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Theoretical computation of input impedance of gap-coupled circular microstrip patch antennas loaded with shorting post

Pradeep Kumar · G. Singh

Abstract In this paper, theoretical analysis of the input impedance of the two gap-coupled circular microstrip path antennas loaded with shorting post has been performed. The concept of coupled microstrip lines is applied to the gap-coupled microstrip antennas loaded with shorting post and using circuit theory approach the input impedance of the structure is calculated. The effect of mutual coupling between the radiating apertures has been taken into account. Simulated results are presented for input impedance of the gap-coupled circular microstrip patch antenna loaded with shorting post which supports the theoretical predictions. The simulation work has been performed using the method-of-moment based commercially available simulator IE3D. The comparison shows good agreement between simulated and numerically computed results.

Keywords Microstrip antenna · Gap-coupling · Shorting post · Feed patch · Parasitic patch

1 Introduction

Microstrip patch antennas are resonant antennas and receiving much attention at present due to their many favorable characteristics, such as light weight, low profile and printed circuit construction cheapness. The major disadvantages of the microstrip antennas are low efficiency and narrow bandwidth [1]. This antenna may be regarded as cavity with magnetic conductor walls between the radiating patch and ground plane. The radiation occurring from the electric field distribution around the patch boundary is being dominated by that cause by the patch end. The energy radiated during each RF cycle is small compared to that stored in the cavity, and bandwidth of only about 1% is obtained for antennas on typical printed circuit board substrate. Increase of the bandwidth of this type of the antenna, in general, requires reducing the substrate permittivity or increasing its thickness, since the exact shape of the patch does not have a dominant effect on the bandwidth if the overall dimensions are similar. Using the gap-coupled resonators, the bandwidth of the microstrip antennas can be increased [2–5]. Recently, researchers have presented a bandwidth enhancement method for low profile E-shaped microstrip patch antennas in [6]. At lower frequencies, the size of the microstrip antennas becomes large. There are few method presented in literature to reduce the size of a patch antenna [7–11]. These include using high permittivity substrates, loading the patch with shorting pins and meandering the ground plane or the perimeter of the patch. In the case of using high permittivity substrate, the dielectric constant is inversely proportional to the square of the resonant frequency of the antenna. As the dielectric constant increases, the resonance frequency and consequently the antenna patch dimension decreases. However, it should be noted that using high permittivity substrate result the excitation of the greater surface waves, which reduces the performance of antennas. The use of shorting post also reduces the resonant frequency and overall the patch antenna dimension. The size of the microstrip antennas can be decreased by shorting a patch [12–18]. The theory behind is that the electric field has the maximum value at the edge and goes to zero at the center. Therefore, a shorting post can be placed without affecting the basic operation. The electrical length of the patch increases while the res-

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P. Kumar (✉) · G. Singh
Department of Electronics and Communication Engineering,
Jaypee University of Information Technology, Solan 173215,
India
e-mail: erpradeep_tiet@yahoo.co.in

