

SB EMR Submission

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HFSS Analysis of Electromagnetic Wave Propagation

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Abstract

Ansyz HFSS was used to simulate two waveguides and a dipole antenna. This report describes the methodology for this analysis and discusses the results, including consideration of accuracy and comparison to simulation, overall concluding the suitability of HFSS for simulation of electromagnetic radiation in the context of waveguides and dipole antennas.

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1 Introduction

In electromagnetic systems engineering, modelling software can be used to predict the performance and behaviour of designs and concepts. In this report, Ansys Electronics, with the HFSS module, was used to simulate two waveguides and a dipole antenna.

A waveguide is a structure which is used to guide a wave with minimal energy loss, and is typically used to direct high-frequency waves such as microwaves and radio waves [1] [2]. These can be used in the Ordnance, Munitions, and Explosives (OME) sector as part of communication, tracking, and targeting systems, to direct electromagnetic waves in a specific direction

A dipole antenna is a straight, conductive wire, divided into two equal parts, with the feed coming from the centre [3] [4]. It is used to convert electrical current into electromagnetic waves and vice-versa allowing for the transmission and receiving of signals.

2 Method

2.1 Waveguide Method

Two waveguides were modelled, one with walls made of Perfect Electric Conductor (PEC), and filled with Vacuum, and one with walls also made of PEC, but filled with Teflon. The models were created in line with a supplied method [5], which is detailed below.

First, a box was drawn with dimensions 21 x 7 x 50 mm to create a rectangular prism, with 'Vacuum' being selected as the material for the first waveguide, and 'Teflon' for the second.

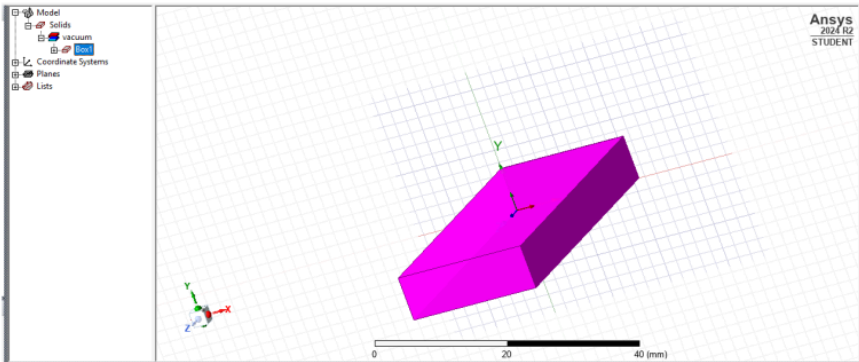


Figure 1: The PEC/Vacuum Waveguide Highlighted in HFSS

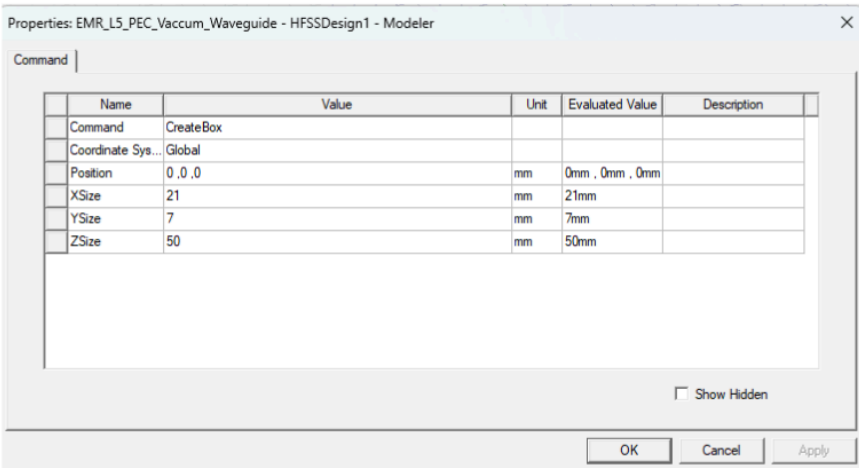


Figure 2: The Dimensions of the PEC/Vacuum Waveguide

Next, the four walls of the waveguide were selected and assigned the 'Perfect E' boundary condition, representing a Perfect Electrical Conductor.

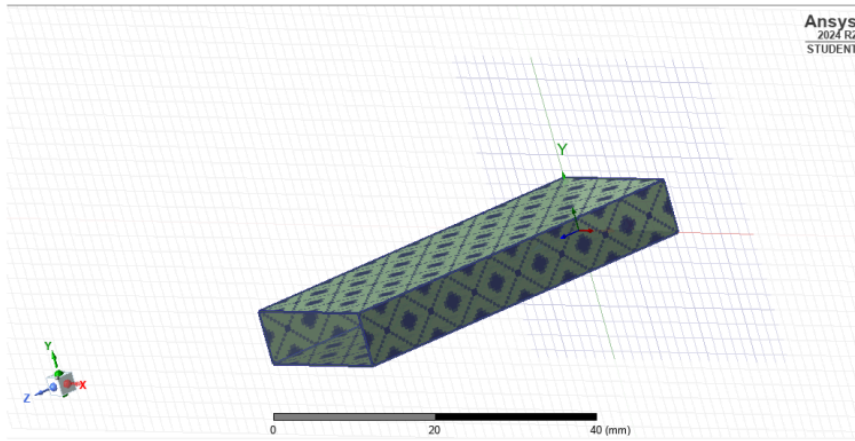


Figure 3: The PEC Walls of the Rectangular Waveguide Highlighted

Once the boundary condition was assigned, excitations were assigned at each port of the waveguide, each with 3 modes.

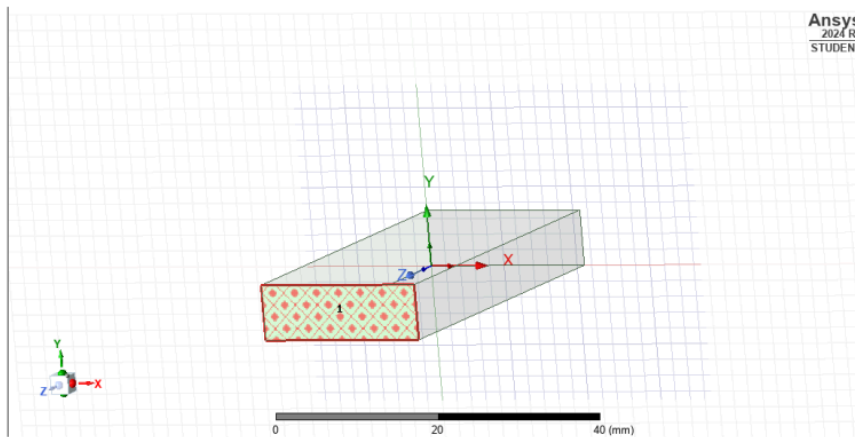


Figure 4: One of the Wave Port Excitation Highlighted on the Rectangular Waveguide

Wave Port

General
Post Processing
Defaults

Name: 1

Number of Modes: 3

Mode	Integration Line	Characteristic Impedance (Z_0)
1	None	Z_{pi}
2	None	Z_{pi}
3	None	Z_{pi}

Mode Alignment and Polarity:

☒ Set mode polarity using integration lines
☐ Align modes using integration lines
☐ Align modes analytically using coordinate system

U Axis Line: Undefined
☒ Reverse V Direction

☐ Filter modes for reporter

Use Defaults

OK
Cancel

Figure 5: The Mode Settings Used for Both Wave Port Excitations

Once both wave ports were set up, the solution set up was added to the system. A frequency sweep with 90 passes at 7GHz was selected, with a starting frequency of 2GHz and a final frequency of 30GHz.

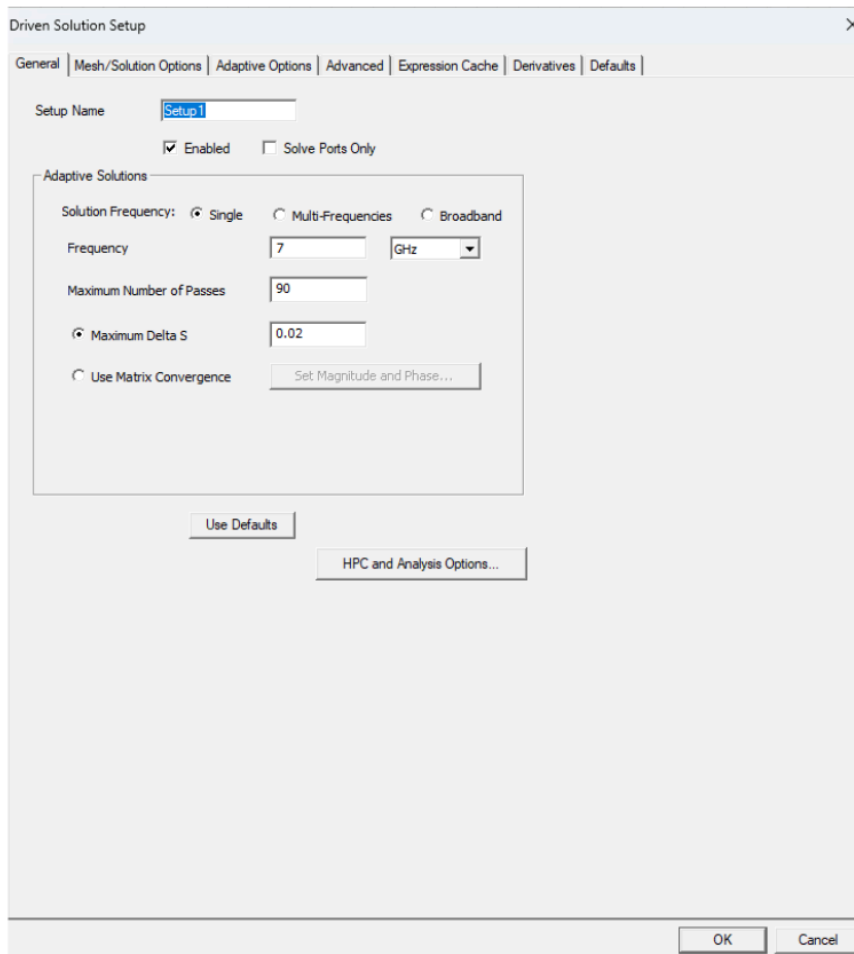


Figure 6: The solution setup for the Rectangular Waveguide

Edit Frequency Sweep

X

General

Interpolation

Defaults

Sweep Name:

Sweep

Enabled

Sweep Type:

Interpolating

Frequency Sweeps [401 points defined]

	Distribution	Start	End		
1	Linear Count	2GHz	30GHz	Points	401

Add Above

Add Below

Delete Selection

Preview ...

