Comparison of Feeding Modes for a Rectangular Microstrip Patch Antenna for 2.45 GHz Applications

Ouadiaa Barrou, Abdelkebir El Amri and Abdelati Reha

Abstract A microstrip patch antenna consists of a metal patch on a substrate on a ground plane. Different feeding modes are used such as: coaxial probe feed, microstrip line feed, proximity-coupled feed, and coplanar wave guide feed (CPW). The patch can take different shapes to meet various design requirements. The most known forms are rectangular, square, circular, hexagonal… The microstrip patch antenna is low-profile, conformable to planar and nonplanar surfaces, simple and cheap to manufacture using modern printed-circuit technology. There are many methods of analysis for the microstrip patch antennas. The most popular models are the transmission-line, cavity and full wave methods. In this paper, a microstrip patch antenna for 2.45 GHz applications is designed based on the transmission line method. The design is optimized with the Method of the Moments (frequency domain method) because it's one of the accurate methods for wire and planar antennas. Also, the four feeding modes are simulated and compared.

Keywords Antenna design · Feeding modes · Microstrip patch antenna

1 Introduction

With the development of wireless applications and their integration in restrict environment like smartphones, laptops and other embedded systems, the microstrip patch antennas are widely used because of their planer structure, low profile, light weight good efficiency, ease of manufacturing and integration with active devices.

There are many configurations that can be used to feed microstrip antennas. The most popular are the coaxial probe, microstrip line, proximity coupling, coplanar wave guide and others. Each feeding mode have some advantages and disadvantages and it was be used in depending on the requirements.

O. Barrou (✉) · A. El Amri · A. Reha
RITM Laboratory, CED Engineering Sciences, ESTC, Hassan II University of Casablanca, Casablanca, Morocco
e-mail: ouadiaa.barrou@gmail.com

R. El-Azouzi et al. (eds.), *Advances in Ubiquitous Networking 2*, Lecture Notes in Electrical Engineering 397, DOI 10.1007/978-981-10-1627-1_36

In this paper, first, a design methodology is presented. Next, the four feeding modes are simulated with CADFEKO, a Method of Moment (MoM) based solver. Finally, a comparison of the results is presented [1–7].

2 The Patch Antenna Design Methodology

2.1 The Design of Miscrostrip Patch Antenna

The microstrip patch antennas can be analyzed in various methods, the most popular are:

- Transmission-line method (TLM)
- Cavity method (CM)
- Full-wave methods: Are based on solving Maxwell's equations in differential or integral forms. The most popular are the Method of the Moments (MoM), the Finite element method (FEM), Finite-Difference Time Domain (FDTD).

Although the transmission line model has the least accuracy, it is the easiest method to implement and gives good physical insight. According to Balanis, the transmission-line model represents the microstrip antenna by two slots with a width of W and separated by a transmission line of length L (Fig. 1).

For the microstrip line shown in Fig. 2a, the field lines are inside the substrate and some of them are extended to outer space (Fig. 2b). For this, an effective dielectric constant (ε_{reff}) is introduced to account for fringing and the wave propagation in the line (Fig. 2c).

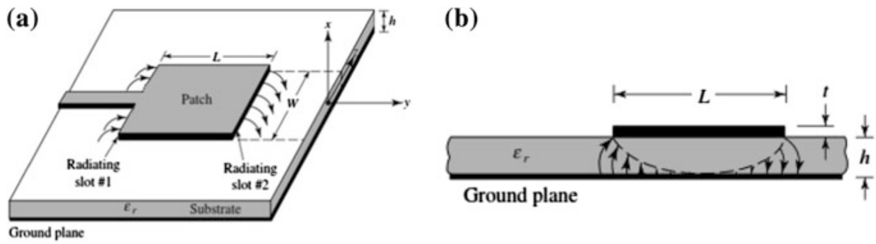


Fig. 1 Microstrip antenna [1]. **a** Microstrip antenna. **b** Side view

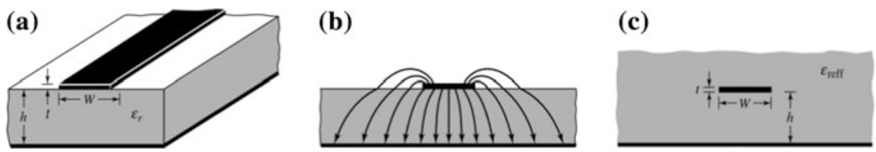


Fig. 2 Microstrip line and its electric field lines, and effective dielectric constant geometry [1]. **a** Microstrip line. **b** Electric field lines. **c** Effective dielectric constant

