Input Impedance and Polarization Properties of Rectangular Microstrip Edge-Fed Patch

Nikola I. Dodov[1] and Alexander G. Toshev[2]

Abstract — **Dependence of the input impedance of rectangular microstrip edge-fed patch from the position of the junction point of the feeding microstrip line is investigated. Polarization properties of the radiated far field with respect to the feeding point are investigated and presented as well. Simulation results of the rectangular patch utilizing Moment Method are presented for verification of the results.**

Keywords — **Microstrip rectangular patch, Input impednace, Polarization properties**

I. INTRODUCTION

Microstrip patches are often used as radiating elements for phased array antennas [2]. These radiating elements are commonly narrowband [1], but wide used PCB technology for their production is very attractive and low cost. For that reason many investigations have been made in the resent years concerning modeling of the patches [1], [3]; impedance matching and bandwidth widening; polarization purity improvement of the radiated field etc.

The most popular models of microstrip patches are: transmission-line model [1], [4], [7]; cavity model [5], [4]; and full-wave analysis mainly involving moment methods (MoM) [6].

This paper emphasizes on a rectangular microstrip edge-fed patches operating at its dominant TM_{010} mode [1]. Input impedance of such patches is investigated in [1] using the results obtained from transmission-line model and cavity model. According to the cavity model it is obtained that input impedance does not depend upon location of the feeding line along the feeding edge of the patch, because for TM_{010} mode electric field is constant along this edge. Subject of this paper is investigation of the dependence of the input impedance with respect to the position of the feeding microstrip line along the edge of the patch and scope of applicability of the cavity model for analysis of such structure. Polarization properties are also taken into account when results are presented. The moment method is used for analysis of the structures.

II. MATHEMATICAL BACKGROUND AND RESULTS FROM TRANSMISSION-LINE AND CAVITY MODELS

When fringing effects can be neglected (L/h>>1 on Fig.1) field between microstrip patch and substrate is well described using cavity model [1]. Using coordinates designated on Fig.1 for the dominant TM_{010} mode the following expressions for the field are valid [1]:

$$\begin{aligned} E_x &= E_0 \cos\left(\frac{\pi}{L} y'\right) \\ H_z &= H_0 \sin\left(\frac{\pi}{L} y'\right) \\ E_y &= E_z = H_x = H_y = 0 \end{aligned} \qquad (1)$$

where y' is used to designate the fields inside the cavity; $E_0 = -j\omega A_{010}$ and $H_0 = \frac{\pi}{\mu L} A_{010}$. The magnitude of the field is A_{010} and its structure is depicted on Fig. 1. The resonant frequency is determined by [1]:

$$(f_r)_{010} = \frac{v_0}{2L\sqrt{\varepsilon_r}} \qquad (2)$$

where v_0 is the speed of light in the free space.

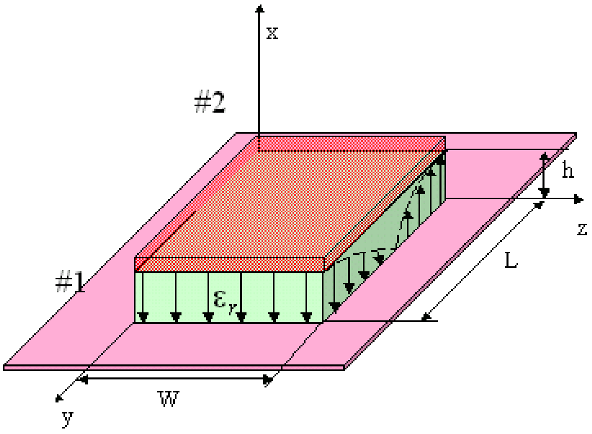

Fig. 1: Rectangular microstrip patch and its dominant TM_{010} mode

Because of the fringing effects resonant length of the patch is smaller than its electrical length. The extension ΔL that

---

[1] Nikola I. Dodov is with the faculty of Communications and Communications Technologies, TU Sofia, “Kl. Ohridsky” blvd. N8, 1756 – Sofia, Bulgaria, E-mail: ndodov@tu-sofia.bg

[2] Alexander G. Toshev is with the faculty of Communications and Communications Technologies, TU Sofia, “Kl. Ohridsky” blvd. N8, 1756 – Sofia, Bulgaria, E-mail: toshev_a@skygate.bg

takes into account fringing is dependent on the ratio $\frac{W}{h}$ and is given by [1]:

$$\Delta L = 0.412 \frac{\left(\varepsilon_{reff} + 0.3\right)\left(W/h + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(W/h + 0.8\right)} \qquad (3)$$

where ε_{reff} is effective permittivity of the transmission line of width W. The effective length of the patch is $L_{eff} = L + 2\Delta L$. This influences also the resonant frequency, given with Eq. (2), where ε_{reff} and L_{eff} should be used.

