Modelling the Effect of A Thin Shorting Post in an Arbitrary Position Along the Outer Radiating Edge of A Rectangular Patch Antenna

Budhaditya Majumdar
Centre for Electromagnetic and Antenna Engineering
Dept. of Engineering, Macquarie University
Sydney 2109, Australia
budhaditya.majumdar@mq.edu.au

Karu P. Esselle
Centre for Electromagnetic and Antenna Engineering
Dept. of Engineering, Macquarie University
Sydney 2109, Australia
karu.esselle@mq.edu.au

***Abstract*—An extended transmission-line model is proposed for a shorted rectangular patch antenna. The transmission-line model represents the effect of a thin shorting post placed at an arbitrary position along the outer radiating edge of the patch antenna. A comparative study has been conducted with a 3D full-wave solver. An example patch antenna having a resonance frequency of 2280 MHz without any shorting post, can be re-tuned between 2375 MHz and 2511 MHz by varying the location of the shorting post. A special case with the post at one of the outer vertices is also considered. Maximum deviation between results obtained from the extended transmission-line model and the full-wave solver is 0.74% for the example patch antenna.**

I. Introduction

Shorted patch antenna is of interest for quite a few decades, for minimization of antenna size, optimization of impedance bandwidth or implementing polarization diversity. One of the original findings about reduction of patch antenna size to quarter wavelength was published in [1]. Few recent works on shorted patch for ultra-wideband applications are discussed in [2], [3]. Polarization diversity achieved with shorting pins has been discussed in [4] and another form of miniaturization of patch antenna with multiple shorting pins is published in [5].

The focus of this paper is on the effect of one thin shorting post, on the resonant frequency of the antenna, when the shorting post is placed in any position along the outer radiating edge of the patch. The post connects the outer edge of the patch to the ground plane of the antenna. The transmission-line model of a rectangular patch antenna [6]–[10] is extended to model the effect of the relative position of the shorting post and analytically obtained results are compared with 3D full wave solver results.

II. Antenna Configuration

A conventional rectangular patch antenna with a resonance frequency of 2280 MHz is designed for fabrication on a Taconic TRF-43 substrate ($\epsilon_r = 4.3$, $tan\,\delta = 0.0035$), having a thickness of 1.2mm. Fig. 1 illustrates the layout of the antenna. The length and width of the substrate are $L_S = 70$mm and $W_S = 65$mm, respectively. The length and width of the patch are $L_P = 31$mm and $W_P = 42$mm, respectively. The length and width of the transformer are $L_T = 15.5$mm

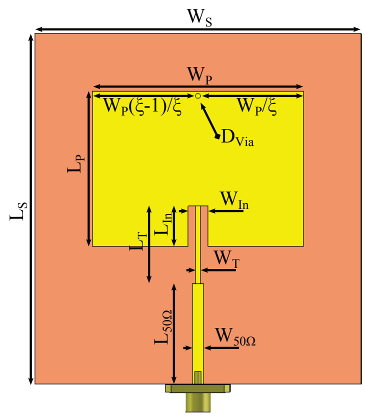

Fig. 1: Layout of the antenna.

and $W_T = 1$mm. The length and width of the feed-line are $L_{50\Omega} = 20$mm and $W_{50\Omega} = 2.2$mm, respectively. The cut-out of the inset has the dimensions of $L_{In} = 8$mm and $W_{In} = 4$mm, respectively. The via is formed by a 18AWG wire with a diameter (D_{Via}) of 1mm.

It can be noted from Fig. 1 that the relative position of the thin shorting pin is denoted by a factor $\{1/\xi\}$ from one end. The relative position of the shorting pin then has a different factor $\{(\xi - 1)/\xi\}$ from the other end. The summation of both factors is always 1.

III. Extended Transmission-Line Model

The transmission-line model for a rectangular patch antenna has been extensively discussed in the literature [9], [10]. Two slots, each having a complex admittance, are placed at a distance of about $\lambda_{eff}/2$ [10]. For a standard rectangular patch antenna, each of the complex slot admittance is denoted by $G + jB$ where G is the slot conductance and B is the slot susceptance, respectively. The formulas for the slot conductance and susceptance are given in [10].

