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ACDA6019 - Advanced RF Systems

Design and Analysis of RF Antennas

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Introduction

The use of software packages to design and analyse antennas makes the world of RF a much more accessible place to work in. This report will investigate different antennas and analyse their performance.

Task 1 - Microstrip Patch

The task was set to design a Microstrip Patch Antenna to be optimised for 2.1GHz on a substrate of FR4 epoxy with a relative permittivity of 4.4 and relative permeability of 1. The length and Width of the substrate is 70mm and the thickness is 1.6mm. A lumped port feed drives a microstrip transmission line to the rectangular patch antenna.

Design Calculations

To calculate the dimensions of the patch antenna the wavelength of the target frequency must first be calculated; the length L of the patch antenna is normally $\lambda/3 < L < \lambda/2$ [1], so for 2.1GHz (14.28 cm) the length L could range from 47.49mm to 71.43mm however the closer to $\lambda/2$ the better in order to be resonant [2]. A Patch antenna's width is normally smaller than λ [2].

The width of the patch antenna can be calculated with the equation Equation 1 where c is the speed of light in a vacuum in m/s, f is the target frequency in Hz and ϵ_r is 4.4, resulting in a calculated width of 43.47mm.

$$w = \frac{c}{2f} \sqrt{\frac{2}{\epsilon_r + 1}} = \frac{3 \times 10^8}{2 \times 2.1 \times 10^9} \sqrt{\frac{2}{4.4 + 1}} = 0.04347004425 \text{ m} = 43.47 \text{ mm}$$

Equation 1-Calculating the width of a patch antenna for 2.1GHz

The effective dielectric constant can be calculated next, this is required due to the electric field lines exhibiting a behaviour known as fringing, Figure 1, whereby electric field lines extend beyond the edges of the patch antenna down to the ground plane thus electrically extending the length of the antenna. The effective dielectric constant is an approximation of the dielectric constant of air, and of the substrate material and is calculated below in Equation 2 where ϵ_r is the substrate dielectric constant of 4.4, the height h is 1.6mm and the width w is as calculated in Equation 1.

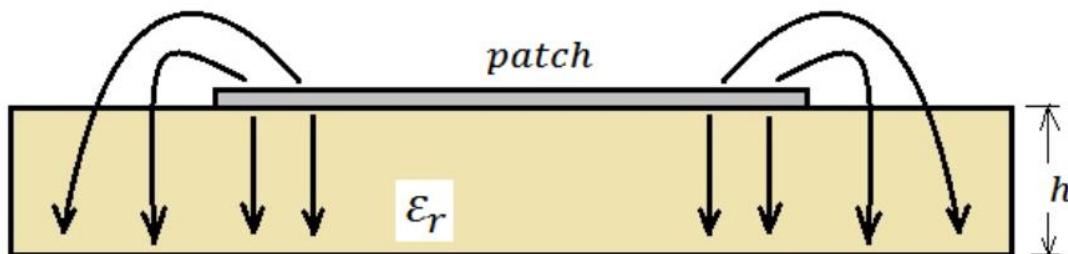


Figure 1-Visulisation of the Electric Field Lines of a patch antenna [3]

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(\frac{1}{\sqrt{1 + 12 \left(\frac{h}{w} \right)}} \right) = 4.115839296$$

Equation 2- Equation to calculate the Effective Dielectric Constant

The fringe effect causes an electrical length extension noted as ΔL and the length can be calculated by the below Equation 3, coming to 0.74mm on all sides.

$$\Delta L = 0.412h \left[\frac{(\epsilon_{reff} + 0.3) \left(\frac{w}{h} + 0.264 \right)}{(\epsilon_{reff} - 0.258) \left(\frac{w}{h} + 0.8 \right)} \right] = 0.74008674 \times 10^{-3} = 0.74mm$$

Equation 3- Calculation of fringe effect length extension.

The physical length L of the antenna is calculated by Equation 4 and equates to 35.21mm. Which then can be used to calculate, with Equation 5, the effective length of the patch antenna when taking into account the fringe effect length extensions.

$$L = \frac{c}{2f\sqrt{\epsilon_{reff}}} = 35.20811383 \times 10^{-3} = 35.21mm$$

Equation 4- Calculation for physical length of a patch antenna.

$$L_{eff} = L + 2\Delta L = 36.68828731 \times 10^{-3} = 36.69mm$$

Equation 5- Calculation for the effective length of a patch antenna

The typical impedance at the edge of a resonant rectangular patch antenna falls in the range of 100 - 400 Ω [2] and can be calculated using the below Equation 6.

$$Z_{ANT} = 90 \frac{\epsilon_r^2}{\epsilon_r - 1} \left(\frac{L}{W} \right)^2 = 336.1818789\Omega$$

Equation 6- Equation to approximate the Input Impedance of a rectangular patch antenna.

