EE308L : Engineering Electromagnetics
Course Project Report

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Design and Comparison of a 2.5 GHz Inset-Fed Patch Antenna Using Rogers RT5880 and FR-4 in Ansys HFSS

1. Objective

The objective of this project is to design an inset fed patch antenna operating at 2.5 GHz and to examine how different substrate materials influence its electromagnetic performance. The antenna is implemented on two substrates, Rogers RT5880 and FR-4, and their behaviour is compared through simulated return-loss curves and resonant frequencies. The goal is to identify how variations in dielectric properties affect antenna matching, efficiency, and overall performance.

2. Design Specifications

- Operating frequency: 2.5 GHz
- Feeding method: Inset-fed
- Input impedance: 50 ohms
- Substrate materials used: Rogers RT5880 and FR-4
- Substrate thickness: 1.575 mm for RT5880 and 1.6 mm for FR-4

These specifications form the basis for calculating the patch dimensions and determining the position of the inset feed for proper impedance matching.

3. Formulas Used

The Formulas used to calculate the dimensions are :

- Patch width:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}}$$

- Effective dielectric constant:

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

- Fringing length extension:

$$\Delta L = 0.412h\frac{(\epsilon_{\text{eff}} + 0.3)(W/h + 0.264)}{(\epsilon_{\text{eff}} - 0.258)(W/h + 0.8)}$$

- Actual patch length:

$$L = \frac{c}{2f_r\sqrt{\epsilon_{\text{eff}}}} - 2\Delta L$$

- Inset feed position (impedance variation):

$$y_0 = \frac{L}{\pi}\arccos\left(\sqrt{\frac{Z_0}{R_{in}(edge)}}\right)$$

- The Approximate Ratio Formula: For a 50Ω line, the ratio of Width to Height (W/h) is primarily determined by ϵ_r :

$$\frac{W}{h} \approx \frac{7.48 \times e^{-Z_0\frac{\sqrt{\epsilon+1.41}}{87}} - 1.25}{1}$$

- Alternatively, a simplified multiplier is used:
  - For $\epsilon_r \approx 2.2 \rightarrow \ W/h \approx 3.08$
  - For $\epsilon_r \approx 4.4 \rightarrow \ W/h \approx 1.95$

4. Calculated Dimensions

Parameter	Rogers RT5880	FR-4 Epoxy
Dielectric Constant (ϵ_r)	2.2	4.4
Substrate Height (h)	1.575 mm	1.6 mm
Patch Width (W)	47.4 mm	36.5 mm
Patch Length (L)	39.6 mm	28.2 mm
Feed Line Width (W_f)	4.85 mm	3.12 mm
Inset Depth (y_0)	13.9 mm	9.9 mm
Inset Gap (g)	1.0 mm	1.0 mm

Table 1: Comparison of calculated antenna dimensions for Rogers and FR-4 substrates.

