Personal Project

“Computer Aided Design (CAD) of Microstrip Patch Antenna”

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Project description:

In this project, a microstrip-fed patch antenna on a grounded substrate is designed. A sequence of steps is followed in the design process. The steps are listed as follows:

Step 1: The resonant frequency of the antenna and the characteristic impedance of the microstrip transmission line are obtained based on my student ID.

Step 2: The microstrip line is designed

Step 3: The unmatched patch antenna is designed

Step 4: The antenna is matched with the transmission line

Project Steps:

Step 1: Calculating the resonance frequency (f_0) and characteristic impedance (Z_0)

My student ID is 38807776. So, my assigned resonant frequency (f_0) and the characteristic impedance (Z_0) of the microstrip transmission line are as follows:

$f_0 = 2 + 0.1 * 6 = 2.6\ (GHz)$

$Z_0 = 70 - 0.25 * 38 = 60.5\ (\Omega)$

Step 2: Microstrip transmission line design

The substrate properties are $\varepsilon_r = 2.33$ and thickness $h = 0.787\ (mm)$. The resonant frequency (f_0) and the characteristic impedance (Z_0) are obtained in the previous step.

The online microstrip line calculator (https://www.emtalk.com/mscalc.php.) is used to calculate the width of the microstrip line. The online calculator gives us the initial value for the microstrip width as $W_m = 1.7339544889796\ (mm)$ as shown below.

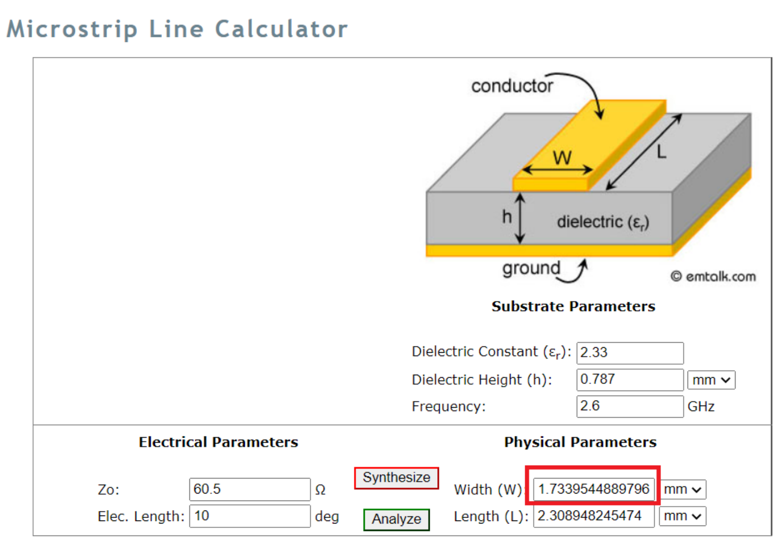


Fig.1: Online microstrip line calculator

But, during simulation, it was noticed that this value does not give us the Z_0 of 60.5 (ohms). After tuning the width of the microstrip line, I was able to get the required characteristic impedance at a width of W_m = 1.656 (mm).

- Width of the microstrip line (W_m) = 1.656 (mm)

The characteristic impedance of the transmission line versus frequency is plotted in Fig.2.

As we can see in Fig.2, at the center frequency f_0 = 2.6 (GHz) the transmission line has a characteristic impedance of Z_0 = 60.51 (Ω), which has an error of about 0.01 (Ω) from the required characteristic impedance of 60.5 (Ω).