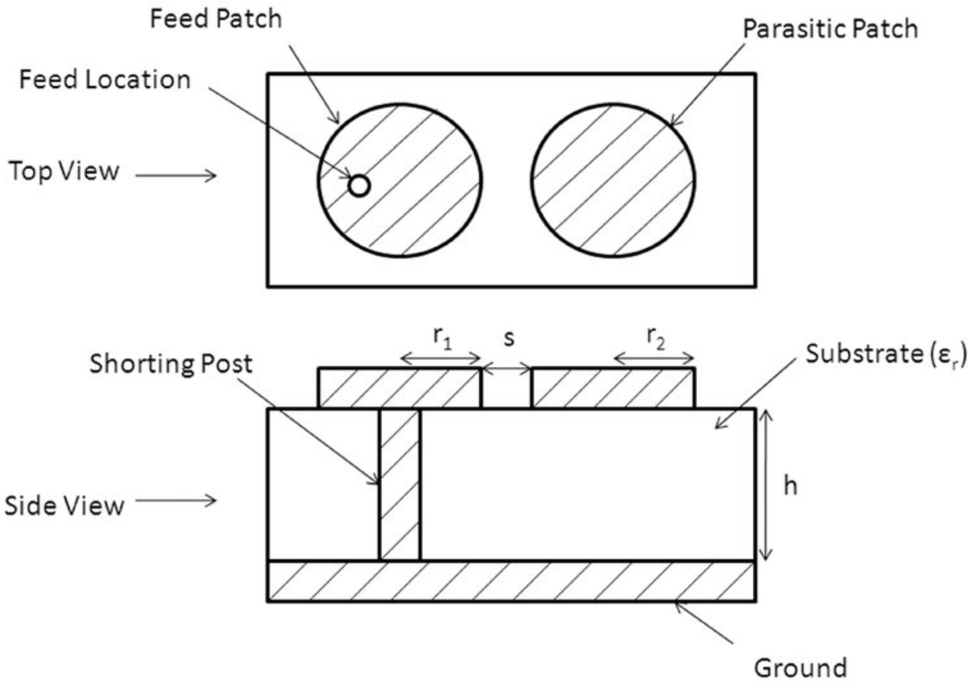

Fig. 1 Geometrical configuration of the gap-coupled circular microstrip patch antennas loaded with shorting post

onant frequency decreases. For the antenna to resonate at the desired frequency, its dimension has to be reduced. Using this technique, the diameter of a shorting-pin loaded circular microstrip patch [1] or the linear dimension of a shorting-pin-loaded rectangular microstrip patch [14] can be as small as one-third of that of a corresponding conventional microstrip patch without a shorting pin at the same operating frequency. This patch size reduction is mainly due to the shifting of the null voltage point at the centre of the rectangular patch (excited at TM_{01}, mode) and the circular patch (operated at TM_{11}, mode) to their respective patch edges, which makes the modified patches resonate at a much lower frequency. Thus, at a given operating frequency, the required patch dimensions can be significantly reduced, and the reduction in the patch size is limited by the distance between the null-voltage point in the patch and the patch edge.

In this paper, the concept of two gap-coupled circular microstrip patch antennas reported in [19] is extended to the gap-coupled circular microstrip patch antennas loaded with shorting post in the feed patch and the numerical model for calculating the input impedance has been developed. The analyzed results are compared with the simulated results. Rest of the paper is organized as follows: The geometrical configuration of the designed antenna is described in Sect. 2. The numerical model for calculating the input impedance of the designed microstrip antenna is derived in Sect. 3. Section 4 presents the simulated and numerically calculated results and discussion about results. Finally, Sect. 5 concludes the work.

2 Antenna geometry

The geometrical configuration of the two gap-coupled circular microstrip antennas loaded with shorting post is shown in Fig. 1. The one circular patch of radius r_1 is feed patch and the other circular patch of radius r_2 is the parasitic patch. The feed patch is excited using probe feeding technique and the parasitic patch is excited by the gap-coupling. The feed patch is shorted by a shorting post of diameter p at the center of the patch as shown in Fig. 1. The height and relative permittivity of the substrate is h and ε_r, respectively. The gap distance between the adjacent edges of the feed patch and parasitic patch is s.

3 Theory

The coupled microstrip structures is characterized for the two modes as reported in [20]. These modes are known as even and odd modes. The capacitances can be expressed in terms of even and odd mode values for the two modes of propagation [20]. The concept of coupled microstrip lines has been applied to the gap-coupled circular microstrip antennas in [19]. The total capacitance of the gap-coupled circular microstrip antennas can be determined for even mode and odd mode as in [19].

The equivalent circuits of gap-coupled circular microstrip antennas loaded with shorting post for even mode and odd mode are given in Figs. 2 and 3 respectively. From Figs. 2, and 3, the input impedance for even mode and odd mode is calculated. In Figs. 2 and 3, Y_1, L_1, C_1 and Y_2, L_2, C_2 are

