

CHAPTER 4

MICROSTRIP PATCH ANTENNA DESIGN AND RESULTS

In this chapter, the procedure for designing a rectangular microstrip patch antenna is explained. Next, a compact rectangular microstrip patch antenna is designed for use in cellular phones. Finally, the results obtained from the simulations are demonstrated.

4.1 Design Specifications

The three essential parameters for the design of a rectangular Microstrip Patch Antenna are:

- Frequency of operation (f_o): The resonant frequency of the antenna must be selected appropriately. The Personal Communication System (PCS) uses the frequency range from 1850-1990 MHz. Hence the antenna designed must be able to operate in this frequency range. The resonant frequency selected for my design is 1.9 GHz.
- Dielectric constant of the substrate (ϵ_r): The dielectric material selected for my design is Silicon which has a dielectric constant of 11.9. A substrate with a high dielectric constant has been selected since it reduces the dimensions of the antenna.
- Height of dielectric substrate (h): For the microstrip patch antenna to be used in cellular phones, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate is selected as 1.5 mm.

Hence, the essential parameters for the design are:

- $f_o = 1.9$ GHz
- $\epsilon_r = 11.9$
- $h = 1.5$ mm

4.2 Design Procedure

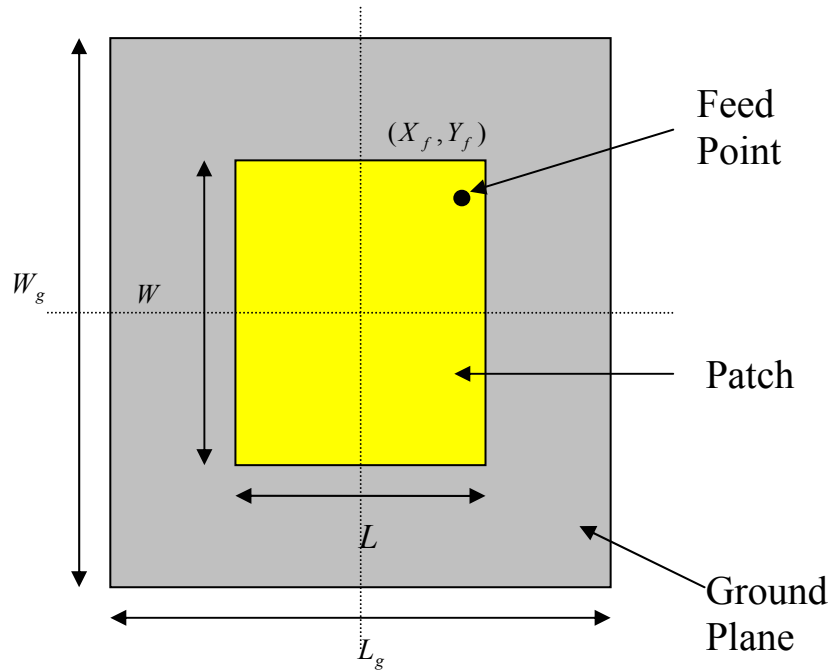


Figure 4.1 Top view of Microstrip Patch Antenna

The transmission line model described in chapter 3 will be used to design the antenna.

Step 1: Calculation of the Width (W): The width of the Microstrip patch antenna is given by equation (3.6) as:

$$W = \frac{c}{2f_o \sqrt{\frac{(\epsilon_r + 1)}{2}}} \quad (4.1)$$

Substituting $c = 3e8$ m/s, $\epsilon_r = 11.9$ and $f_o = 1.9$ GHz, we get:

$$W = 0.0311 \text{ m} = 31.1 \text{ mm}$$

Step 2: Calculation of Effective dielectric constant (ϵ_{reff}): Equation (3.1) gives the effective dielectric constant as:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}} \quad (4.2)$$

