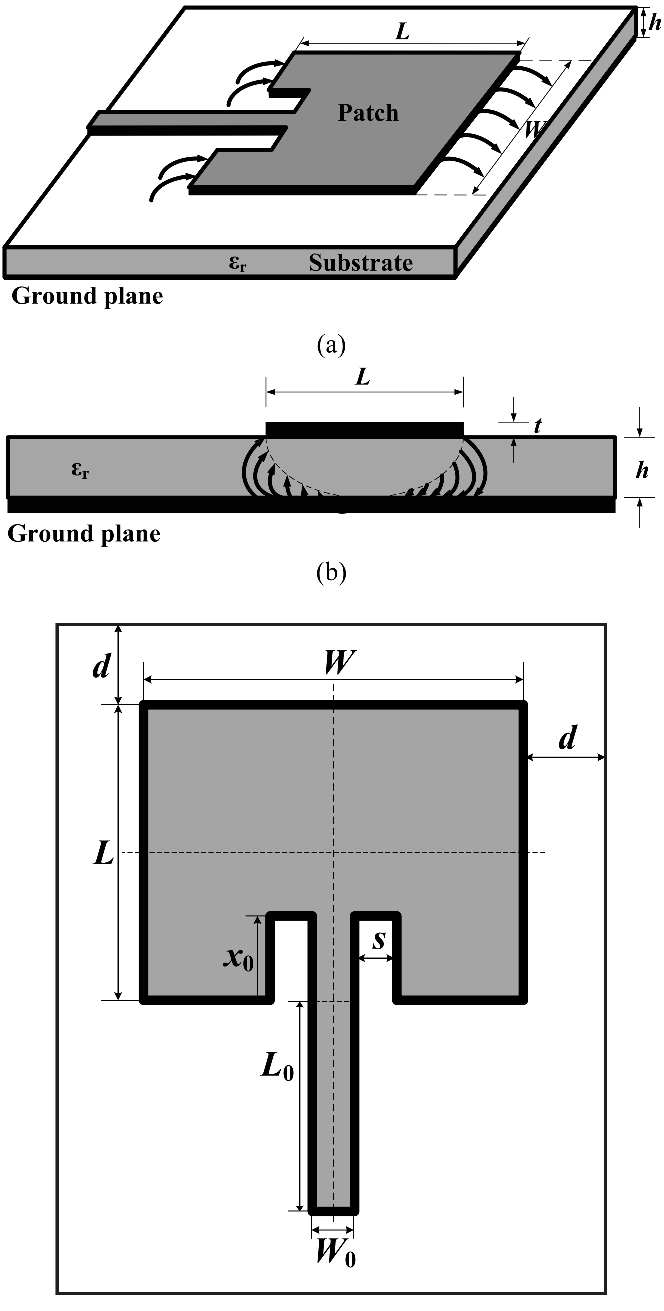
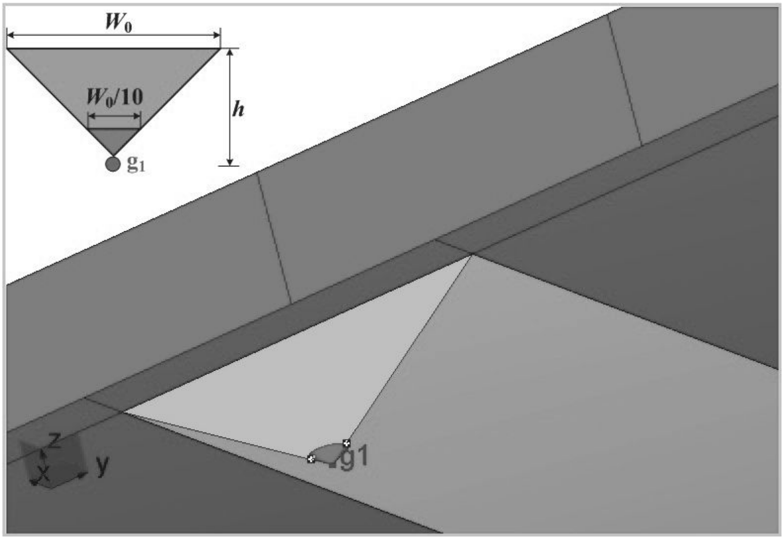
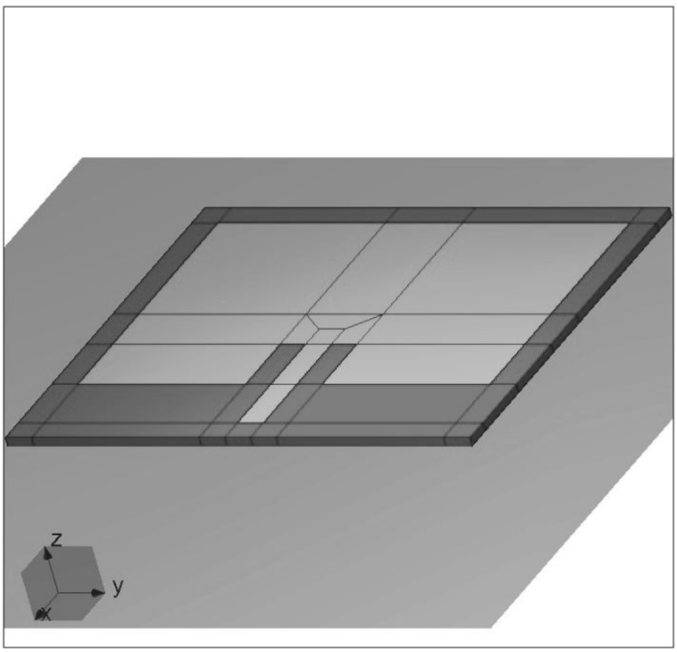


