Mathematical Analysis of Commonly Used Feeding Techniques in Rectangular Microstrip Patch Antenna

Ekta Thakur, Dinesh Kumar, Naveen Jaglan, Samir Dev Gupta and Shweta Srivastava

Abstract In the presented work, different feeding techniques are employed to design microstrip patch antenna for wireless applications. These feeding techniques are as follows: microstrip inset feed, quarter wavelength feed, and coaxial probe feed. Parameters valuated for comparing these feeding techniques are: return loss, directivity, gain, and radiation efficiency. In the presented work, it is observed that by using coaxial probe feed, the values achieved for maximum directivity and gain are 5.43 dBi and 5.33 dB, respectively.

Keywords Microstrip patch antenna · Feeding techniques · Directivity · Gain Bandwidth

1 Introduction

The Microstrip Patch Antenna (MPA) antennas are popularly engaged for improving the performance of wireless application. This is due to their conformal structure, small

E. Thakur · D. Kumar · N. Jaglan
Department of Electronics and Communication Engineering,
Jaypee University of Information Technology, Solan, Himachal Pradesh, India
e-mail: ektathakurbu92@gmail.com

D. Kumar
e-mail: dineshparee@gmail.com

N. Jaglan
e-mail: naveen.jaglan@juit.ac.in

S. D. Gupta · S. Srivastava (✉)
ECE Department,
Jaypee Institute of Information Technology, Sector 128, Jaypee Wish Town Village, Sultanpur, Noida 201304, Uttar Pradesh, India
e-mail: shweta.srivastava@jiit.ac.in

S. D. Gupta
e-mail: samirdev.gupta@jiit.ac.in

B. S. Rawat et al. (eds.), *Advances in Signal Processing and Communication* ,
Lecture Notes in Electrical Engineering 526,
https://doi.org/10.1007/978-981-13-2553-3_3

size, moderate efficiency, lightweight, and ease of integration with active devices. The MPA consists of metallic ground plane, dielectric substrate, and radiating patch. The ground plane and patch are made up of conducting material like gold and aluminum whereas substrate is made up of dielectric material like RT/duroid, FR4, etc. There are multiple approaches to feed the microstrip antennas which are generally divided into two varieties namely, the contacting and the non-contacting approach [1]. In the former, the microstrip line is used to feed patch however, in the latter, the coupling is exploited to transfer the power among the patch and the microstrip line. In this microstrip feed line method, the radiating patch is connected to a straight feed using conducting copper strip line. The width of the microstrip line is less as compared to width of the patch. There are various substrates that are used to design and fabricate the antenna with dielectric constant ranging between $2.2 \le \varepsilon_r \le 12$ [1]. The coaxial feed or probe feed is mostly used to feed the MPA. Due to the easy implementation of the coaxial feed, it is one of the popular feeding techniques used. The internal and external conductors are separated by dielectric in the coaxial feed. The internal conductor of the coaxial feed is attached to the patch, while the external conductor is attached to the ground plane [2]. The MPA can also be designed using inset feed, which is the simplest method due to easy impedance matching.

Among the various non-contacting feeding techniques, proximity coupling [3] and aperture coupling are studied by the researchers [4]. In the former technique, the strip line is amid two dielectric substrates and the patch is on the top of upper substrate. In the latter technique, the ground plane is in between the patch and feed line. Among the four feeds discussed, the proximity coupling consumes the largest bandwidth despite its difficulty.

2 Antenna Design

For the better antenna performance, the thick dielectric substrate is used because it provides larger bandwidth and better radiation however, the thick dielectric substrate results in the large antenna dimension [4]. Moreover, the thick dielectric substrate has low dielectric constant value. The three antennas are simulated using high-frequency structure simulator (HFSS) software.

2.1 Coaxial Feed MPA Design

The MPA is designed at the frequency of 2.4 GHz, where the FR4 substrate is used with dielectric constant 4.7 and loss tangent 0.002. The parameters of the patch are calculated by using the given formulas.

