Effects of Feeding Techniques on the Performance of Rectangular Patch Antennas

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Abstract: *A detailed study of the effects of feeding techniques on the performance of rectangular patch antenna is reported. Return loss, VSWR, gain, input impedance and bandwidth are studied. Co-axial line, Microstrip line, and Co-planar waveguide feeds are used. The patch is placed over a 1.6 mm thick FR-4 substrate. The patch is fed using a 50 Ω co-axial line, a 50 Ω microstrip line, and a 50 Ω co-planar waveguide, respectively. An average gain of 5.06 dB with ± 1.56 dB tolerances is observed. The bandwidth obtained is 150 MHz to 3.04 GHz for VSWR ≤ 2. It is observed that antenna resonance frequency changes significantly, when co-planer wave guide feed is used and patch dimensions need to be optimized. It is also observed that the coplanar waveguide feed helps in obtaining wideband operation.*

Index Terms - Rectangular microstrip patch, co-axial feed, microstrip line feed, co-planar waveguide (CPW) feed, bandwidth.

I. INTRODUCTION

The microstrip patch antenna falls under the category of printed antennas. The patch is a radiating element placed over a substrate of dielectric constant ε_r, with a ground plane on the other side of the substrate. The shape of radiating element can be rectangular, square, circular, triangular, pentagon, rectangular/circular ring, semi-circular, etc. The microstrip transmission line design was reported by Deschamps in 1953 [1] and microstrip antenna design was patented by Gutton and Baissinot in 1955 [2]. Since then, researchers have been reported numerous new designs of the microstrip patch antenna [3-8].

The patch antenna has many advantages like low profile, light weight, compact and low fabrication cost. However, one of its main disadvantages is narrow bandwidth, which is about 5 % to 10 % and can be improved by several novel techniques. A thicker substrate with lower dielectric constant helps in widening the bandwidth. However, a thicker substrate gives rise to surface waves, thereby affecting the antenna efficiency. The broadband response is obtained only when resonant modes are closer to each other in the frequency band [3-8]. A microstrip antenna is generally fed using a co-axial line or microstrip line or proximity coupled techniques, or aperture coupled and coplanar waveguide feed techniques [9]. The feed selection depends on the power transfer from feed structure to the patch which requires a good impedance matching between feed and radiating patch. An impedance mismatch results in increased side lobe level and increased cross-polar radiation. This results in a reduction of transmitted power and a reduction in a gain of the antenna.

In this work, the effects of feeding methods on return loss, VSWR, gain, input impedance and bandwidth of microstrip patch are studied. A rectangular patch on FR-4 substrate with a finite ground plane on the other side of the substrate is placed. Co-axial line feed, microstrip line feed and coplanar waveguide feed are used and effects are investigated.

II. ANTENNA DESIGN AND FORMULATION

The design of a rectangular patch antenna begins with the selection of resonant frequency followed by the selection of the substrate material and substrate thickness. The selection of feeding mechanism is the next important consideration. Gain, return loss, efficiency, bandwidth and voltage standing wave ratio are dictated by the intended application of antenna. For efficient radiation, dielectric constant (ε_r), substrate height (h) and length (L) should be within the following range [9].

$$2 < \varepsilon_r < 12 \tag{1}$$

$$0.333\lambda_0 < L < 0.5\lambda_0 \tag{2}$$

$$0.003\lambda_0 \leq h \leq 0.05\lambda_0 \tag{3}$$

The antenna's length, width, effective length, and effective dielectric constant are calculated using the following equations [9].

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-0.5} \quad (4)$$

$$\Delta L = \frac{c}{2f_0\sqrt{e_{eff}}} \quad (5)$$

$$L = \frac{c}{2f_0\sqrt{e_{eff}}} - 2\Delta L \quad (6)$$

$$W = \frac{c}{2f_0}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (7)$$

where, L is the length of the patch, W is the width of the patch, ΔL is the incremental length of patch due to the fringing field, c is the velocity of light in free space, $\varepsilon_{reff}$is effective dielectric constant, λ_0 is wavelength and f_0 is the resonant frequency. Fig. 1(a) shows the geometry of the antenna using microstrip feed and Fig. 1(b) shows the geometry of antenna using CPW feed.