When a thin via ($D_{Via} \ll W_P$) is shorted at the outer vertex (any one end of the outer edge of the radiating slot) of the rectangular patch, it can be approximated that the admittances of both the slots have the same values as before,

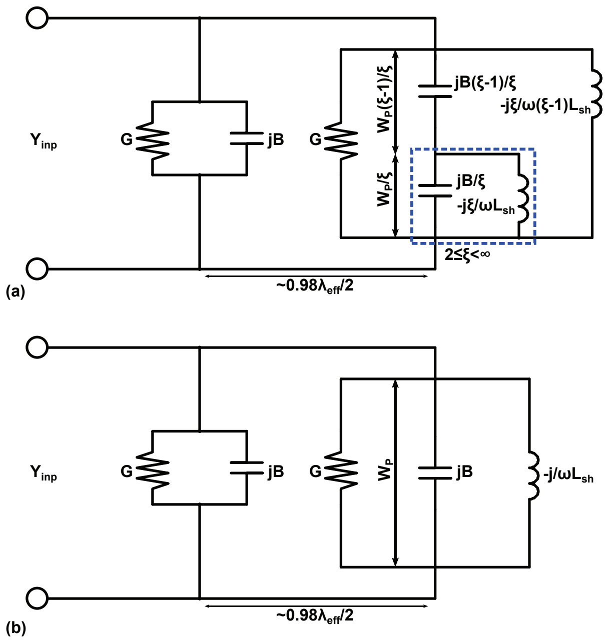

Fig. 2: Transmission-line model of a patch antenna with a thin shorting post placed (a) in an arbitrary position of the outer radiating slot of the patch, and (b) placed at one of the two outer vertices of the patch.

with the susceptance of the via, $-j\omega L_{sh}$, added in parallel to the complex admittance of the outer slot. The extended transmission-line model for this special case (SETLM) is illustrated in Fig. 2(b).

When the thin via is placed in an arbitrary position along the radiating slot of the antenna where the position can be measured by a factor of $1/\xi$ from one end and $(\xi - 1)/\xi$ from the other, the slot susceptance and the susceptance of the via are proportionally divided. Due to the negligible diameter of the shorting post, the conductance of the outer slot remains unaffected. The general extended transmission-line model (GETLM) for this case is illustrated in Fig. 2(a).

Due to the asymmetric nature of the transmission-line model a limiting condition of $2 \leq \xi < \infty$ is implemented. That means the lower LC resonator (marked with a blue boundary in Fig. 2(a)) can have a slot capacitance to a maximum of half of the original value B from a minimum of 0 and similarly the shunt inductance can have a maximum of half of the original value of the L_{sh} from a minimum of 0. When $\xi = 2$ the value of B and L_{sh} is equally divided into two half and denotes the fact that the shorting post is at the centre of the outer edge of the radiating slot of the patch antenna. With $\xi \to \infty$ both the values become negligible and the GETLM transforms itself into the SETLM as shown in Fig. 2(b). The actual patch antenna has a magnetic symmetry across the centre of the radiating slot. The shorting position on either side of the magnetic symmetry can be implemented in the GETLM by interchanging the factors mentioned before in this section.

A. Patch Admittance - GETLM

The input impedance of the patch model, shown in Fig. 2(a) can be expressed as:

$$Y_{inp} = G + jB + Y_p \frac{G + j\left(\Psi + Y_p tan\, kL_P\right)}{Y_p - \Psi tan\, kL_P + jG tan\, kL_P} \tag{1a}$$

where

$$\Psi = \frac{B\left(1-\frac{1}{\xi}\right)^2 \left(\frac{\omega B L_{sh}}{\xi^2} - 1\right) - \frac{B}{\xi} + \frac{1}{\omega L_{sh}}}{\left(1-\frac{1}{\xi}\right)\left(\frac{\omega B L_{sh}}{\xi} - 1\right)} \tag{1b}$$

and k is the effective wave number. L_P is the length of the patch and Y_p is its respective characteristic impedance.