Substituting $\epsilon_r = 11.9$, $W = 31.1$ mm and $h = 1.5$ mm we get:

$$\epsilon_{reff} = 10.7871$$

Step 3: Calculation of the Effective length (L_{eff}): Equation (3.4) gives the effective length as:

$$L_{eff} = \frac{c}{2f_o \sqrt{\epsilon_{reff}}} \quad (4.3)$$

Substituting $\epsilon_{reff} = 10.7871$, $c = 3e8$ m/s and $f_o = 1.9$ GHz we get:

$$L_{eff} = 0.024 \text{ m} = 24 \text{ mm}$$

Step 4: Calculation of the length extension (ΔL): Equation (3.2) gives the length extension as:

$$\Delta L = 0.412h \frac{\left(\epsilon_{reff} + 0.3 \right) \left(\frac{W}{h} + 0.264 \right)}{\left(\epsilon_{reff} - 0.258 \right) \left(\frac{W}{h} + 0.8 \right)} \quad (4.4)$$

Substituting $\epsilon_{reff} = 10.7871$, $W = 31.1$ mm and $h = 1.5$ mm we get:

$$\Delta L = 6.3455 \text{ e-4 mm}$$

Step 5: Calculation of actual length of patch (L): The actual length is obtained by re-writing equation (3.3) as:

$$L = L_{eff} - 2\Delta L \quad (4.5)$$

Substituting $L_{eff} = 24 \text{ mm}$ and $\Delta L = 6.3455 \text{ e-4 mm}$ we get:

$$L = 0.0228 \text{ m} = 22.8 \text{ mm}$$

Step 6: Calculation of the ground plane dimensions (L_g and W_g):

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. It has been shown by [9] that similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence, for this design, the ground plane dimensions would be given as:

$$L_g = 6h + L = 6(1.5) + 22.8 = 31.8 \text{ mm}$$

$$W_g = 6h + W = 6(1.5) + 31.1 = 40.1 \text{ mm}$$

Step 7: Determination of feed point location (X_f, Y_f):

A coaxial probe type feed is to be used in this design. As shown in Figure 4.1, the center of the patch is taken as the origin and the feed point location is given by the co-ordinates (X_f, Y_f) from the origin. The feed point must be located at that point on the patch, where the input impedance is 50 ohms for the resonant frequency. Hence, a trial and error method is used to locate the feed point. For different locations of the feed point, the return loss (R.L) is compared and that feed point is selected where the R.L is most negative. According to [5] there exists a point along the length of the patch where the R.L is minimum. Hence in this design, Y_f will be zero and only X_f will be varied to locate the optimum feed point.

4.3 Simulation Setup and Results

The software used to model and simulate the microstrip patch antenna is Zeland Inc's IE3D software. IE3D is a full-wave electromagnetic simulator based on the method of moments. It analyzes 3D and multilayer structures of general shapes. It has been widely used in the design of MICs, RFICs, patch antennas, wire antennas, and other RF/wireless antennas. It can be used to calculate and plot the S_{11} parameters, VSWR, current distributions as well as the radiation patterns. An evaluation version of the software was used to obtain the results for this thesis.

For simplicity, the length and the width of the patch and the ground plane have been rounded off to the following values: $L = 22$ mm, $W = 31$ mm, $L_g = 31$ mm, $W_g = 40$ mm.