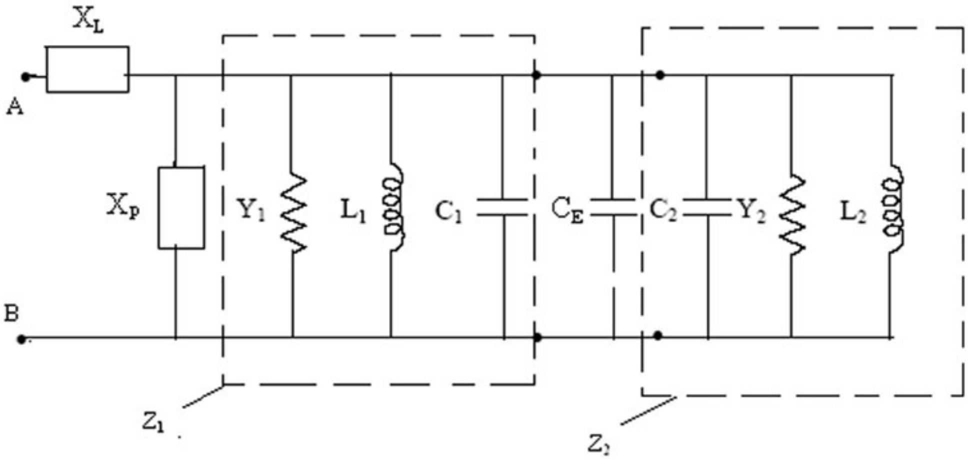

Fig. 2 Equivalent circuit model of the two gap-coupled circular microstrip patch antenna loaded with shorting post for even mode

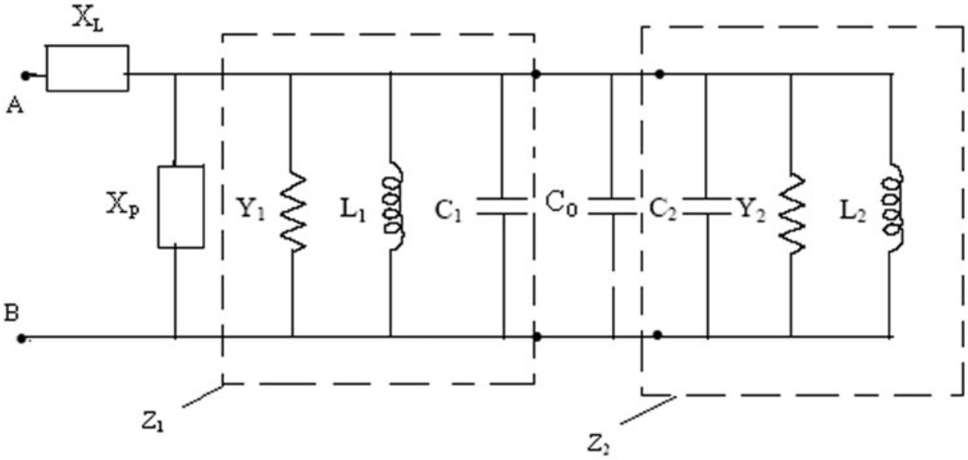

Fig. 3 Equivalent circuit model of the two gap-coupled microstrip patch antenna loaded with the shorting post for odd mode

the conductance, inductance, capacitance of feed patch and the parasitic patch respectively, C_E and C_O are the capacitances for even mode and odd mode respectively. The feed patch is shorted by a shorting post, which is in shunt to the patch. The impedance per unit length due to shorting post is given by [21]:

$$X_P = \frac{\eta k}{4}\left[1 - J_0^2(kr_d) + j\left\{\frac{2}{\pi}\ln\left(\frac{2}{\gamma k\Delta}\right) + J_0(kr_d)N_0(kr_d)\right\}\cdot F_1\right] \quad (1)$$

where r_d is the radial distance of the post from the centre of the patch, k is the propagation constant, η is intrinsic impedance. J_0, N_0 are the Bessel functions of first and second kind respectively of order zero, and F_1 is given by:

$$F_1 = \frac{\sin(\frac{\pi}{4})(J_0(\frac{1}{8}))^2}{J_0^{1.3}(\frac{r_d}{r_e})J_0^{1.8}(\frac{r_d}{r_e})}$$

where r_e is the effective radius of the patch due to fringing fields and is given by [22]:

$$r_e = r_1\sqrt{1 + \left(\frac{2h}{\pi\varepsilon_r r_1}\right)\Delta}$$

here

$$\Delta = \ln\left(\frac{\pi r_1}{2h}\right) + 1.7726$$

The total input impedance of the gap-coupled structure is given by [19]:

$$Z_{in} = Z_{in}^E + Z_{in}^O \quad (2)$$

where Z_{in}^E and Z_{in}^O are the input impedances of the structure for the even and odd mode, respectively.