B. Patch Admittance - SETLM

As the factor $\xi \to \infty$, it is understood that the shorting post is moved extremely towards one of the outer vertices. The effective value of the slot susceptance changes to:

$$\Psi_{\xi\to\infty} = B - \frac{1}{\omega L_{sh}} \tag{2}$$

resulting in special patch admittance of:

$$Y_{inp} = G + jB + Y_p \frac{G + j\left(B - 1/\omega L_{sh} + Y_p tan\, kL_P\right)}{Y_p - \left(B - 1/\omega L_{sh}\right) tan\, kL_P + jG tan\, kL_P} \tag{3}$$

C. Antenna Admittance

The overall antenna admittance depends on the length of the inset, quarter wave transformer and the 50Ω feed-line, respectively. Admittance for an inset-fed patch is given by [10]:

$$Y_{inp'} = Y_{inp} sec^2\left(\frac{\pi}{L_P} L_{In}\right) \tag{4}$$

where L_{in} is the inset feed length and $Yinp$ is the edge impedance of the patch as given in Eq. (1)(a) or Eg. (3) depending on the position of the thin shorting post. Another admittance transformation takes place with the quarter-wave transformer and the admittance of the patch at the input of the quarter-wave transformer is given by:

$$Y_{inp''} = Y_T \frac{Y_{inp'} + jY_T tan\, kL_T}{Y_T + jY_{inp'} tan\, kL_T} \tag{5}$$

where L_T is the length of the quarter-wave transformer and Y_T is the characteristic admittance of the transformer. The overall admittance at the SMA port is given by:

$$Y_{inp50\Omega} = Y_{50\Omega} \frac{Y_{inp''} + jY_{50\Omega} tan\, kL_{50\Omega}}{Y_{50\Omega} + jY_{inp''} tan\, kL_{50\Omega}} \tag{6}$$

where $Y_{50\Omega}$ is approximately $0.02S$ and $L_{50\Omega}$ is the length of the feed-line as shown in Fig. 1.

IV. Implementation and Results

Implementation of the GETLM and SETLM was done in Matlab using Eq. (1) - Eq. (6). For accuracy of results, the respective effective relative permittivity were calculated for every different width (of the patch, transformer and the feed-line), and used to obtain their equivalent free-space values.

Full wave numerical simulation was done using CST Microwave Studio 2015 and the results obtained were used to validate the results predicted by the GETLM and SETLM.

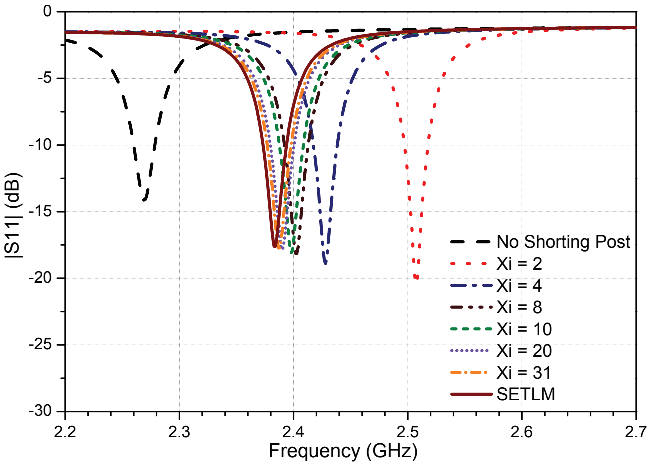

Fig. 3: Predicted return loss of the patch antenna obtained using GETLM and SETLM.

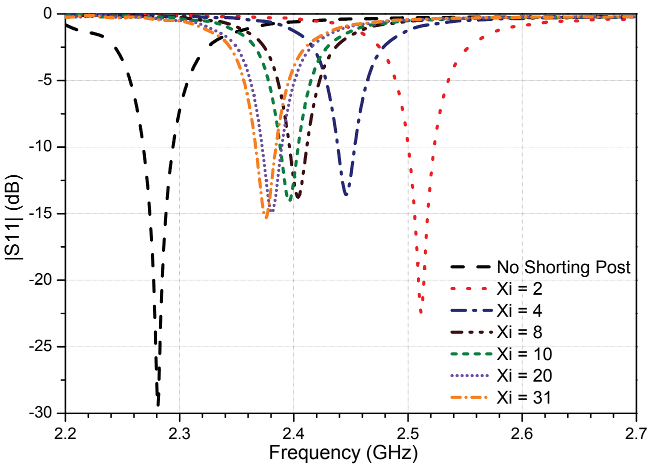

Fig. 4: Predicted return loss of the patch antenna obtained using CST Microwave Studio 2015.