3D Fields Save Options

Save Fields (At Basis Freqs)

Save radiated fields only

Time Domain Calculation...

S Matrix Only Solve

Auto

Manual - Allow for frequencies above

1

MHz

OK

Cancel

Figure 7: The Frequency Sweep Setup for the Rectangular Waveguide

Once the solution setup was complete, the simulation was validated and run, and the results analysed as discussed in Section 3.

2.2 Dipole Antenna Method

The Dipole Antenna was designed to radiate at a wavelength of 211mm in line with the task briefing [6]. This allows the required length of the halfwave dipole antenna to be calculated using the equation below

$$L = \frac{\lambda}{2}, \text{ where } \lambda \text{ is the wavelength and } L \text{ is the length of the antenna}$$

Equation 1: The Equation for the Length of a Half-Wave Dipole Antenna [3]

Thus, the length of the dipole antenna can be expressed as:

$$L = \frac{211}{2} = 105.5\text{mm}$$

Equation 2: Calculation of the Length of the Simulated Dipole Antenna

Then, using the equation for frequency, given below, the expected operating frequency of the antenna can be calculated.

$$f = \frac{c}{\lambda}, \text{ where } f \text{ is the frequency, } c \text{ is the speed of light, and } \lambda \text{ is the wavelength}$$

Equation 3: The Equation for the Frequency of a Wave based on its Wavelength [3]

$$f = \frac{3 \times 10^8}{0.211} = 1.42\text{GHz}$$

Equation 4: Calculation of the Theoretical Operating Frequency of the Simulated Dipole Antenna

Once HFSS had been configured in line with the method in [7], the following steps were carried out.

First, a cylinder was created with a radius of 1mm and a length of 105.5mm, centred on the co-ordinates (0,0,52.75) and assigned the material PEC.

Name	Value	Unit	Evaluated Value	Description
Command	CreateCylinder			
Coordinate Sys...	Global			
Center Position	0,0,-105.5/2	mm	0mm, 0mm, -5...	
Axis	Z			
Radius	1	mm	1mm	
Height	105.5	mm	105.5mm	
Number of Seg...	0		0	

Figure 8: The cylinder Characteristics used to create the dipole antenna

Next, the cylinder was copied and pasted to create a second cylinder, and its dimensions were changed to be a radius of 1mm, and a length of 1mm, placed at the centre of the dipole cylinder. This smaller cylinder's material was then set to 'vacuum'.

Using the Boolean function in HFSS, this smaller cylinder was subtracted from the main dipole to create a 1mm gap in the centre. This gap was then selected and a lump port was created in the YZ plane.

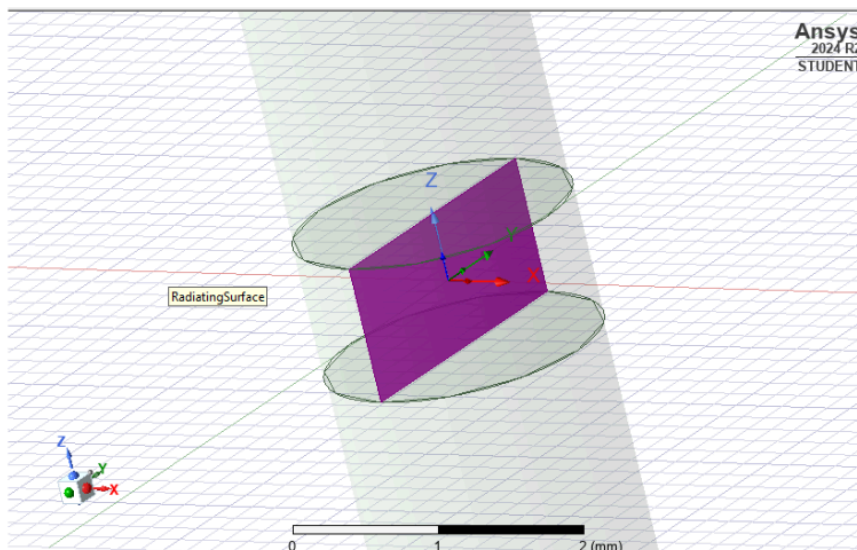


Figure 9: The Lumped Port shown in the gap of the Dipole Antenna

Next, an excitation was assigned to this port with an integration line running from bottom to top.

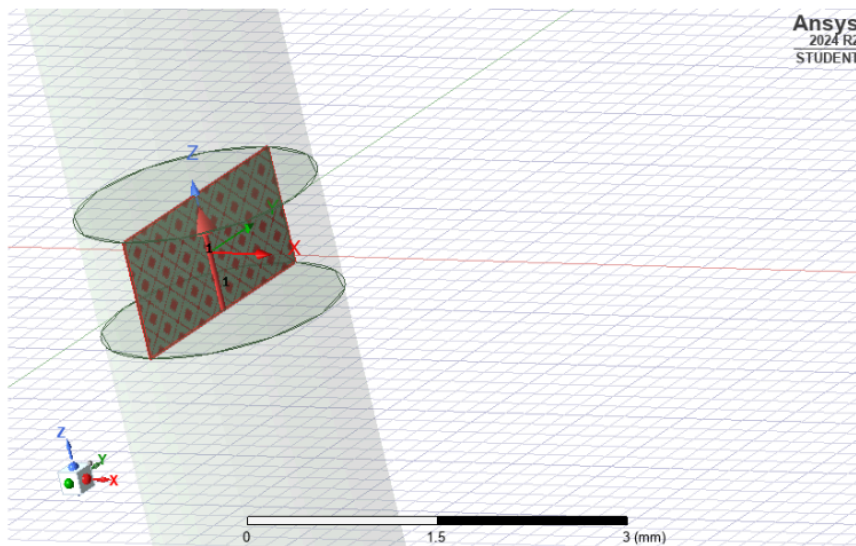


Figure 10: The Excitation for the Dipole

Next, an open region was created, with an operating frequency set at 1GHz.

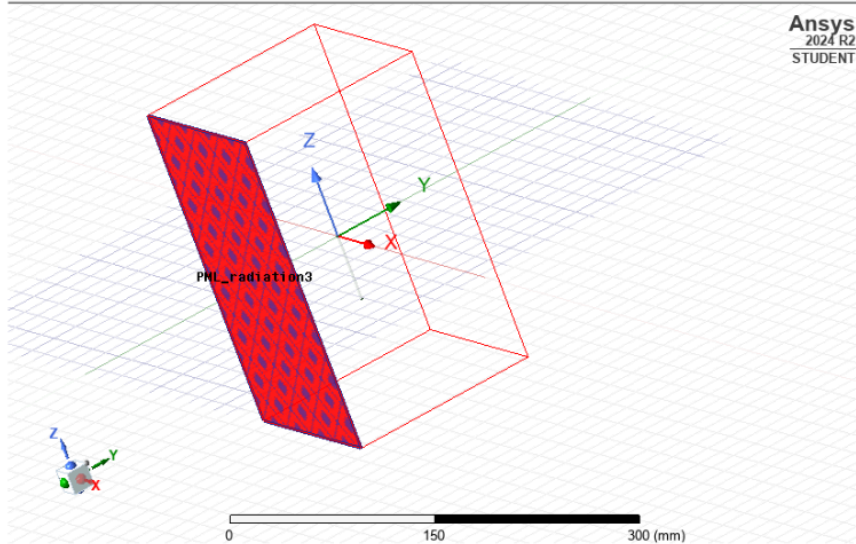


Figure 11: The Open Region and its boundaries for the Dipole Analysis

Once this was completed, the solution was set up with the parameters shown below.