4.3.1 Return Loss and Antenna bandwidth calculation

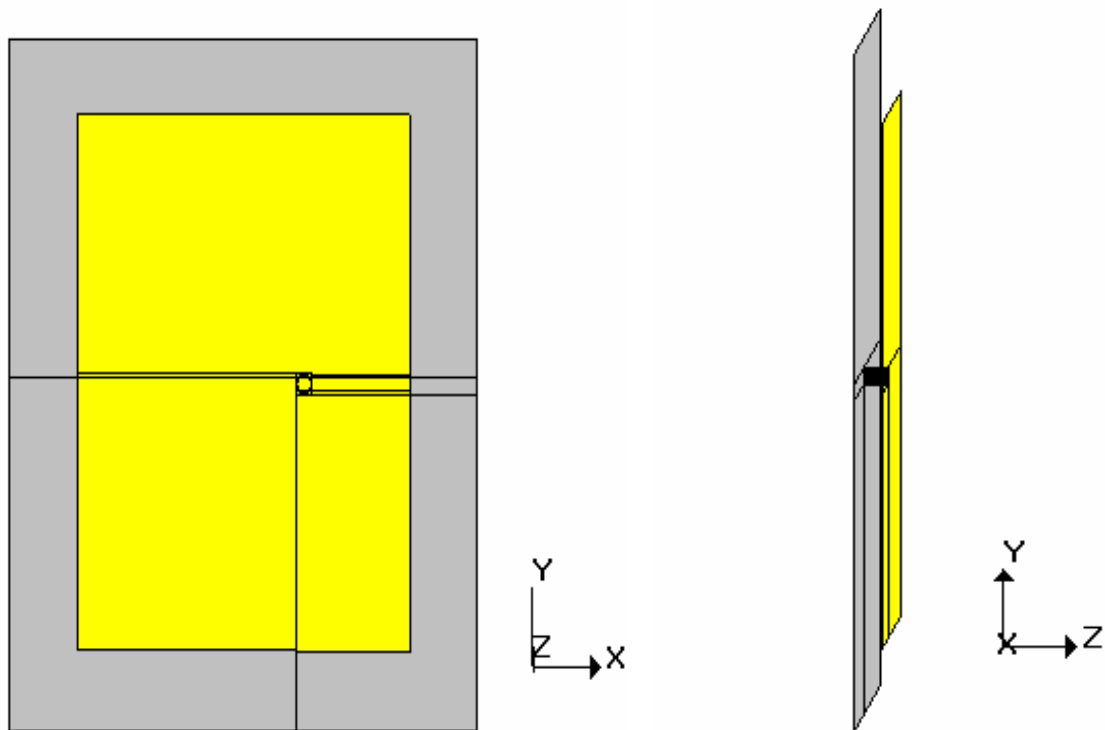


Figure 4.2 Microstrip patch antenna designed using IE3D

The results tabulated below are obtained after varying the feed location along the length of the patch from the origin (center of patch) to its right most edge. The coaxial probe feed used

is designed to have a radius of 0.5mm. A frequency range of 1.7-2.1 GHz is selected and 401 frequency points are selected over this range to obtain accurate results. Table 4.1 shows the calculated results for different feed locations.

Table 4.1 Effect of feed location on center frequency, return loss and bandwidth

No.	Feed Location (X_f, Y_f) (mm)	Center Frequency (GHz)	Return Loss (RL) (dB)	Bandwidth (RL > -9.5dB) (MHz)
1	(1,0)	1.9153	-1.1384	-
2	(2,0)	1.9147	-4.5967	-
3	(3,0)	1.9127	-10.9602	9.97
4	(3.25,0)	1.9133	-13.3696	15.32
5	(3.5,0)	1.9127	-16.6242	18.84
6	(3.75,0)	1.9127	-21.2769	21.43
7	(4,0)	1.9120	-31.3585	23.28
8	(4.25,0)	1.9127	-28.5068	24.40
9	(4.5,0)	1.9127	-21.2952	25.16
10	(4.75,0)	1.9120	-17.6845	25.23
11	(5,0)	1.9120	-15.0623	24.30
12	(6,0)	1.9087	-10.2221	13.57
13	(7,0)	1.9087	-7.7754	-
14	(8,0)	1.9087	-6.3367	-
15	(9,0)	1.9073	-5.5806	-
16	(10,0)	1.9073	-5.0228	-

Figure 4.3 below shows the return loss plots for some of the feed point locations.