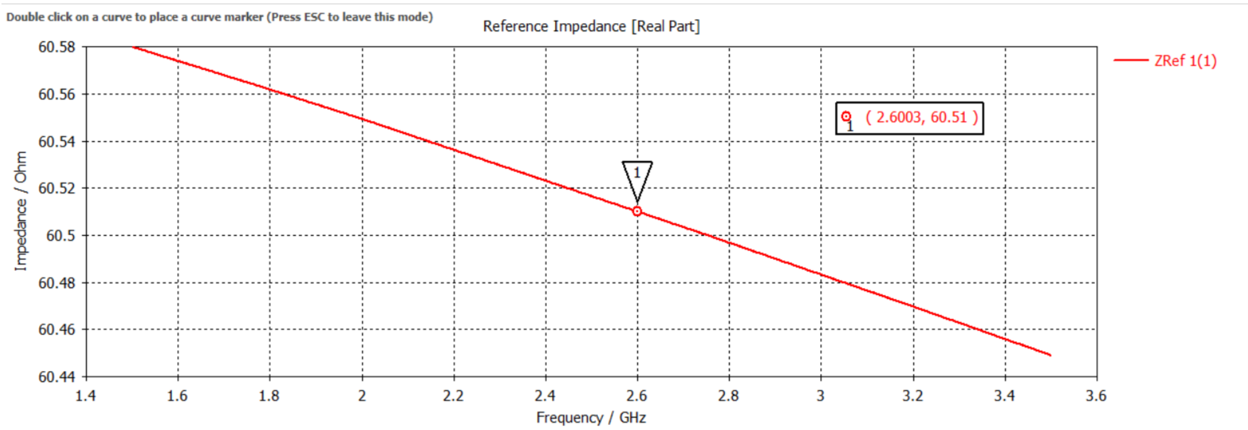


Fig 2: Characteristic impedance of the transmission line versus frequency

The designed microstrip line is shown in Fig. 3.

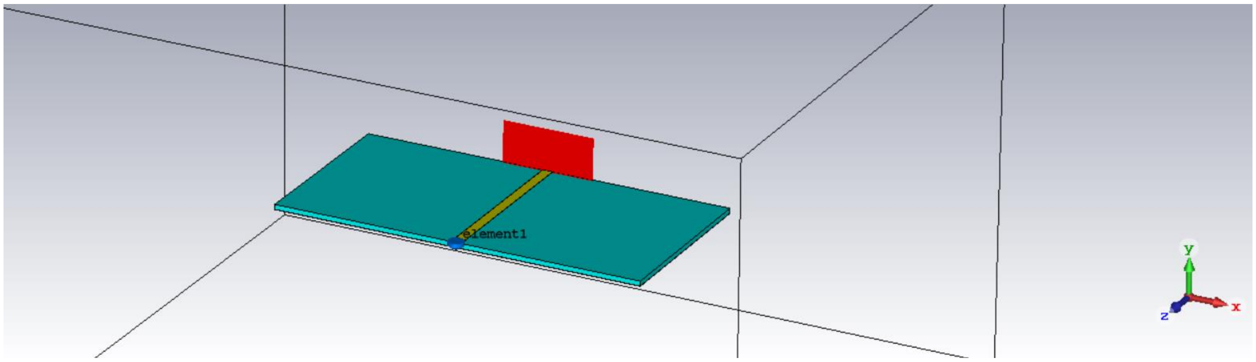


Fig. 3: The designed microstrip line

The electric field profile at $f_0 = 2.6$ (GHz) is shown in Fig. 4.

