

EMR Lab Report Final

by James Cawte

Submission date: 25-Apr-2025 10:56AM (UTC+0100)

Submission ID: 256584451

File name: 52013_James_Cawte_EMR_Lab_Report_Final_659657_1174517704.docx (6.16M)

Word count: 2779

Character count: 13731



UWTSD
Ordnance Munitions & Explosives

BEng

Academic Year 2024 - 2025

James Cawte

Electromagnetic Radiation

© UWTSD 2025. All rights reserved. No part of this publication may be reproduced without the written permission of the copyright owner.

Academic integrity declaration

I declare that:

- the thesis submitted has been written by me alone.
- the thesis submitted has not been previously submitted to this university or any other.
- that all content, including primary and/or secondary data, is true to the best of my knowledge.
- that all quotations and references have been duly acknowledged according to the requirements of academic research.

I understand that to knowingly submit work in violation of the above statement will be considered by examiners as academic misconduct.

Contents



Academic integrity declaration	2
Table of Figures	5
Table of Equations	7
Abstract	8
Introduction	9
Background	9
Section 1 – Waveguide	9
1.1 – Method	9
1.2 – Results	10
1.3 – Calculations	23
1.4 – Conclusions	23
1.5 – Teflon Method	24
1.6 – Teflon Results	24
1.7 – Teflon Calculations	36
1.8 Teflon Conclusions	37
Section 2 – Dipole Antenna	38
2.1 – Method	38
2.2 – Results	38
2.3 – Calculations	40
2.4 – Conclusions	41
References	42



Table of Figures



Figure 1 - Waveguide Simulated Cutoff Frequency.....	10
Figure 2 - Port 1, Mode 1 ($m=1$ $n=0$).....	11
Figure 3 - Port 1, Mode 2 ($m=2$ $n=0$).....	12
Figure 4 - Port 1, Mode 2 ($m=3$ $n=0$).....	13
Figure 5 - Vacuum, Mode 1 E-Field Heat Map.....	13
Figure 6 - Vacuum, Mode 1 E-Field Direction	14
Figure 7 - Vacuum, Mode 1 H-Field Heat Map.....	15
Figure 8 - Vacuum, Mode 1 H-Field Direction	16
Figure 9 - Vacuum, Mode 2 E-Field Heat Map.....	17
Figure 10 - Vacuum, Mode 2 E-Field Direction	18
Figure 11 - Vacuum, Mode 2 H-Field Heat Map.....	19
Figure 12 - Vacuum, Mode 2 H-Field Direction	20
Figure 13 - Vacuum, Mode 3 E-Field Heat Map.....	20
Figure 14 - Vacuum, Mode 3 E-Field Direction	21
Figure 15 - Vacuum, Mode 3 H-Field Heat Map.....	22
Figure 16 - Vacuum, Mode 3 H-Field Direction	22
Figure 17 - Teflon Gamma Plot	24
Figure 18 - Teflon, Mode 1, E-Field.....	25
Figure 19 - Teflon, Mode 1, E-Field Direction.....	26
Figure 20 - Teflon, Mode 1, H-Field	27
Figure 21 - Teflon, Mode 1, H-Field Direction	28

Figure 22 - Teflon, Mode 2, E-Field.....	29
Figure 23 - Teflon, Mode 2, E-Field Direction.....	30
Figure 24 - Teflon, Mode 2, H-Field	31
Figure 25 - Teflon, Mode 2, H-Field Direction	32
Figure 26 - Teflon, Mode 3, E-Field.....	33
Figure 27 - Teflon, Mode 3, E-Field Direction.....	34
Figure 28 - Teflon, Mode 3, H-Field	35
Figure 29 - Teflon, Mode 3, H-Field Direction	36
Figure 30 - Dipole Antenna being Constructed	38
Figure 31 – Excitation being added.....	39
Figure 32 - Scope of the simulation.....	39
Figure 33 - S Parameter Plot.....	40
Figure 34 - Graphical representation of emission.....	40

Table of Equations

Equation 1 - Cutoff Frequency	23
Equation 2 - Length of a Dipole	38
Equation 3 - Frequency, Speed, Wavelength	40

Abstract

A rectangular waveguide was constructed in a simulation program and then 3 modes were simulated passing through it. These were then visualized providing evidence that some instances of simulation the wave guide functioned and clearly transported the wave along its length. The cutoff frequencies were theoretically calculated and then generated from the simulation to get very similar values for all 3 modes. Once this had been completed the waveguide was altered to contain a Teflon fill instead of vacuum to investigate how this would alter the cutoff frequencies. The result of this was significantly reduced cutoff frequencies due to the slower speed of light through the medium. However, there were larger discrepancies between the theoretical values and simulated values for cutoff frequencies.

A dipole antenna was constructed in the same software and set to emit in a controlled region of the simulation. This provided a visual aid to the emission pattern of a dipole antenna. Using data extracted from the simulation the operating frequency was compared to the theoretically calculated one but there was significant difference between the values. Reasons for this could include the simulation not being accurate to real world scenarios.

Introduction

Section 1 of this document will cover the process and results of creating a virtual rectangular waveguide with perfect electric conductor walls and a vacuum fill. This was simulated to produce results used to visualize cutoff frequencies. This was then repeated with a Teflon fill to compare against. Section 2 covers the design of a dipole antenna simulation used to obtain a radiation pattern.

Background

Waveguides are pieces of hardware designed to guide waves into a specific place and direction [1]. These come in many forms such as rectangular or cylindrical which act similarly to pipes for signals. There are optical waveguides which rely on reflecting signals along line of sight to where they need to be. Similarly, fiber optic cables are a type of waveguide relying on total internal reflection.

Antennae receive and transmit signals. There are a wide range of antennae such as dipoles which are discussed in this document, Yagi-Uda arrays, parabolic dishes and helical antenna which are used in satellites [2].

Antennae and waveguides both interact with waves on the electromagnetic spectrum and utilize them as a means of communication. Most common use in communication are radio and microwaves although most other types of EM waves can be used for specific communication purposes [3].

Section 1 – Waveguide

1.1 – Method

The first task was to create a rectangular waveguide in Ansys Electronics with measurements 23mm by 6.5mm by 50mm. The 4 long faces were then assigned as

perfect electric conductors as per the assignment brief. The solution type was edited to High Frequency Structure Simulator to allow for a high frequency wave to be simulated along the waveguide. The transparency of the model was increased to allow for easier viewing of the internals. The 2 end faces were then assigned excitations with 3 modes. This allowed for 3 modes of vibration to be tested simultaneously. The fullport impedance was set to 50 ohms. These excitations were then verified visually on the model. Next, a solution was set up to run the simulation and gather results. A suitable number of passes for the simulation were selected and the frequency band it would sweep was set from 2 GHz to 30 GHz to ensure the cutoff frequency would be included. The solution was validated and run to produce results.

1.2 – Results

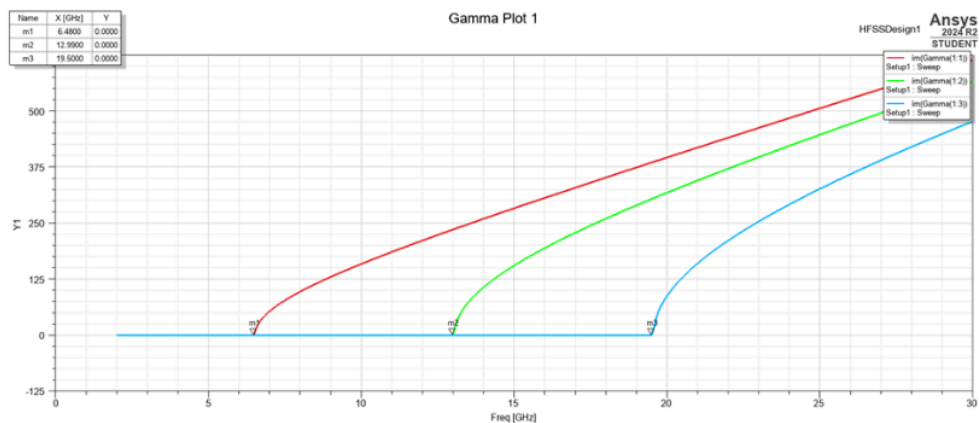


Figure 1 - Waveguide Simulated Cutoff Frequency

This graph shows the exact values for the cutoff frequency f_c . According to the simulation data, mode 1 has a cut of frequency of **6.48 GHz**. Mode 2 has a cutoff frequency of **12.99 GHz**. Mode 3 has a cutoff frequency of **19.50 GHz**.