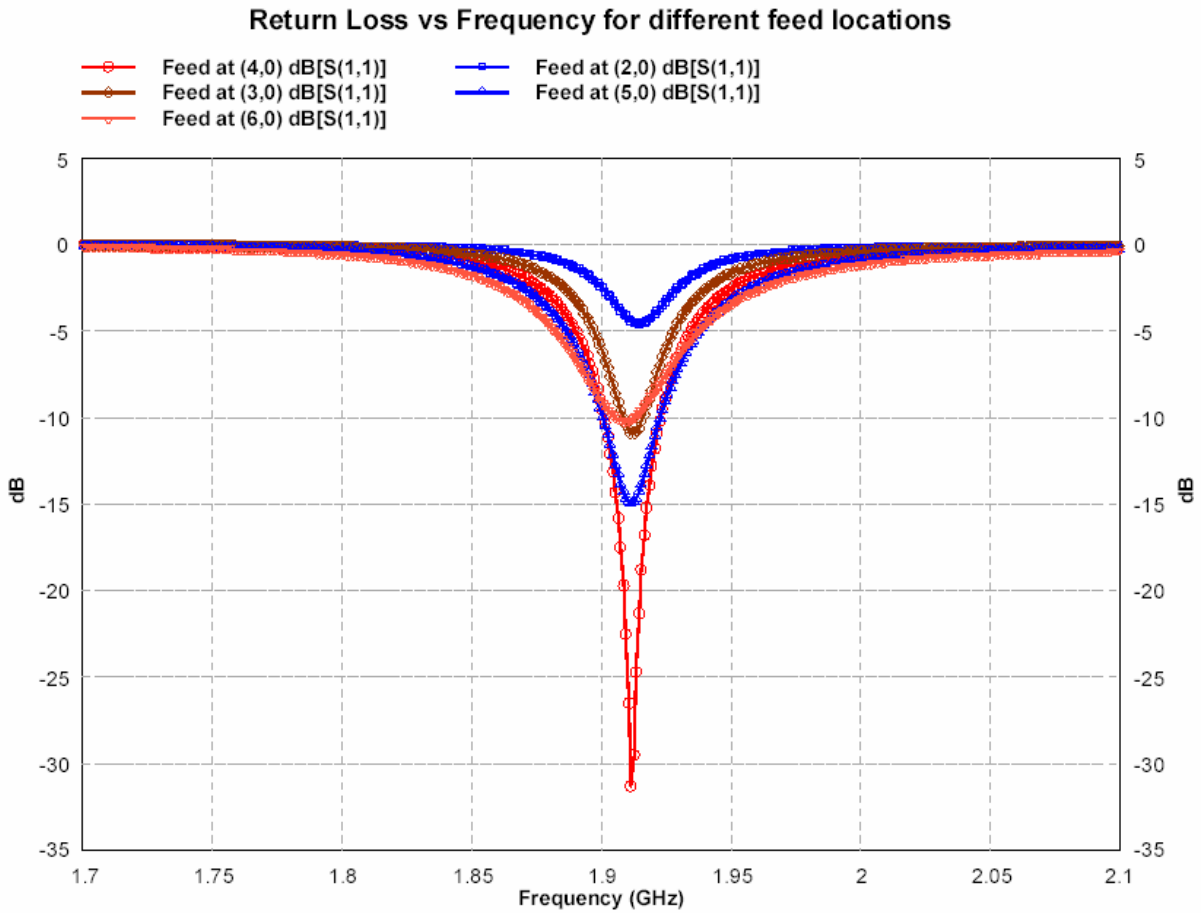


Figure 4.3 Return loss for feed located at different locations

The center frequency is selected as the one at which the return loss is minimum. As described in chapter 2, the bandwidth can be calculated from the return loss (RL) plot. The bandwidth of the antenna can be said to be those range of frequencies over which the RL is greater than -9.5 dB (-9.5 dB corresponds to a VSWR of 2 which is an acceptable figure). From table 4.1, the optimum feed point is found to be at $(X_f, Y_f) = (4, 0)$ where a RL of -31.3585 dB is obtained. The bandwidth of the antenna for this feed point location is calculated (as shown below in Figure 4.4) to be 23.28 MHz and a center frequency of 1.9120 GHz is obtained which is very close to the desired design frequency of 1.9 GHz. It is observed from the table that, as the feed point location is moved away from the center of the patch, the center frequency starts to

decrease slightly. It is also seen that though the maximum return loss is obtained at $(X_f, Y_f) = (4, 0)$, the maximum bandwidth is obtained at $(X_f, Y_f) = (4.75, 0)$.