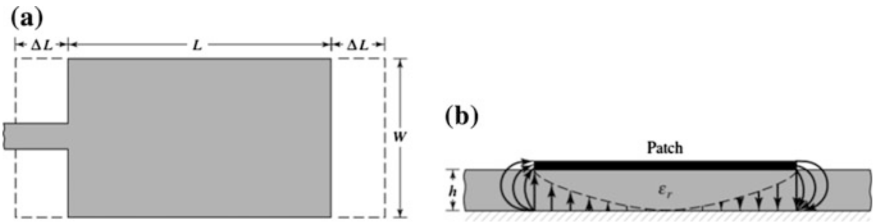


Fig. 3 Physical and effective lengths of rectangular microstrip patch [1]. **a** Top view. **b** Side view

ε_{reff} can be calculated from [1] by the formula (1)

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r \quad 1}{2} \times \left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{1}$$

where, W/h > 1
ε_{reff} :Effective dielectric constant
ε_r: Dielectric constant of the substrate
W: Width of the radiating patch
h: Height of the substrate

As shown in Fig. 3, fringing effects looks greater than the microstrip patch dimensions. For the principal E-plane (xy-plane), the dimensions of the patch along its length have been extended on each end by a distance ΔL, which is a function of ε_{reff} and W/h given from [1] by the formula (2).

$$\frac{\Delta L}{h} = 0.412 \times \frac{(\varepsilon_{reff} + 0.3) \times (\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258) \times (\frac{W}{h} + 0.8)} \tag{2}$$

The effective length of the patch is given by the Eq. (3).

$$L_{eff} = L + 2.\Delta L \tag{3}$$

It is also given by the Eq. (4).

$$L_{eff} = \frac{\lambda}{2\sqrt{\varepsilon_{reff}}} \tag{4}$$

The width of the patch is given from [1] by the Eq. (5)

$$W = \frac{\lambda}{2}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{5}$$

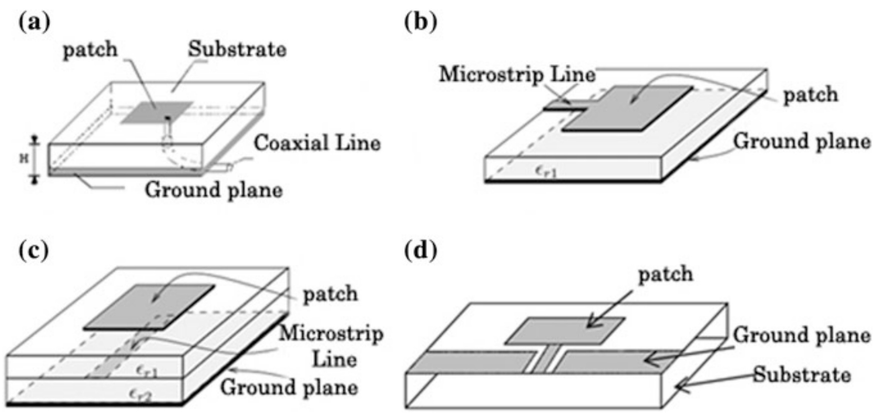


Fig. 4 Feeding Techniques. **a** Coaxial probe feed. **b** Microstrip line feed. **c** Proximity-coupled feed. **d** CoPlanar Wive guide feed (CPW)

Where, λ is the wavelength given by the Eq. (6)

$$\lambda = \frac{c}{f} \tag{6}$$

To design a microstrip patch antenna operating in the frequency of 2.45 GHz with the parameters: h = 1.6 mm and $\varepsilon_r = 4.4$ we follow the previous steps.

The results are: W = 37.26, L = 28.83 mm.

2.2 *Feeding Modes*

There are many configurations that can be used to feed microstrip antennas. The most popular are the microstrip line, coaxial probe, proximity coupling, and CPW (Fig. 4).

In the next section, a comparison of some patch antenna parameters will be done when we feed it with the four feeding techniques.

3 CADFEKO Simulation Results for Different Feeding Modes

To validate the previous design, the microstrip patch antenna was simulated with CADFEKO witch based on the Method of the Moments (MoM), one of the more accurate methods for wire and planar antennas [8–12]. Four feeding modes are simulated: coaxial probe, microstrip line, proximity coupling, and CPW.