The antenna performs optimally when the patch impedance matches perfectly with the excitation impedance. The characteristic impedance of co-axial feed, microstrip feed and CPW feed are calculated using the following equations, respectively [11-12].

$$Z_{0=}\frac{138}{\sqrt{\varepsilon_r}}\log_{10}\left(\frac{b}{a}\right) \quad (8)$$

$$Z_0 \cong \frac{377}{\left[\left(\frac{W_m}{h}\right) + 2\right]\sqrt{\varepsilon_r}} \quad (9)$$

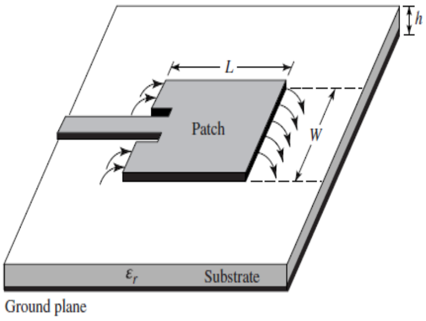
$$Z_0 = \frac{30\pi}{\sqrt{\varepsilon_{reff}}}\frac{K(K_0')}{K(K_0)} \quad (10)$$

where $$k_0 = \frac{W_m}{W_m + 2S} \quad (11)$$

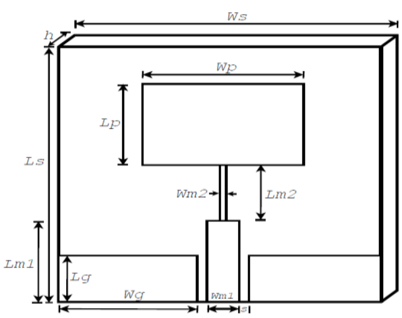
$$k_1 = \frac{sinh\left(\frac{\pi W_m}{4h}\right)}{sinh\left\{\frac{\pi(W_m + 2S)}{4h}\right\}} \quad (12)$$

$$k_1' = \sqrt{1 - K_1^2} \quad (13)$$

$$\varepsilon_{reff} = 1 - \frac{(\varepsilon_r - 1)}{2}\frac{K(k_1)}{K(k_1')}\frac{K(k_0')}{K(k_0)} \quad (14)$$



(a)



(b)

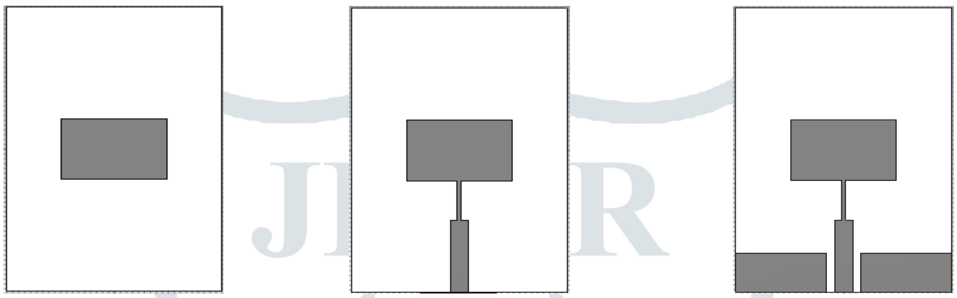
Fig. 1 (a) Microstrip patch antenna with microstrip line feeding [9], (b) Geometry of the designed CPW fed antenna.

Using the above-mentioned equations, a rectangular patch antenna on a 1.6 mm thick FR-4 substrate with dielectric constant of $\varepsilon_r = 4.4$ was designed to operate at 5.2 GHz resonant frequency. Three different feeding techniques co-axial feed line, microstrip feed line and coplanar waveguide feed, were investigated using the commercial CST-microwave studio version 18 [18].

III. Result and Discussion

The simulation results presented in this section were obtained using commercial CST microwave studio for co-axial line, microstrip line and coplanar waveguide feed. The investigations were made over the frequency range of 4 - 10 GHz. The various antenna schematics are presented in Fig. 2 and chosen parameters are listed in Table 1.

In co-axial feed, impedance matching is achieved by directly connecting the center conductor of the connector via the substrate to the patch. The location of feed point is determined so as to achieve the best impedance matching. The microstrip line feed is achieved by matching the patch impedance with a λ/4 transmission line. In the CPW feed, the ground plane and patch are on the same side of the substrate and feed dimensions needs to be optimized.



(a) (b) (c)

Fig. 2 (a) Co-axial line feed (b) Microstrip line feed and (c) CPW feed Rectangular microstrip patch antenna (Top views)