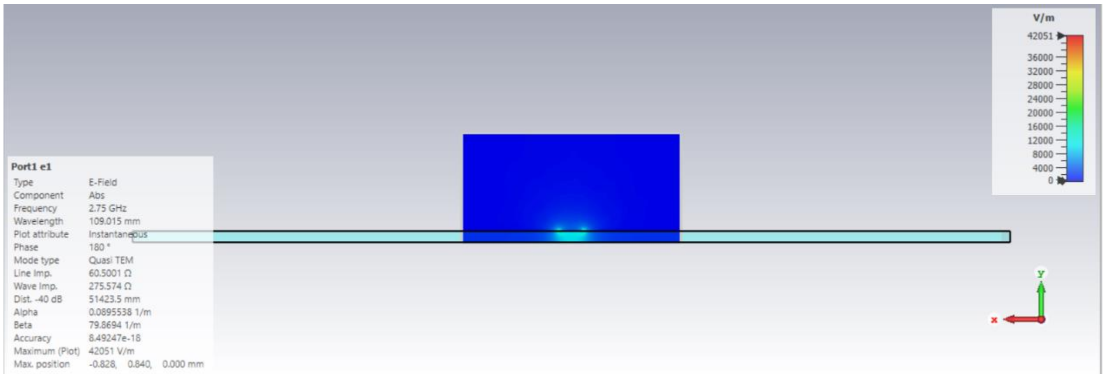


Fig. 4: The electric field profile at $f_0 = 2.6$ (GHz)

Step 3: Patch Antenna design

Now, I must design the patch antenna. First, the width of the patch is designed. Next, the length of the patch is designed. The steps followed are described below.

a) The initial width of the patch:

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{1+\varepsilon_r}}$$

Using the above formula, W = 44.6801 (mm)

b) The initial length of the patch is calculated as follows:

i) First, I calculated the effective permittivity

$$\varepsilon_r^{eff} = \frac{\varepsilon_r + 1}{2} + \left(\frac{\varepsilon_r - 1}{2}\right)\left[1 + 12\left(\frac{h}{W}\right)\right]^{-1/2}$$

The value of ε_r^{eff} = 2.3299

ii) Next, I calculated the normalized extension of length

$$\Delta L / h = 0.412 \left[\frac{\left(\varepsilon_r^{eff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_r^{eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \right]$$

The value of $\Delta L = 4.1156 * 10^{-4}$ (mm)

iii) Now, I calculate the physical length of the patch

$$L = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0 \varepsilon_r}} - 2\Delta L$$

The value of L = 36.9466 (mm)

Thus, the dimensions of the patch are as follows:

- Width of the patch (W): 44.6801 (mm)
- Length of the patch (L): 36.9466 (mm)

After simulation, I tried to optimize the input impedance around the center frequency by altering the width of the patch over multiple iterations. The tuned width and length are:

- Width of the patch (W): 47 (mm)
- Length of the patch (L): 36.9466 (mm)

The input impedance of the patch by setting the appropriate de-embedding distance of the waveguide port is shown in Fig. 5.

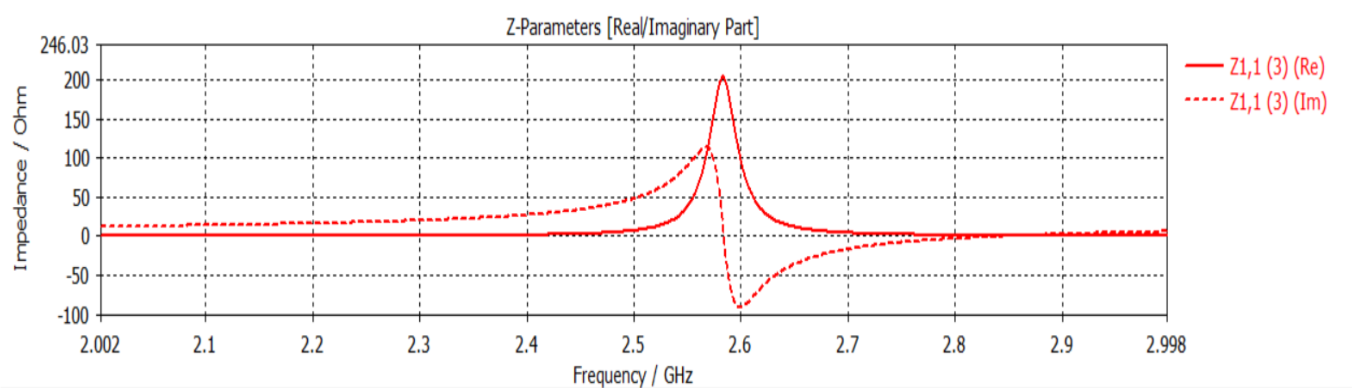


Fig. 5: Input Impedance of the patch vs Frequency (unmatched case)

Here, the real part of the input impedance is much larger than the characteristic impedance of the microstrip line. So, we can expect a high reflection coefficient around the resonance frequency.