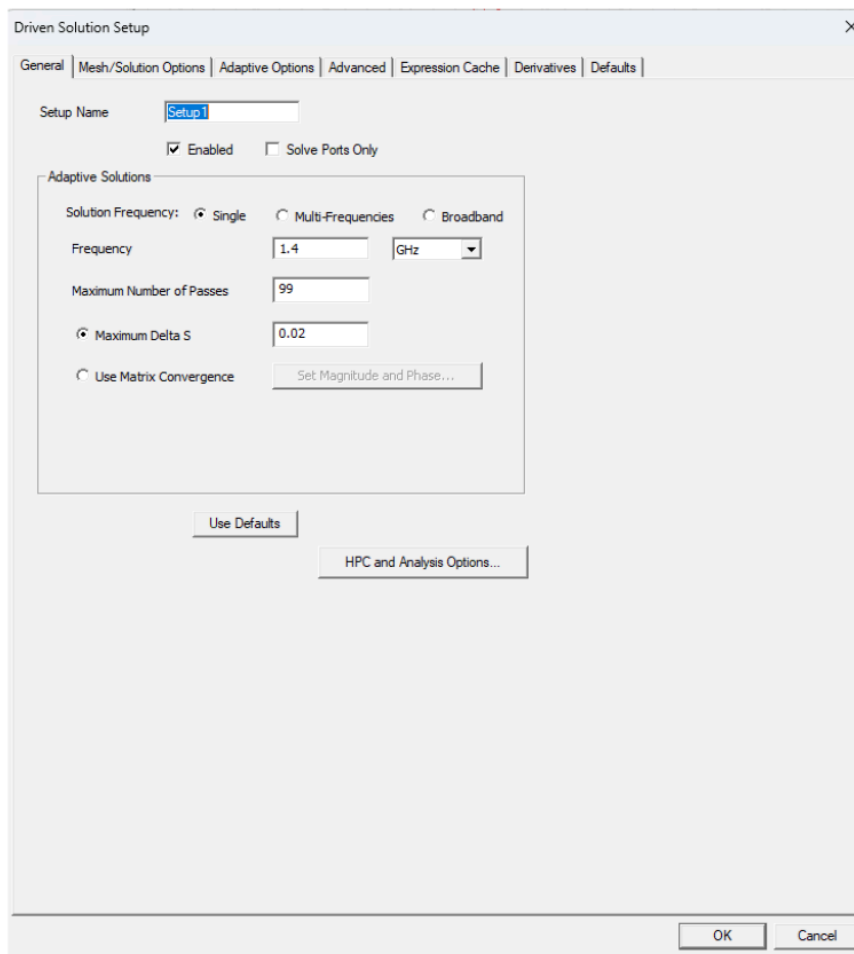


Figure 12: The Solution Setup for the Dipole Simulation

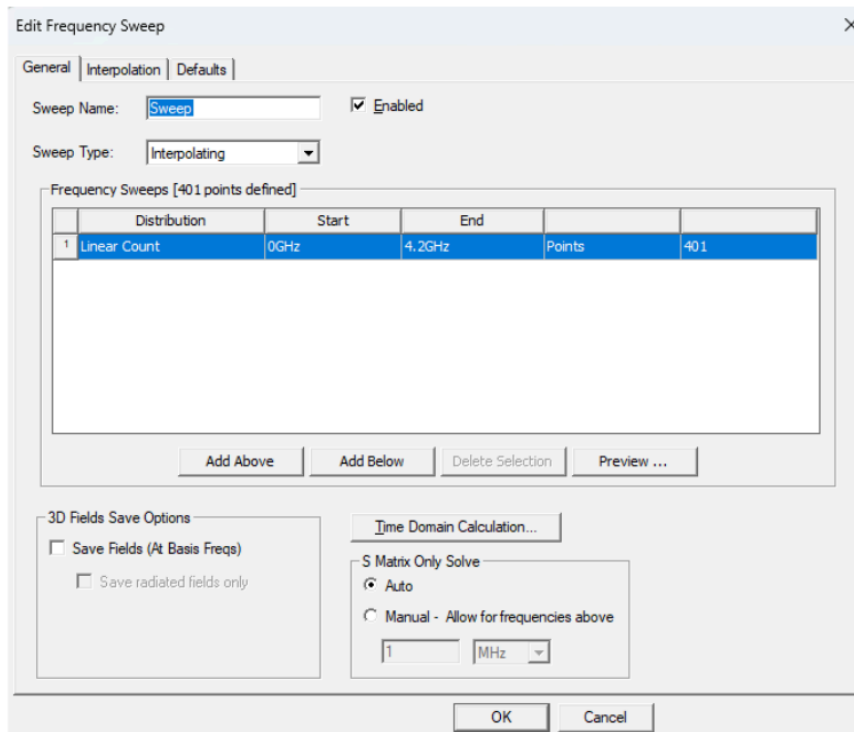


Figure 13: The Solution Sweep Setup for the Dipole Simulation

When the solution was set up and validated, the simulation was run, producing the results shown in Section 3.2.

3 Results

3.1 Waveguide Results

3.1.1 Calculations

In order to analyse the results produced by the simulation, it is necessary to calculate the predicted cutoff frequencies, using the equations given in [2] and [8], and reproduced below.

$$f_c = \frac{c}{2} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

Where:

f_c is the Cutoff Frequency

c is the Speed of Light

m is the Number of Half Wavelength Variations of the Electric or Magnetic Field in the Width of the Waveguide

n is the Number of Half Wavelength Variations of the Electric or Magnetic Field in the Height of the Waveguide

a is the Width of the Waveguide

b is the Height of the Waveguide

Equation 5: The Equation for Cutoff Frequency in a Rectangular Waveguide [2] [8]

$$c = \frac{1}{\sqrt{\epsilon\mu}}$$

Where:

c is the Speed of Light in a Medium

ϵ is the Permittivity of the Medium

μ is the Permeability of the Medium

Equation 6: The Equation for the Relative Speed of Light in a Medium [2] [8]

These equations allow the cutoff frequencies for the simulated waveguides to be calculated. For a vacuum, the speed of light is known to be $3 \times 10^8 \text{ms}^{-1}$, however this will have to be calculated for Teflon.

$$f_c = \frac{3 \times 10^8}{2} \sqrt{\left(\frac{m}{0.021}\right)^2 + \left(\frac{n}{0.007}\right)^2}$$

In the TE_{10} mode, $m = 1, n = 0$, therefore $f_c = 7.14 \text{GHz}$

In the TE_{20} mode, $m = 2, n = 0$, therefore $f_c = 14.29 \text{GHz}$

In the TE_{30} mode, $m = 3, n = 0$, therefore $f_c = 21.43 \text{GHz}$

Equation 7: The calculation for the Cutoff Frequencies of the PEC/Vacuum Waveguide

In the Ansys materials database, the values of ϵ and μ are given as 2.1 and 1 respectively, hence using Equation 2, the speed of light in Teflon can be calculated.

$$c_{Teflon} = \frac{1}{\sqrt{2.1}} \times 3 \times 10^8$$

$$\therefore c_{Teflon} = 2.07 \times 10^8 \text{ ms}^{-1}$$

Equation 8: Calculation of the speed of light in Teflon

Using this value for C, the cutoff frequencies for the Teflon waveguide can be calculated as shown below.

$$f_c = \frac{2.07 \times 10^8}{2} \sqrt{\left(\frac{m}{0.021}\right)^2 + \left(\frac{n}{0.007}\right)^2}$$

In the TE_{10} mode, $m = 1, n = 0$, therefore $f_c = 4.93\text{GHz}$

In the TE_{20} mode, $m = 2, n = 0$, therefore $f_c = 9.86\text{GHz}$

In the TE_{30} mode, $m = 3, n = 0$, therefore $f_c = 14.79\text{GHz}$

3.1.2 Simulation Results

In a rectangular waveguide, the TE_{10} mode is the dominant mode [9], as seen below for both the Vacuum and Teflon Waveguides.

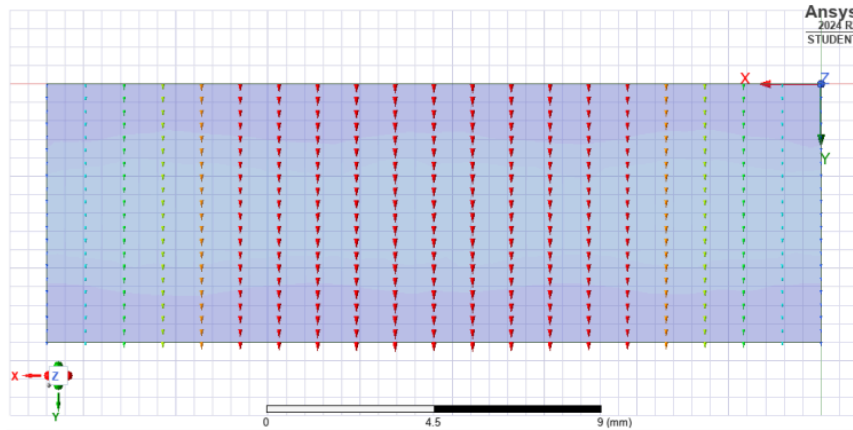


Figure 14: The TE_{10} Mode of the Vacuum Waveguide

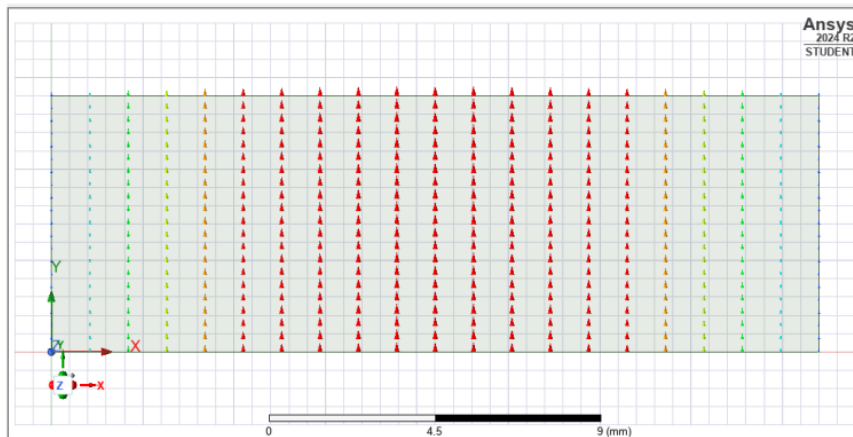


Figure 15: The TE₁₀ Mode of the Teflon Waveguide

In addition, both waveguides exhibit the TE₂₀ and TE₃₀ modes, as calculated in Section 3.1.1.