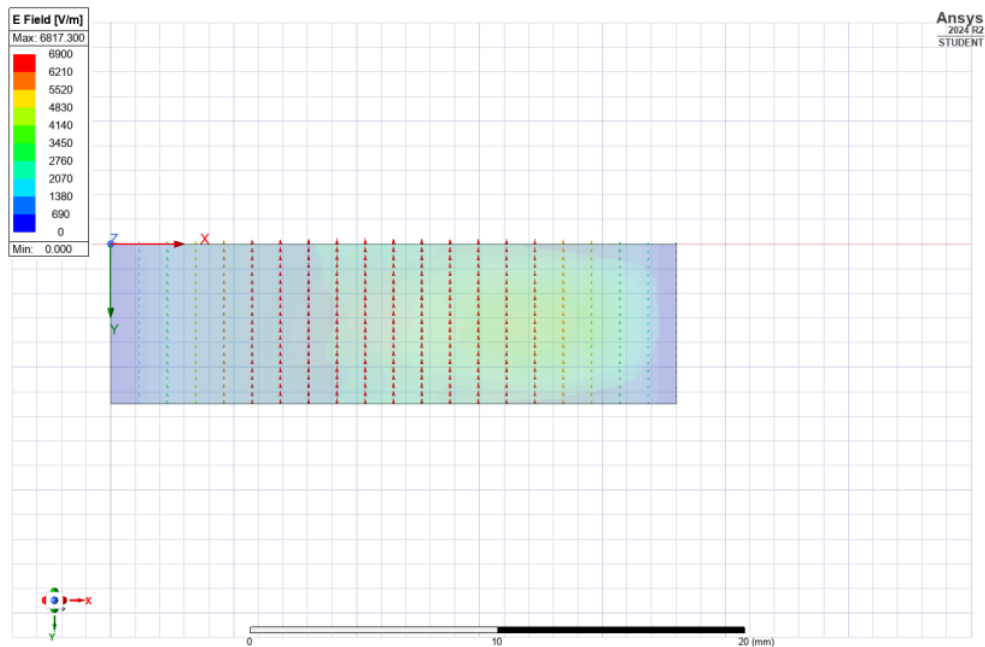


Figure 2 - Port 1, Mode 1 ($m=1$ $n=0$)

This figure shows mode 1 for the vacuum filled waveguide with half a wavelength horizontally and no wavelength vertically. This means that for later use in equations $m=1$ and $n=0$.

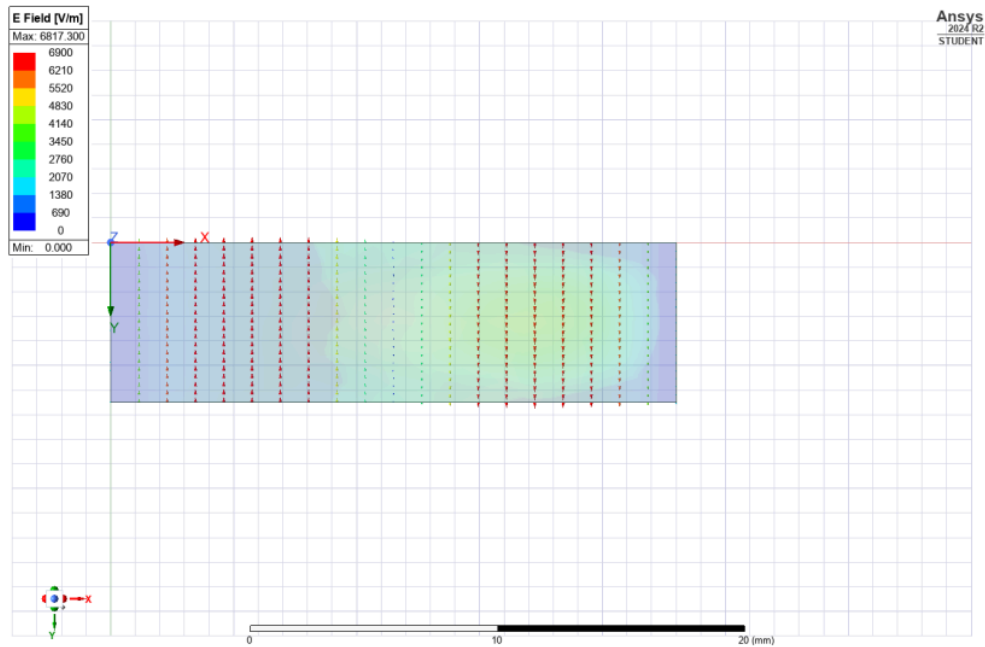
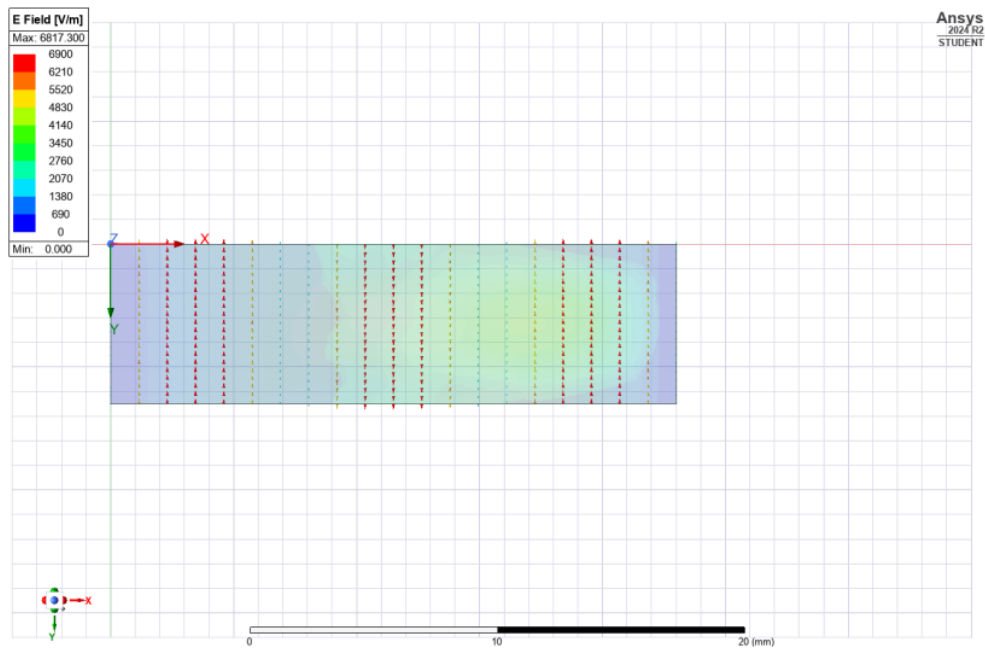


Figure 3 - Port 1, Mode 2 ($m=2$ $n=0$)

This figure shows mode 2 for the vacuum filled waveguide. There is one full wavelength visible due to the directional arrows meaning that $m=2$ and $n=0$ as there are no wavelengths vertically.



This figure shows mode 3 for the waveguide. Visible horizontally are three half wavelengths and no vertical wavelengths meaning $m=3$ and $n=0$ for the calculations.

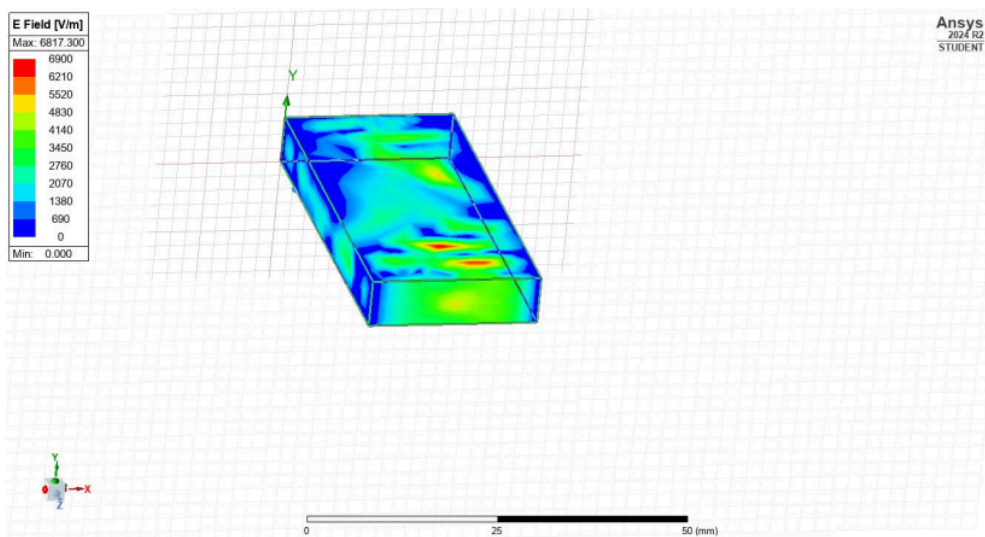


Figure 5 shows the electric field strength along the waveguide. The areas of higher electric field strength will be points of major energy transfer due to the geometry of the waveguide. If this was a real-world waveguide and not a simulation then these points could be expected to heat up. At the end of the waveguide there is the approximate shape of the mode being propagated through the waveguide showing it functions to some degree.