The magnitude of S_{11} versus frequency is plotted in Fig.6.

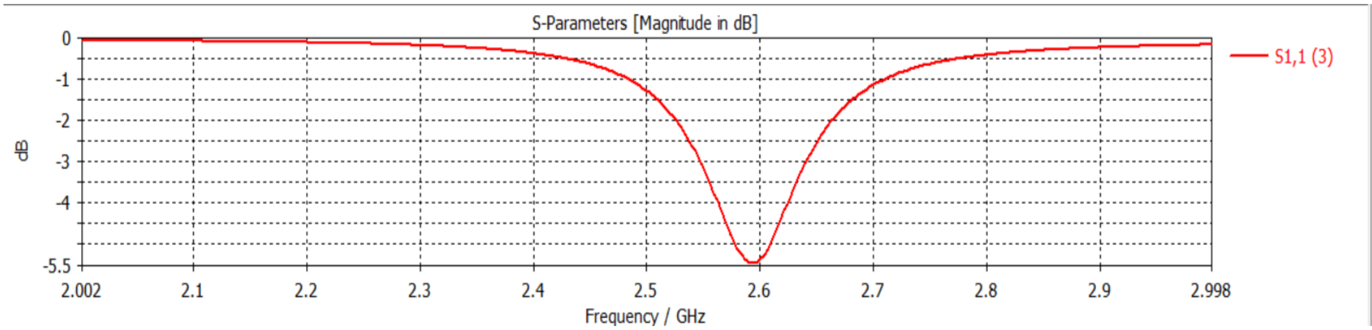
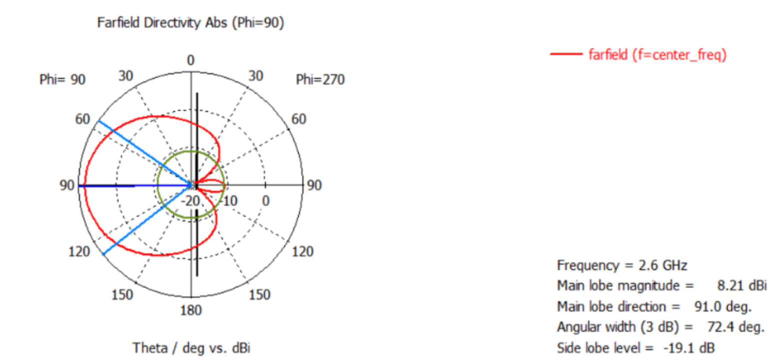


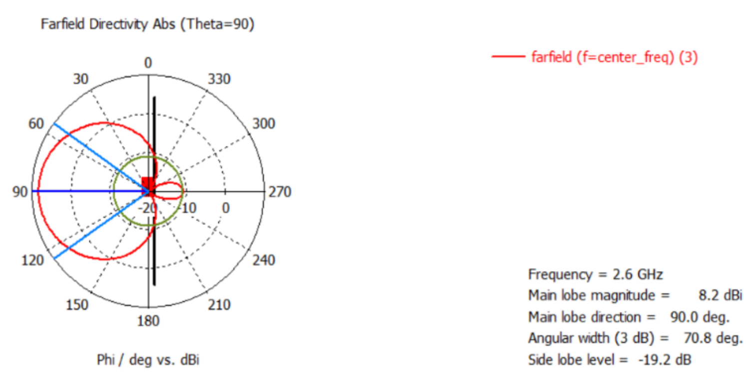
Fig. 6: The magnitude of S_{11} versus frequency (unmatched case)

Just as expected, we do not see a zero ($|S_{11}| < -10$ dB) reflection coefficient at the operating frequency. So, we must match our patch antenna with the transmission line.