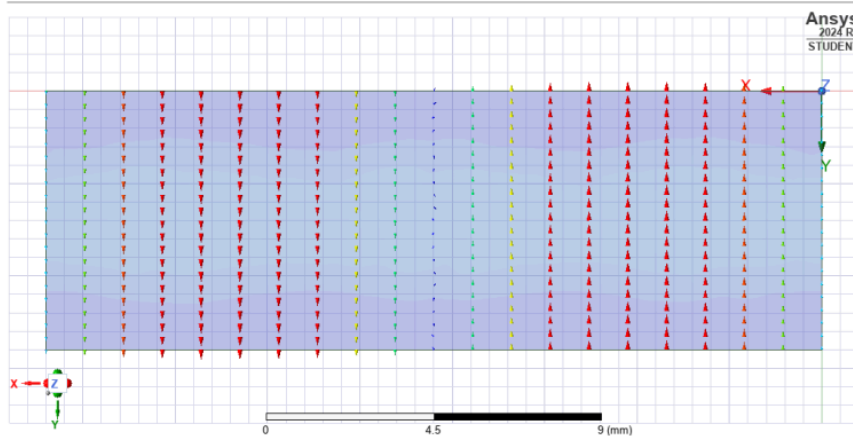


Figure 16: The TE₂₀ Mode

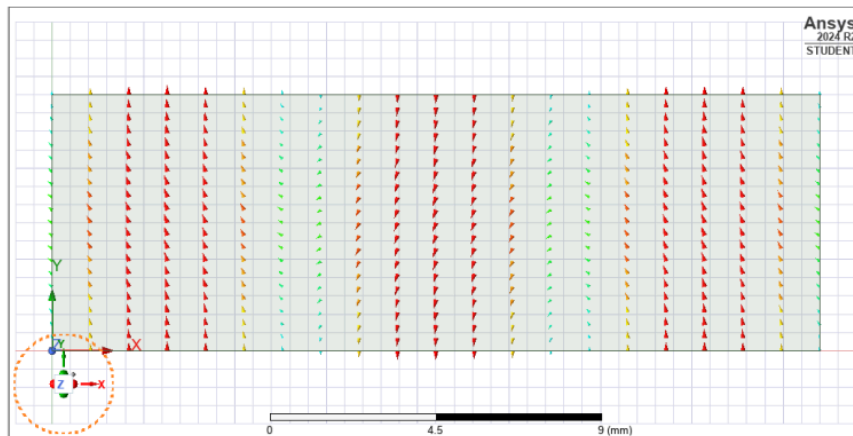


Figure 17: The TE₃₀ Mode

The Magnitudes and Vectors of the Electric and Magnetic Fields were also Obtained as shown below.