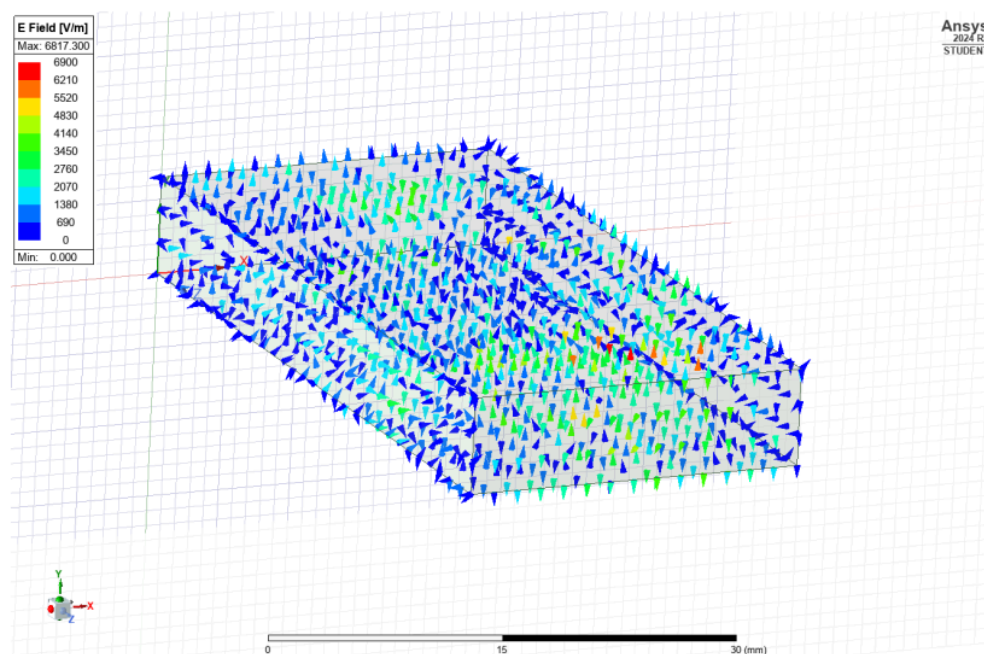


Figure 6 - Vacuum, Mode 1 E-Field Direction

This visualization shows the directions of the electric field strength throughout the waveguide.

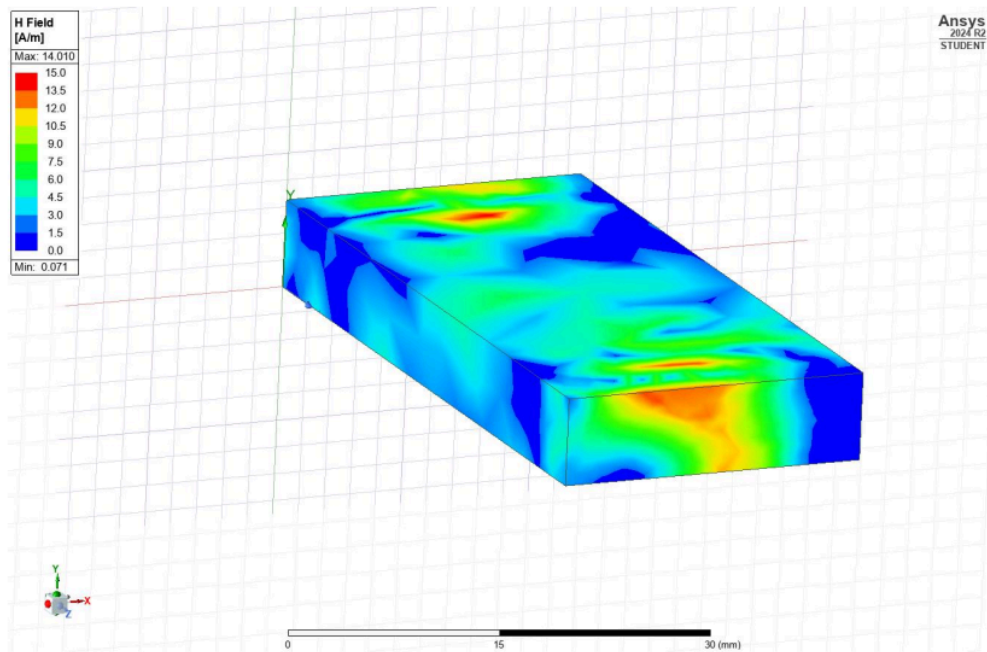


Figure 7 - Vacuum, Mode 1 H-Field Heat Map

This figure shows the waveguide with mode 1 being passed through it. This is a visual representation of the magnetic field intensity. An increased magnetic field intensity would induce larger current due to faradays law [4]. This needs considering in real world applications where unknown induction of current could cause issues for equipment.

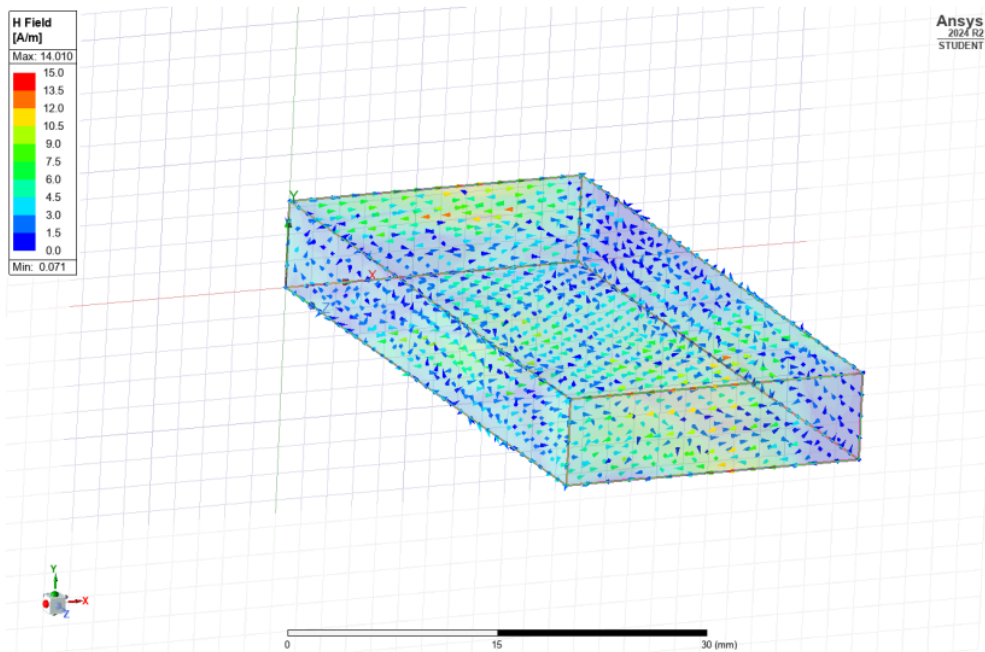


Figure 8 - Vacuum, Mode 1 H-Field Direction

This figure represents the direction of the magnetic field at all points along the waveguide.

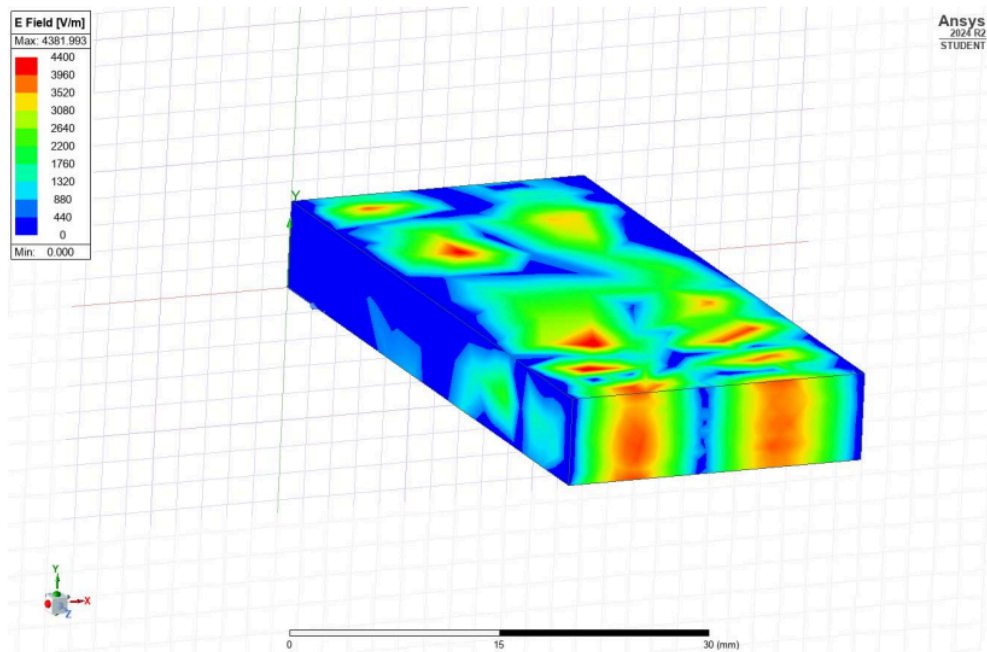


Figure 9 - Vacuum, Mode 2 E-Field Heat Map

This image show the electric field strength for the waveguide being simulated for mode 2. This mode is clearly visible at the port of the waveguide with the areas of high field strength corresponding to the areas of maximum amplitude in Figure 3. This is a more typical waveguide field however there are still unexpected areas of low electric field strength. These are likely due to the dimensions of the waveguide.

