Analysis and Optimizationof Linearly Polarized, Rectangular, Microstrip Line-Fed 3GHz Patch

Nebojša Vojnović[1]

Abstract – **In this paper, the main characteristics of a single microstrip patch antenna – it's efficiency and bandwidth, are defined.A dependence of these characteristics on the antenna physical dimensions is investigated, and some suggestions for antenna construction are listed.Various combinations of dielectric type and height have been used during the analysis, having the working frequency set at3GHz.**

Keywords – **antenna bandwidth, antenna efficiency, optimization, single microstrip patch**

I. INTRODUCTION

Microstrip patch antennasand antenna arrays are widely used in many of the today's applications where such parameters as the antennasize, weight, cost, ease of manufacturing and aerodynamic properties are very important [1]. Microstrip technology implies an unbalanced structure consisting of a dielectric slabon whose one side a thin layer of metallization is printed in a desired shape, while the other side is completely covered with metallization.These antennas are simple and cheap to manufacture using the modern printed circuit technology. They can be mounted on planar and non-planar surfaces, and when the desired shape is set, are very stabile in terms of resonant frequency, polarization, input impedance and radiation pattern. The biggest flaws of single-layered microstrip antennas and antenna arrays are, in fact, low efficiency, high Q-factor, poor scanning capabilities, existence of surface waves and a very narrow bandwidth in the order of a fraction of a percent or a few percent, at best.Patch antennascan be made in various shapes, they can be fed in various ways and made to have different polarizations.

In this paper, rectangular, linearly polarized, microstrip line-fed 3GHz patches are considered, as shown in Fig. 1. A patch element is defined with several dimensions:

L - antenna length,
W - antenna width,
L_{slit} - the length by which the feeding line is inserted into the patch (inset feed), and
W_{slit} - the width of the gap between the feeding line and the patch.

It is known that the antenna length (L) defines it's resonant frequency. With the L_{slit} parameter a patch can be successfully matched to a given characteristic impedance of the feeding transmission line. The input impedance of a patch can also be manipulated with the W parameter, while theL_{slit} parameter remains constant[2]. Breaking the antenna efficiency into it's factors and the analysis of each factor individually, using the method of moments, has shown that each factor peeks at a different patch width [3].Theoretical calculations of the microstrip patch characteristics depending on the surface current distribution [4] and using the method of moments [5], have given results similar tothoseobtained by this analysis.

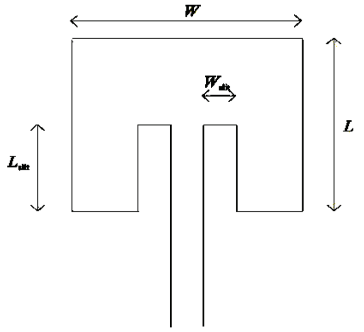

Fig. 1 -Structure considered in this paper

This paper is intended to give a more detailed perspective on the influence of the $W_{\text{slit}}$and$W$parameters on the overall antenna characteristics[6]. During the analysis, various combinations of dielectric type and height have been used, having the working frequency set at 3GHz.The program package WIPL-D Pro [7] was used for the simulation.

II. INFLUENCE OF THE W AND W_{SLIT} PARAMETERS ON THE ANTENNA CHARACTERISTICS

A. The parameters analyzed

In the following text the analysis of the influence of the W and W_{slit} parameters on the efficiency, bandwidth, resonant frequency and the needed position of the inset feed, are given.The influences of the$W_{\text{slit}}$and$W$parameters on the antenna characteristics were tested separately. The analysiswas done on two types of dielectricsubstrate and for two heights each, using the same working frequency of 3GHz.The Rogers (ε_r=3.38, $tg\delta$=0.0027) andFR4 (ε_r=4.5, $tg\delta$=0.02) dielectric substrates were used. The heights used for the Rogersdielectric were0.508mmand0.813mmand for the FR41mmand1.5mm.The metallization thickness was set to have a constant value of 17μm.Single patch models were constructed for two dielectric types and for two heights each (four sets of parameters, altogether). The length of the patch was initially taken to have the exact same value as the half-