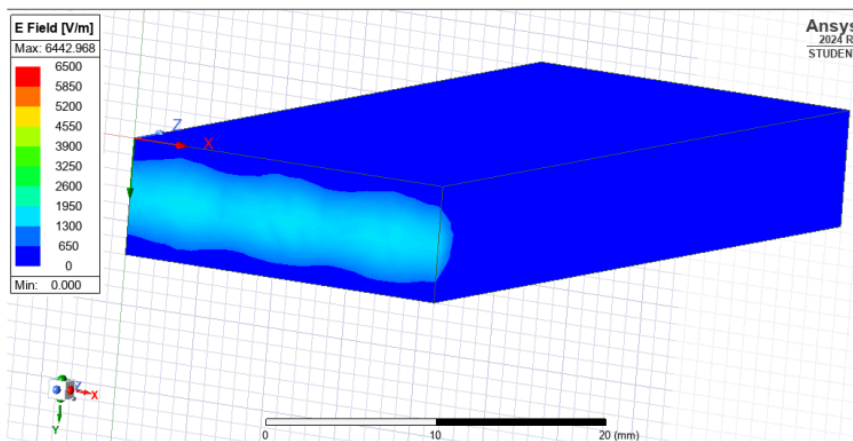


Figure 18: The E Field Magnitude for the Vacuum Waveguide at 7.25GHz

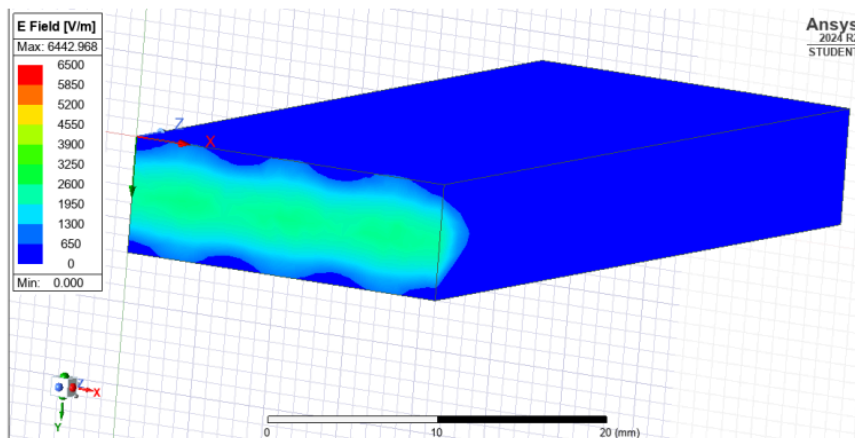


Figure 19: The E Field Magnitude for the Vacuum Waveguide at 14.32GHz

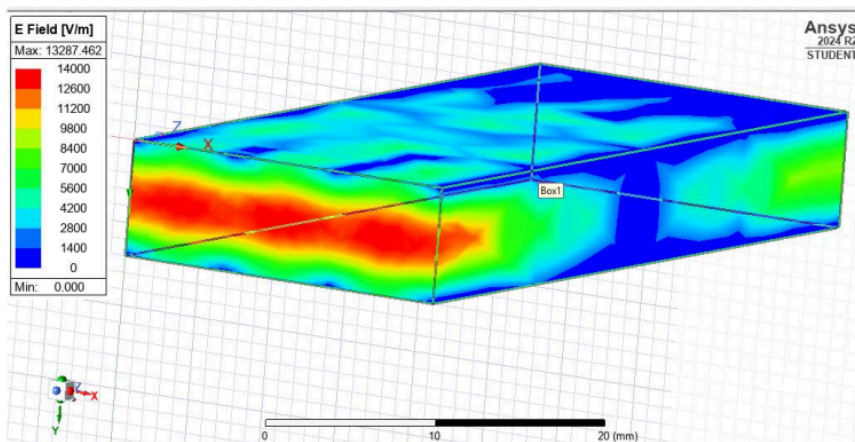


Figure 20: The E Field Magnitude for the Vacuum Waveguide at 21.47GHz

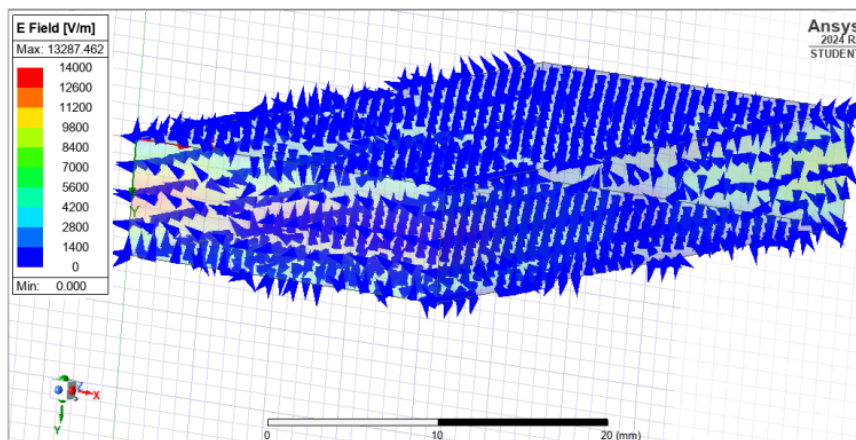


Figure 21: The E Field Vectors for the Vacuum Waveguide at 7.25GHz

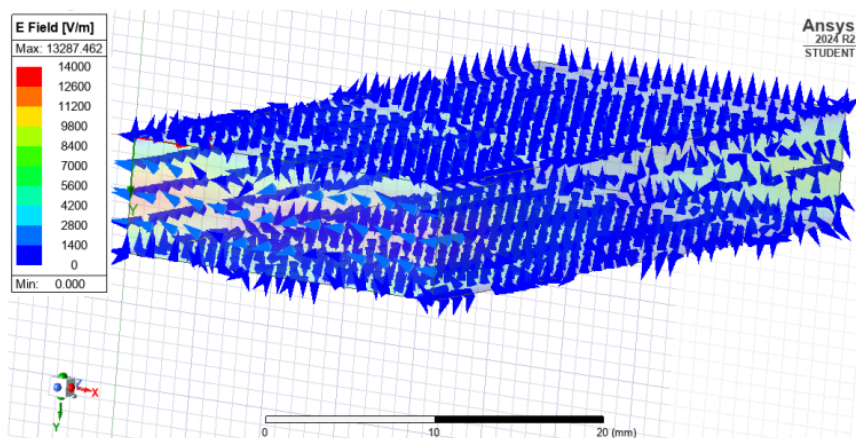


Figure 22: The E Field vectors for the Vacuum Waveguide at 14.32GHz

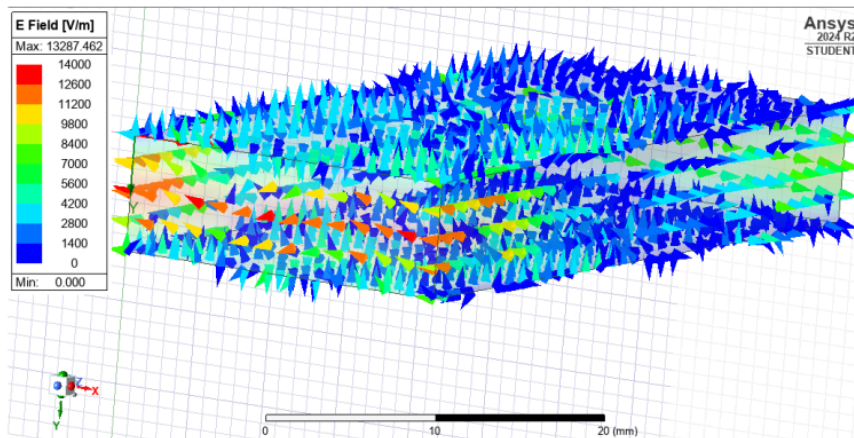


Figure 23: The E Field Vectors for the Vacuum Waveguide at 21.47GHz

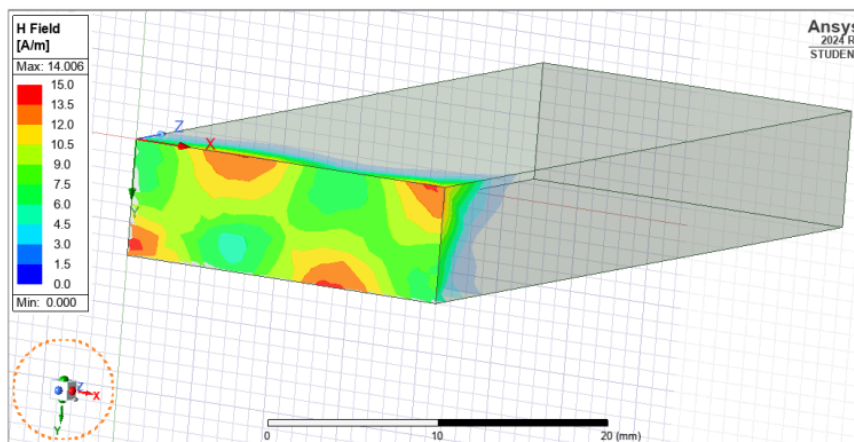


Figure 24: The H Field Magnitude for the Vacuum Waveguide at 7.25GHz

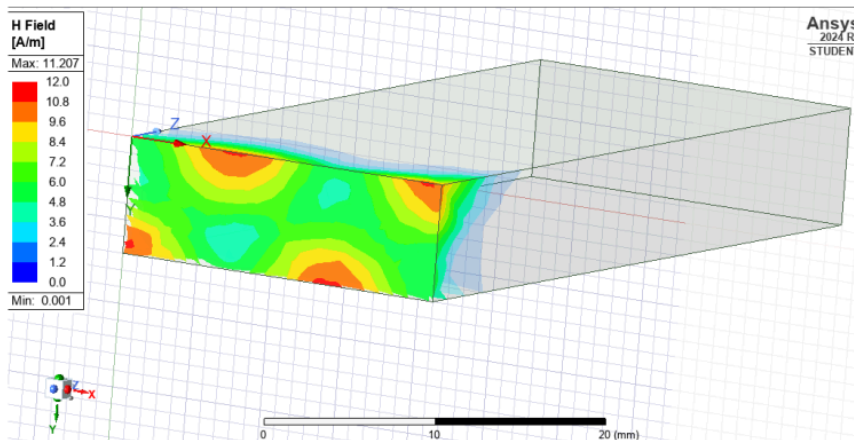


Figure 25: The H Field Magnitude for the Vacuum Waveguide at 14.32GHz

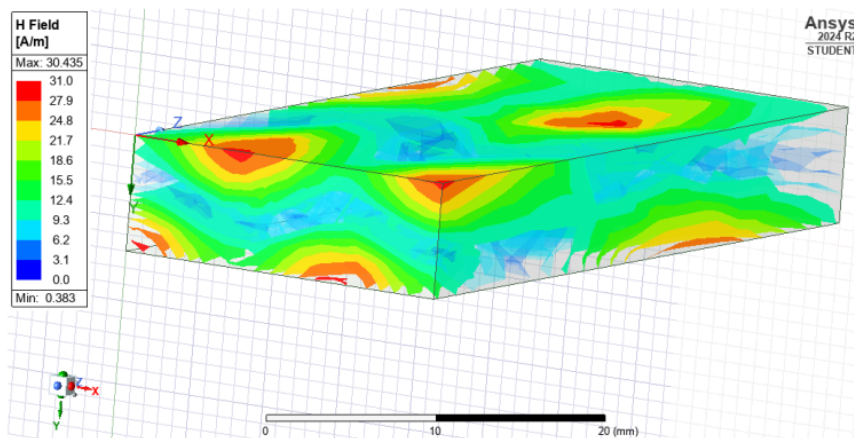


Figure 26: The H Field Magnitude for the Vacuum Waveguide at 21.47GHz

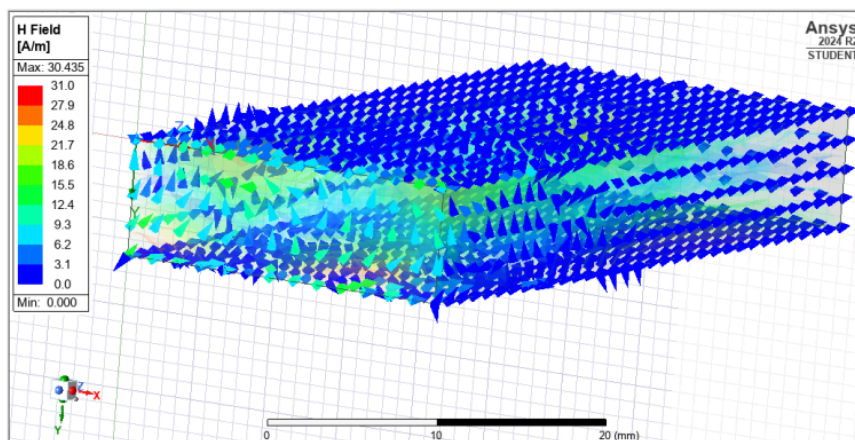


Figure 27: The H Field Vectors for the Vacuum Waveguide at 7.25GHz

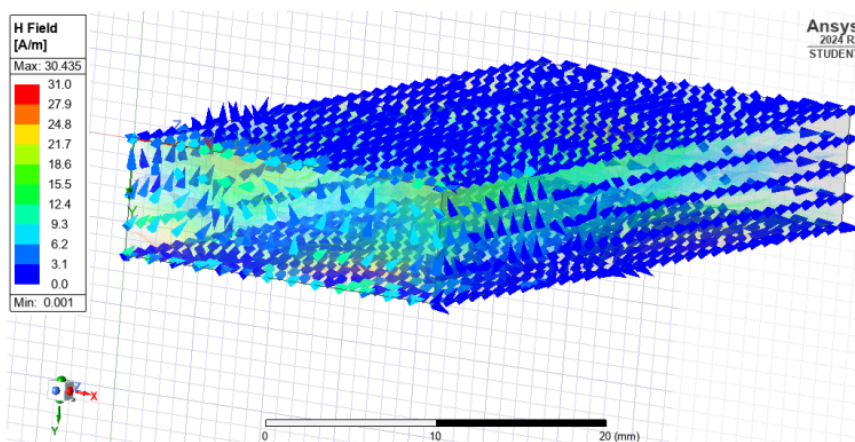


Figure 28: The H Field Vectors for the Vacuum Waveguide at 14.32GHz

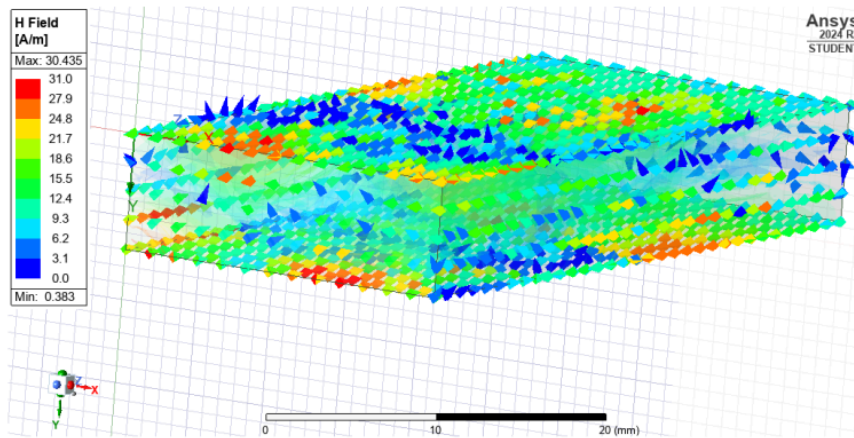