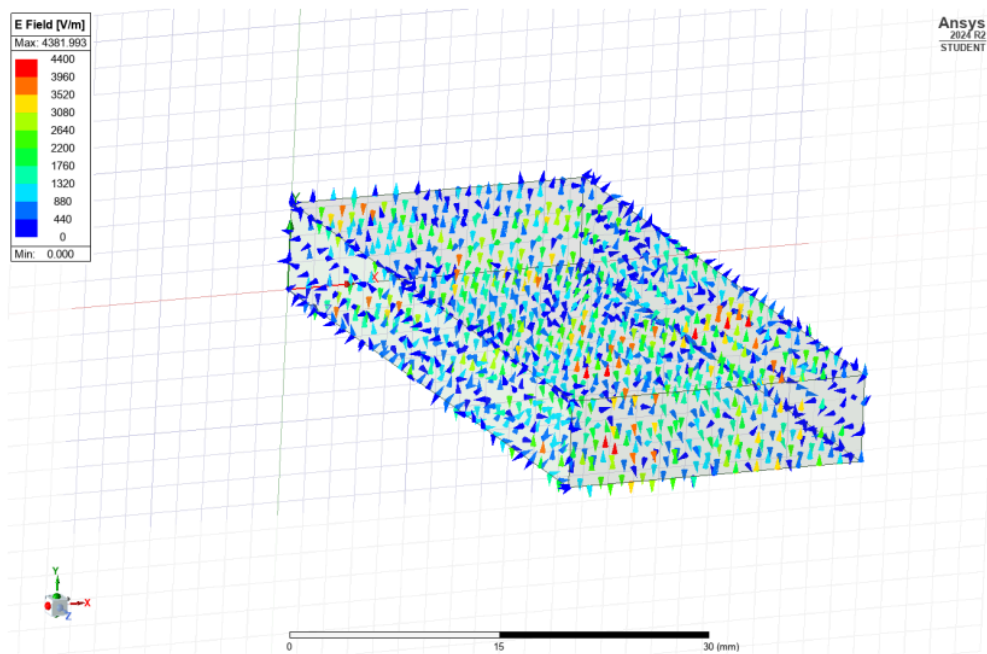


Figure 10 - Vacuum, Mode 2 E-Field Direction

This figure shows the direction of the electric field for mode 2. Noteworthy is the end of the waveguide where the directions of the E-field correspond to the directions of the mode in Figure 3.

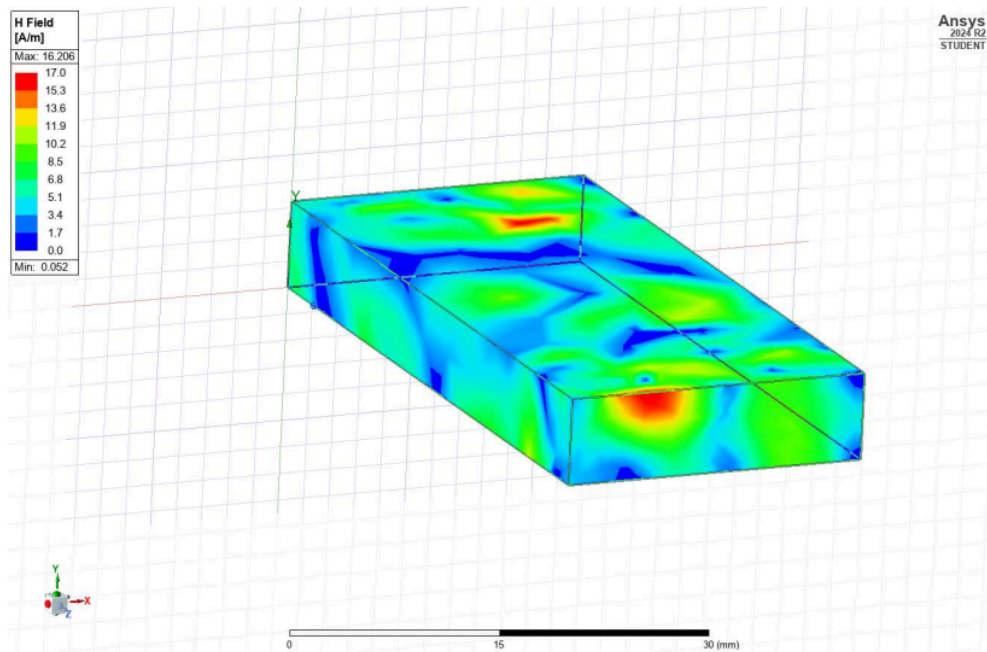


Figure 11 - Vacuum, Mode 2 H-Field Heat Map

This image shows the magnetic field intensity for mode 2 with obvious focus points at both ends. These are likely to induce current. The end of the waveguide almost corresponds to the mode being passed through it.

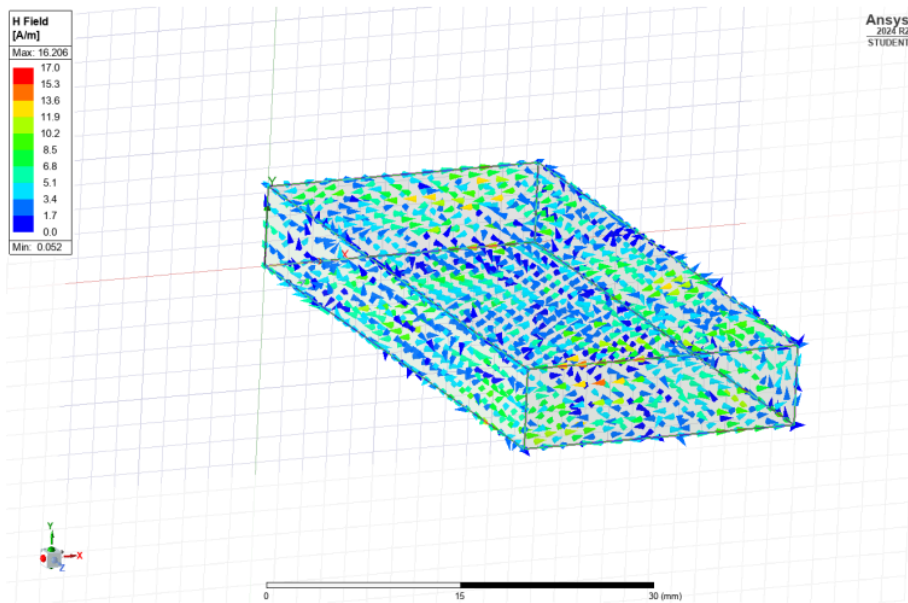


Figure 12 - Vacuum, Mode 2 H-Field Direction

This shows the direction of the magnetic field intensity for mode 2.

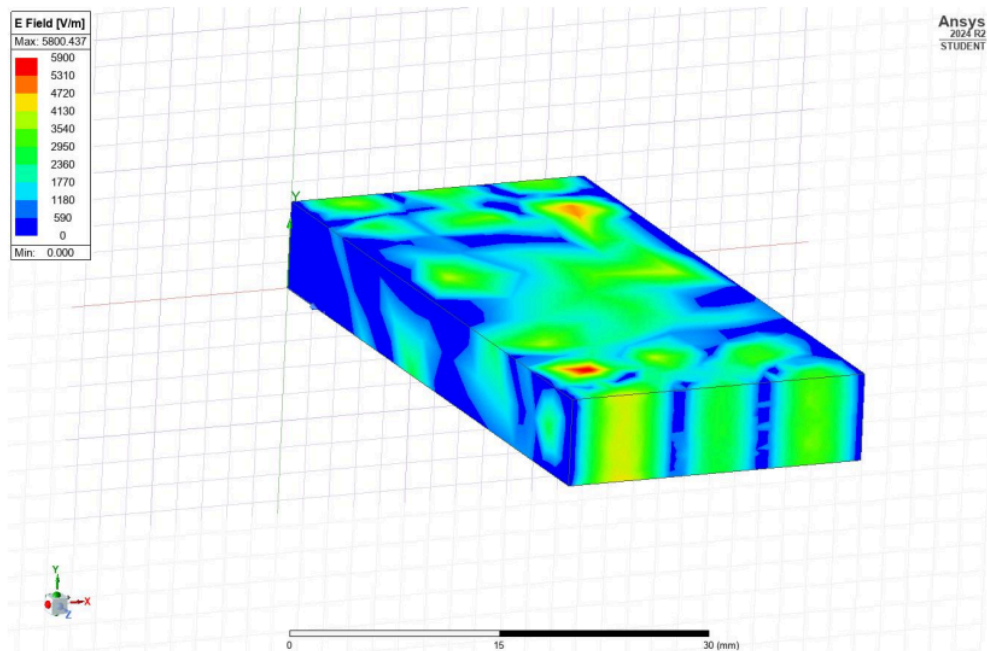


Figure 13 - Vacuum, Mode 3 E-Field Heat Map

This figure displays the electric field strength for mode 3. The pattern on the end of the waveguide matches what would be expected based on the mode in Figure 4.