Fig. 1 – *The rectangular microstrip patch antenna fed by an inset microstrip line:* (a) *the model*, (b) *the side view of the patch*, (c) *the labeled dimensions*.



(a)



(b)

Fig. 2 – *3D EM model in WIPL-D software*:
(a) *the feeding microstrip line,* (b) *the microstrip line-fed patch antenna.*

3 Analysis of the Input Impedance

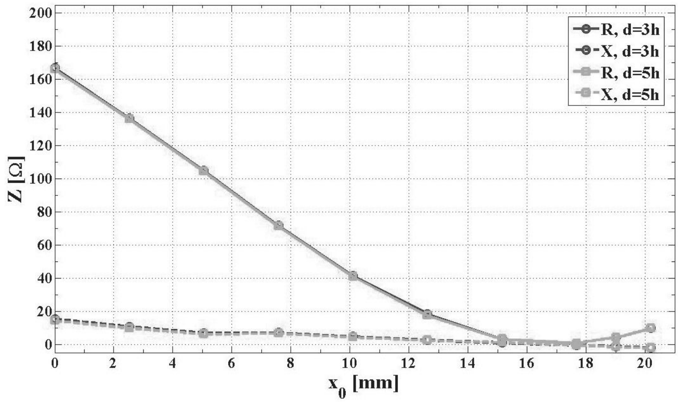
The influence of various parameters on the input impedance of the considered antenna has been investigated. The analysis of the antenna is performed for different lengths of the feeding line, in order to confirm that the line is perfectly matched and that it does not affect the characteristics of the antenna. For the chosen length of the feeding line and the inset width, the simulations are performed for various inset lengths ($0 \le x_0 \le L/2$). Further, the finite size of the substrate is taken into account, and the input impedance is analyzed for various dimensions of the substrate. Finally, the input impedance is considered in case of lossless and lossy dielectric. We were able to obtain the values of the input impedance at the position where the feeding line, extended for the inset length, connects to the patch, using the port translation property of WIPL-D software. This property provides the possibility to set the port impedance to the required value and to move the reference planes, at which the results are calculated, for the specified length [6].