Fig. 3 shows the predicted return loss obtained with GETLM for different values of ξ and with SETLM. It also shows the base resonance frequency of the patch without a shorting post. Fig. 4 shows the predicted return loss obtained using 3D full-wave simulation in CST Microwave Studio. The transmission-line model results are in good agreement with the full-wave simulation results. Table I shows a comparison of the resonance frequencies for different values of ξ. The maximum deviation relative to the full-wave results occurs at the value of $\xi = 4$ and it is less than 1%.

Maximum shift of resonance frequency due to the shorting post occurs when $\xi = 2$, or in other words when the thin shorting post is placed right in the middle of the outer radiating slot of the patch. For this particular patch antenna this shift is around 230 MHz from the base resonance frequency. The minimum shift occurs when the thin shorting post is placed at one of the extreme ends of the slot (outer vertex) of the patch. For this patch antenna this shift is around 100 MHz.

TABLE I: Comparison of predicted resonant frequencies for the patch antenna, obtained from GETLM and CST MWS. All frequencies are in MHz.

ξ	Matlab (MHz)	CST (MHz)	Deviation (%)
2	2507	2511	0.16
4	2428	2446	0.74
8	2402	2404	0.08
10	2398	2396	0.08
20	2390	2381	0.38
31	2387	2375	0.50
∞	2384	-	-

V. Conclusion

An extended transmission-line model is presented to model a thin shorting post at the outer radiating slot of the conventional rectangular patch antenna at any location. Quick design solutions can be obtained when the model is implemented in Matlab. The model provides an insight about how a conventional rectangular patch antenna can be re-tuned to few other frequencies by selecting the position of a thin shorting post.

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References

[1] C. Garvin, R. Munson, L. Ostwald, and K. Schroeder, "Missile base mounted microstrip antennas," *IEEE Trans. Antennas Propag.*, vol. 25, no. 5, pp. 604-610, Sep 1977.

[2] M. N. Shakib, M. Moghavvemi, and W. N. L. Binti Wan Mahadi, "A Low Profile Patch Antenna for Ultrawideband Application," *IEEE Antennas Wireless Propag. Lett.*, IEEE, vol. PP, pp. 1-1, 2015.

[3] W. Sai Wai, H. Tian Gui, M. Chun Xu, C. Zhi Ning, and C. Qing Xin, "Planar Filtering Ultra-Wideband (UWB) Antenna With Shorting Pins," *IEEE Trans. Antennas Propag.*, vol. 61, no. 2, pp. 948-953, Feb 2013.

[4] W. Jianjun, Y. Yingzeng, W. Zedong, and L. Ruina, "Broadband Circularly Polarized Patch Antenna With Parasitic Strips," *IEEE Antennas Wireless Propag. Lett.*, vol. 14, pp. 559-562, 2015.

[5] Y. Mei, C. Zhi Ning, L. Pui Yi, Q. Xianming, and Y. Xiaoxing, "Miniaturized Patch Antenna With Grounded Strips," *IEEE Trans. Antennas Propag.*, vol. 63, no. 2, pp. 843-848, Feb 2015.

[6] R. Munson, "Conformal microstrip antennas and microstrip phased arrays," *IEEE Trans. Antennas Propag.*, vol. 22, no. 1, pp. 74-78, Jan 1974.

[7] A. G. Derneryd, "Linearly polarized microstrip antennas," *IEEE Trans. Antennas Propag.*, vol. 24, no. 6, pp. 846-851, Nov 1976.

[8] A. G. Derneryd, "A theoretical investigation of the rectangular microstrip antenna element," *IEEE Trans. Antennas Propag.*, vol. 26, no. 4, pp. 532-535, July 1978.

[9] K. R. Carver and J. Mink, "Microstrip antenna technology," *IEEE Trans. Antennas Propag.*, vol. 29, no. 1, pp. 2-24, Jan 1981.

[10] C. A. Balanis, *Antenna Theory: Analysis and Design,* Wiley-Interscience, 2005.