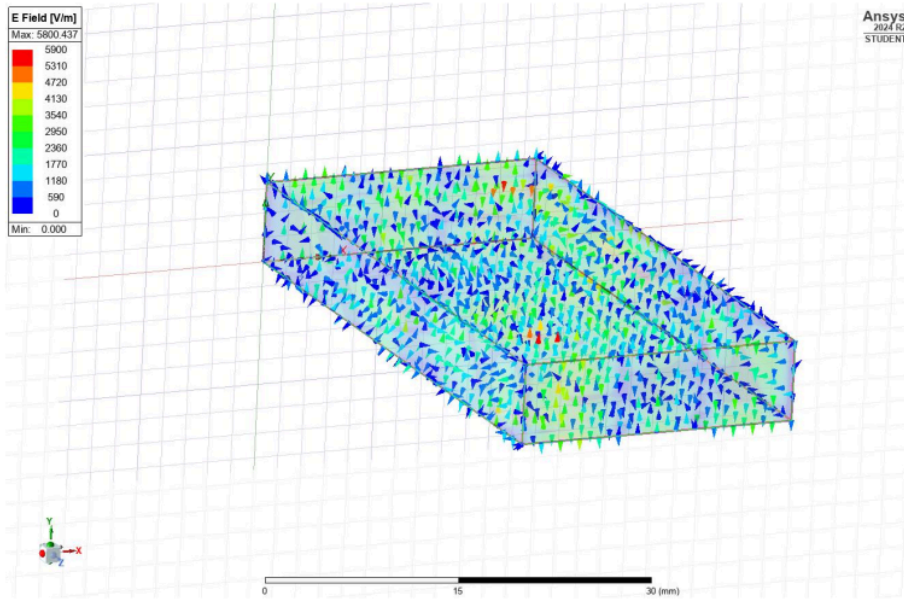
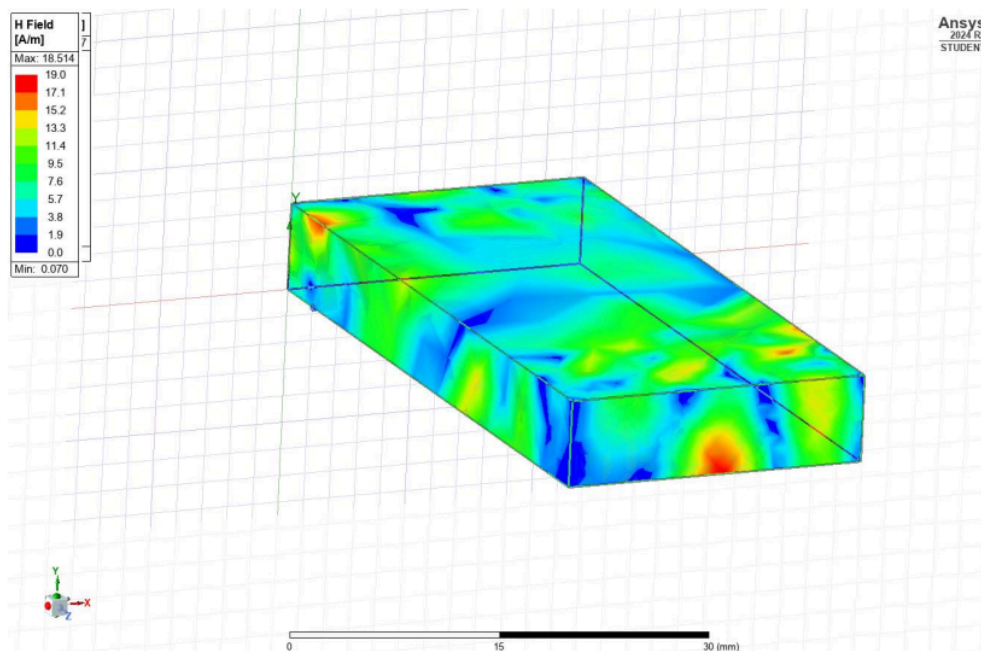
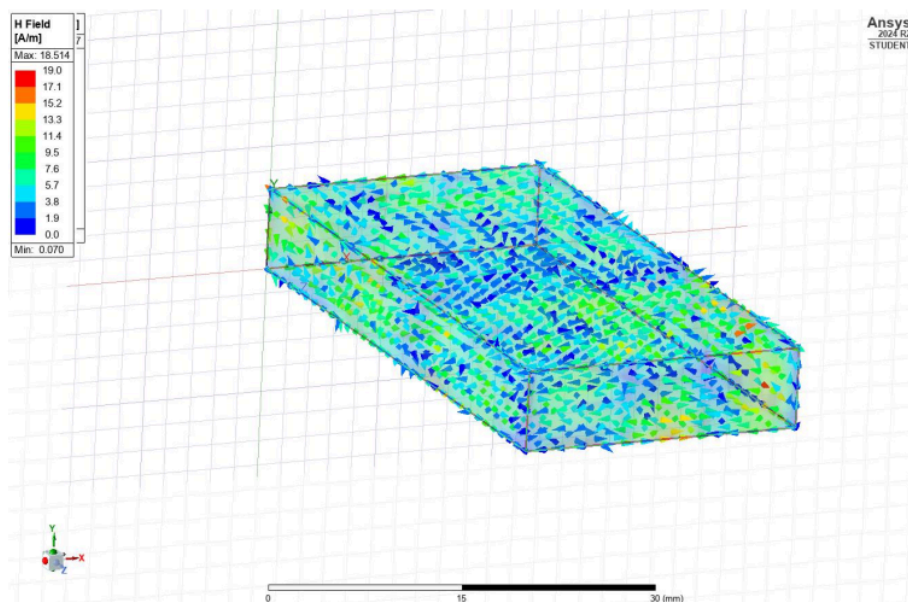


Figure 14 - Vacuum, Mode 3 E-Field Direction

This figure shows the direction of the electronic field for mode 3.



This figure shows the magnetic field intensity for mode 3 in the waveguide.



This figure shows the direction of the magnetic field.

1.3 – Calculations

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

Equation 1 - Cutoff Frequency

$$c=3*10^8$$

ϵ_r = permittivity of free space

μ_r = permeability of free space

$$a=23*10^{-3}$$

$$b=6.5*10^{-3}$$

Mode 1

$$m=1$$

$$n=0$$

$$f_c=6521739130 \text{ Hz} = \mathbf{6.52 \text{ GHz (2.d.p)}}$$

Mode 2

$$m=2$$

$$n=0$$

$$f_c=13043478260 \text{ Hz} = \mathbf{13.04 \text{ GHz (2.d.p)}}$$

Mode 3

$$m=3$$

$$n=0$$

$$f_c=19565217390 \text{ Hz} = \mathbf{19.57 \text{ GHz (2.d.p)}}$$

1.4 – Conclusions

The conclusions which can be drawn are that the waveguide does not always function as expected. If the waveguide was achieving its purpose of transferring a wave from one end to the other then the same modal pattern as seen in Figure 2, Figure 3 and

Figure 4 would be seen at the exit port. This is not the case in every one of the graphical representations of the E-field and H-field. Figure 13 and Figure 9 provide an accurate recreation of the mode that was fed in from the other end suggesting that the waveguide works as intended.

The theoretically calculated values for the cutoff frequency are very close to the simulated values (6.48 GHz vs 6.52 GHz for mode 1, 12.99 GHz vs 13.04 GHz for mode 2 and 19.50 GHz vs 19.57 GHz for mode 3). This suggests that the simulation is accurate.

1.5 – Teflon Method

The method to create the Teflon filled waveguide was identical to the method outlined in 1.1 – Method. The only difference is the inside being Teflon instead of vacuum.

1.6 – Teflon Results

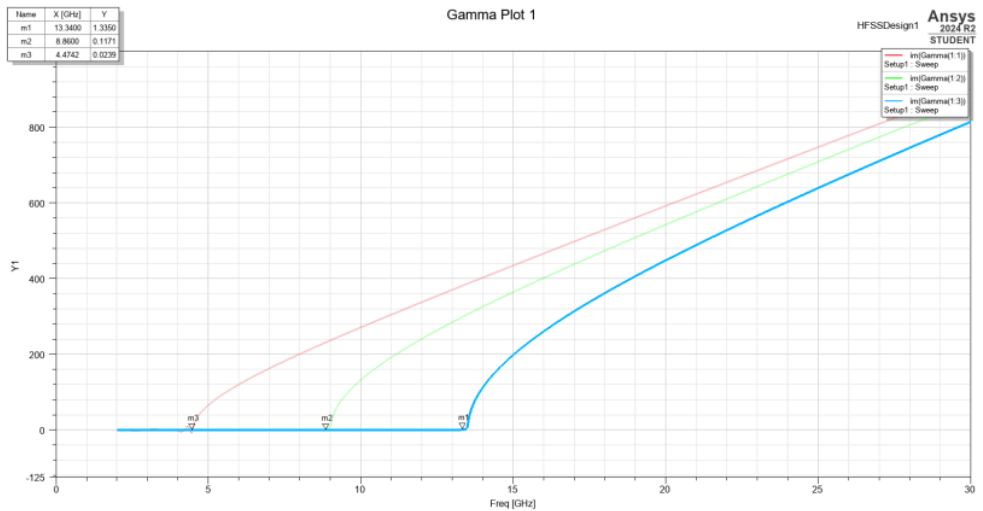


Figure 17 - Teflon Gamma Plot

This graph shows the simulated cutoff frequencies for all 3 modes in a Teflon waveguide. Mode 1 is **4.47 GHz**, mode 2 is **8.86 GHz** and mode 3 is **13.34 GHz**.