The patch length is calculated by

$$L = L_{eff} - 2\Delta L \tag{1}$$

$$L_{eff} = \frac{c}{f\sqrt{\epsilon_{eff}}} \tag{2}$$

where *L*, L_{eff} represents the length of the patch, effective length. The width and the effective dielectric constant of the patch is obtained by

$$W = \frac{c}{2f\sqrt{\epsilon_r + 1}} \tag{3}$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-1/2} \tag{4}$$

where *f*, *c*, *W*, ε_r,h and ε_{eff} represents the resonant frequency, speed of light, width of the patch, dielectric constant, height of substrate, and effective dielectric constant, respectively. The effective length of the patch is L $= \frac{\lambda}{2}$ for TM_{010} mode with no fringing [5].

$$\Delta L = 0.412h\frac{\left(\epsilon_{eff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\epsilon_{eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{5}$$

Characteristic impedance is given by [6]

$$Z_C = \begin{pmatrix} \frac{60}{\sqrt{\epsilon_{eff}}}\ln\left(\frac{8h}{w_0} + \frac{w_0}{4h}\right) & \frac{w_0}{h} \le 1 \\ \frac{120\pi}{\sqrt{\epsilon_{eff}}\left[\frac{w_0}{h} + 1.393 + 0.667\left(\frac{w_0}{h} + 1.444\right)\right]} & \frac{w_0}{h} \ge 1 \end{pmatrix} \tag{6}$$

where w_0 is the width of the microstrip line. The calculated effective dielectric $\left(\varepsilon_{eff}\right)$ is equal to 4.04.

Therefore, the length due to fringing effect (ΔL) is equal to 1.116 mm. Further, the calculated dimensions like width and length of patch of coaxial feed MPA are presented in Table 1. The calculated effective dielectric $\left(\varepsilon_{eff}\right)$ is equal to 4.04. The length and width of ground plane is the same as the substrate dimensions.

Table 1 Dimensions of coaxial feed MPA Design

Parameters	Values (mm)
Width of patch (W_{P1})	30
Length of patch (L_{P1})	39.5
Width of substrate (W_{S1})	90
Length of substrate (L_{S1})	100
Feeding point (Y_O)	4.3
Radius of internal conductor	0.7
Radius of external conductor	1.7

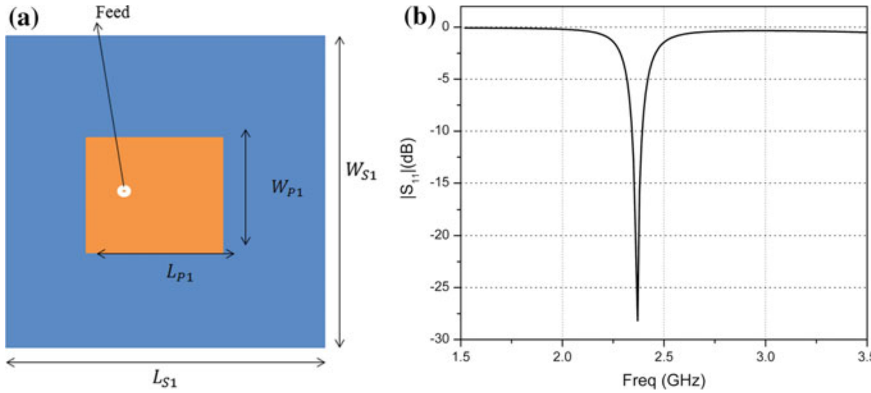

Fig. 1 **a** Antenna designed using coaxial probe feed. **b** Return loss of coaxial feed MPA

2.2 Results of Coaxial Probe Feed MPA

Return loss of the coaxial probe feed MPA at 2.4 GHz is −26 dB as shown in Fig. 1b. If the dip is below −10 dB, this means that 1/10th of incident power is reflected back at the interferences of the transmissions lines and the antenna [6]. Bandwidth achieved for 50 MHz is calculated by the formula given in Eq. (8). The return loss and bandwidth are given as [7]

$$RL = -20\log(\Gamma) \tag{7}$$

$$BW = \frac{(f_h - f_1)}{f_c} \times 100 \tag{8}$$

where the RL, Γ, BW, f_l, f_h, and f_c signify the return loss, reflection coefficient, bandwidth, lower frequency, upper frequency, and center frequency, respectively. The ideal matching between the transmitter and antenna is achieved when the reflection coefficient and RL is zero and 0 dB, respectively. This signifies that there is zero power reflected back however, when the reflection coefficient and RL is one and infinity, respectively, indicates the total reflection of incident power. The field pattern of the MPA with coaxial feed is obtained as Fig. 3a.