4 Numerical Results

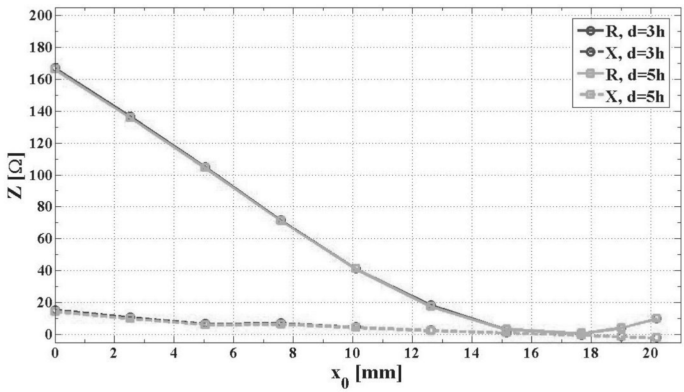
The goal of the analysis of the considered microstrip line-fed patch antenna, performed for various parameters as described in the previous section, was to verify the accuracy of the results found in the available literature. Therefore, the values of the input impedance are chosen at the frequencies where the maximum resistance occurs, in order to be able to compare the obtained results with those previously published in [3, 4].

It should be emphasized that the size of the substrate does not influence the results of the performed analysis regarding the input impedance. As mentioned before, the substrate of the finite size is used in each case, and two models have been considered, with $d = 3h$ and $d = 5h$ according to the labels in Fig. 1c. The comparison of the results for the input impedance variation, for the inset width of $s = W_0$ and various values of the feeding line length ($L_0 = \lambda_g/8$, $\lambda_g/4$, $\lambda_g/2$), is given in Fig. 3. As can be seen, the results are matched relatively good, thus the model using the substrate with extension of $d = 3h$ around the patch is adopted for the further analysis of the input impedance.

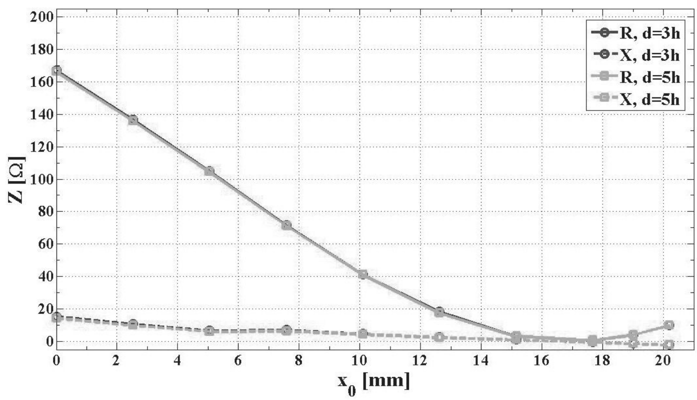
First, the input impedance is analyzed for various lengths of the feeding line, for the inset width of $s = 0.5W_0$, W_0, $2W_0$ and the inset length set to be $0 \le x_0 \le L/2$. These results are given in Fig. 4. Since there is good mutual agreement of the obtained results, for each of these three examples, it is confirmed that the length of the feeding line does not influence the input impedance.



(a)

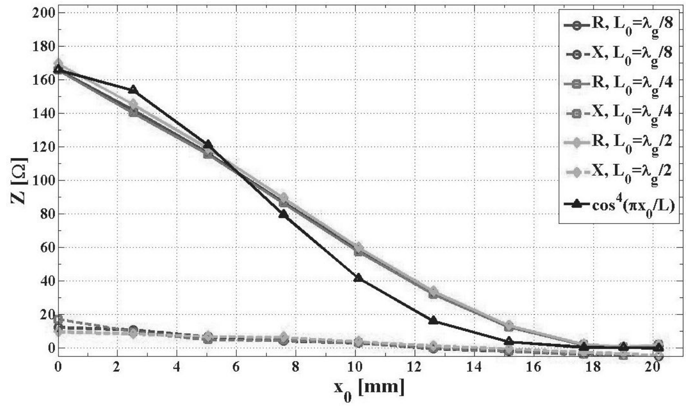


(b)