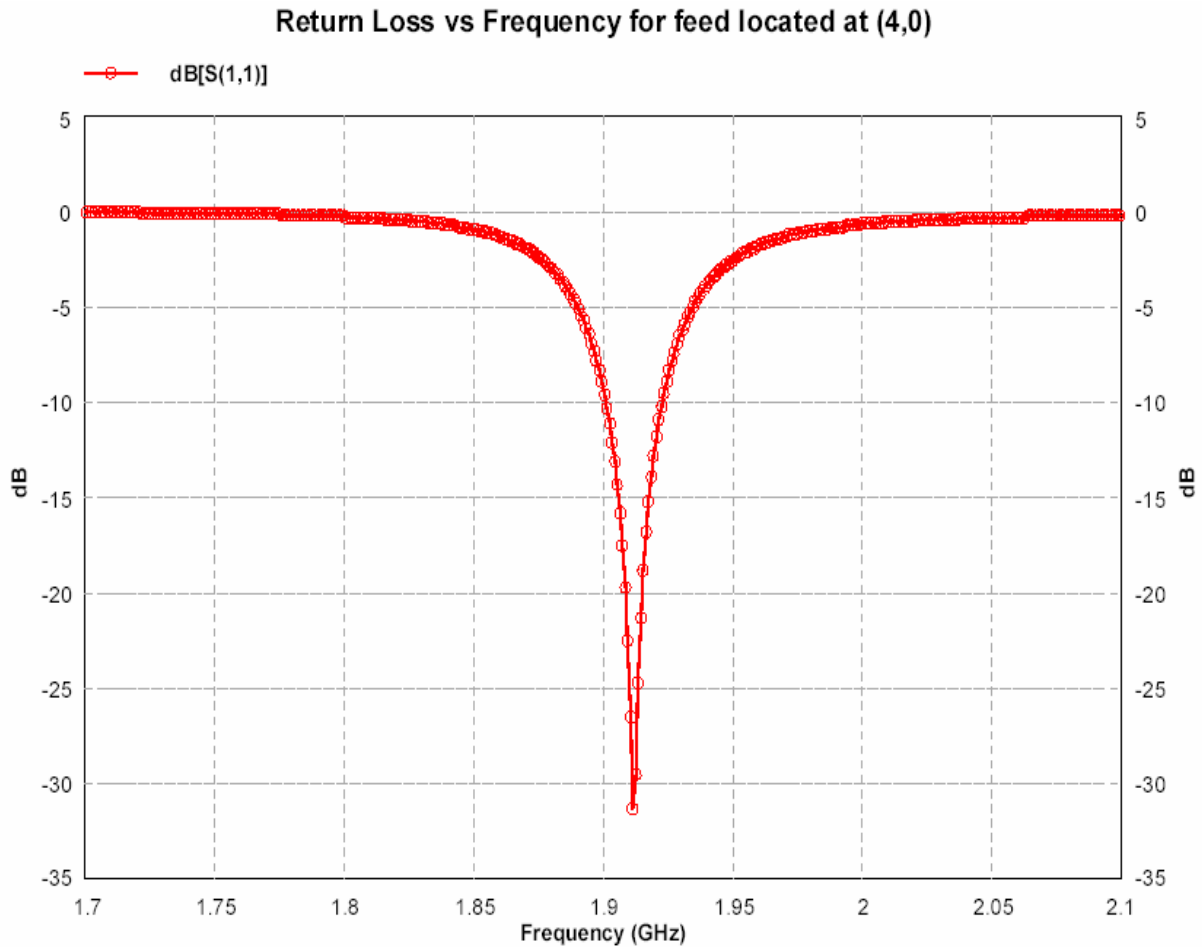


Figure 4.4 Return loss for feed located at (4, 0)

4.3.2 Radiation Pattern plots

Since a microstrip patch antenna radiates normal to its patch surface, the elevation pattern for $\phi = 0$ and $\phi = 90$ degrees would be important. Figure 4.5 below shows the gain of the antenna at 1.9120 GHz for $\phi = 0$ and $\phi = 90$ degrees.