2.3 Inset Feed MPA Design

The impedance of feedline should match to the patch to obtain good antenna efficiency which can be achieved using inset feed. The input impedance can be altered by using an inset feed. The input resistance for the inset feed is calculated as [8]

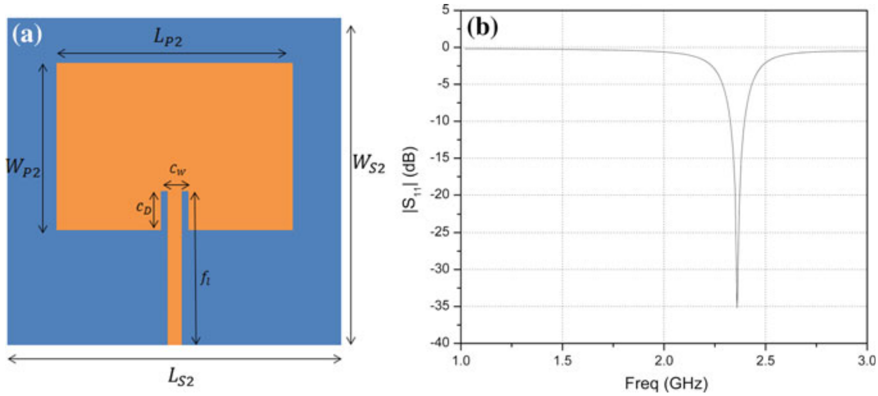

Fig. 2 **a** Antenna designed using inset feed. **b** Return loss of inset feed MPA

$$R_{in}(C_D) = \frac{1}{2(G_1 + G_{12})}\cos^2\left(\frac{\pi}{L}C_D\right) \tag{9}$$

$$G_1 = \begin{pmatrix} \frac{1}{90}\left(\frac{W}{\lambda}\right)^2 \ W \ll \lambda \\ \frac{1}{120}\left(\frac{W}{\lambda}\right) \ W \gg \lambda \end{pmatrix} \tag{10}$$

$$G_{12} = \frac{1}{120\pi^2}\int_0^{\pi}\left[\frac{\sin^2\left(\frac{k_0 W}{2}\right)^2}{\cos\theta}\right] J_0(k_0\sin\theta)\sin^3\theta d\theta \tag{11}$$

where R_{in} (C_D) is the input impedance at point C_D.

2.4 Results of Inset Feed MPA

Figure 2b illustrates the return loss of the inset feed. The calculated dimensions of inset MPA are shown in Table 2. The electric field plane and magnetic field plane pattern of a rectangular microstrip antenna with inset feed at 2.4 GHz center frequency shown in Fig. 3b [9] (Fig. 4).

2.5 Quarter Wavelength Feed MPA Design

The characteristic impedance of quarter wavelength transmission line [10–15]

$$Z_{in} = \frac{Z_0^2}{Z_A} \tag{12}$$

Table 2 Dimensions of inset feed MPA Design

Parameters	Values (mm)
Width of patch (W_{P2})	29.44
Length of patch (L_{P2})	38.04
Width of substrate (W_{S2})	49.75
Length of substrate (L_{S2})	50
Slot width (C_W)	2.4
Slot Depth (C_D)	5
Feed Length (f_l)	20
Feed width (f_w)	1.6