The TM_{010} field is not dependent on z coordinate and therefore input impedance should not depend on the position of the feeding line along W dimension of the patch – Fig. 2. If the feeding microstrip line is parallel to y-axes, the patch has two radiating slots designated on Fig. 2, with equivalent conductance G_1 and susceptance B_1, determined by the fields, given with Eq. (1) from the cavity model [1]. Input resonant impedance of the inset-fed rectangular patch is determined by the two radiating slot separated by the transmission line of width W [1]:

$$R_{in}\left(y = y_0\right) = \frac{1}{2\left(G_1 - G_{12}\right)} cos^2\left(\frac{\pi}{L} y_0\right) \qquad (4)$$

where G_{12} is mutual conductance between radiating slots and y_0 determines inset-feed point as shown on Fig. 2. Eq. (4) is valid if $G_1 / Y_c << 1$ and $B_1 / Y_c << 1$, where Y_c is the characteristic admittance of the feeding line. Inset-feed is used for matching between characteristic impedance of the input line and input impedance of the patch as described in [1]. According to Eq. (4) input impedance of the patch does not depend on z-coordinate, because neither G_1 nor G_{12} depend on it.

III. MOMENT METHOD ANALYSIS – SIMULATION RESULTS

For adequate estimation of the input impedance Z_{in} of the patch and its variation with respect to the position z_{feed} of the inset feeding microstrip line, with characteristic impedance Z_c and width w_0, cavity model of the patch and transmission line model are not sufficient, because they do not take into account fringing effects as feeding line approaches edges of the patch. Full wave analysis and particularly Moment Method is good approach for these purposes.

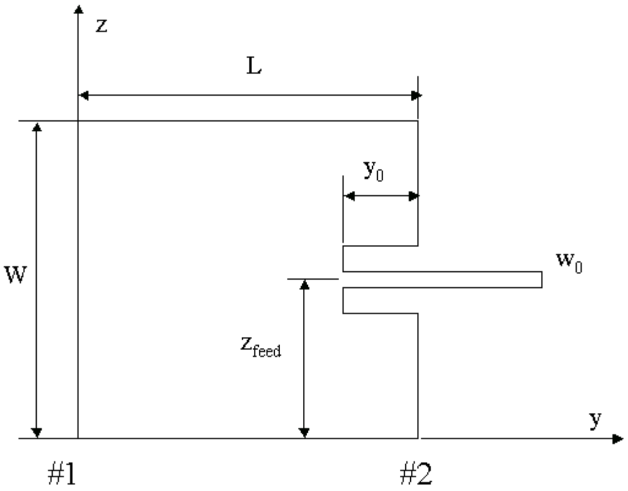

Fig. 2: Rectangular patch inset-feed dimensions

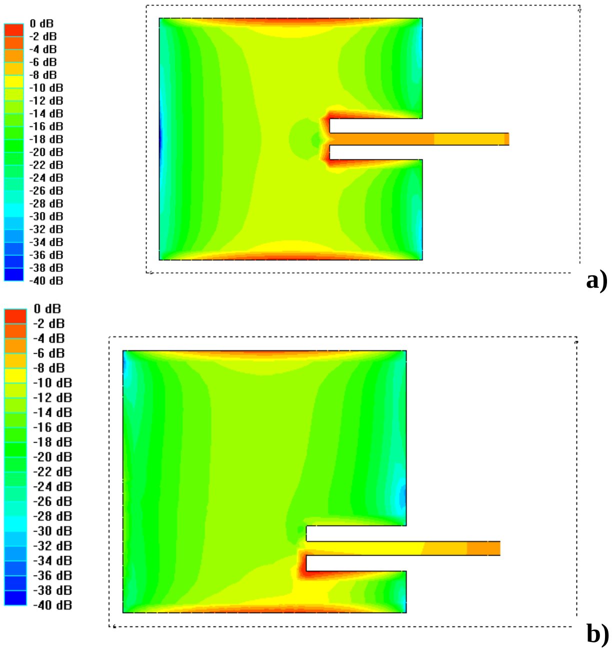

Fig. 3: Excitation average current density (MoM solution) for edge-fed microstrip patch operating at f=12.5GHz – a) - $z_{feed} / W = 0.5$; b) $z_{feed} / W = 0.25$