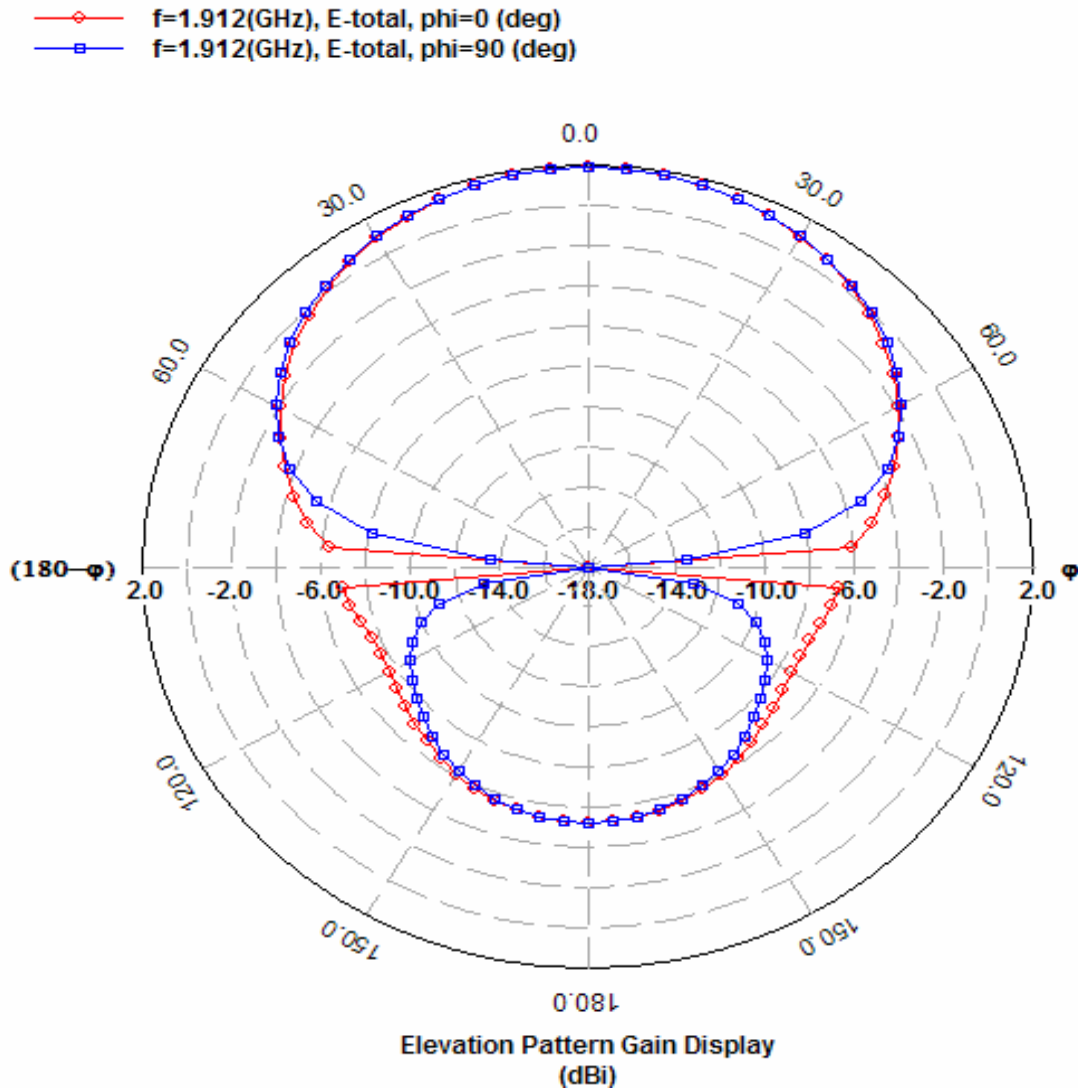


Figure 4.5 Elevation Pattern for $\phi = 0$ and $\phi = 90$ degrees

The maximum gain is obtained in the broadside direction and this is measured to be 1.87 dBi for both, $\phi = 0$ and $\phi = 90$ degrees. The backlobe radiation is sufficiently small and is measured to be -5.3 dBi for the above plot. This low backlobe radiation is an added advantage for using this antenna in a cellular phone, since it reduces the amount of electromagnetic radiation which travels towards the users head. The 3D plots for the antenna are shown in Figure 4.6 at different angles, so that it is easier to understand the radiation from the antenna.