As the calculated input impedance doesn't match well with the standard 50 Ω transmission line, a quarter-wave transformer should be employed to impedance match the system. The Impedance of the quarter wave transformer can be calculated by Equation 7 and then the resulting figure used to calculate the width of the transformer using Equation 8 and Equation 9.

$$Z_T = \sqrt{50\Omega + Z_{ANT}} = \sqrt{50 + 336.18} = 19.65151086\Omega$$

Equation 7- Characteristic impedance of the quarter-wave transformer.

$$Z_T = \frac{60}{\sqrt{\epsilon_r}} \ln\left(\frac{8d}{W_T} + \frac{W_T}{4d}\right)$$

Equation 8-Equation to calculate the width of a quarter-wave transformer transmission line.

$$W_T = 2d \left(e^{\frac{Z_T \sqrt{\epsilon_r}}{60}} \pm \sqrt{e^{\frac{2Z_T \sqrt{\epsilon_r}}{60}} - 8} \right) = 0.0064 = 6.4\text{mm}$$

Equation 9-Equation 8 rearranged to find W_T , width of the quarter-wave transformer.

Design and Simulation

With the above values calculated, the patch antenna could be designed in Ansys Electronics Design as seen in Figure 2.

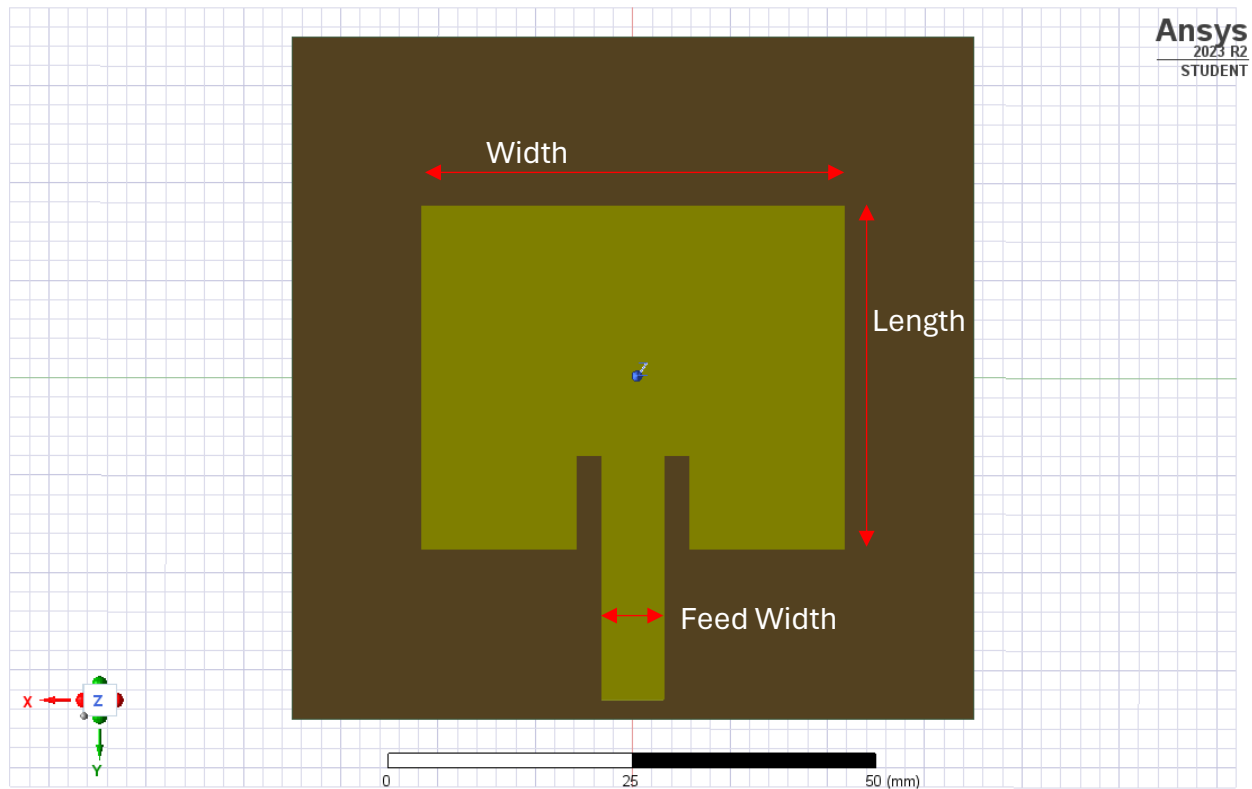


Figure 2-Patch antenna designed in Ansys Electronics Desktop

Analysis

The antenna could then be analysed within Ansys to determine the expected performance of the design, this was done as a broadband sweep from 1GHz to 8GHz and the S11 dB performance plotted on a chart shown in Figure 3. The chart clearly

The results obtained from the design simulation show that the antenna is not resonant on 2.1GHz despite being designed to be so and instead shows two points where the antenna is particularly performant, 2.05GHz and 3.73GHz.