The following results treat microstrip edge-fed patches with approximately square shape ($W \approx L$). When feeding point is placed in the center of the patch ($z_{feed} / W = 0.5$) excitation current distribution is shown on Fig. 3 a). In the central part of the patch, when $z_{feed} / W \approx 0.5$, excitation current density is symmetrical and fringing effects are negligible as shown on Fig. 3 a). When feeding microstrip line approaches non-radiating edge of the patch ($z_{feed} / W \approx 0$ or $z_{feed} / W \approx 1$) excitation current distribution becomes asymmetrical and it is concentrated close to the approached non-radiating edge. This situation is depicted on Fig. 3 b) for the case $z_{feed}/W = 0.25$. Since the excitation current concentrates close to the non-radiating edge, it may excite parasitic TM$_{001}$ mode with smaller amplitude than dominant TM$_{010}$ mode. Thus the patch starts to operate in dual mode regime and its input impedance changes according to the ratio between amplitudes of the parasitic and dominant modes.

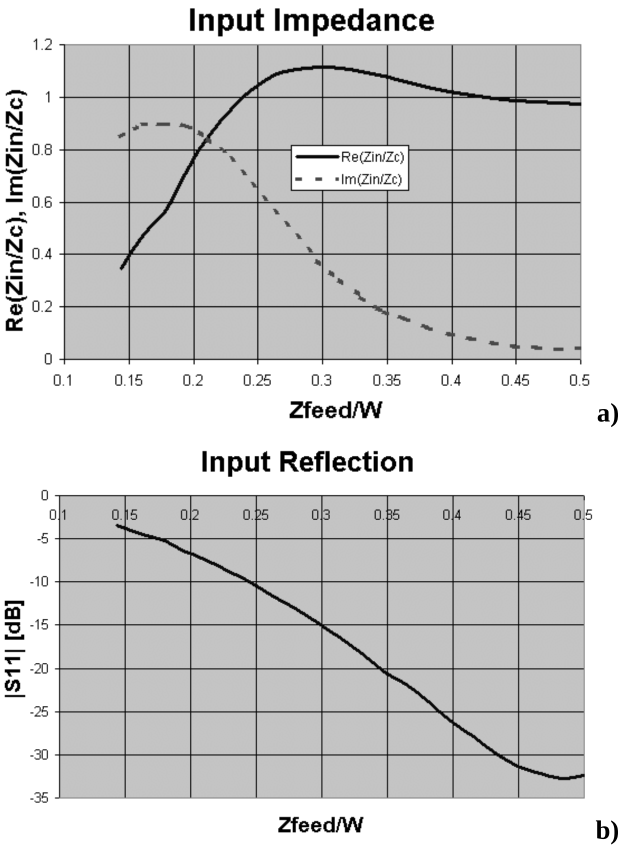

Fig. 4: Input impedance – a) and input reflection – b) for edge-fed microstrip patch (f=12.5GHz) with respect to the position of the feeding line (z_{feed}/W)

The normalized real and imaginary parts of the input impedance (Z_{in}/Z_c) are shown on Fig. 4 a). The input impedance is almost constant only in central part of the patch ($z_{feed}/W \approx 0.5$) and it becomes different in the regions close to the non-radiating edges. On Fig. 4 b) is shown input reflection of the patch as a function of the position of the feeding line. The curves are presented only in the range $0 < \frac{z_{feed}}{W} < 0.5$, because the other halves are symmetrical to the presented ones. Practical rule could be extracted based on the simulation results. For square microstrip edge-fed patches in order to obtain input reflection less than –10dB, position of the feeding line could be in the region:

$$0.25 < \frac{z_{feed}}{W} < 0.75 \tag{5}$$

If Eq. (5) is satisfied the amplitude of the parasitic TM$_{001}$ mode is not large enough to destroy significantly input matching of the patch.