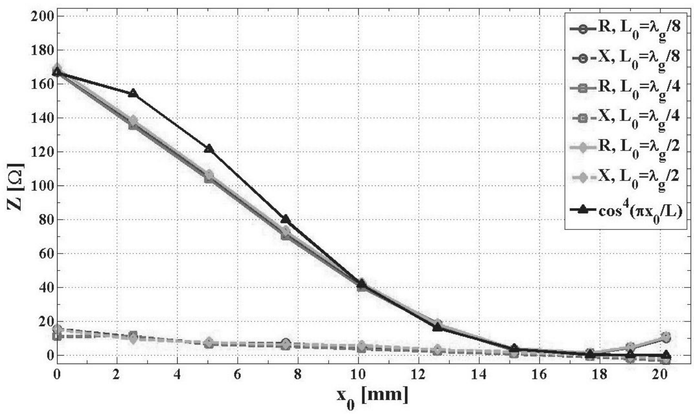


(c)

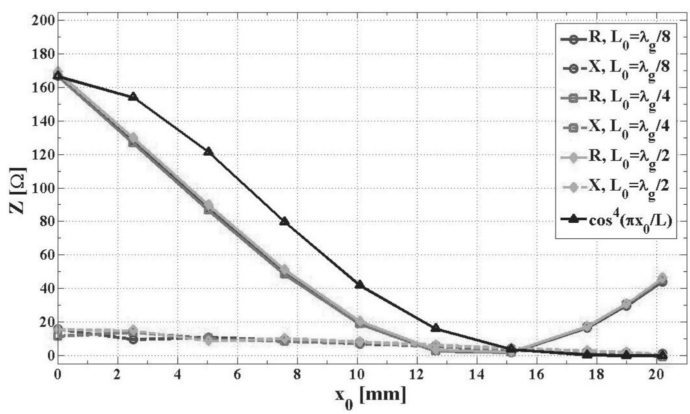
Fig. 3 – *The influence of the substrate size on the input impedance for chosen inset width ($s = W_0$) and the feeding line length of*: (a) $L_0 = \lambda_g/8$, (b) $L_0 = \lambda_g/4$, (c) $L_0 = \lambda_g/2$.



(a)



(b)



(c)

Fig. 4 – *The impedance variation with feed position, for different lengths of the feeding line and the inset width of*: (a) $s = 0.5W_0$, (b) $s = W_0$, (c) $s = 2W_0$.

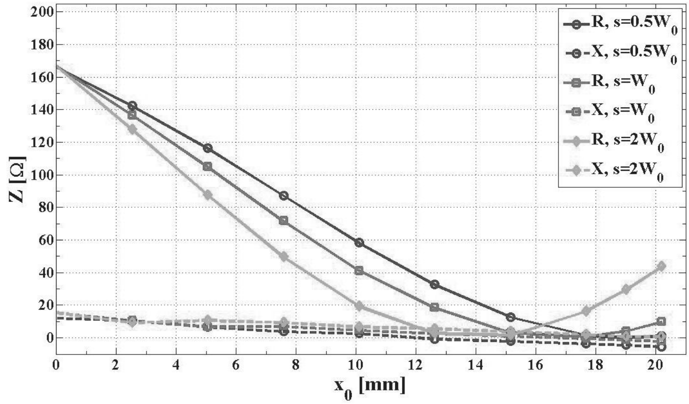
These results, obtained for the inset width of $s = W_0$, are compared with previously published ones, and they show relatively good agreement with those presented in [3] and [4] in terms of numerical values, as given in **Table 1**, but the cosine to the fourth power function cannot be used to describe the behavior of the input resistance. The curve representing $\cos^4$ dependence is also given in Figs. 4a, 4b and 4c and the difference is obvious.

Table 1
Comparison of Numerical Results Obtained Using WIPL-D Simulations with those Previously Published.