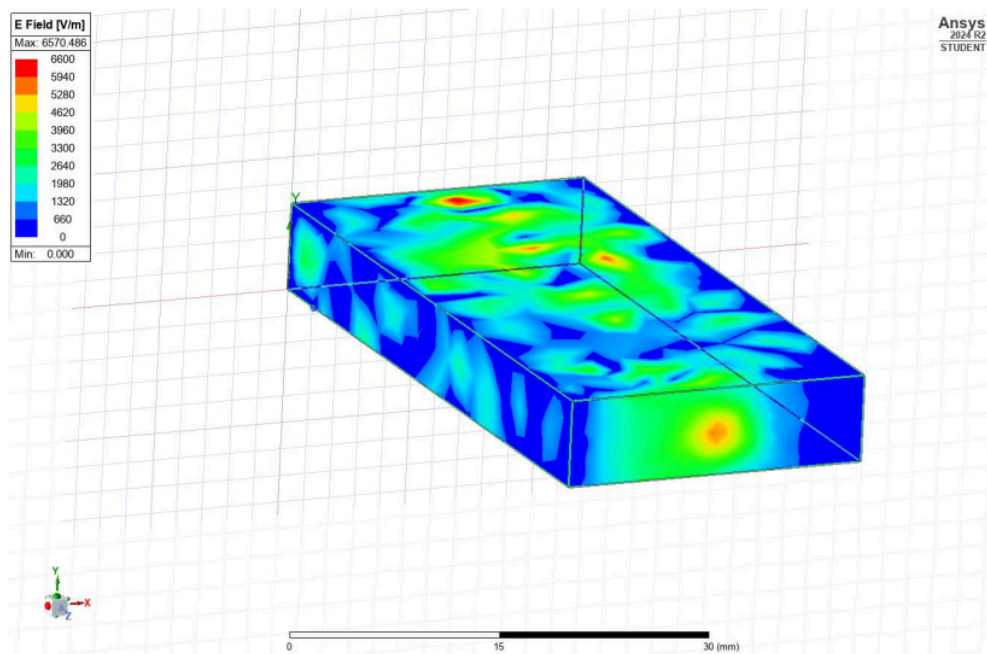


Figure 18 - Teflon, Mode 1, E-Field

This figure shows the electric field strength on the Teflon waveguide. The pattern lines up with what would be expected from mode 1.

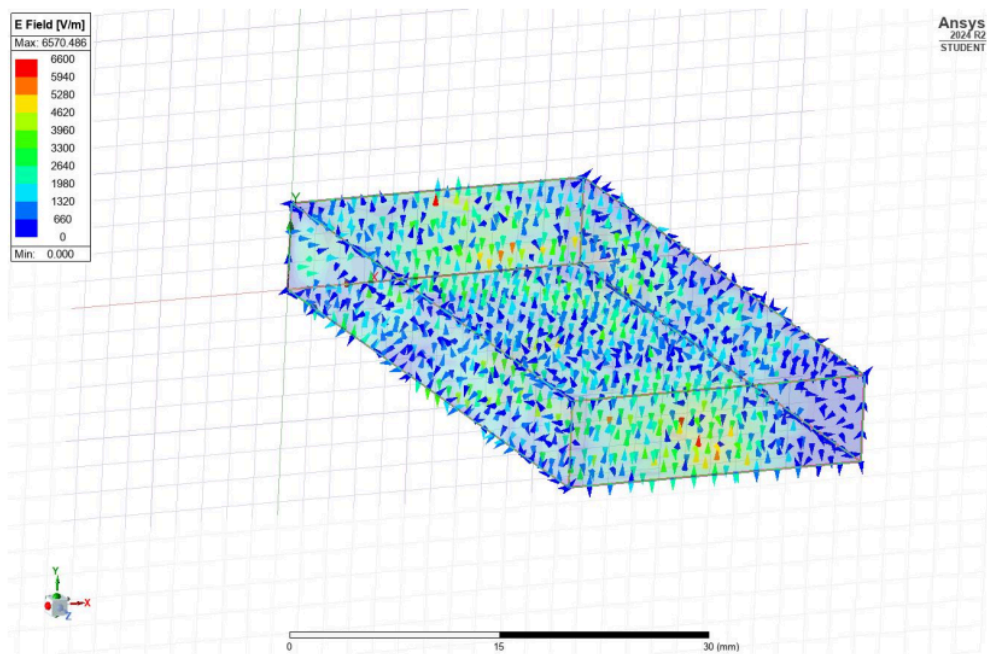


Figure 19 - Teflon, Mode 1, E-Field Direction

This figure shows the direction of the electric field for mode 1.

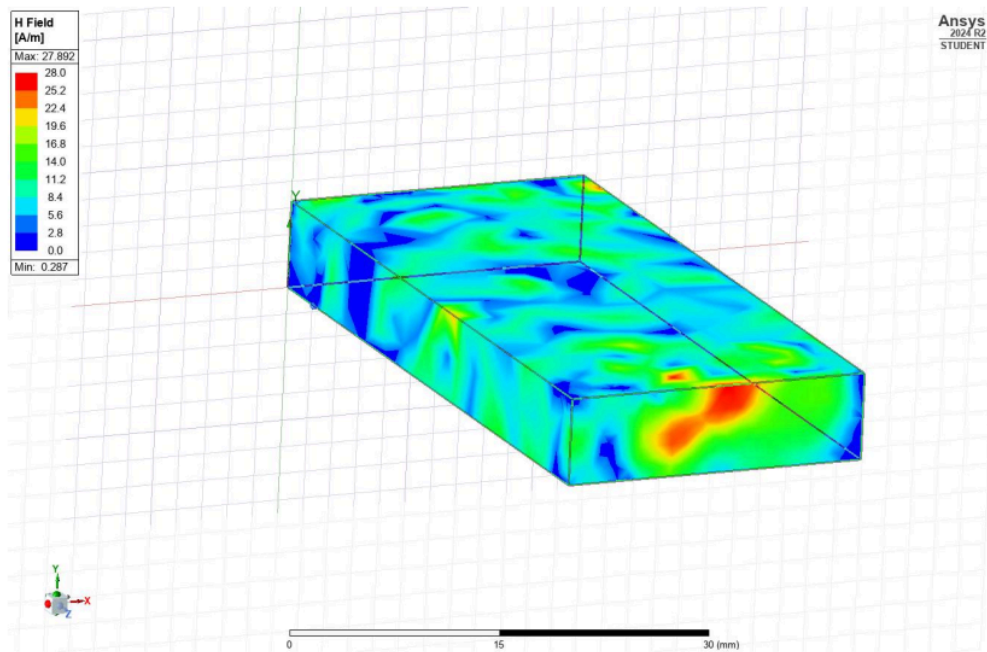


Figure 20 - Teflon, Mode 1, H-Field

This figure shows the magnetic field intensity. The pattern of high and low intensity matches the mode.

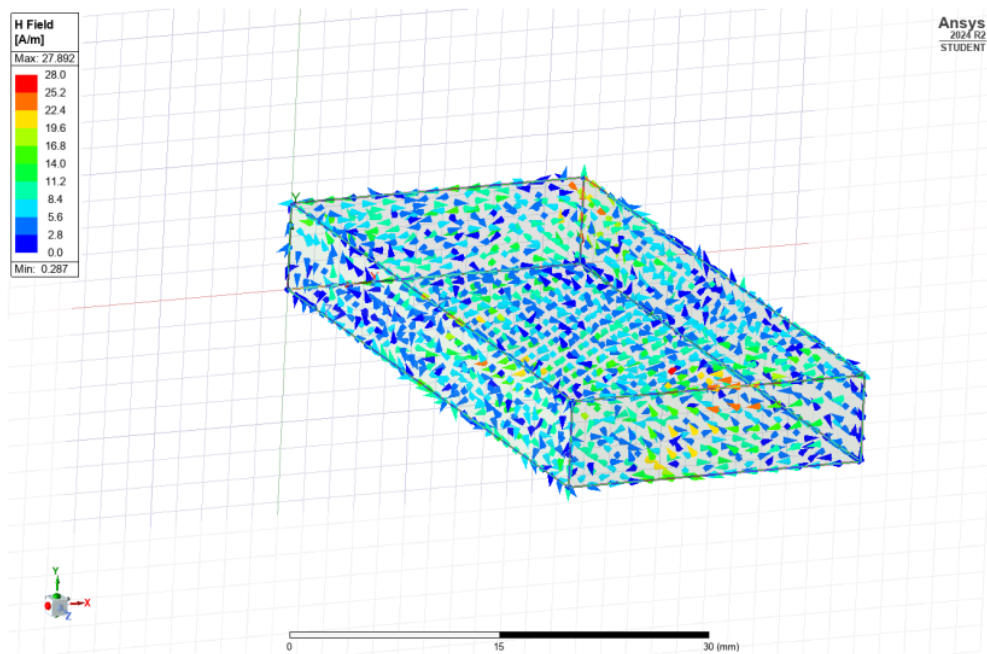


Figure 21 - Teflon, Mode 1, H-Field Direction

This figure shows the direction of the magnetic field for mode 1.