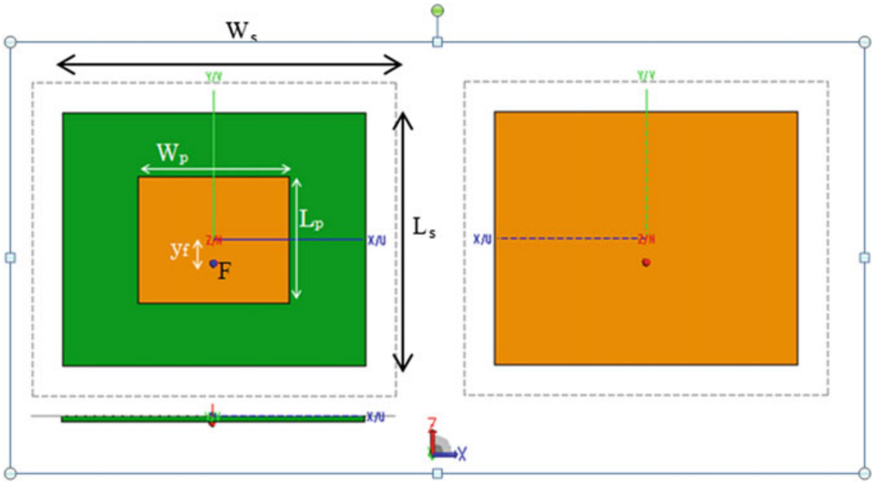


Fig. 5 Geometry of the patch antenna with coaxial probe fed

3.1 Coaxial Probe Feeding

Figure 5 illustrates the geometry of the patch antenna fed by a coaxial prob. The antenna is printed on a substrate EPOXY FR4 with relative permittivity $\varepsilon_r = 4.4$ and a thickness of 1.6 mm. The other parameters are: $W_p = 37.26$, $L_p = 28.83$ mm, $W_s = 2W_p$, $L_s = 2L_p$. The feeding probe is placed at the point F, placed at the y_f position from the center of the patch ($y_f = 4$ mm).

Figure 6 shows the S_{11} parameters. The simulated resonance frequency is 2.33 GHz, 130 MHz lower than the resonance frequency given by TLM. The design is optimized to have 2.45 GHz as the resonance frequency with MoM. The new dimensions of the patch are: $W_p = 35.66$ and $L_p = 27.56$ mm. Figure 7 shows the S_{11} for the optimized antennas.

To have a good impedance matching, the feeding point must be placed at a specific position. For that a parametric study is done. Fig 8 shows the behavior of S_{11} versus y_f. We observe that we have a good impedance matching for $y_f = 6$ mm. The 3D gain pattern is shown in Fig. 9, the maximum gain is 4.6 dB.

3.2 Microstrip Line Feed

The same patch antenna is fed by a microstrip line smaller in width as compared to the patch and having a characteristic impedance of 50 Ω. The width of this line is 2.95 mm based on the Eq. (7) [2].