Figure 29: The H Field Vectors for the Vacuum Waveguide at 21.47GHz

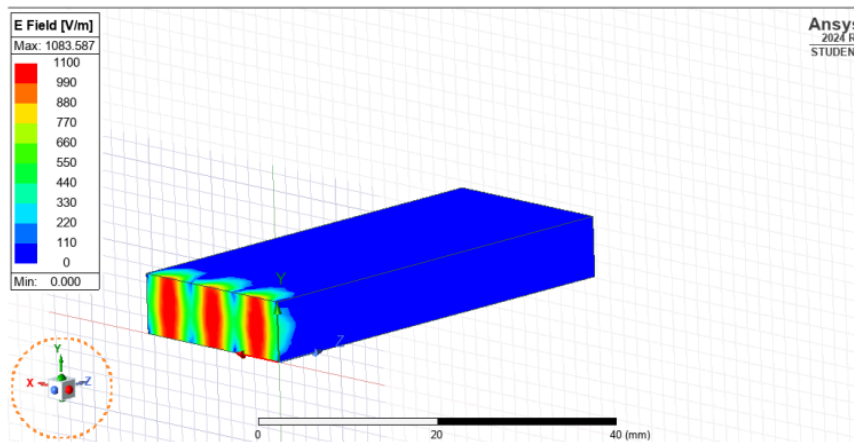


Figure 30: the E Field Magnitude for the Teflon Waveguide at 4.625GHz

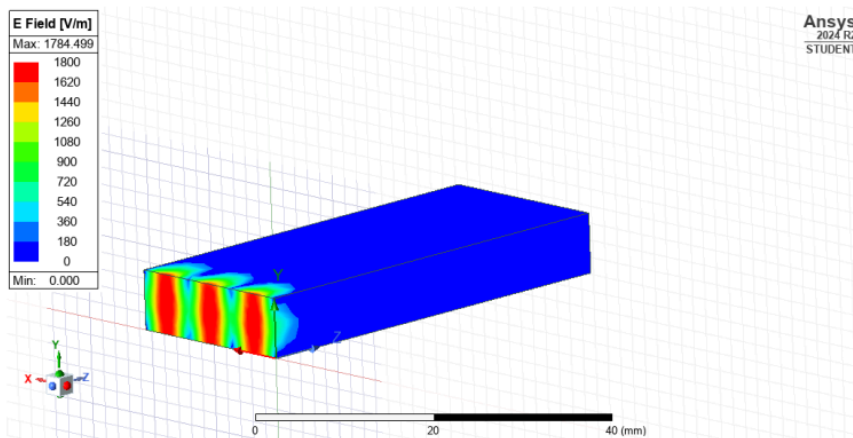


Figure 31: The E Field Magnitude for the Teflon Waveguide at 9.875GHz

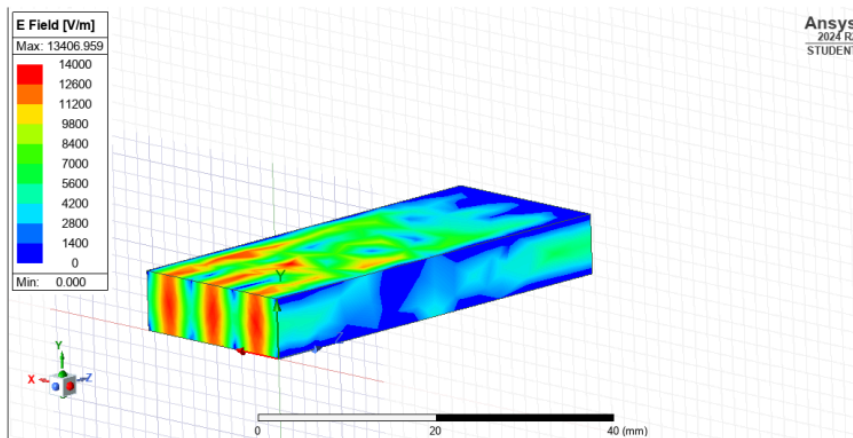


Figure 32: The E Field Magnitude for the Teflon Waveguide at 14.78GHz

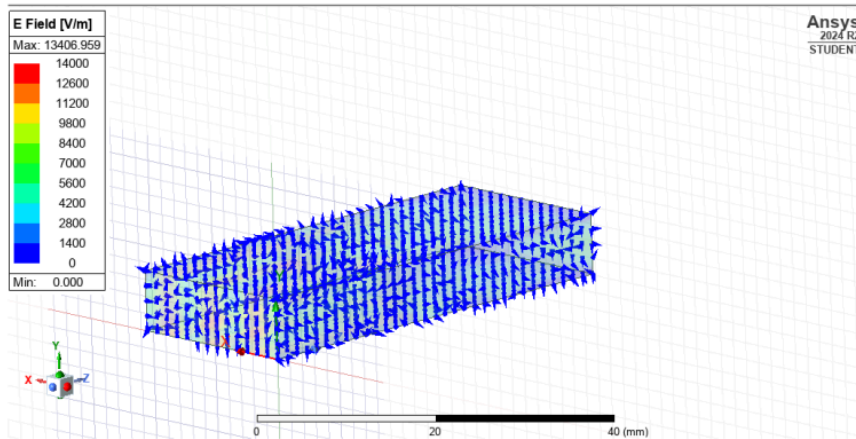


Figure 33: The E Field Vectors for the Teflon Waveguide at 4.625GHz

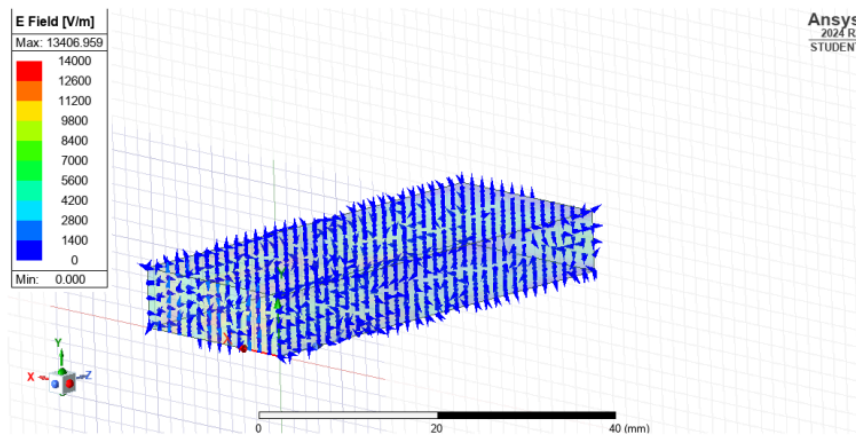


Figure 34: The E Field Vectors for the Teflon Waveguide at 9.875GHz

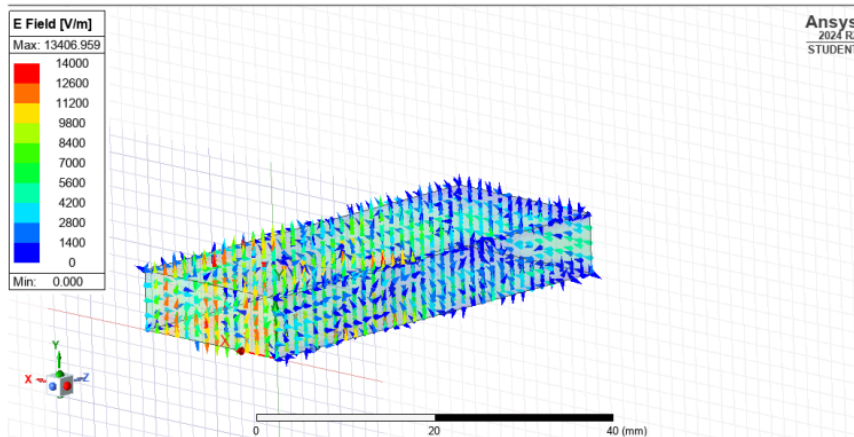


Figure 35: The E Field vectors for the Teflon Waveguide at 14.85GHz

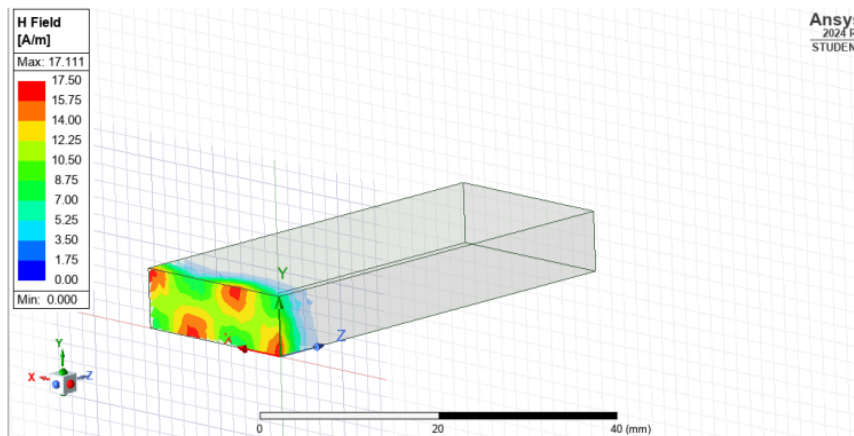


Figure 36: The H Field Magnitude for the Teflon Waveguide at 4.87GHz

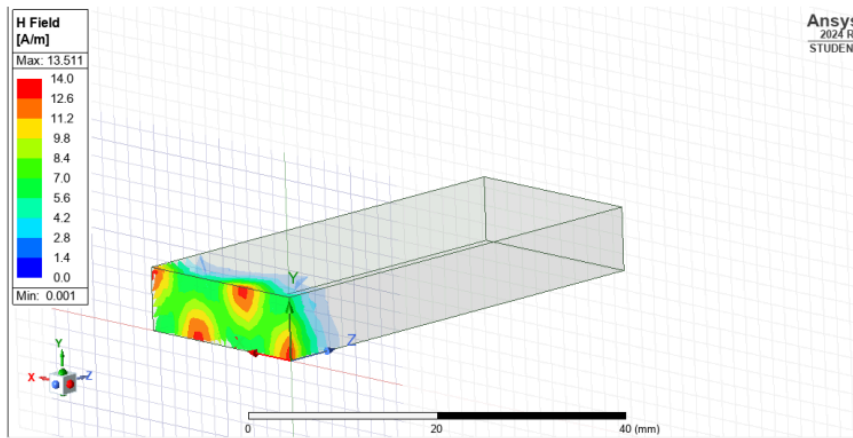


Figure 37: The H Field Magnitude for the Teflon Waveguide at 9.875GHz

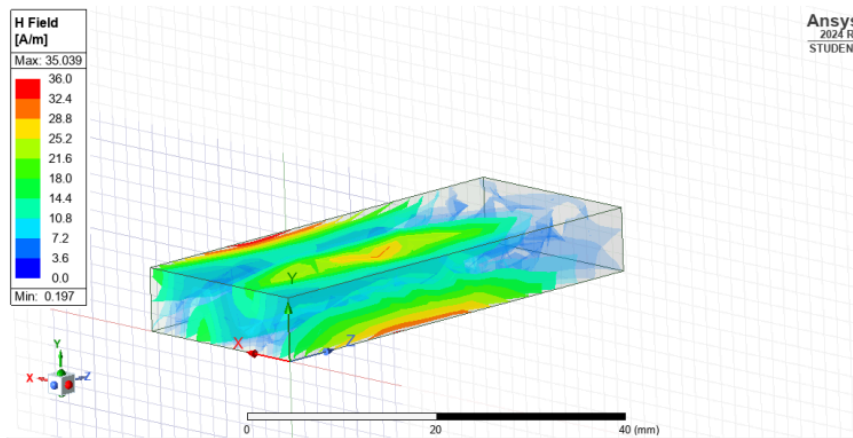


Figure 38: The H Field Magnitude for the Teflon Waveguide at 14.85GHz

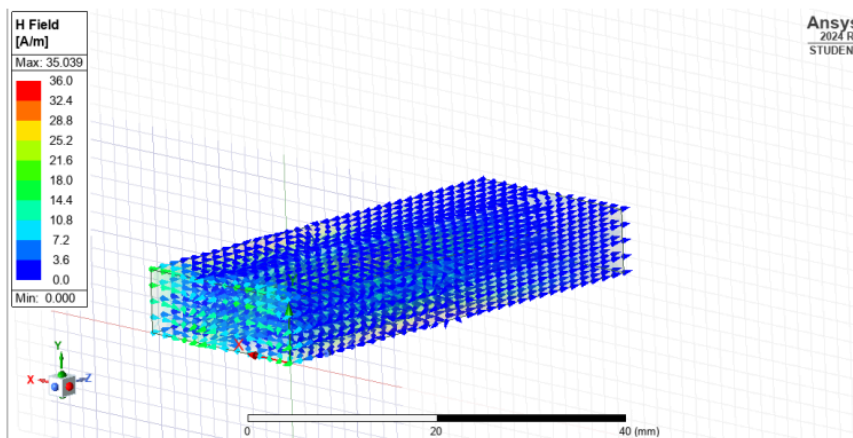


Figure 39: The H Field Vectors for the Teflon Waveguide at 4.87GHz

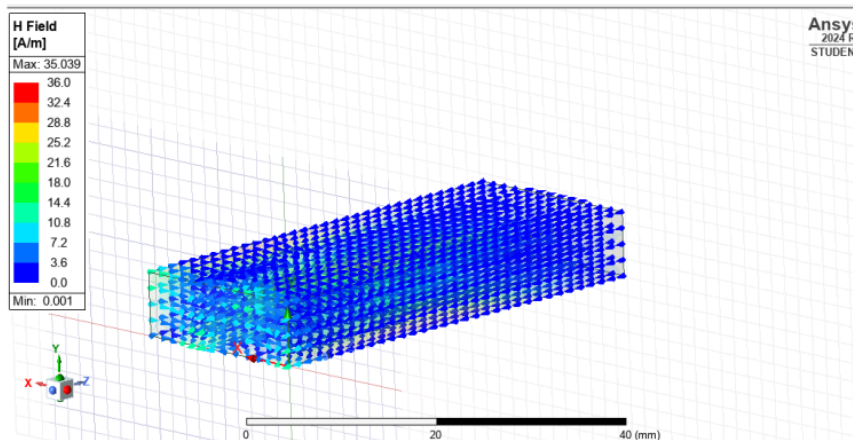


Figure 40: The H Field Vectors for the Teflon Waveguide at 9.875GHz