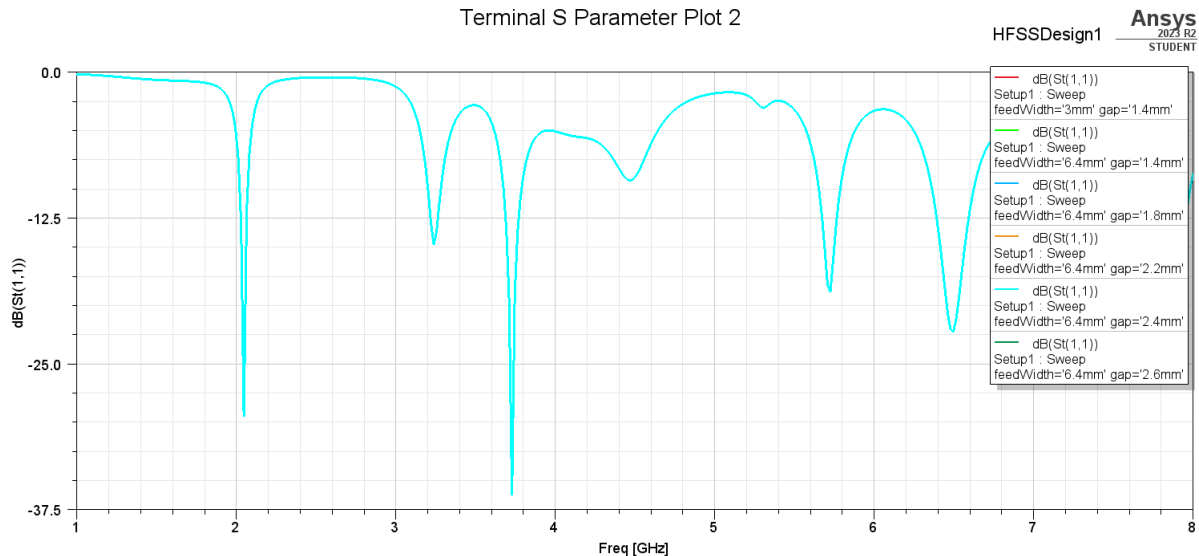


Figure 3-S11 Gain of the antenna design.

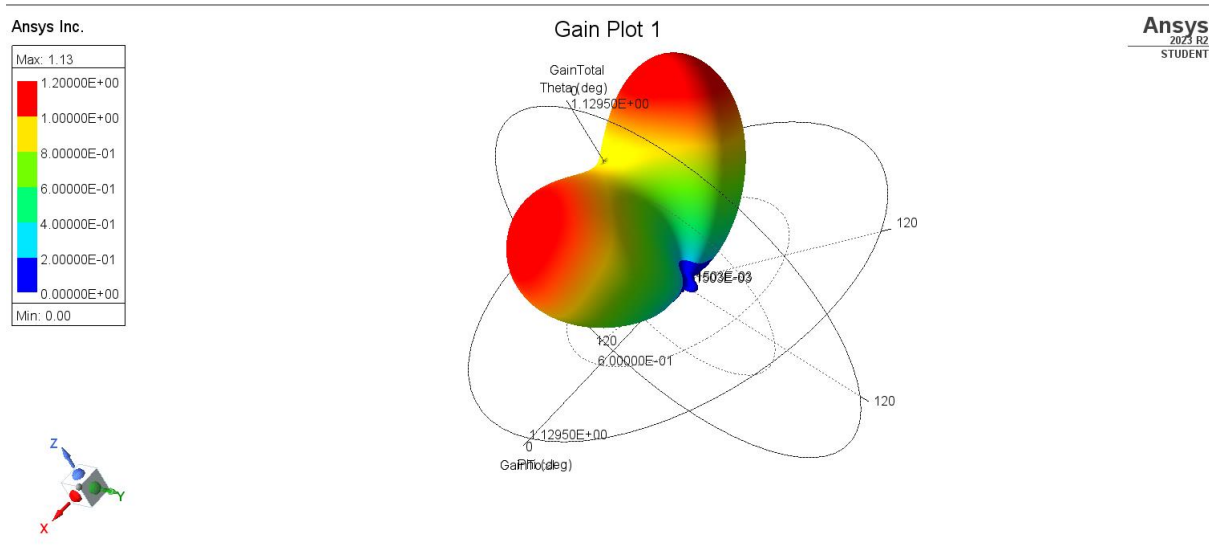


Figure 4-3D Radiation pattern from the designed antenna.

The radiation pattern clearly shows a bi-directional pattern with the two main lobes being roughly 80° apart from each other in the same plane. This was not the expected result of a singular broadband main lobe, however does exhibit some of the same qualities.

The cause of the unexpected results is unknown, however further investigation into the mathematics is warranted. The calculated length L of the antenna also does not fall within the expected range of 47.49mm to 71.43mm however is close to half-wavelength.

Conclusions

While I was unable to design a microstrip antenna that was resonant at 2.1GHz, or have time to complete Task 2, I learned a lot about the mathematics surrounding microstrip patch antennas and intend to investigate them further in my own time.

Bibliography

- [1] C. A. Balanis, Antenna Theory: Third Edition, Analysis and Design, Hoboken, New Jersey: John Wiley & Sons, Inc., 2005.
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- [3] A. F. Alsager, "Design and Analysis of Microstrip Patch Antenna Arrays," University College of Borås, Borås, Sweden, 2011.