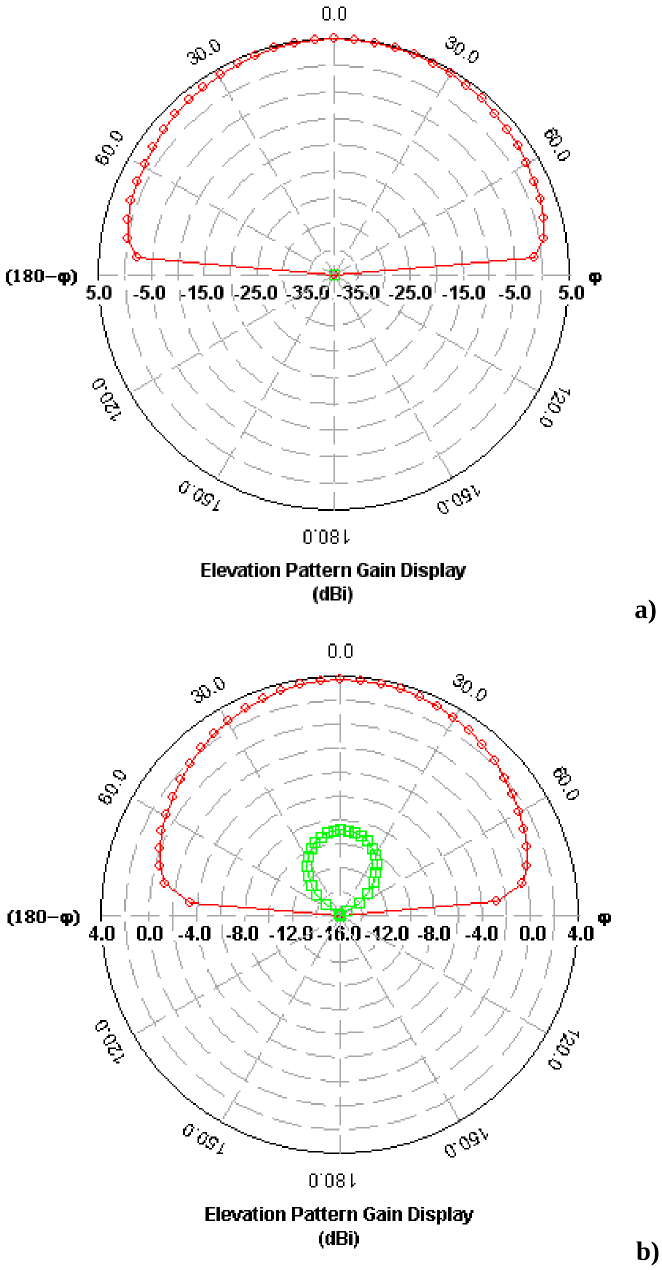

Fig. 5: Radiation in the E-plane, (x,y) plane, for square microstrip edge-fed patch (f=12.5GHz) for the case: a) - $z_{feed}/W = 0.5$ and b) - $z_{feed}/W = 0.25$

Very interesting is the question about radiating properties of the patch, when feeding line approaches non-radiating edges. The dominant TM$_{010}$ mode radiates with the radiating slots #1 and #2 designated on Fig. 1 and Fig. 2. The field of the TM$_{010}$ mode is polarized in the plane (x,y), which is the E-plane for this mode - Fig. 1. The parasitic TM_{001} mode has radiating slots orthogonal to slots #1 and #2 and therefore radiates linear polarized field in the plane orthogonal to that of TM_{010} mode. The plane (x,z) is H-plane for TM_{010} mode and E-plane for TM_{001} mode. Therefore radiation from the parasitic TM_{001} mode is orthogonal to that of the dominant TM_{010} mode. In other words non-radiating slots become partially radiating (because of the parasitic TM_{001} mode) when position of the feeding line approaches edge of the patch.