4 Results and discussion

The resonant length of the microstrip patch antenna is too large for many applications at low frequencies. One signif-

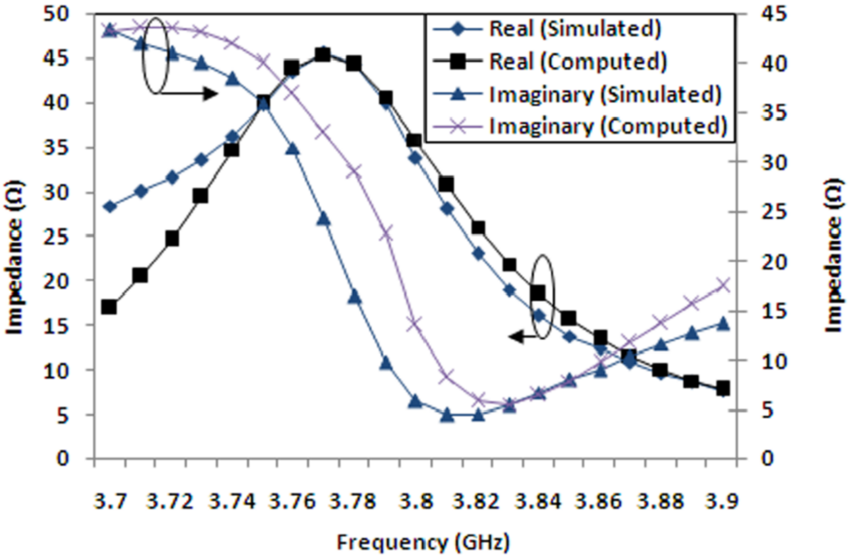

Fig. 4 Frequency characteristics of input impedance (diameter of shorting post = 0.4 mm and gap between adjacent edges = 1 mm)

icant technique to reduce the resonant length is addition of shorting pin in close proximity to the probe feed. This shorting pin is inductively shunted to the resonant circuit of the patch. The electric field inside the patch is contributed from two sources the current on the patch and the current on the probe. We use the current on the surface of the probe as the primary sources to determine the induced current on the microstrip patch. The current on the both the probe and the patch, has been taken in to account in obtaining the input impedance. The simulation work has been performed using the method-of-moment based software (IE3D from M/S Zeland software). For the simulation, two circular patches are placed close to each other and fed patch is shorted by a post as shown in Fig. 1. The input impedance is defined as the ratio of voltage across the patch and ground plane to the feed point current. The microstrip line feeding and probe feeding methods are very similar in operation, and offer essentially one degree of freedom in the design of antenna element through the positioning of the feed point to adjust the input impedance level. The input impedance of the antenna can be controlled with feed by adjusting the size of the aperture and the separation distance between the feed point and shorting post. The input impedance of the antenna is very sensitive to the separation in distance between the two conductors. The input impedance of the antenna is calculated using (2) and the computed results are compared with simulated results. The dimensions of the designed antenna are given in Table 1.

The frequency characteristics of the real and imaginary part of the input impedance are shown in Fig. 4. The real part of the impedance is maximum and the imaginary part is minimum at the resonant frequency of the designed antenna. The comparison between simulated and computed results for the real part of the input impedance shows good agreement except for initial range of frequencies. It is due to the presence of another mode in the simulated results because of gap-coupled structure. The variation of real and imaginary part with gap distance between adjacent edges of the patches is shown in Fig. 5. The computed and simulated results in the particular range of the gap distance between the feed patch and parasitic patch of the proposed antenna are well matched. Further the variation of real and imaginary part of impedance with diameter of shorting post is shown in Fig. 6. The comparison of simulated and computed results shows good agreement.