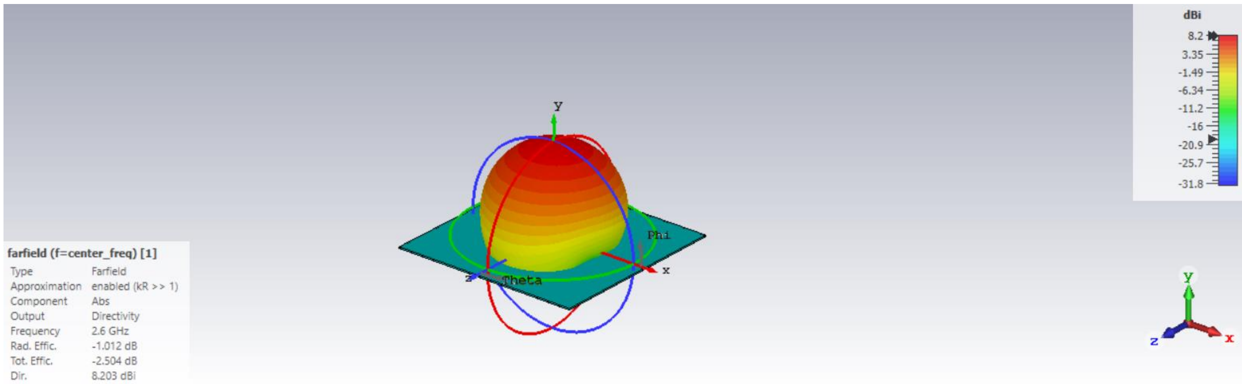
The 3D directivity pattern along with the directivity pattern on both E and H planes at the operating frequency $f_0 = 2.6\ (GHz)$ is shown in Fig. 7.



(a)



(b)



(c)

Fig. 7: Directivity pattern on (a) E plane (b) H plane (c) 3D directivity pattern

Step 4: Impedance Matching

Here, I have designed the insets which are used to match the input impedance of the patch with the characteristic impedance of the microstrip line. The input impedance of the patch without matching is given by:

$$Z_{in} = 45 * \left(\frac{\lambda}{W}\right)^2$$

By using the above equation, $Z_{in} = 300.1087\ (ohms)$

The approximate length of the inset feed is given by:

$$L_i = \frac{L}{\pi}\ cos^{-1}\sqrt{\frac{Z_o}{Z_{in}}}$$

From the above formula, $L_i = 12.9972$ (mm)

The approximate width of the inset feed is given by:

$$W_i = \frac{W_m}{20}$$

Using the above equation, $W_i = 0.0828$ (mm)

From the above calculations,

- Width of the inset feed (W): 0.0828 (mm)
- Length of the inset feed (L): 12.9972 (mm)

After running the simulation, I tuned the length and width of the insets for better matching. The final values of the dimensions of the inset feed are:

- Width of the inset feed (W): 1.7 (mm)
- Length of the inset feed (L): 11.2 (mm)

The input impedance of the patch after setting the appropriate values for the inset feed is shown in Fig. 8.