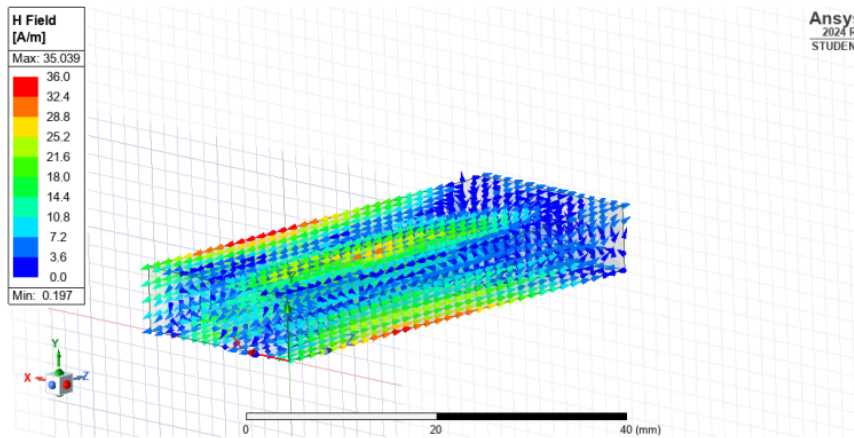


Figure 41: The H Field Vectors for the Teflon Waveguide at 14.85GHz

Finally, a rectangular plot for each waveguide was obtained, allowing the cutoff frequencies to be identified. These are shown below.

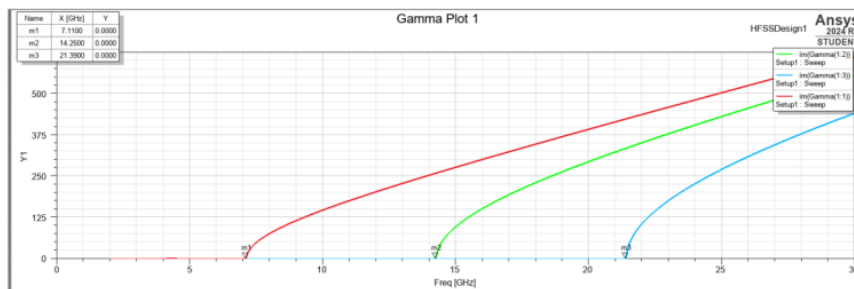


Figure 42: A Rectangular Plot of the Frequencies for the Vacuum Waveguide

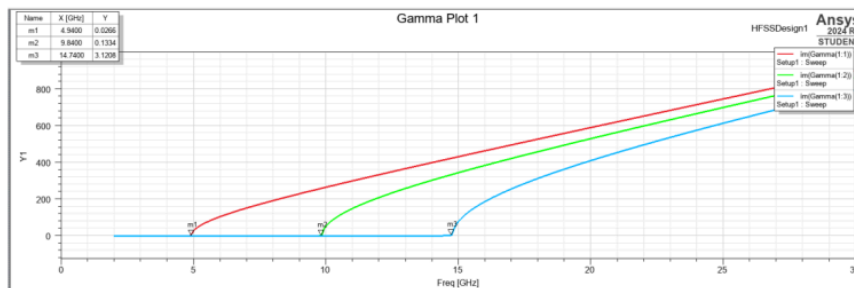


Figure 43: A Rectangular Plot of the Frequencies for the Teflon Waveguide

These plots allow the simulated cutoff frequencies to be compared to the theoretical frequencies calculated in Section 3.1.1, as shown in the table below.

Mode	Vacuum	Teflon		
	Predicted Cutoff Freq.	Simulated Cutoff Freq.	Predicted Cutoff Freq.	Simulated Cutoff Freq.
TE ₁₀	7.14GHz	7.11GHz	4.93GHz	4.94GHz
TE ₂₀	14.29GHz	14.25GHz	9.86GHz	9.84GHz
TE ₃₀	21.43GHz	21.39GHz	14.79GHz	14.74GHz

Table 1: The Predicted vs Simulated Frequencies for both Waveguides

3.2 Dipole Antenna

The S-Parameter plot was obtained for the dipole antenna, which is shown below.

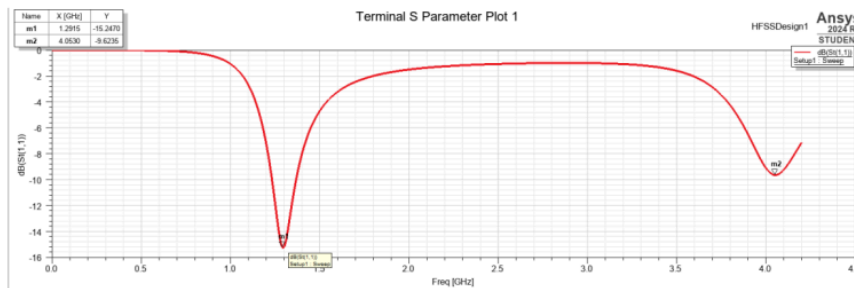


Figure 44: S-Parameter Plot for the Simulated Dipole Antenna

This plot suggests that the operating frequency of the antenna would be 1.29GHz, as opposed to the 1.42GHz initially calculated.