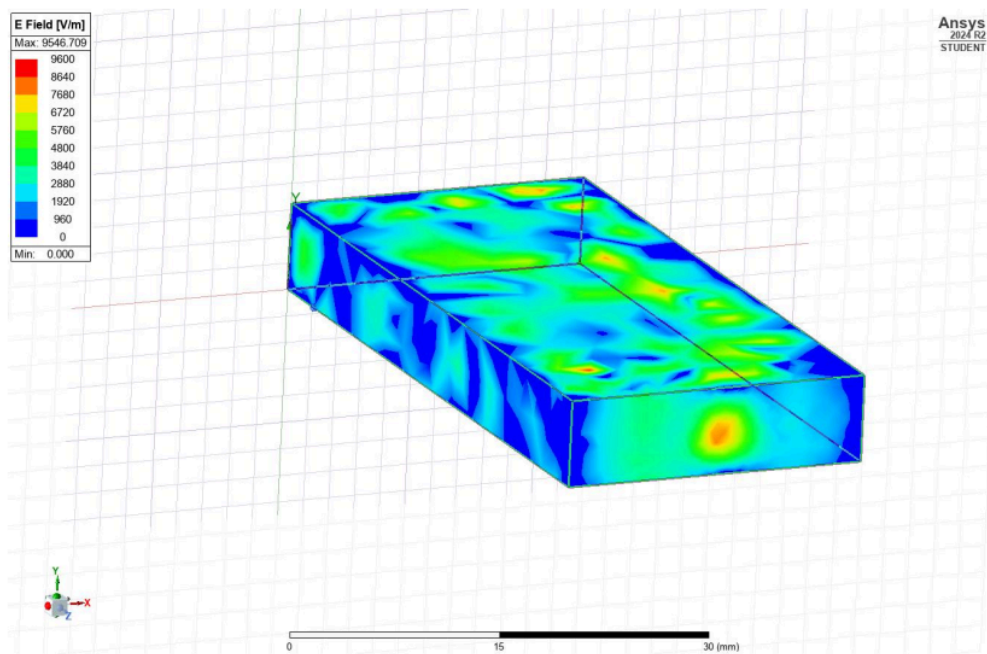


Figure 22 - Teflon, Mode 2, E-Field

This figure shows the electric field strength for mode 2 and the pattern does not match what would be expected.

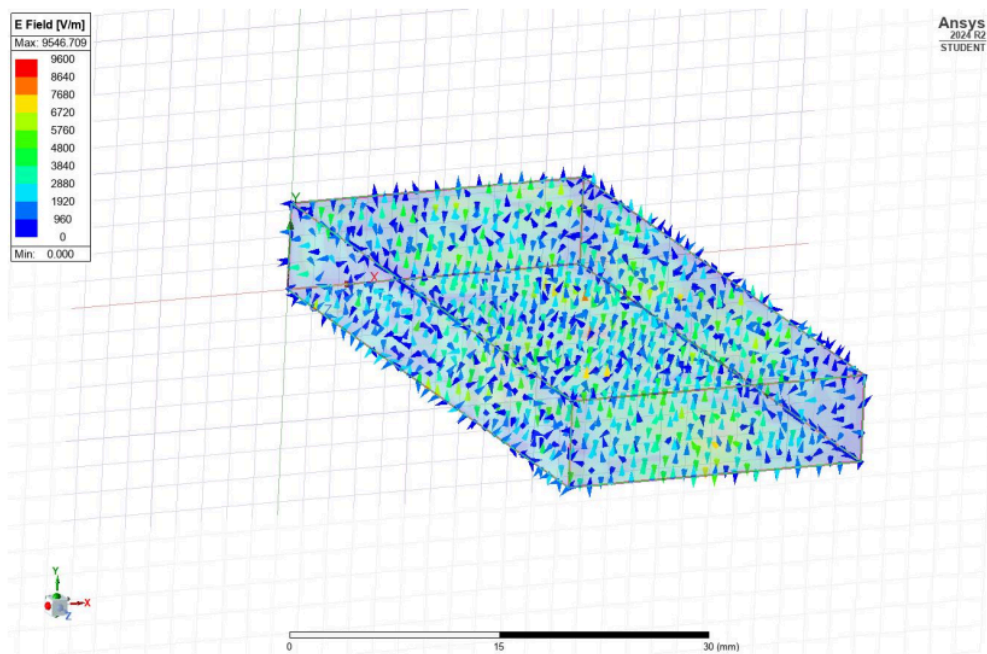


Figure 23 - Teflon, Mode 2, E-Field Direction

This figure shows the direction of the electric field for mode 2.

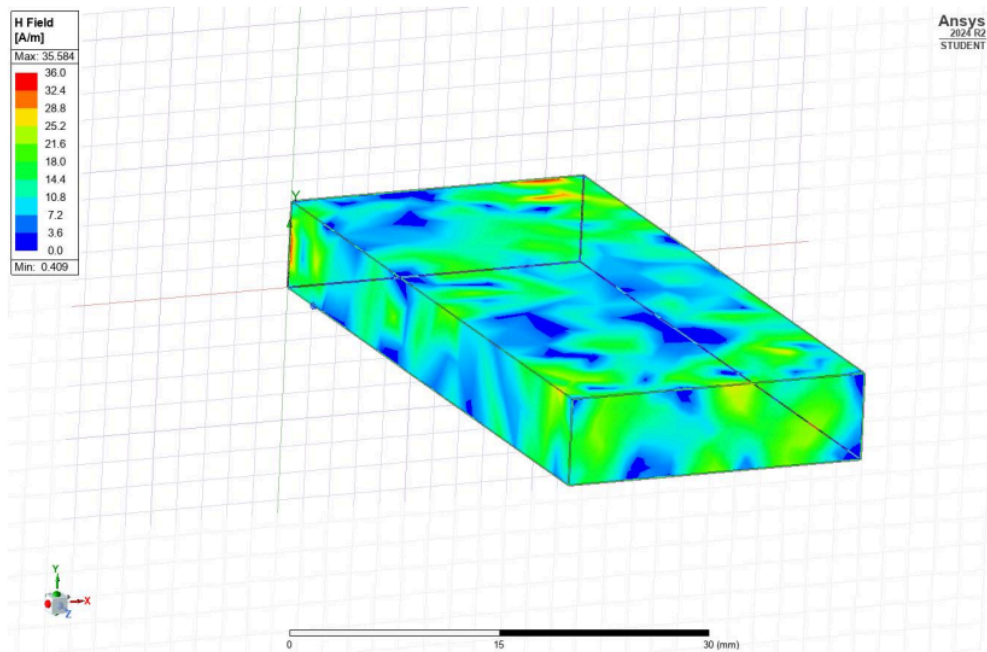


Figure 24 - Teflon, Mode 2, H-Field

This figure shows the magnetic field intensity for mode 2. This does not match the pattern of mode 2 and is likely caused by the geometry of the waveguide.

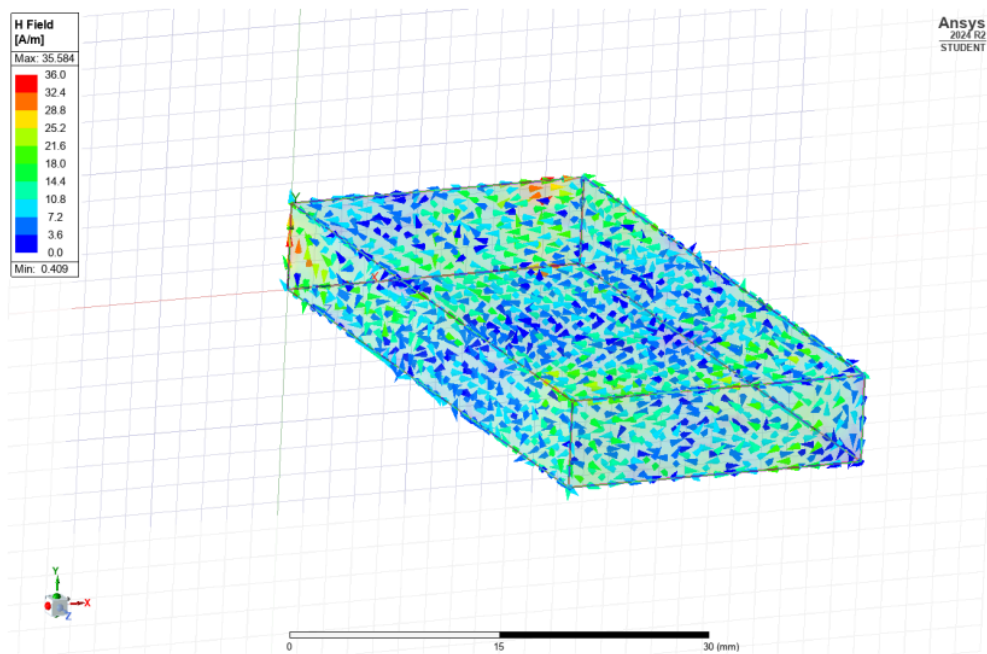


Figure 25 - Teflon, Mode 2, H-Field Direction

This figure shows the direction of the magnetic field for mode 2.

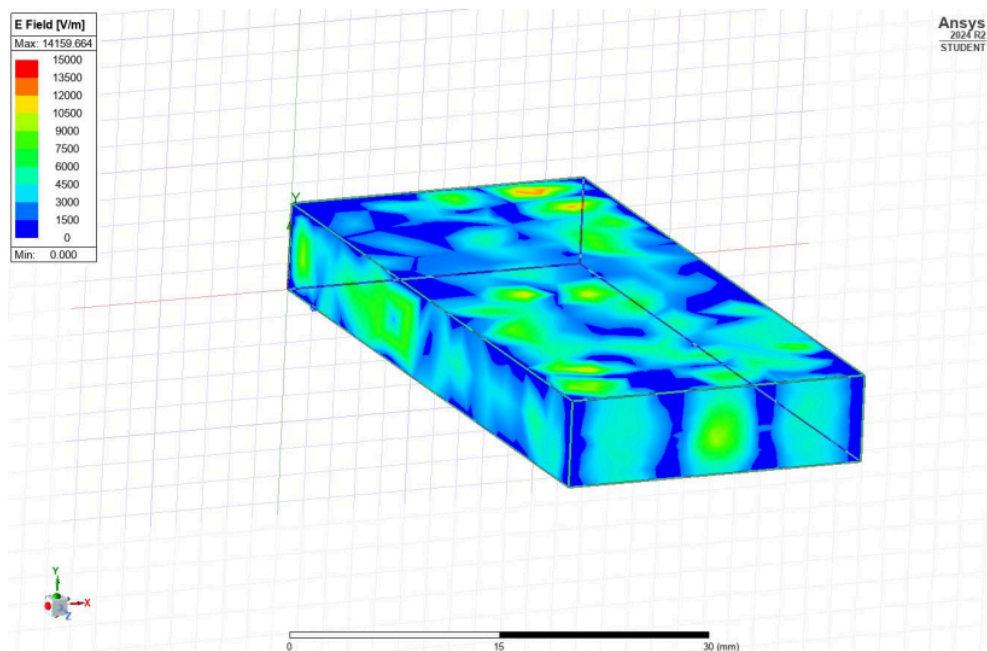


Figure 26 - Teflon, Mode 3, E-Field

This figure shows the electric field strength for mode 3. The pattern produced by the simulation matches what would be expected from mode 3.