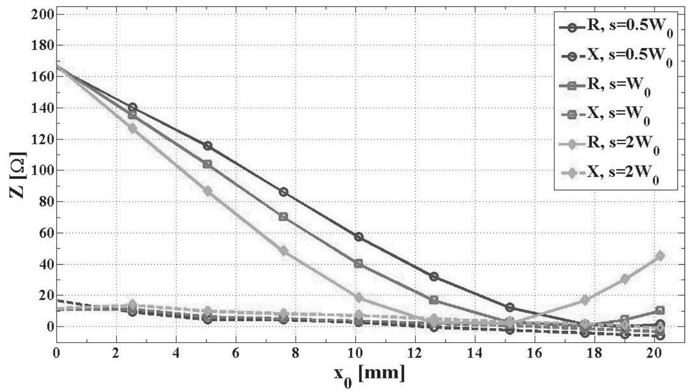
Normalized inset length ($2x_0/L$)	Input resistance, $R\ [\Omega]$		
	WIPL-D software simulation results	FDTD software based results [3]	Measurement results [4]
0.00	166.93	163.00	145.00
0.24	107.53	112.00	109.00
0.30	91.46	92.00	80.00
0.50	41.27	42.00	38.00
0.65	13.57	13.00	9.00
1.00	9.94	11.00	10.00

The influence of the inset width is also considered in the analysis of the input impedance, although this parameter was not taken into account for input impedance characterization in the available literature. The variation of the input impedance with feed position for the various inset widths ($s = 0.5W_0$, W_0, $2W_0$), is shown in Fig. 5. It can be noticed that for the higher values of inset width, the curve representing input resistance becomes steeper and the input resistance faster decreases to zero. Therefore, this parameter should be also taken into account for the impedance evaluation. However, there is no significant discrepancy regarding the results for the reactance, for different values of the inset width.

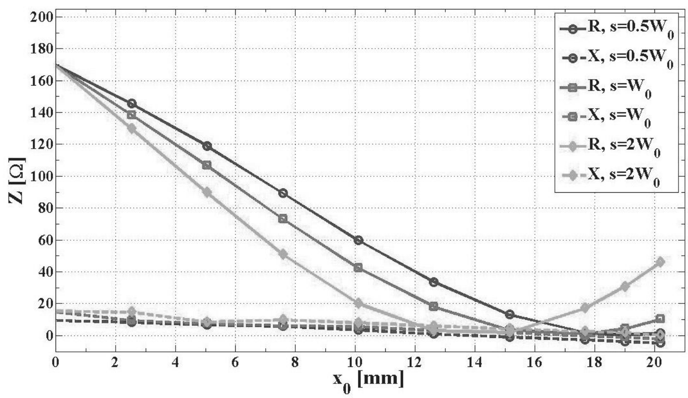
Finally, the influence of the losses in the substrate is also investigated. In Fig. 6, the results for the input impedance are presented for the chosen length of the microstrip feeding line, and similar results are obtained for other lengths of the feeding line. According to these results, it has been concluded that the input resistance has lower values in case of the lossy dielectric, compared with those obtained for the lossless dielectric. The values for the reactance remain practically the same.



(a)

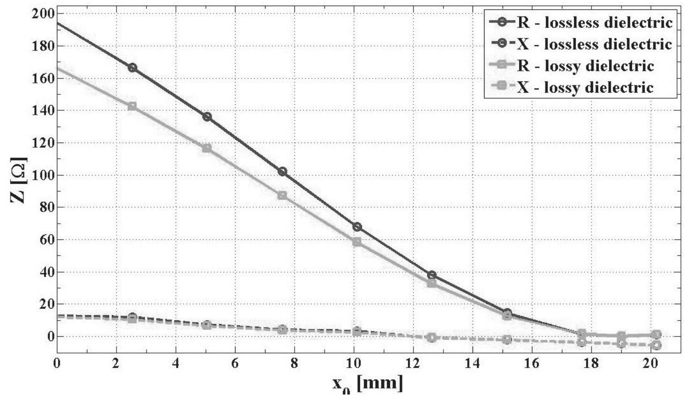


(b)

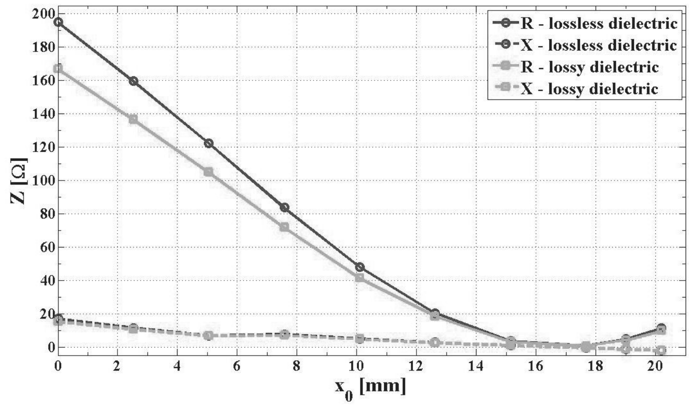


(c)