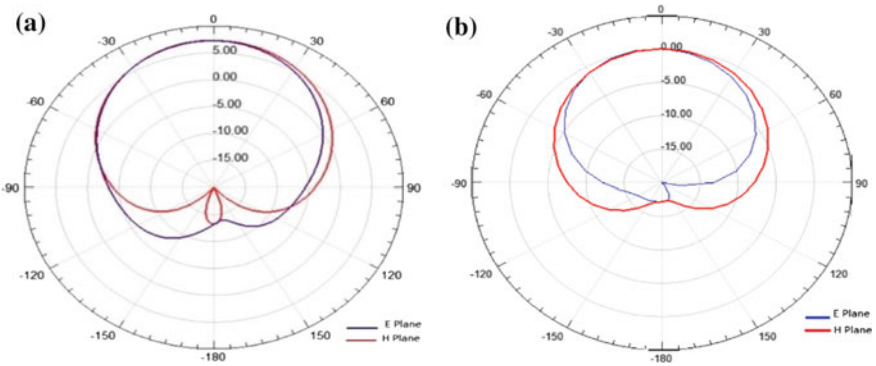

Fig. 3 **a** E plane and H plane of coaxial feed MPA. **b** E plane and H plane of inset feed MPA

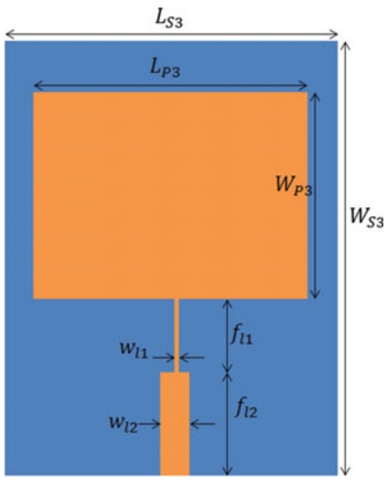

Fig. 4 Antenna designed using quarter wavelength feed

Table 3 Dimensions of quarter wavelength MPA

Parameters	Values (mm)
Width of patch (W_{P3})	29.26
Length of patch (L_{P3})	36.26
Width of substrate (W_{S3})	45
Length of substrate (L_{S2})	60.94
Feed length (f_{l1})	5
Feed length (f_{l2})	15
Feed width (w_{l1})	0.62
Feed width (w_{l2})	3.05

$$Z_0 = \sqrt{Z_A Z_{in}} \tag{13}$$

where Z_0 is characteristic impedance, Z_{in} is input impedance, and Z_A is load impedance. The calculated dimensions of quarter wavelength feed microstrip patch antenna is shown in Table 3.

2.6 Results of Quarter MPA Feed

The return loss of the quarter wavelength feed antenna at 2.4 GHz is −27 dB shown in Fig. 5b. The bandwidth achieved 80 MHz that is calculated by using Eq. (8). The radiation pattern of a rectangular microstrip antenna with quarter wavelength feed at 2.4 GHz center frequency shown in Fig. 5a.

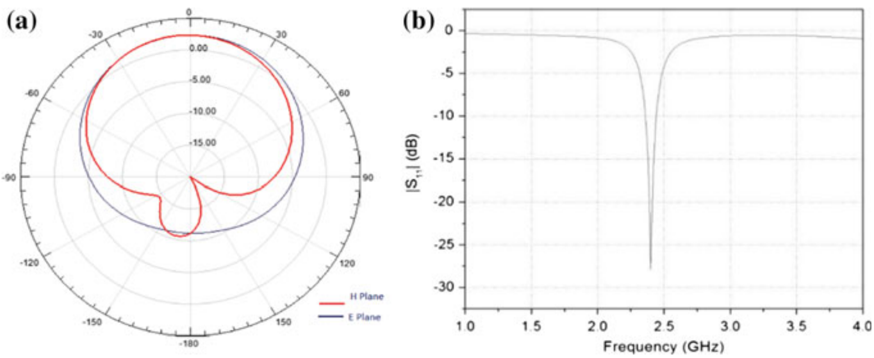

Fig. 5 **a** Radiation pattern of quarter wavelength feed MPA. **b** Return loss of quarter wavelength feed MPA

Table 4 Comparison of various feeding techniques of MPA

Parameters	Coaxial feed	Inset feed	Quarter wavelength feed
Return loss (dB)	−26	−35	−27
Frequency (GHz)	2.4	2.4	2.4
Max U(W/sr)	0.0036528	0.070014	0.13607
Bandwidth(MHz)	50	10	80
Peak Gain(dB)	5.3308	1.2	1.7167
Radiated Power (W)	0.0084524	0.047574	0.54238
Peak Directivity(dBi)	5.4309	1.8494	3.152
Accepted power(W)	0.008611	0.86261	0.99607
Incident Power (W)	0.010122	0.0094294	1
Radiation Efficiency	0.98157	0.5515	0.5452
Front to Back Ratio	113.48	56.188	25.795

3 Comparison

The simulated result of all feeding techniques is shown in Table 4. Those feeding methods are microstrip inset feed, quarter wavelength, and co-axial probe feed. Table 4 also gives the variation in different parameters like directivity, gain, etc.