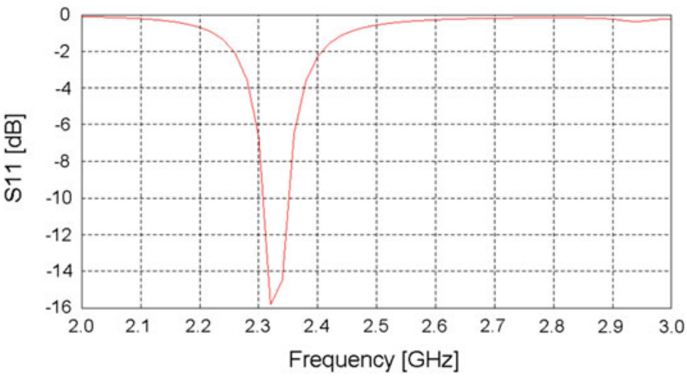


Fig. 6 S_{11} parameter for the patch antenna with coaxial probe fed

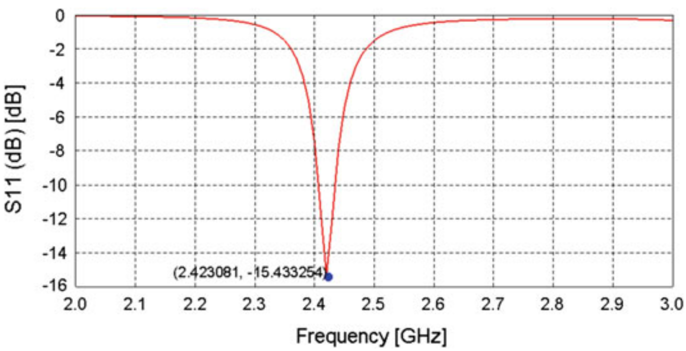


Fig. 7 S_{11} parameter for the optimized patch antenna with coaxial probe fed

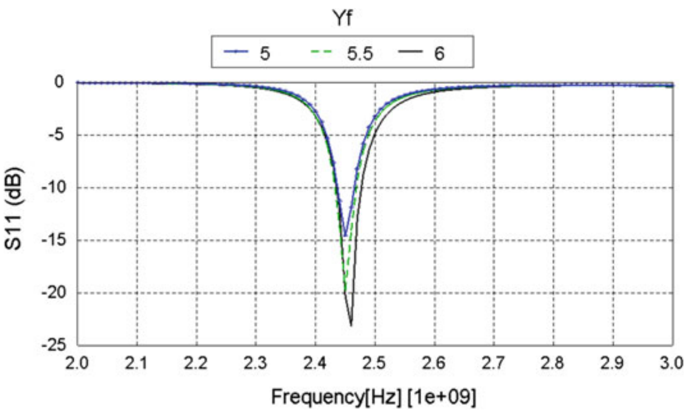


Fig. 8 Parametric study of S_{11} versus y_f

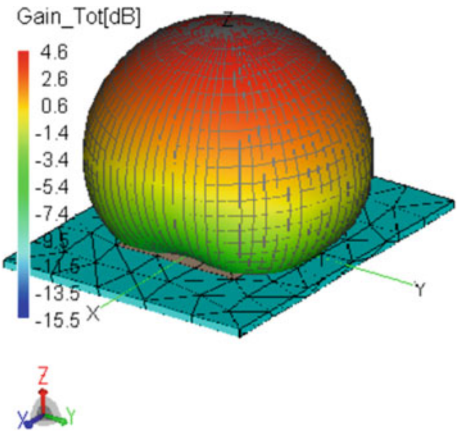


Fig. 9 3D gain pattern for the resonance frequency (fr = 2.45 GHz)

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_r}\left(\frac{W_f}{h} + 1.393 + 0.667\ln\left(\frac{W_f}{h} + 1.44\right)\right)} \quad (7)$$

With Z_0: the characteristic impedance of the microstrip line.
W_f: the width of the microstrip line.
h: the high of the substrate.

Two configurations are studied, the first one without the inset feed point (Fig. 10a), the second one with the inset feed point (Fig. 10b). The S_{11} parameter and the 3D gain pattern for the two configurations are given by Fig. 11. We observe that when we set up the inset feed point; we obtain a good impedance matching and a better efficiency. Also a parametric study is done to know the effect of the length of the inset point (y_0). Figure 12 shows the variation of S_{11} versus y_0. A better impedance matching is obtained when y_0 = 7.5 mm.