Table 1 Dimensions of the designed antenna

Radius of feed patch (r_1) (mm)	Radius of parasitic patch (r_2) (mm)	Height of the substrate (h) (mm)	Dielectric constant of the substrate (ε_r)
15	15	1.59	2.2

5 Conclusion

In the present paper, a numerical model for the two gap-coupled circular microstrip antenna loaded with shorting post has been developed. The concept of coupled microstrip line is applied to gap-coupled circular microstrip antennas loaded with shorting post and input impedance is calculated. Input impedance for different gaps between adjacent edges is shown as well as for different diameter of shorting post is shown. The analysis presented above can be easily programmed to determine the input impedance of gap-coupled circular microstrip patch antenna loaded with shorted post. A shorting pin reduces the size of the antenna to less than half of the conventional microstrip antennas with only a moderate loss in the antenna performance. This structure

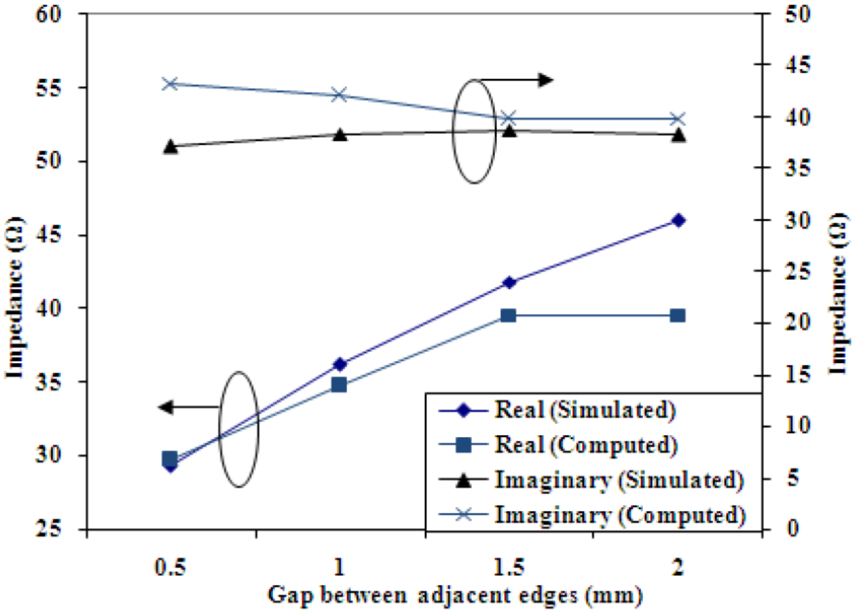

Fig. 5 The variation of input impedance with the gap distance between the adjacent edges at 3.74 GHz for the diameter of shorting post is 0.4 mm

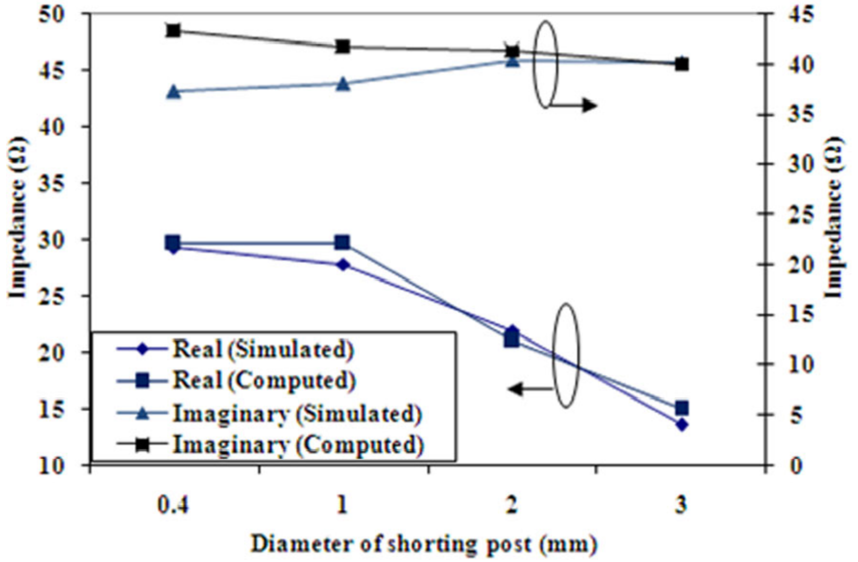

Fig. 6 Variation of input impedance with the diameter of shorting post at 3.74 GHz at gap distance between the adjacent edges is 0.5 mm

also provides extra freedom to choose design parameters and renders the antenna easier to manufacture. The comparison between computed and simulated results shows good agreement.