4 Conclusion

It is observed that all considered feeding techniques of the microstrip patch antenna provide different results. Selection of feed is a significant decision because it varies almost all the parameters of the antenna (Fig. 4).

The variations in bandwidth, directivity, gain, and efficiency of MPA under different feeding techniques are considered. It can be seen that coaxial feed achieves better gain and directivity of 5.43 dBi and 5.33 dB, respectively. These values are better as compared to other feeding methods.

References

1. Balanis, C.A.: Antenna Theory: Analysis and Design, 3rd edn. Wiley, New Jersey (2005)
2. Garg, R., Bhartie, P., Bahl, I., Ittipiboon, A.: Microstrip Antenna Design Handbook, pp. 253–316. Artech House Inc., Norwood (2001)
3. Chen, H.D.: Compact circularly polarised microstrip antenna with slotted ground plane. Electron. Lett. **13**(2), 616–617 (2002)

4. Caloz, C., Itoh, T.: Transmission line approach of left-handed (LH) materials and microstrip implementation of an artificial LH transmission line. IEEE Trans. Antennas Propag. **52**(4), 1159–1166 (2004)
5. Heidari, A.A., Heyrani, M., Nakhkash, M.: A dual-band circularly polarized stub loaded microstrip patch antenna for GPS applications. Prog. Electromagn. Res. **92**, 195–208 (2009)
6. Jaglan, N., Kanaujia, B. K., Gupta, S. D., Srivastava, S.: Triple band notched Uwb antenna design using electromagnetic band gap structures. Prog. Electromagn. Res.C. **66**, 21–37 (2017)
7. Jaglan, N., Gupta, S. D., Kanaujia, B. K., Srivastava, S., and Thakur, E.: Triple band notched Dg-Cebg structure based Uwb MIMO/diversity antenna. Prog. Electromagn. Res.C. **80,** 21–37 (2018)
8. Mobashsher, A.T., Abbosh, A.: Utilizing symmetry of planar ultra-wideband antennas for size reduction and enhanced performance. IEEE Antennas Prop. Mag. **57**(2), 153–166 (2015)
9. Massie, G., Caillet, M., Clemet, M., Antar, M.M.: A new wideband circularly polarized hybrid dielectric resonator antenna. IEEE Antennas Wirel. Propag. Lett. **9**, 347–350 (2010)
10. Wang, Z., Fang, S., Fu, S., Lu, S.: Dual-band probe-fed stacked patch antenna for GNSS applications. IEEE Antennas Wirel. Propag. Lett. **9**, 100–103 (2009)
11. Jaglan, N., Kanaujia, B., Gupta, S., Srivastava, S.: Dual band notched Ebg structure based Uwb Mimo/diversity antenna with reduced wide band electromagnetic coupling. Freq. J. RF-Eng. Telecommun. **71**, 1–11 (2017)
12. Ali, W.A., Moniem, R.: Frequency reconfigurable triple band notched ultra wideband antenna with compact size. Prog. Electromagn. Res. C **73**, 37–46 (2017)
13. Zhang, Q., Fukuoka, Y., Itoh, T.: Analysis of a suspended patch antenna excited by an electromagnetically coupled microstrip feed. IEEE Trans. Antennas Propag. **33**(8), 895–899 (1985)
14. Sánchez, L., Roy, J.L., Iglesias, E.: Proximity coupled microstrip patch antenna with reduced harmonic radiation. IEEE Trans. Antennas Propag. **5**, 2392–2396 (2009)
15. Chen, W.S.: Single feed dual frequency rectangular microstrip antenna with square slot. Electron. Lett. **4**, 231–232 (1998)