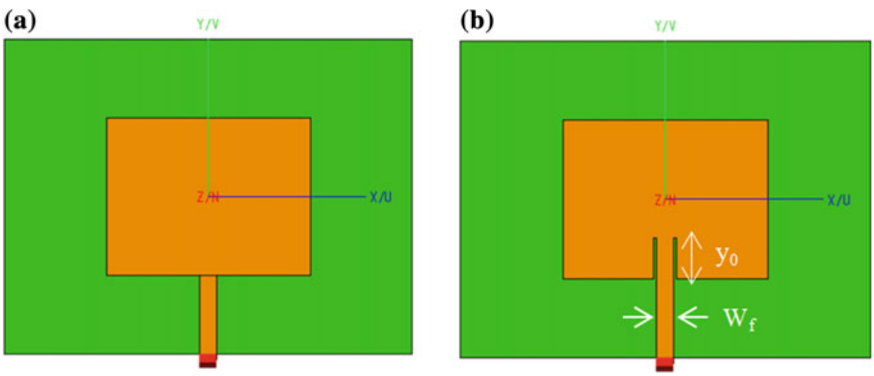


Fig. 10 Geometry of the patch antenna with Microstrip Line Feed

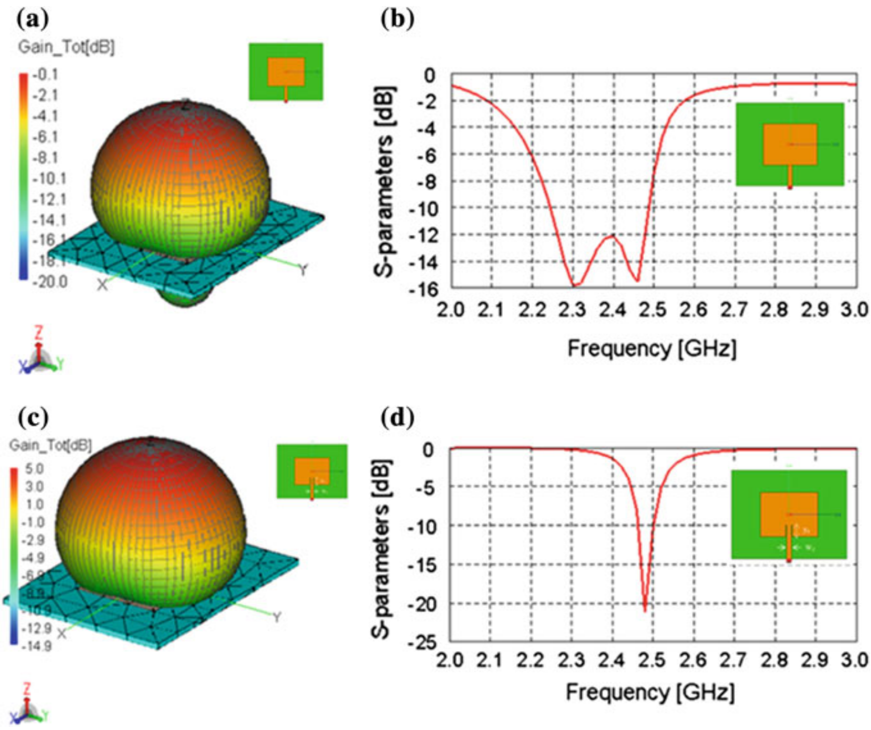


Fig. 11 3D gain pattern (**a**) and S_{11} parameter (**b**) without the inset feed point, and 3D gain pattern (**c**) and S_{11} parameter (**d**) for the second configuration (i.e., with the inset feed point)

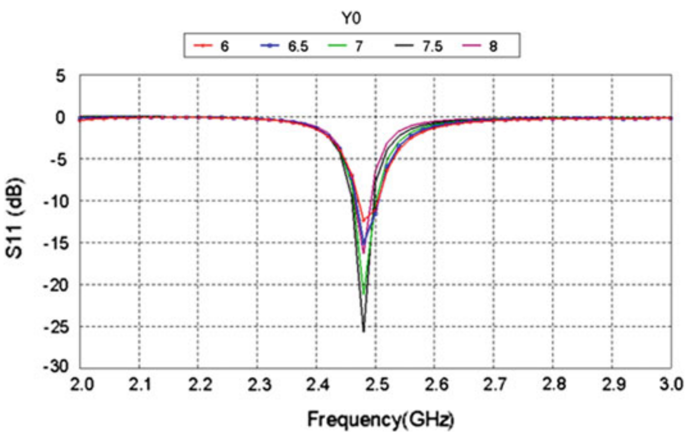


Fig. 12 Parametric study of S_{11} versus y_0

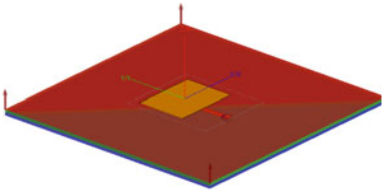


Fig. 13 Geometry of the patch antenna with Proximity coupled Feeding

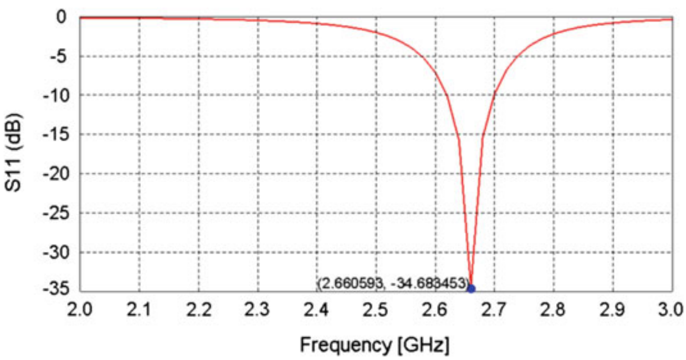


Fig. 14 S_{11} parameter for the patch antenna with Proximity coupled Feeding

3.3 Proximity Coupled Feed

For this feeding technique two dielectric substrates are used, not having necessarily the same electric characteristics and the microstrip line is placed between them (Fig. 13). The ground plane is placed on the bottom of the two substrates.