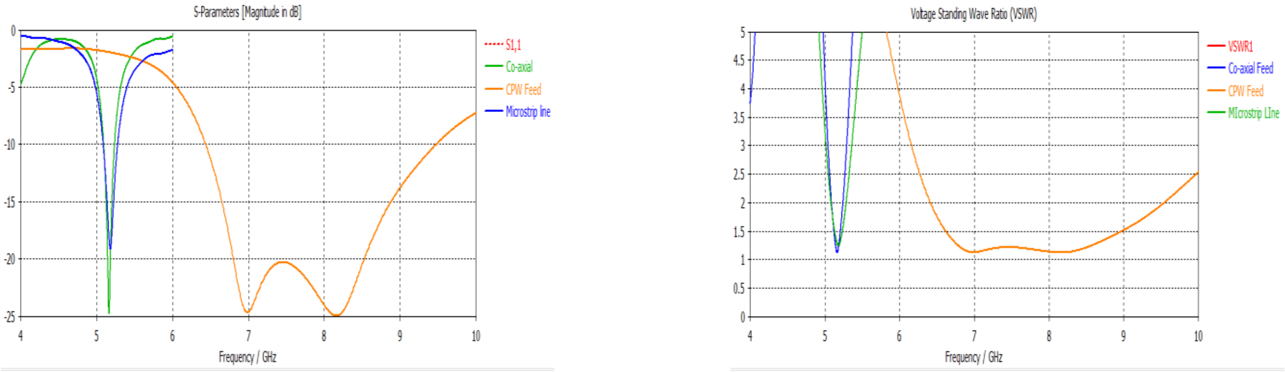
Table 1. List of selected parameter.

Parameter	Value	Description
Ls	58.94 mm	Substrate length
Ws	35.90 mm	Substrate width
Lp	12.56 mm	Patch length
Wp	17.56 mm	Patch width
h	1.6 mm	Substrate thickness
t	0.05 mm	Metal thickness
ε_r	4.4	Dielectric constant of the substrate
Lg	8.06 mm	Length of the ground plane in CPW feed
Wg	15.09 mm	Width of the ground plane in CPW feed
S	1.33 mm	Spacing in CPW feed
Lm1	14.896 mm	Length of microstrip line 1
Wm1	3.059 mm	Width of microstrip line 1
Lm2	8.294 mm	Length of microstrip line 2
Wm2	0.723 mm	Width of microstrip line 2

Fig. 3 (a) and Fig. 3(b) display the simulated data obtained using the three different feeding techniques. The behavior of return loss and VSWR is plotted with frequency for the three different feeding techniques. It is found that patch resonates at 5.16 GHz with a return loss of 24.75 dB at resonance with the bandwidth of 143.2 MHz (5.094 GHz -5.237 GHz) for VSWR $\leq$ 2 in co-axial feeding. The same patch gives a bandwidth of 184.7 MHz (5.092 GHz – 5.276 GHz) at the resonance frequency of 5.18 GHz with microstrip line feed. With CPW feed, a bandwidth of 3.03 GHz (from 6.437 GHz to 9.472 GHz) is obtained.

In Fig 4(a), Fig. 4(b) and Fig. 4(c), input impedance plot for three different feed techniques are presented. The value of impedance at a resonant frequency can be obtained from impedance plot. The variation of bandwidth can easily be seen in these plots.

The impedance at the resonant frequency is 47.48 Ω, if we use the co-axial line feed. The input impedance changes to 50.95 Ω, if we use the microstrip line. The change of input impedance from coaxial feed to microstrip line feed is not too significant. However, when we use CPW feed, the input impedance changes to 73 Ω, which is a significant change. Better impedance matching technique is needed to match this impedance to the system.

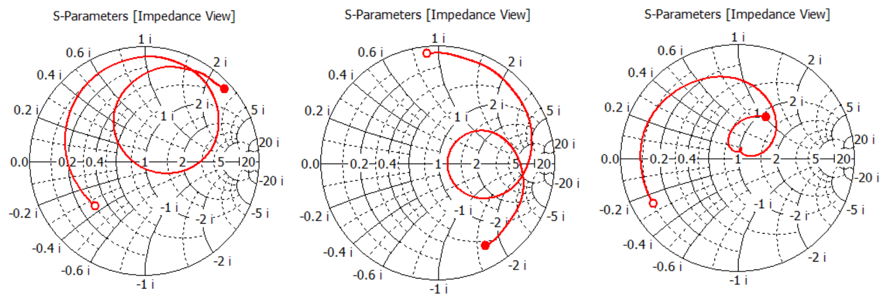


(a) (b)

Fig. 3 Co-axial line, microstrip line and CPW feed (a) Return loss vs frequency, (b) VSWR vs frequency.