References

1. Garg, R., Bhartiya, P., Bahl, I., Ittipiboon, A.: Microstrip Antenna Design Handbook. Artech House, London (2001)
2. Aanandan, C.K., Mohanan, P., Nair, K.G.: Broad-band gap coupled microstrip antenna. IEEE Trans. Antennas Propag. **38**(10), 1581–1586 (1990)
3. Kumar, P., Chakravarty, T., Singh, G., Bhooshan, S., De, A., Khah, S.K.: Numerical computation of resonant frequency of gap-coupled microstrip antennas. J. Electromagn. Waves Appl. **21**(10), 1303–1311 (2007)
4. Kumar, P., Singh, G., Chakravarty, T.: Numerical computation of resonant frequency of shorting post loaded gap-coupled circular microstrip patch antennas. J. Electromagn. Anal. Appl. **1**, 259–264 (2009)
5. Kumar, P., Singh, G., Bhooshan, S., Chakravarty, T.: Gap—coupled microstrip antennas. In: Proc. of International Conference on Computational Intelligence and Multimedia Applications, pp. 434–437 (2007)
6. Chen, Y., Yang, S., Nie, Z.: Bandwidth enhancement method for low profile E-shaped microstrip patch antennas. IEEE Trans. Antennas Propag. **58**(7), 2442–2447 (2010)
7. Kan, H.K., Waterhouse, R.B.: Size reduction technique for shorted patches. Electron. Lett. **35**, 948–949 (1999)
8. Shackelford, A.K., Lee, K.F., Luk, K.M.: Design of small size wide bandwidth microstrip patch antennas. IEEE Antennas Propag. Mag. **45**, 75–83 (2003)

9. Park, I., Mitra, R.: Aperture-coupled small microstrip antenna. Electron. Lett. **32**(11), 1741–1742 (1996)
10. Rowely, J.J., Waterhouse, R.B.: Performance of shorted microstrip patch antenna for mobile communication handset at 1800 MHz. IEEE Trans. Antennas Propag. **47**(5), 815–822 (1999)
11. Waterhouse, R.B., Targonski, S.D., Kokotoff, D.M.: Design and performance of small printed antennas. IEEE Trans. Antennas Propag. **46**, 1629–1633 (1998)
12. Dey, S., Mittra, R.: Compact microstrip patch antenna. Microw. Opt. Technol. Lett. **13**(1), 12–14 (1996)
13. Waterhouse, R.B.: Small microstrip patch antenna. Electron. Lett. **31**, 604–605 (1995)
14. Porath, R.: Theory of miniaturized shorting post microstrip antennas. IEEE Trans. Antennas Propag. **48**(1), 41–47 (2000)
15. Kumar, P., Singh, G.: Computation of mutual coupling for gap-coupled circular patch antennas loaded with shorting post. Int. J. Electron. Eng. **1**(1), 99–102 (2009)
16. Sharma, A., Singh, G.: Design of single pin shorted three-dielectric-layered substrates rectangular patch microstrip antenna for communication systems. Prog. Electromagn. Res. Lett. **2**, 157–165 (2008)
17. Kumar, P., Dwevidi, V.K., Singh, G., Bhooshan, S.: Miniaturization of gap-coupled circular microstrip antennas. In: Proc. of International Conference on Microwave, pp. 489–491 (2008)
18. Kumar, P., Singh, G.: Microstrip antennas loaded with shorting post. Engineering **1**(1), 41–45 (2009)
19. Kumar, P., Singh, G.: Theoretical investigation of input impedance of gap-coupled microstrip antennas. J. Infrared Millim. Terahertz Waves **30**(11), 1148–1160 (2009)
20. Garg, R.: Design equations for coupled microstrip lines. Int. J. Electron. **47**(6), 587–591 (1979)
21. Chakravarty, T., Roy, S.M., Sanyal, S.K., De, A.: Loaded microstrip disk resonator exhibits ultra-low frequency resonance. Prog. Electromagn. Res. **50**, 1–12 (2005)
22. Randy, B.: Microstrip and Printed Antenna Design. Prentice-Hall, New York (2006)