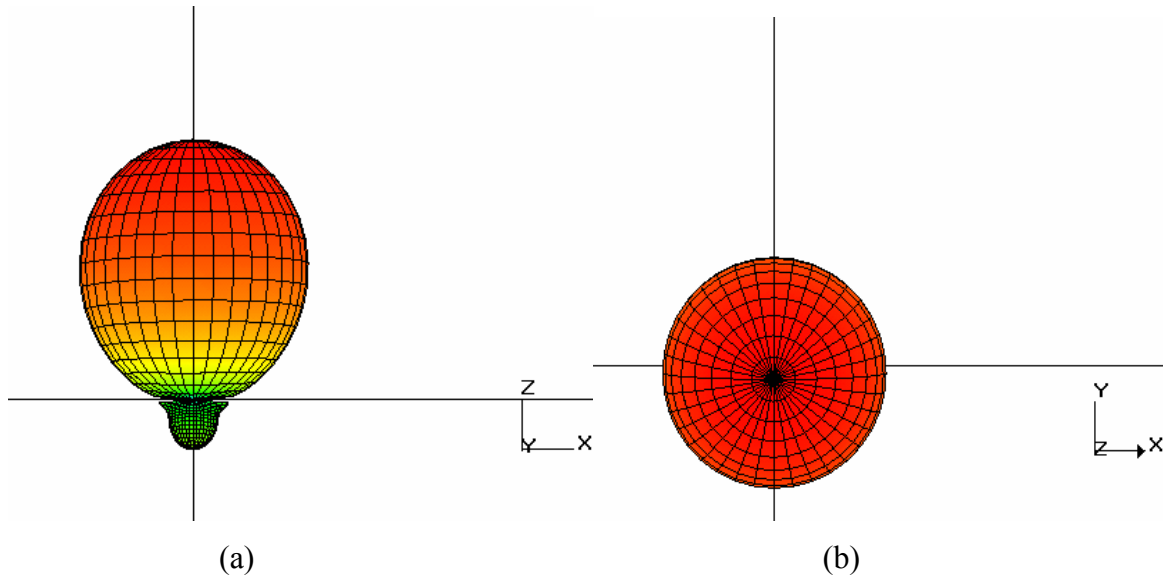


Figure 4.6 (a) 3D view of radiation pattern looking along the Y axis in the XZ plane
 (b) 3D view of radiation pattern looking along the Z axis in the XY plane

When the microstrip patch antenna designed would be placed into a cellular phone, its orientation would be such that the z axis would be parallel to the surface of the earth. Figure 4.7 shows the 3D radiation pattern plots for this scenario.

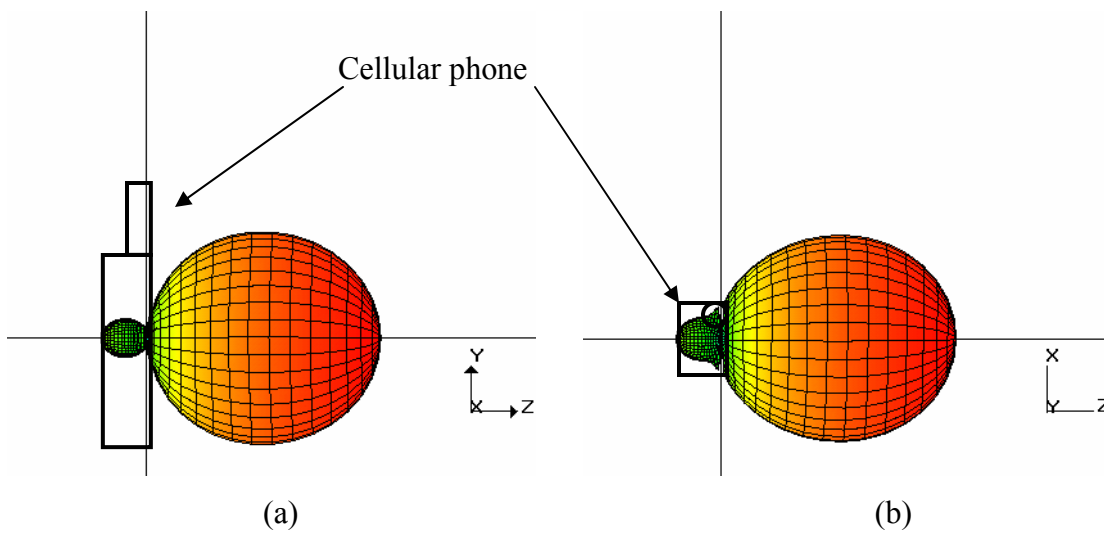


Figure 4.7 (a) 3D view of radiation pattern for cellular phone orientation in the YZ plane
 (b) 3D view of radiation pattern for cellular phone orientation in the XZ plane

4.3.3 Other calculated parameters

Some of the other calculated parameters, such as the gain, directivity, antenna efficiency and 3 dB beamwidth for the antenna at 1.912 GHz are given below.

- Gain = 1.8717 dBi
- Directivity = 5.56 dBi
- Antenna Efficiency = 42.77%
- 3 dB Beamwidth = (106.85, 110.24) degrees