5. Simulation Results

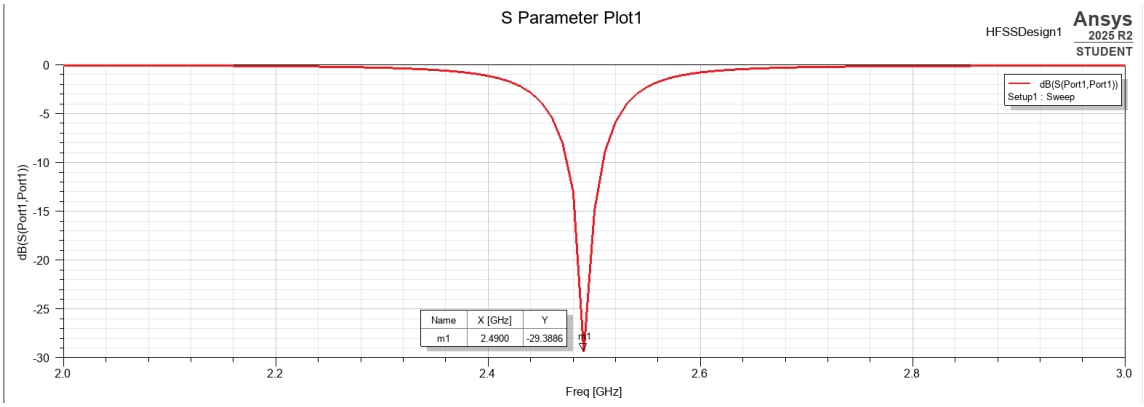

Figure 1: Simulated S_{11} for Rogers RT5880

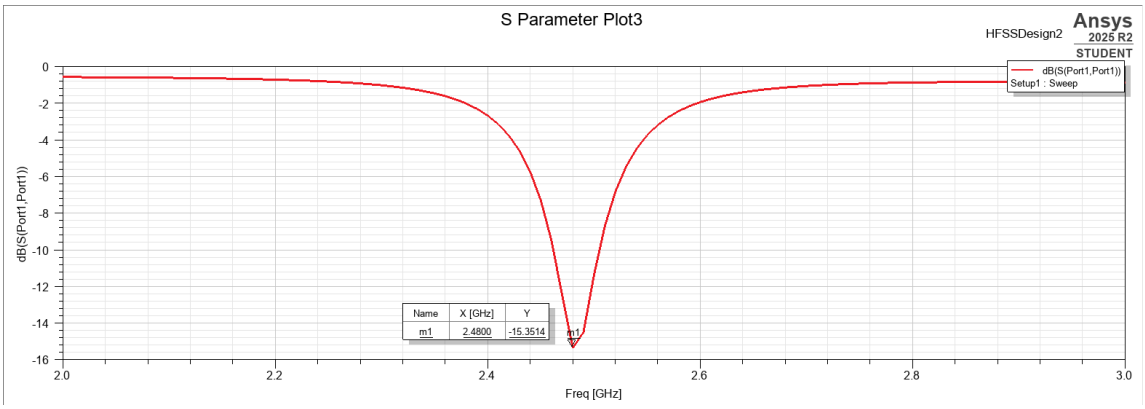

Figure 2: Simulated S_{11} for FR-4 substrate

Rogers RT5880

- The main resonance occurs around 2.49 to 2.50 GHz.
- The S_{11} curve shows a deep dip of approximately -29 dB.
- This indicates a very small amount of reflection at the feed point.
- The low dielectric loss of RT5880 contributes to a stronger impedance match.

FR-4

- The resonance appears slightly lower, around 2.48 to 2.49 GHz.
- The dip in the S_{11} curve is around -15 dB.
- This indicates a higher level of feed line reflection compared to the RT5880 case.
- The higher dielectric losses in FR-4 weakens the impedance matching.

Parameter	FR-4	RT5880
Resonant Frequency	2.48 to 2.49 GHz	2.49 to 2.50 GHz
Min S_{11}	-15 dB	-29 dB
Dielectric Constant	4.4	2.2
Loss Tangent	0.02	0.0009
Impedance Matching	Moderate	Perfect

Table 2: Comparison of substrates based on HFSS results

6. Observations

- The simulated results show clear differences in the behaviour of the inset-fed patch antenna for the two substrates. The antenna on Rogers RT5880 resonates close to the intended 2.5 GHz frequency, while the antenna on FR-4 shifts slightly downward to around 2.48 GHz due to its higher dielectric constant.
- The return loss plays a major role in comparing the performance of the two antennas. The RT5880 antenna achieves a return loss of approximately –29 dB, indicating very low reflected power and a strong impedance match at the feed point.
- In contrast, the FR-4 antenna shows a return loss of about –15 dB.It represents a noticeably higher reflection level compared to the return loss obtained with RT5880.
- The sharper S_{11} curve of the RT5880 model indicates a cleaner resonance, whereas the FR-4 return loss curve is broader and less pronounced, which is consistent with the higher loss tangent of FR-4 and the additional signal absorption occurring in the substrate.
- Overall, the RT5880 substrate provides better performance, stronger matching, and the resonance closer to the design frequency, whereas the FR-4 substrate shows reduced performance due to its dielectric properties.

7. Conclusion

The design and simulation of the inset-fed patch antenna demonstrate that the choice of substrate has a significant impact on antenna performance. The antenna implemented on Rogers RT5880 resonates close to the intended 2.5 GHz frequency and provides a lower return loss, indicating better impedance matching and reduced signal reflection. In comparison, the antenna on FR-4 shows a downward frequency shift and a higher return loss, mainly due to its higher dielectric constant and loss tangent. Overall, the RT5880 substrate offers better matching and more efficient operation, making it more suitable for high frequency antenna applications.