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[1] Nebojša Vojnović, Institut IMTEL komunikacijea.d., Bulevar Mihaila Pupina 165b, 11070 Belgrade, Serbia
E-mail: nebojsav@insimtel.com

wavelength in the substrate. It should be mentioned that the starting models were chosen to have a square shape, $W=L=W$_nom, and the W_{slit} parameter was chosen to have the exact same value as the width of the50Ω transmission line at the given frequency, substrate type and height,due to the simplicity of the production. The width of the transmission line was calculated using the impedance calculator which is embedded in the WIPL-D program package.Those starting models were then optimized using the optimizer which is embedded in the WIPL-D Pro program package.In this way, by optimizing the length of the antenna, models operating at 3GHz were obtained. Those models had to be further optimized in order to have the appropriate input impedance. The starting value for theL_{slit} parameter,was taken to be 25% of the antenna length.The models were then experimentally optimized, with the precision of 0.5%, in terms of matching (attaining the lowest possible s_{11} parameter at the given frequency or at some frequency very close to the given one)by changing the position of the inset feed line. It was found that the optimal L_{slit} parameter has a value of about 15÷33% of the antenna length, and depends on the dielectric type used and it's thickness. In this way, the optimal patch elements were attained, and the WandW_{slit} parameters were afterwards altered (in steps of 20%, from 80% to 160%).Besides, the functional dependence of antenna electrical characteristics on these physical parameters was tested and the wanted relation was found.

B. The estimation of bandwidth and efficiency method

The bandwidth for each optimized model was calculated using the -10dBlevel of the s_{11} parameter.The reflection coefficient was found in several close points (at severalclose frequencies).The obtained results were then used for the curve fitting by means of interpolation. The antenna efficiency is defined as the ratio between the power that the antenna radiates and the power that is used for it's feeding. Also, it is possible to define the antenna efficiency using the definition of it's losses. If we assume that it is possible to construct an antenna using only the perfect dielectric and conducting materials, then we can be certain that the constructed antenna will be 100% efficient.Bearing in mind that all the created models have losses, we need to choose one representative parameter and compare it with the same parameter of the referent model (antenna with no losses).In this way we can estimate the antenna efficiency.The parameter used for this comparison was the radiation pattern maximum in units [8].

C. The analysis results

The summary of all of the results of the optimized models, is given in Table I.Those results refer to the starting models ($W=L=W$_nom,andW_{slit} equals the width of the50Ω transmission line, $W_{slit}=W_{slit}$_nom) at the frequency 3GHz.

TABLE I

THESTARTING MODEL CHARACTERISTICS AFTER THE OPTIMIZATION

Substrate type	Thickness[mm]	Gain [dB]	Efficiency[%]	BW [%]
Rogers	0.508	4.25	58.00	0.63
Rogers	0.813	5.10	70.68	0.83
FR4	1	0.98	30.59	2.00
FR4	1.5	1.88	40.38	2.33

When two models constructed on the same dielectric having different thicknesses are observed, it can be noted that the models on the thicker dielectric have larger gain, are more efficient and have a wider bandwidth.Comparison of the two models built on different substrates with similar heights (Rogers on 0.813mm and FR4 on 1mm), shows that using the FR4 dielectric lowers the antenna gain and efficiency, but widens it's bandwidth.The widening of the bandwidth when lossier structures are used, can be explained using the Q-factor, which is defined with a relation

$$Q = \frac{f_0}{\Delta f} \qquad (1)$$

where the$f_0$stands for the resonant frequency, and$\Delta f$is the bandwidth. Also, we have the following relation

$$Q \sim \frac{energy\ in\ the\ system}{losses\ in\ the\ system} \qquad (2)$$

Therefore the bandwidth is proportional to the system losses and the results from the Table I are in order.