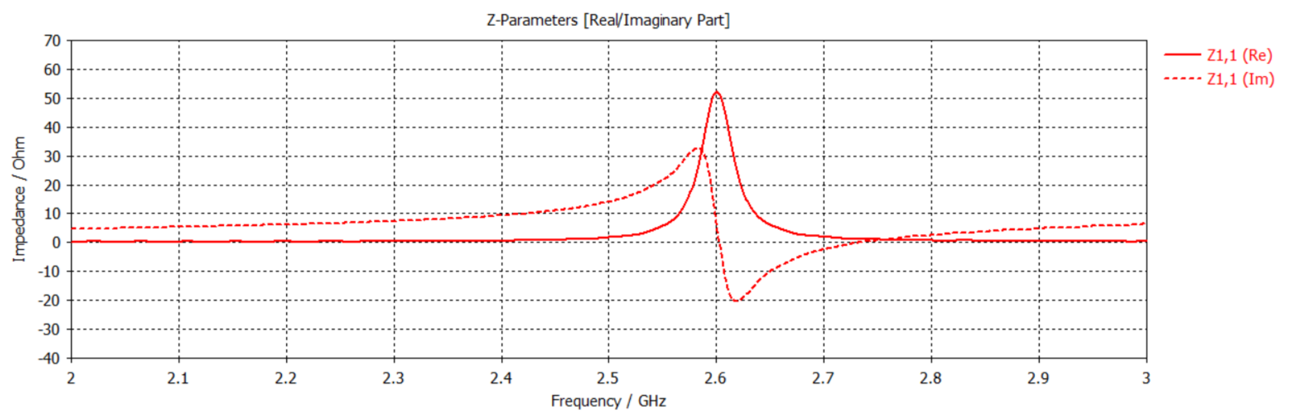


Fig. 8: Input Impedance of the patch vs Frequency (matched case)

We can see that the real part of the input impedance of the patch is equal to 50 (ohms) which is the same as the characteristic impedance of the microstrip line. Thus, the matching has been achieved. Also, we can notice that the imaginary part of the input impedance is very close to zero at the operating frequency.

The magnitude of S_{11} versus frequency is plotted in Fig. 9.

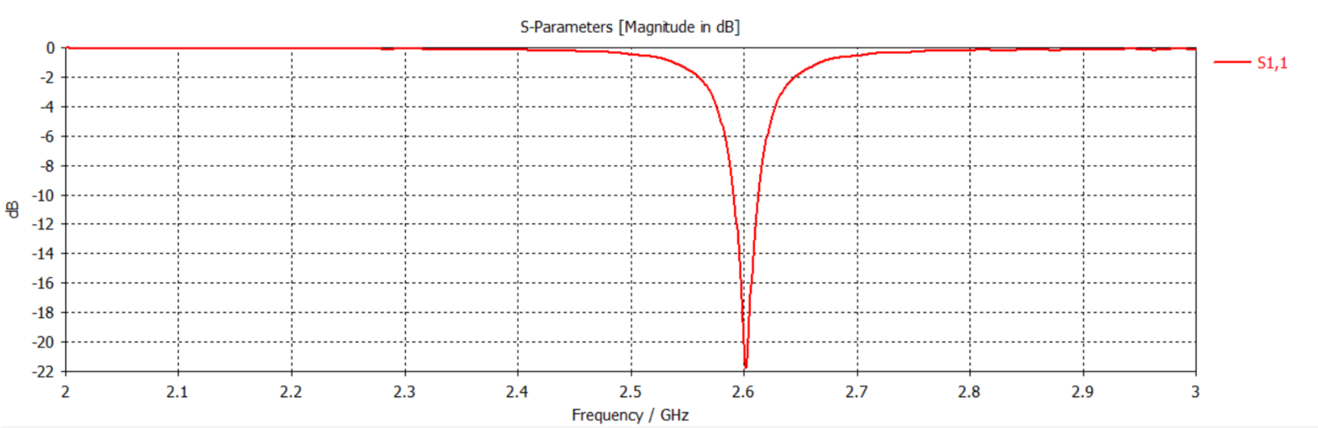


Fig. 9: The magnitude of S_{11} versus frequency (matched case)

At the resonance frequency $f_0 = 2.6$ (GHz) we have $|S_{11}| < -20$ (dB).