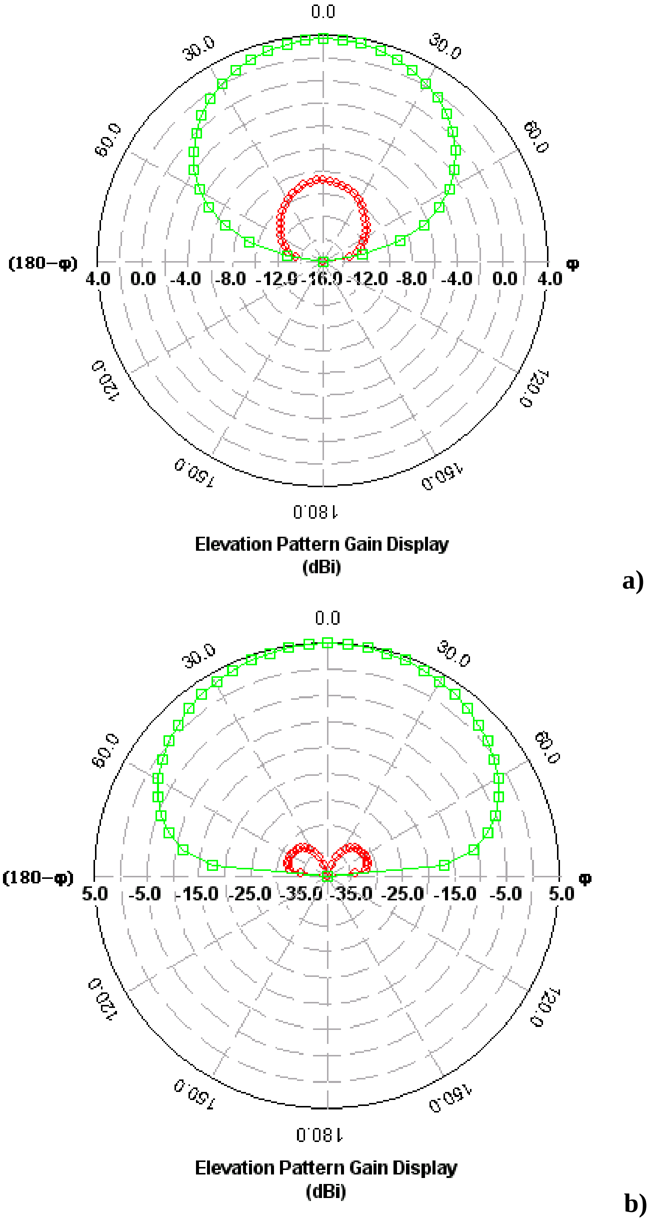

Fig. 6: Radiation in the H-plane, (x,z) plane, for square microstrip edge-fed patch (f=12.5GHz) for the case: a) - $z_{feed}/W = 0.5$ and b) - $z_{feed}/W = 0.25$

The level of the crosspolarization is determined with the ratio between dominant TM_{010} and parasitic TM_{001} modes. It is interesting to know the level of the crosspolarization when Eq. (5) is satisfied. Radiation patterns in the E-plane of the patch calculated upon excitation currents, shown on Fig. 3, are presented on Fig. 5 a) and b) for the cases $z_{feed}/W = 0.5$ and $z_{feed}/W = 0.25$ respectively. Radiation patterns in the H-plane of the patch are presented on Fig. 6 a) and b) for the same cases. The level of the crosspolarization is of order of –12dB when $z_{feed}/W = 0.25$. This leads to the conclusion that amplitude of the parasitic TM_{001} mode is more than 10 dB lower than that of the dominant TM_{010} mode.

IV. DISCUSSION AND CONCLUSION

Investigation of the input impedance of rectangular microstrip edge-fed patch with respect to the position of the feeding line along radiating edge has been presented. It has been shown that cavity and transmission line models are not sufficient for estimation of the input impedance of the patch when feeding line approaches non-radiating edge because they do not take into account fringing effects. Moment method has been employed for analysis. Dependence of the input impedance and input reflection from the position of the feeding line has been presented. Practical design rule for almost square patches has been extracted for placement of the feeding line along radiating edge in order to obtain not large degradation of the input reflection of the patch. Crosspolarization degradation of the not-center-fed microstrip patch has been explained based on cavity model and dominant TM_{010} and parasitic TM_{001} modes.

REFERENCES

[1] Constantine A. Balanis, *Antenna Theory – Analysis and Design*, John Wiley & Sons, Inc., New York 1997

[2] Robert J. Mailloux, *Phased Array Antenna Handbook*, Artech House, 1994

[3] *Microstrip Antennas – The Analysis and Design of Microstrip Antennas anmd Arrays*, edited by David M. Pozar and Daniel H. Schaubert, IEEE PRESS ,1995

[4] K. R. Carver and J. W. Mink, “Microstrip Antenna Technology”, *IEEE Trans Antennas and Propagat.*, Vol. AP-29, No1, pp. 2-24, January 1981

[5] Y. T. Lo, D. Solomon, W. F. Richards, “Theory and Experiment of Microstrip Antennas”, *IEEE Trans Antennas and Propagat.*, Vol. AP-27, No2, pp. 137-145, March 1979

[6] J. R. Mosig and F. E. Cardiol, “General Integral Equation Formulation of Microstrip Antennas and Scatterers”, *Proc. Inst. Elect. Eng.*, pt. H., Vol. 132, No2, pp. 424-432, 1985

[7] J. R. James and P. S. Hall, *Handbook of Microstrip Antennas*, Vols. 1 and 2, Peter Peregrinus, London, UK, 1989