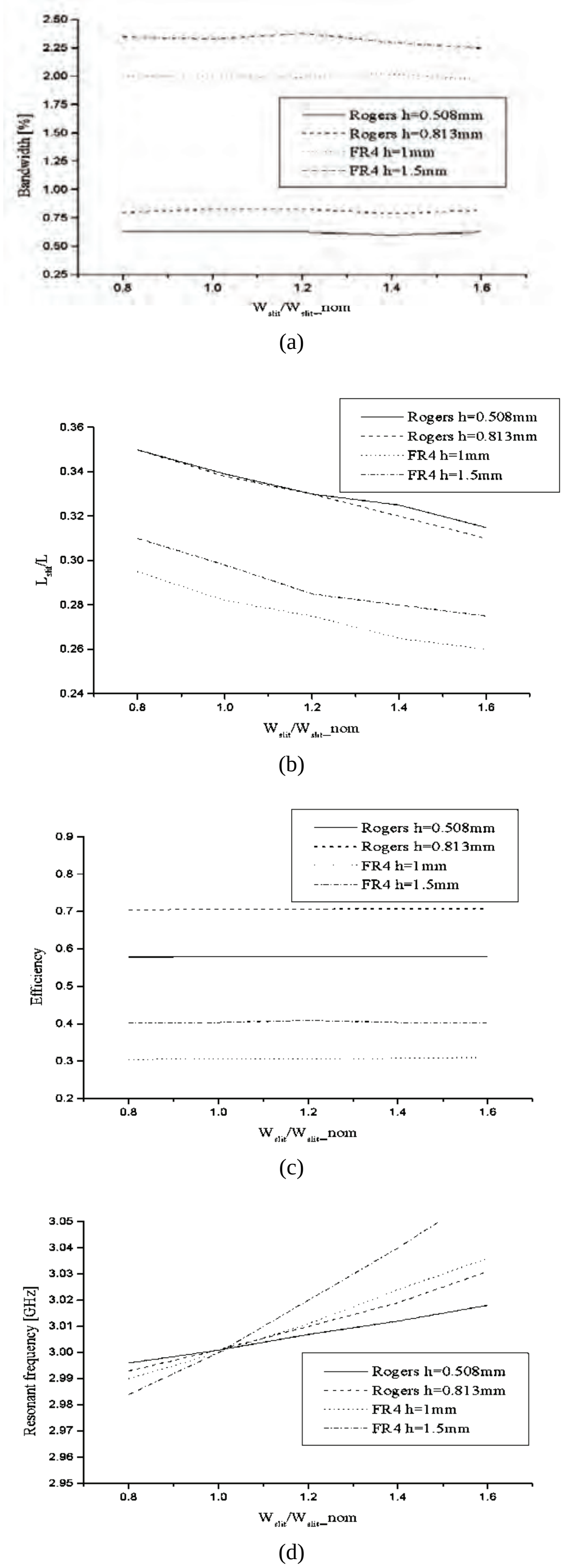
The effects of the W_{slit} parameter on the antenna bandwidth, needed position of the inset feed, efficiency and the resonant frequency are given in the Figs. 2a-2d, respectively.Both types of dielectric with two heights each, were used, having the frequency set at3GHz.

The bandwidth of the antenna is not influenced by theW_{slit} parameter (Fig. 2a).It is noticeable that using thicker substrates or the lossier ones results in wider bandwidths, which was expected.

The change of the W_{slit}parameter, degrades the antenna matching, and reoptimization of the position of the inset feed is needed in order to match the antenna input impedance to the characteristic impedance of the 50Ω transmission line.The dependence of the new inset feed depth is, in general, linear and with equal slope in all considered cases (Fig. 2b).In the case of the Rogers dielectric, the substrate thickness doesn't affect the depth of the inset feed in a significant way.On theFR4 dielectric, lesser inset feed depth is needed compared to the Rogers case.