The screenshot of the patch antenna after matching is shown in Fig. 10

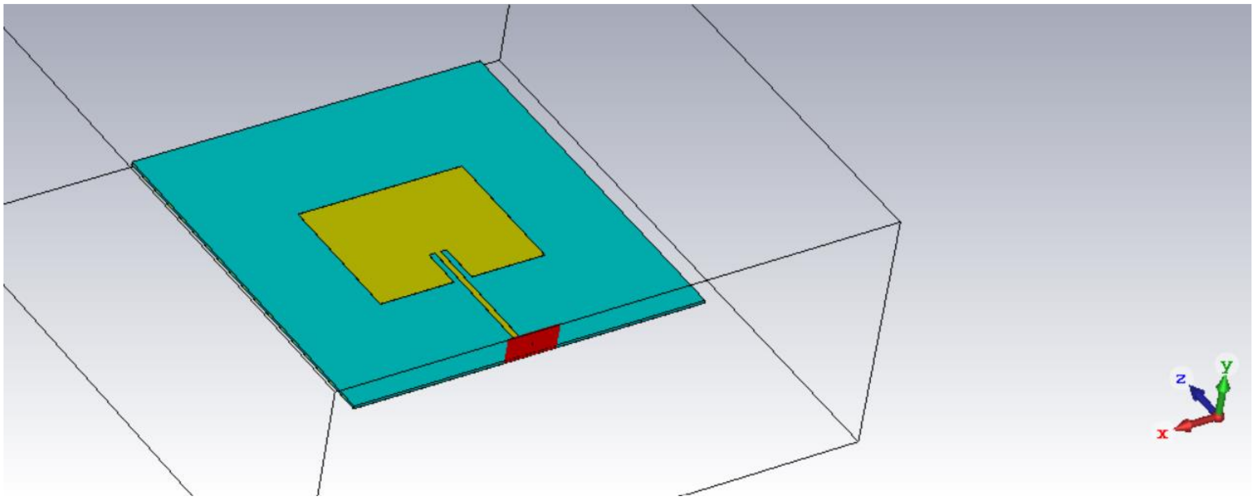
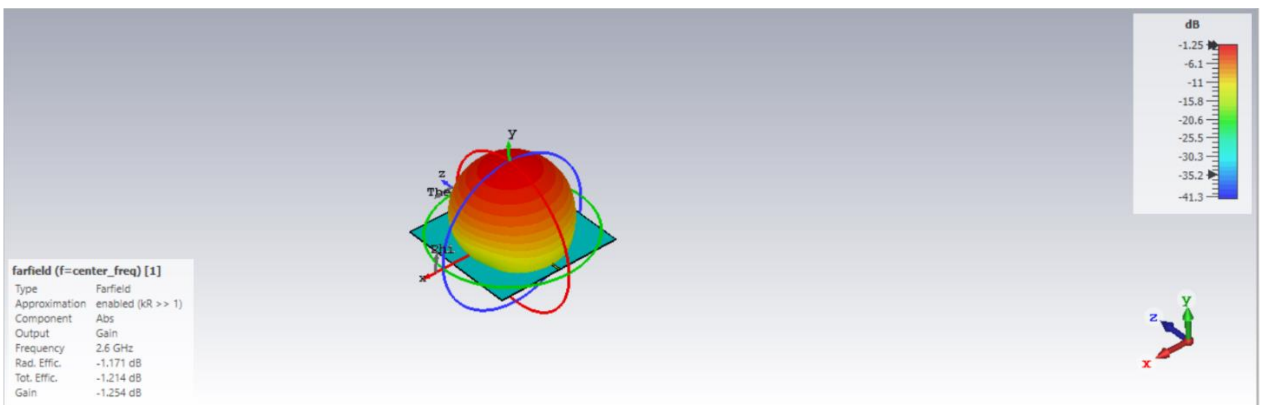
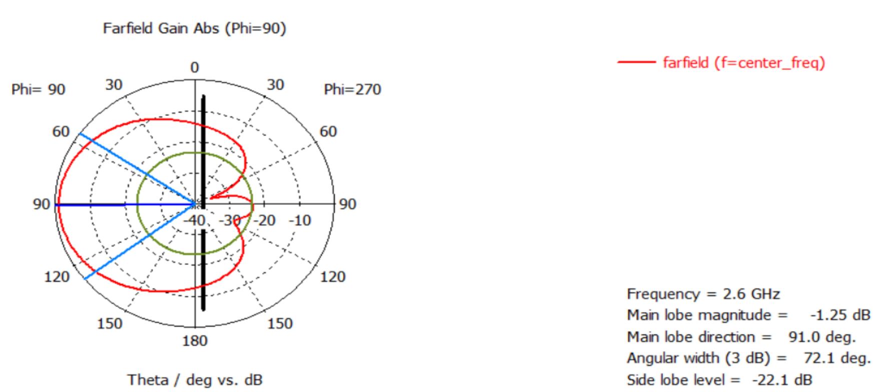