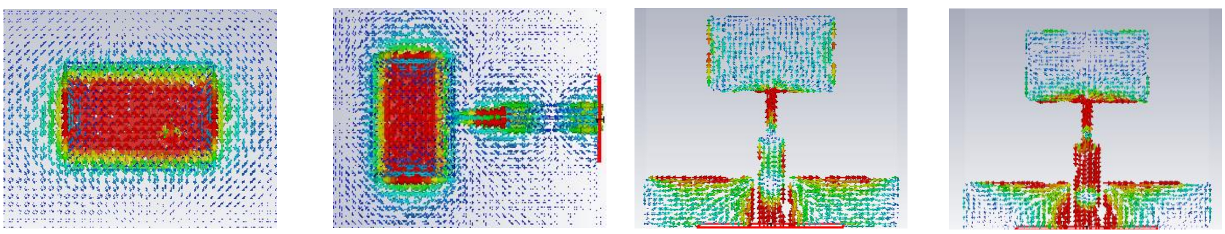
Fig. 5 shows the surface current variation for different feed techniques at the resonant frequency. The surface current is mainly concentrated over the patch, resulting in the radiation of the energy. In CPW feed, the surface current is shown for two different frequencies. Fig 5 (c) and Fig. 5(d) depict the wideband performance in CPW feed.

Fig. 6 shows the radiation pattern plot for the co-axial line feed, microstrip line feed and CPW feed. The maximum realized gain for co-axial line feed is 6.62 dB with 98.69 % radiation efficiency in boresight direction. The same patch gives directivity of 6.59 dB in microstrip line feed. Since CPW feed gives a wider bandwidth, the radiation pattern is calculated for 7 GHz and 8.15 GHz frequency. The radiation plot for CPW feed is presented in Fig. 6(c) and Fig. 6(d). The directivity obtained is 5.29 dB and 6.15 dB for 7 GHz and 8.15 GHz, respectively. A summary of the various results is presented in Table 2.



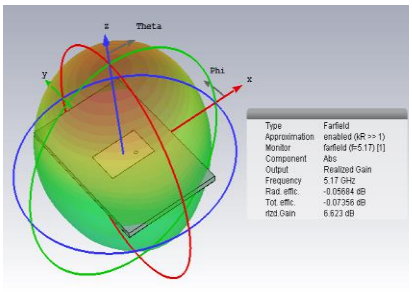
(a) (b) (c)

Fig. 4 Smith chart Plot for (a) Co-axial line feed, (b) Microstrip line feed and (c) CPW feed.

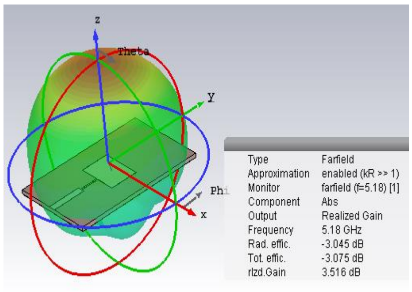


(a) (b) (c) (d)

Fig. 5 Surface currents (a) at 5.16 GHz in co-axial line, (b) at 5.18 GHz in Microstrip line, (c) at 7 GHz and (d) at 8.15 GHz in CPW feed.



(a)



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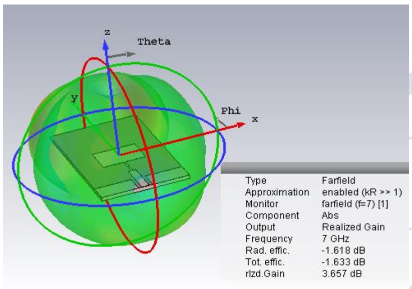
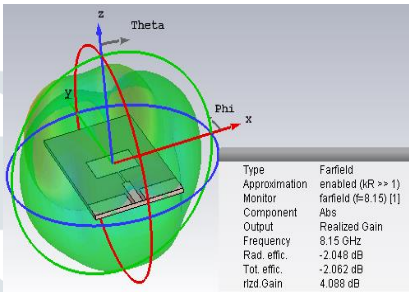


(c)



(d)

Fig. 6 (a) Far-field pattern of the patch at 5.16 GHz in co-axial feed, (b) at 5.18 GHz in the microstrip line feed, (c) at 7 GHz and (d) at 8.15 GHz in CPW feed.

Table 2. Summary of results obtained.

Feeding	Directivity	Gain	Efficiency	Bandwidth
Co-axial	6.69 dB	6.62 dB	98.69%	150 MHz
Microstrip line	6.59 dB	3.51 dB	50.11%	180 MHz
CPW (7GHz)	5.29 dB	3.65 dB	69.02%	3.04 GHz
CPW(8.15 GHz)	6.15 dB	4.08 dB	62.51%	

IV. Conclusion

A study of the effects of coaxial line feed, microstrip line feed, and coplanar wave guide feed on the performance of the rectangular patch antenna is reported. The results show that impedance matching is the most important part of the antenna performance. The results show that for a wider bandwidth operation, coplanar waveguide feeding is the best option, but at the cost of reduced gain and efficiency. The location of feed point in co-axial feed is also very important. In case of the microstrip line feed, a planer structure is obtained and effect of feed location is removed.

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