Antenna efficiency isn't affected by the change of theW_{slit} parameter.Higher efficiency can be obtained by using thicker dielectric slab or by using the substrate with lower losses(Fig. 2c).

The increase of theW_{slit}parameter slightly increases the antenna resonant frequency (Fig. 2d). The slopes of the resulting curves aren't the same in all the cases. Increasing the dielectric thickness and higher substrate losses both result in raising the curve slope.



(a)

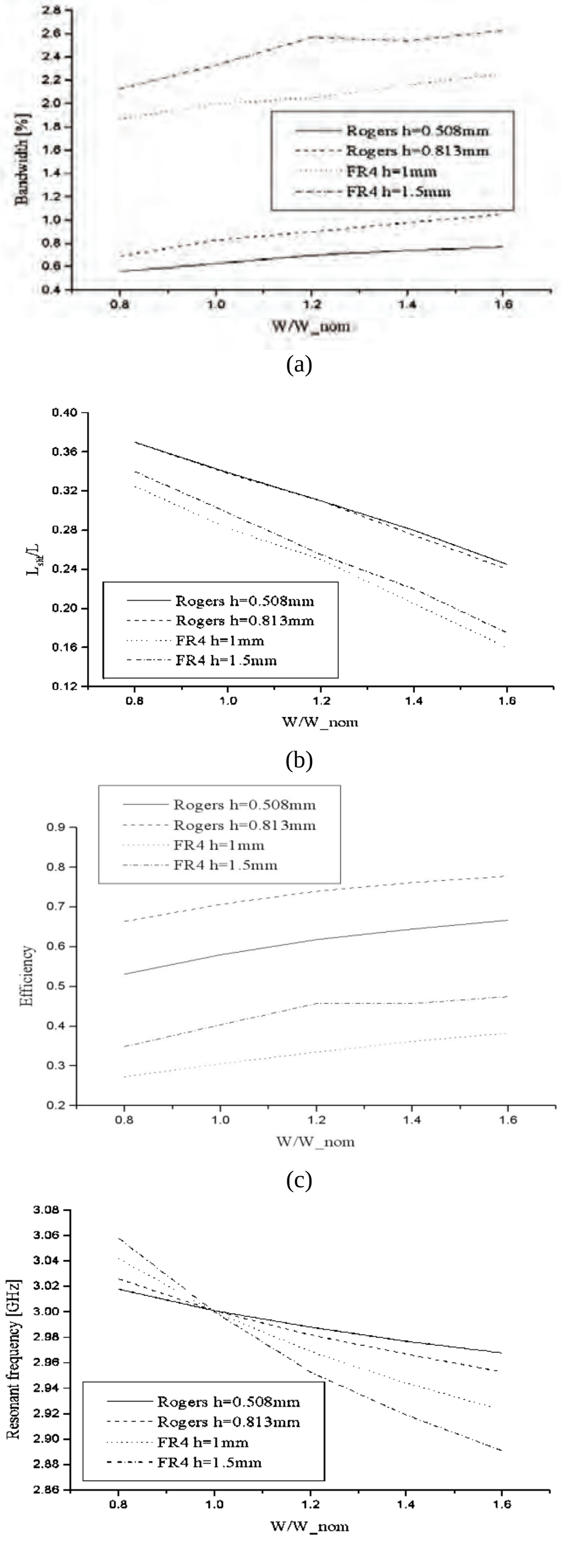
(b)

(c)

(d)

Fig. 2 -The influence of the W_{slit}parameter on the bandwidth (a), needed position of the inset feed (b), efficiency (c) andresonant frequencyof the antenna (d)

The effects of the *W* parameter on the antenna bandwidth, needed position of the inset feed, efficiency and the resonant frequency are given in the Figs. 3a-3d, respectively.Both types of dielectric with two heights each, were used, having the frequency set at 3GHz.