Fig. 10: Patch antenna after matching

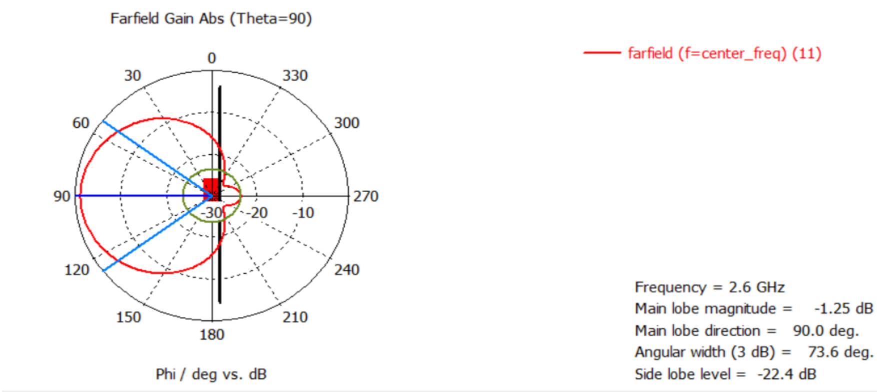
The normalized 3D gain pattern along with the gain pattern on both E and H planes at the operating frequency $f_0 = 2.6\ (GHz)$ is shown in Fig. 11.



(a)



(b)



(c)

Fig. 11: Normalized gain pattern (a) 3D gain pattern (b) E plane (c) H plane

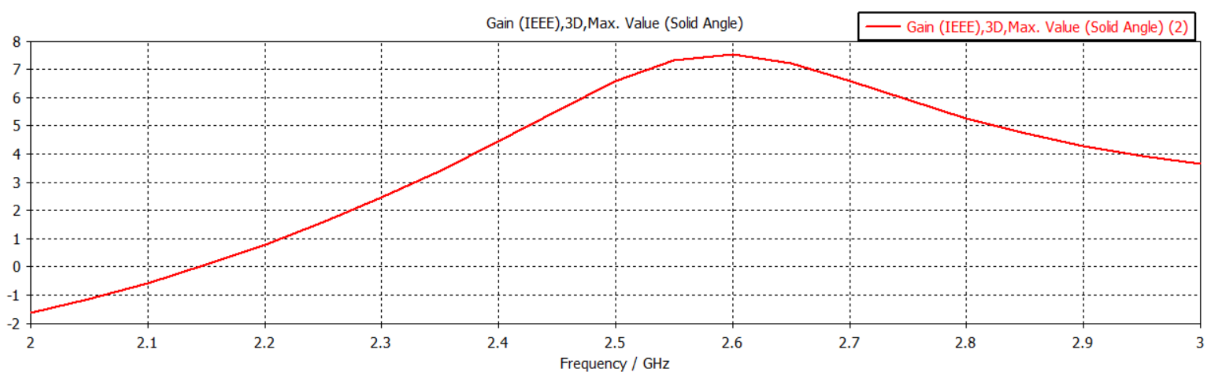


Fig. 12: Gain vs Frequency for the matched antenna