The first configuration studied using $\varepsilon_{r1} = 4.4$ and $\varepsilon_{r2} = 3.3$.
with ε_{r1}: the relative permittivity of the top layer
ε_{r2}: the relative permittivity of the bottom layer

The S_{11} parameter of the antenna is given by Fig. 14. We observe that the resonance frequency is 2.66 GHz, 210 MHz higher than 2.45 GHz, the resonance frequency obtained with the two first feeding modes. Figure 15 shows the 3D gain pattern of the antenna. We observe that the maximum gain is 5.7 dB, bigger compared to those obtained by the two first feeding modes. The S_{11} at the resonance frequency is the −10 dB bandwidth is 80 MHz (2.62–2.7 GHz). A good impedance matching is observed (48 Ω).

The variation ε_{r2} allow changing the resonance frequency. A parametric study is done and we observe that when ε_{r2} increases, the resonance frequency decreases (Fig. 16). This technique is one of the important ways to reduce the resonance frequency without increasing the dimensions of the antenna, so we can consider it

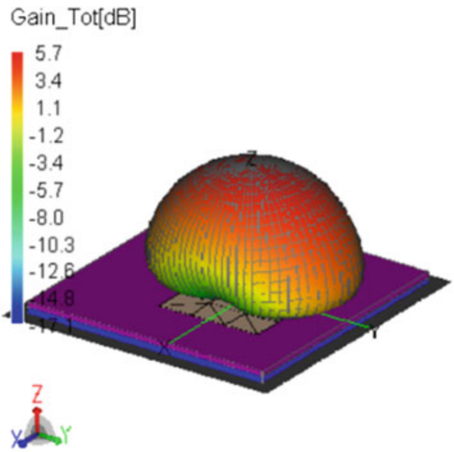


Fig. 15 3D gain pattern for the patch antenna with Proximity coupled Feed

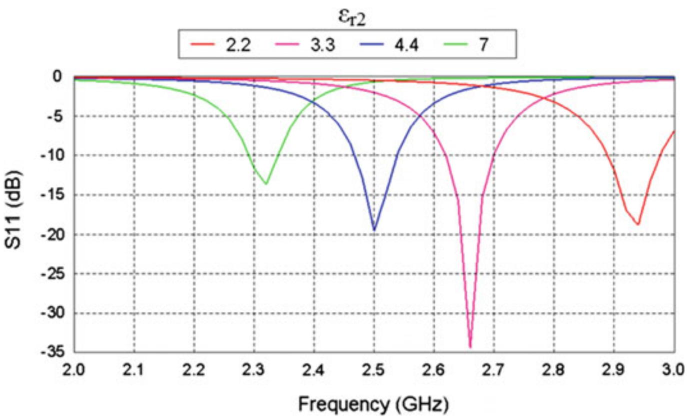


Fig. 16 Parametric study of S_{11} versus ε_{r2}

as a miniaturizing technique. Also, we observe that the −10 dB bandwidth decreases when ε_{r2} increases (Table 1).

3.4 CPW-Feeding Mode

This kind of feeding technique is also called CoPlanar Wave guide feeding (CPW-feeding). The ground plane is placed on the same plane as the patch as shown in Fig. 17. This antenna is easy to manufacture compared to the three first antennas using the Printed Circuit Board technique (PCB), in general it's used to

Table 1 Some results of the four feeding modes

Feeding mode		Resonance frequency (GHz)	S_{11} (dB)	Max. gain (dB)	Impedance	Bandwidth (From-To) (MHz)
Probe		2.44	−17.6	4.6	57−12i	45 (2.415−2.46)
Microstrip line		2.48	−26.2	5.1	54−2.6i	40 (2.46−2.5)
Proximity coupled	ε_{r2} = 2.2	2.93	−18	4.3	3+98i	100 (2.88−2.98)
	ε_{r2} = 3.3	2.65	−34.6	5.7	48	80 (2.62−2.7)
	ε_{r2} = 4.4	2.5	−20	5.4	40−1.5i	70 (2.46−2.53)
	ε_{r2} = 7	2.3	−13.5	5.1	29.5−1.4i	70 (2.29−2.35)
CPW		2.6	−11.4	1.3	85+7.2i	420 (2.4−2.82)