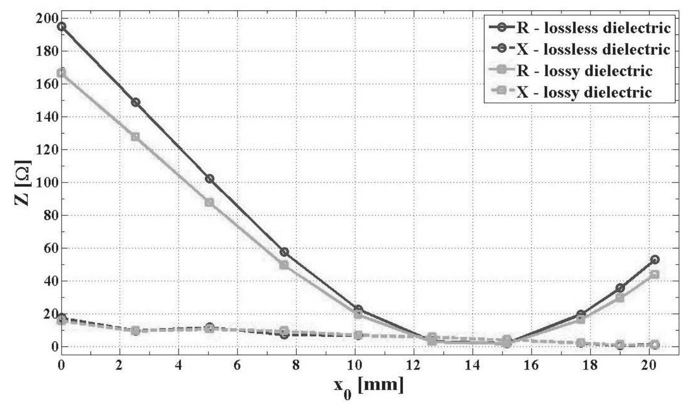
Fig. 5 – *The impedance variation with feed position, for various inset widths* ($s = 0.5W_0$, W_0, $2W_0$) *and the feeding line length of*: (a) $L_0 = \lambda_g/8$, (b) $L_0 = \lambda_g/4$, (c) $L_0 = \lambda_g/2$.



(a)



(b)



(c)

Fig. 6 – *The influence of the dielectric losses on the input impedance for chosen length of the feeding line* ($L_0 = \lambda_g/8$) *and various inset widths*: (a) $s = 0.5W_0$, (b) $s = W_0$, (c) $s = 2W_0$.

5 Conclusion

The microstrip patch antenna, fed by an inset microstrip line, was modeled and analyzed. It was investigated how the inset length and width influence the input impedance. The losses in the dielectric and the finite size of the substrate were also taken into consideration. From the presented results, it can be concluded that the variation of the input impedance depends both on the inset length and width. Dielectric losses decrease the values of the resistance, while the values of the reactance practically remain unchanged. If these results are compared with those given in [3, 4], it can be noticed that, although there is relatively good numerical agreement, the cosine to the fourth power function is not the best approximation for qualification of the input resistance behavior. This topic certainly calls for closer attention and further work should be dedicated to the accurate analytical explanation of the impedance for this type of the microstrip patch antennas.

6 Acknowledgment

This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia under Grant TR32005.

7 References

[1] C.A. Balanis: Antenna Theory: Analysis and Design, John Wiley and Sons, NJ, USA, 2005.

[2] T.A. Milligan: Modern Antenna Design, John Wiley and Sons, NJ, USA, 2005.

[3] L.I. Basilio, M.A. Khayat, J.T. Williams, S.A. Long: The Dependence of the Input Impedance on Feed Position of Probe and Microstrip Line-fed Patch Antennas, IEEE Transactions on Antennas and Propagation, Vol. 49, No. 1, Jan. 2001, pp. 45 – 47.

[4] T. Samaras, A. Kouloglou, J.N. Sahalos: A Note on the Impedance Variation with Feed Position of a Rectangular Microstrip-patch Antenna, IEEE Antennas and Propagation Magazine, Vol. 46, No. 2, April 2004, pp. 90 – 92.

[5] WIPL-D Pro 10.0, 3D Electromagnetic Solver, WIPL-D d.o.o., Belgrade, Serbia, 2012, http://wipl-d.com.

[6] B. Kolundžija, J. Ognjanović, M. Tasić, D. Olćan, M. Božić, M. Kostić, M. Pavlović, B. Mrdaković, T. Milošević, S. Marić, Đ. Petrović, D. Zorić, D. Jeremić, M. Kovač, N. Timko: WIPL-D Pro v10.0 3D Electromagnetic Solver Professional Edition – User's Manual, WIPL D d.o.o., Belgrade, Serbia, 2012.