(a)

(b)

(c)

(d)

Fig. 3 - The influence of the *W* parameter on the bandwidth (a), needed position of the inset feed (b), efficiency (c) and resonant frequency of the antenna (d)

The bandwidth of the patch raises along with it's width (Fig. 3a). The slopes of the resulting curves are approximately the same, which means that the relative change of the bandwidth isn't affected by the substrate type. The change of the FR4 slab thickness from 1mm to 1.5mm results in a larger change in bandwidth than in the case of the Rogers substrate and the 0.508mm and 0.813mm thicknesses. On the Rogers dielectric, with the thickness of 0.508mm, the increase of the *W*parameter of 20%,results in increasing the bandwidth from 0.03% to 0.07%. For the slab thickness of 0.813mm,the range of bandwidth increase is from 0.07% to 0.14%. If we look at the FR4 , 20% increase in the antenna width results in an increase of bandwidth from 0.09% to 0.24% for the dielectric thickness of 1mm, and the bandwidth increases from 0.05% to 0.13% when a 1.5mm thickness is used.

As it was the case with the W_{slit} parameter, changing the antenna width also degrades the patch matching. A reoptimization of the depth of the inset feed is needed in order to match the input impedance of the patch to the characteristic impedance of the 50Ω transmission line. With the increase of the width of the patch, the needed depth of the feed position decreases approximately linearly (Fig. 3b). On the Rogers dielectric, the influence of the substrate thickness on the position of the inset feed is lesser than in the FR4 case. When using the FR4 dielectric, smaller depths of the inset feed are needed than in the Rogers case.

The patch width affects it's efficiency in such a way that it increases approximately linearly along with the antenna width (Fig. 3c).The Rogers dielectric is much more efficient than the FR4, which was expected due to lower dielectric loss tangent. Raising the patch efficiency can also be done by increasing the dielectric height.When using the FR4 substrate, change in dielectric thickness from 1mm to 1.5mm results in a lesser change in efficiency than in the Rogers case, using the thicknesses of 0.508mm and 0.813mm. On the Rogers dielectric 0.508mm thick, increase of 20% of the*W*parameter, increases the bandwidth from1.8% to 4.8%, andfrom 1.6% to 4.3% when using the 0.813mm thickness. If we look at the FR4 dielectric, 20% increase of the antenna width results in a bandwidth increase of 0% to 5.5% on the 1mm thickness, andfrom2.1% to 3.3% on the 1.5mm thickness.

With increasing the *W*parameter, lowering the antenna resonant frequency is achieved (Fig. 3d).The slope of the resulting curve depends on the type and height of the dielectric used.Namely, higher substrate thickness results in higher curve slope. Also, using the higher losses dielectric leads to a greater curve slope.On the Rogers dielectric0.508mm thick,that slope is around -0.06, and on the 0.813mm thick substrate the same slope is around -0.09. On the FR4 dielectric 1mm thick, the slope is -0.15, and on the1.5mmthick dielectricthe slope is -0.21.

III. CONCLUSION

In this paper, the method for printed antenna modeling is given, which allows fast and efficient overview of change of relevant antenna parameters depending on the antenna geometry and characteristics of the dielectric material used.This is necessary due to a constant need for changing the antenna shape and it's place of installation in various devices, and to avoid the situation where the antenna dictates the shape of the final user product.In this way, the device designers have complete control, because it is always possible to adjust the antenna shape and position of it's installation to the shape of the device.For these kinds of applications, a fast and reliable way of printed antenna modeling, is needed.

The influences of the*W*andW_{slit}parameters on the rectangular, single-layered, linearly polarized, microstrip line-fed 3GHz patch antennas, are observed.

Future work should include the analysis of microstrip patch antennaoperating on the second resonant frequency, on it's bandwidth. This concept is still not enough investigated, and the published papers on similar subjects indicatethat this kind of analysis could yield good results.

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