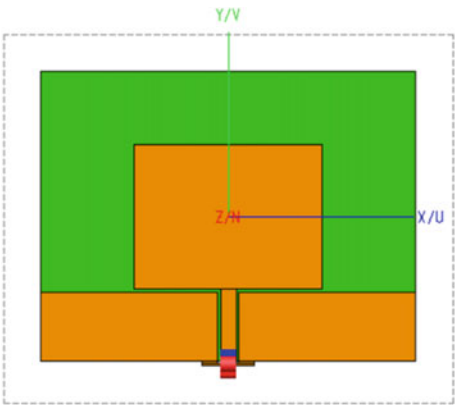


Fig. 17 Geometry of the patch antenna with CPW-feeding

obtain a large bandwidth, several studies used this technique to design antennas for Ultra Wide Band (UWB) and Broadband antennas [13–15].

The S_{11} parameter of the antenna is given by Fig. 18. We observe that the resonance frequency is 2.6 GHz with a large −10 dB bandwidth (420 MHz: 2.4 −2.82 GHz). The 3D gain pattern is given by Fig. 18, we observe that the maximum gain is 1.3 dB, also the antenna is omnidirectional Fig. 19.

4 Comparison of Different Feeding Modes

Each studied configuration has some advantages and disadvantages. The patch antenna with CPW feeding technique is simple to manufacture, omnidirectional, broadband but having a poor gain. The antenna with coaxial probe feed and microstrip line feed have the same behavior. There gain is important, directional but having a low bandwidth. The antenna with proximity-coupled feed is very complicated to manufacture, with medium bandwidth but the gain is very important and directional. Table 1 summarizes these results.

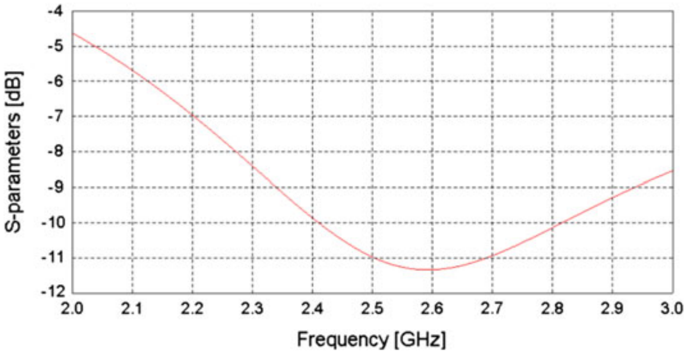
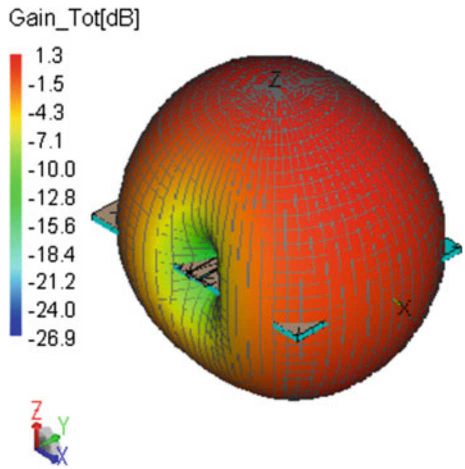


Fig. 18 S_{11} parameter for the patch antenna with CPW-feeding mode

Fig. 19 3D gain pattern for the patch antenna with CPW Feed



5 Conclusion

The microstrip patch is an adequate solution to design low profile antennas with important performances. It's also a good solution for designing embedded systems where the weight, cost and the ease of installation are the important requirements. The different feeding modes allow having some advantages: The proximity coupled allows having antennas with important gains also; the setup of substrate with high permittivity decreases the resonant frequencies. The CPW feeding mode increases the bandwidth of the antenna and having omnidirectional gain pattern. The coaxial probe and microstrip line feeding modes allow having antennas with short bandwidth and important gains.

To design microstrip patch antenna, the adopted feeding mode will be depend on the requirements performances.

As perspective of this work, manufacturing and measurements should be done to confirm these results with simulated ones.

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