The Radiation Pattern was also obtained for the dipole antenna, as shown below

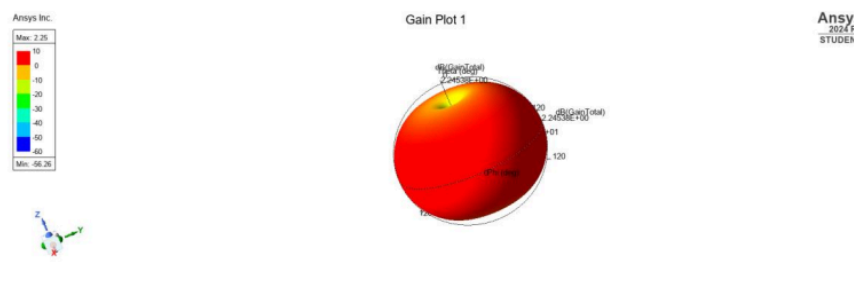


Figure 45: The 3D Radiation Pattern for the Simulated Dipole Antenna

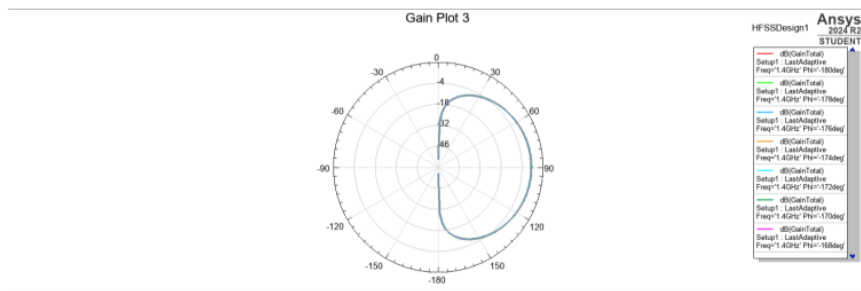


Figure 46: The 2D Radiation Pattern for the Dipole Antenna

4 Discussion

4.1 Waveguides

The calculated waveguide cutoff frequencies are very close to the simulated frequencies, indicating that the simulation had effectively analysed the performance of the waveguide.

4.2 Dipole Antenna

The radiation pattern produced is consistent with literature examples of radiation patterns for Dipole Antennas, examples of which are shown below.

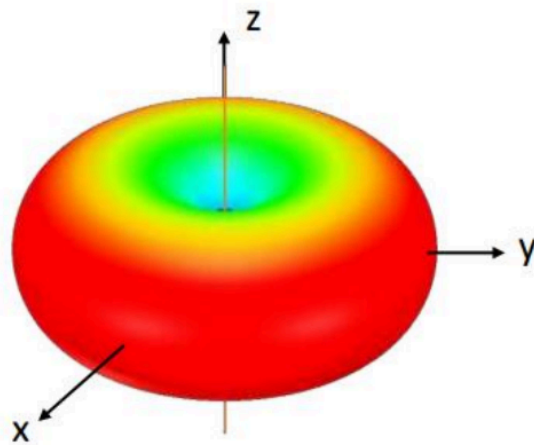


Figure 47: The 3D Radiation Pattern for a half-wave dipole antenna [10]

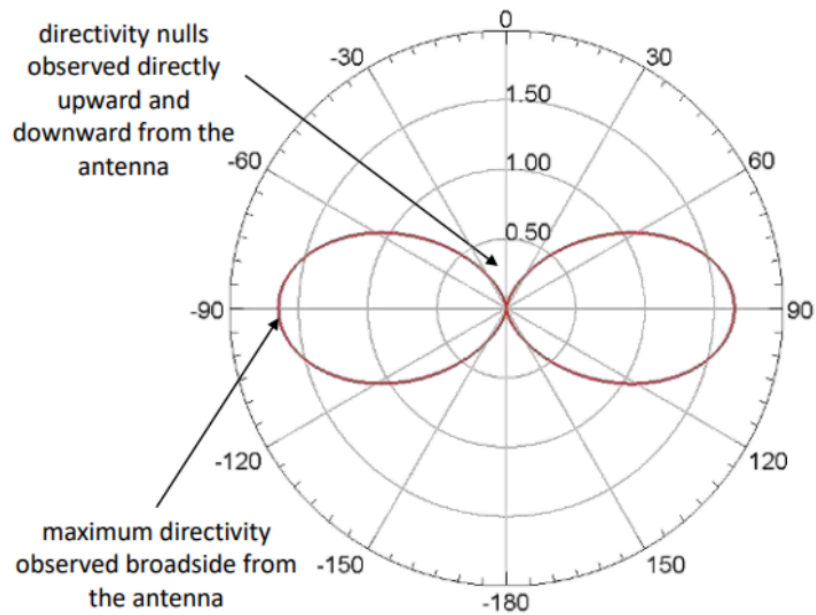


Figure 48: The 2D Radiation Pattern for a half-wave dipole antenna [10]

Despite this general accuracy, it is noted that the simulated operating frequency was notably less than the calculated value. It is theorised that this is due to the length of the dipole not taking into account the size of the gap, but further simulation would be required to prove this.

5 Conclusion

The analysis carried out in this report has demonstrated the effectiveness of Ansys HFSS for the design of Waveguides and Dipole Antennas. The waveguide analysis showed that for rectangular waveguides of the same external dimensions, a fill of Teflon would result in the waveguide having a lower cutoff frequency when compared to an evacuated waveguide. In the context of a dipole, it has demonstrated that a dipole of known length will operate at a frequency in line with the equations given in [3], and that a longer dipole will correspond to a higher wavelength, and so a lower frequency.

References

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- [2] M. L. Kult, "Chapter 16 Waveguides," in *Schaum's Outline of Electromagnetics*, New York, McGraw-Hill Education, 2019.
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- [5] S. J. Dhas, *DESIGN OF RECTANGULAR WAVEGUIDE*, UWTSD.
- [6] UWTSD, *Electromagnetic Radiation - Coursework Question Paper*, UWTSD, 2025.
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- [9] Massachusetts Institute of Technology, "13.4 Rectangular Waveguide Modes," [Online]. Available: https://web.mit.edu/6.013_book/www/chapter13/13.4.html. [Accessed April 2025].
- [10] K. L. Smith, "The Half Wave Dipole: Design," 2020. [Online]. Available: <https://innovationspace.ansys.com/courses/wp-content/uploads/sites/5/2022/07/TheHalfWaveDipole-Design.pdf>. [Accessed April 2025].

SB EMR Submission

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

79/100

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Comment 1

Good work

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Good work

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Comment 3

caption for the table should be included at the top of the table



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no comment

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GRADING FORM: EMR-MAY 2025 OME

SILAS BLEVINS

78.60

ENGAGEMENT WITH LITERATURE

Marks will be awarded based on the extent of research and/or own reading, selection of credible sources, application of appropriate referencing conventions. You MUST include evidence of sources that you have discovered yourself during the course of your own student centred work.



Demonstrates engagement with a wide range of literature, including sources retrieved independently. Relevant and used a varied and credible set of sources. Consider referencing technical sources like Ansys user manuals or datasheets during simulation setup. The number of peer-reviewed academic journal articles is still limited.

6.5

KNOWLEDGE AND UNDERSTANDING

Marks will be awarded for the accuracy of your description of the concepts and principles of EMW and how this relates to the design used.



Demonstrates excellent, detailed knowledge and critical understanding of EM wave theory, cut-off

20

frequency, and antenna design. Accurately calculated cut-off frequencies. Solid awareness of how waveguide and antenna design parameters affect performance. Expand on how properties like material permittivity and permeability influence propagation delay, wave impedance, and field distributions. Could improve by providing more contextualised explanations linked to the specific design simulated.

COGNITIVE AND INTELLECTUAL

Marks will be awarded for the quality and validity of your interpretation of the experimental results gathered. You should consider the differences between the simulated and theoretical and explain possible causes for them.



Provides some critical evaluation and analysis of the concepts and principles of electromagnetic radiation. The antenna frequency mismatch is correctly identified and partially explained. Demonstrates good analytical thinking in comparing Teflon vs. vacuum performance. However, there is limited discussion of simulation tolerances. The discussion would benefit from deeper critical analysis of discrepancies and potential numerical sources of error. Consider including a table comparing theoretical and simulated cutoff/resonant frequencies with percentage errors.

19.5

PRACTICAL SKILLS

Marks will be awarded for the use of the available tools, models and techniques to explain your results and their relationship to the theory of the concepts.



Demonstrates advanced application of a range of established methods, materials, tools, and techniques. Shows excellent use of HFSS to simulate both waveguide and antenna behaviour, effectively applying gamma plots, vector/magnitude overlays, and port field displays. Consistently applies theory to practice in an accurate and logical manner, with well-developed links between the two. The analysis would be improved by justifying specific design choices and including more detail on HFSS configuration.

15.8

TRANSFERABLE SKILLS FOR LIFE

This section will be assessed based on the employability skills gained, written and presentational quality of the report. Style, structure, grammar, spelling etc..



Communicates professionally and consistently using a medium appropriate for the intended audience. The work is coherent, highly fluent, and presented proficiently. The report has a clear structure with effective use of figures, tables, and headings. Report is well structured with logical flow. Writing is technically good, and explanations are mostly professional and focused. A thorough proofread is recommended to address minor grammatical and formality issues (e.g., “permittivity” should be “permittivity”). Abstract and conclusion are clear but could be more concise and technically focused.

16.8