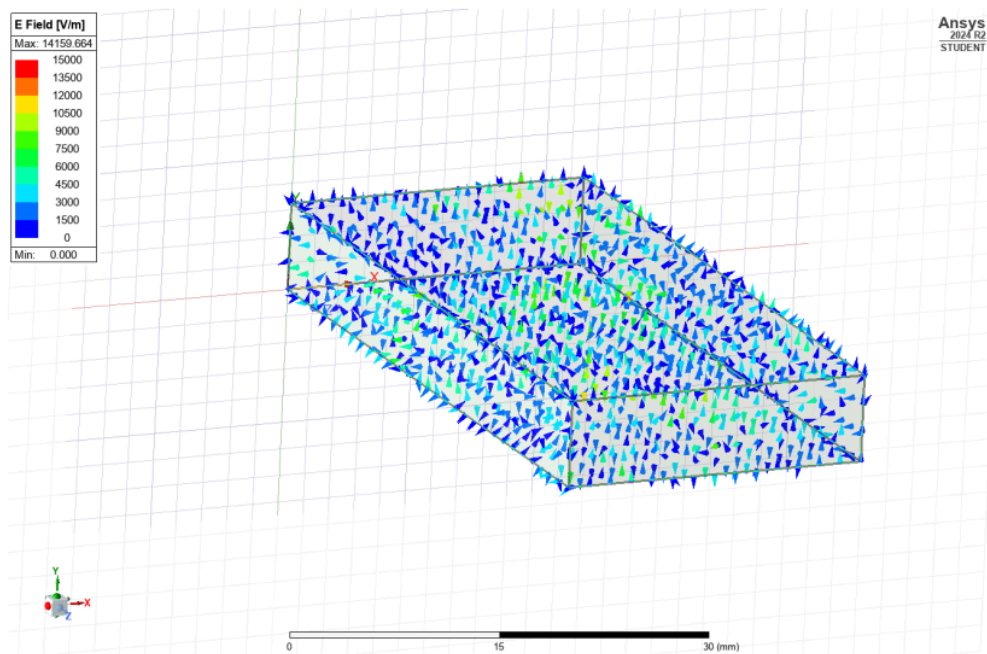


Figure 27 - Teflon, Mode 3, E-Field Direction

This graphic shows the direction of the electronic field for mode 3.

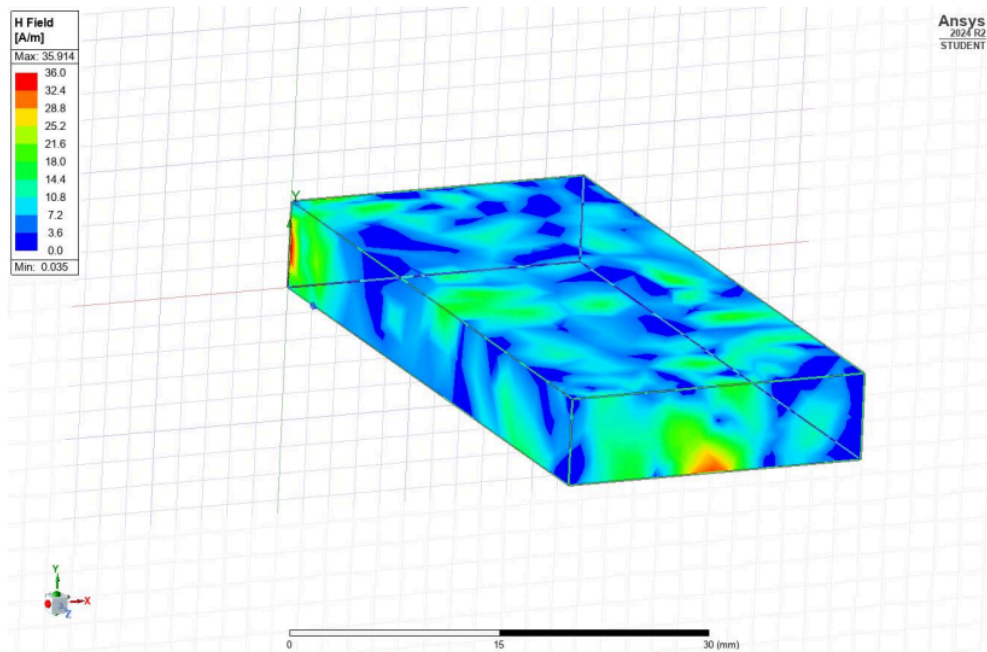


Figure 28 - Teflon, Mode 3, H-Field

This figure shows the magnetic field intensity for mode 3. The pattern produced partially matches what would be expected but does not fully match the pattern of mode 3 meaning the wave is not traveling along the waveguide properly.

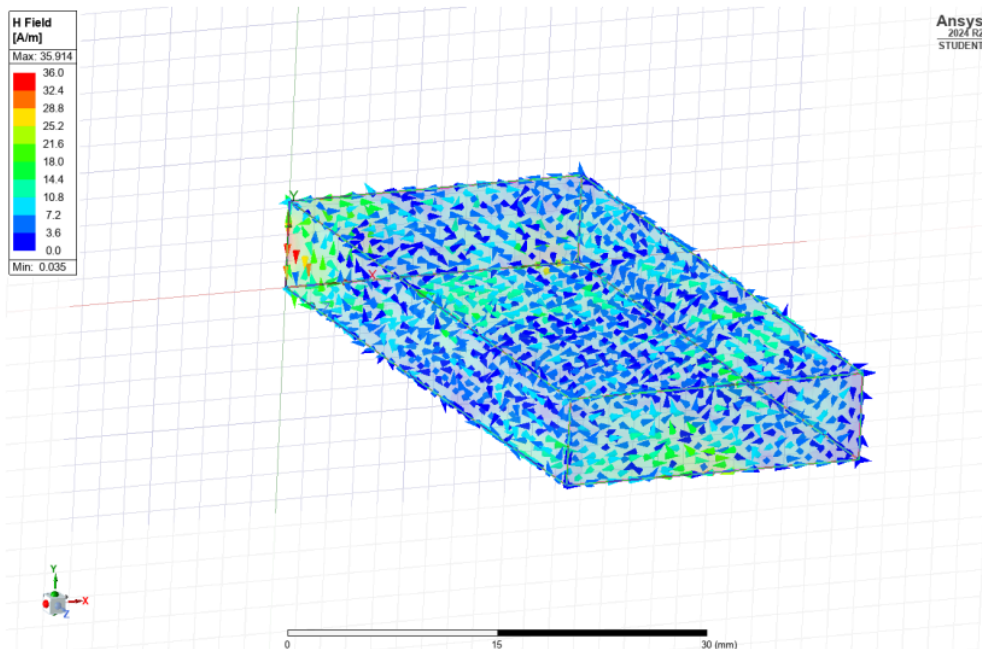


Figure 29 - Teflon, Mode 3, H-Field Direction

This figure shows the direction of the magnetic field for mode 3.

1.7 – Teflon Calculations

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

Equation 1 - Cutoff Frequency

$$c = 3 \times 10^8$$

$$\epsilon_r = \text{permittivity of Teflon} = 2.1 \text{ [5]}$$

$$\mu_r = \text{permeability of Teflon} = 1$$

$$a = 23 \times 10^{-3}$$

$$b = 6.5 \times 10^{-3}$$

Mode 1

$$m = 1$$

$n=0$

$f_c=4500427561 \text{ Hz} = \mathbf{4.50 \text{ GHz}}$

Mode 2

$m=2$

$n=0$

$f_c=9000855122 \text{ Hz} = \mathbf{9.00 \text{ GHz}}$

Mode 3

$m=3$

$n=0$

$f_c=13501282680 \text{ Hz} = \mathbf{13.50 \text{ GHz}}$

1.8 Teflon Conclusions

In conclusion, having a Teflon filling  lead of a vacuum reduced the cutoff frequencies for all modes. This is because the waves travel more slowly through a medium which reduces the wavelength so a lower frequency wave can enter the waveguide and be compressed to the required frequency to propagate through the waveguide [6].

Section 2 – Dipole Antenna

2.1 – Method

To create the dipole antenna, a 1mm radius that was the required length to transmit 231mm waves.

$$L = \lambda / 2$$

Equation 2 - Length of a Dipole

Using Equation 2, the length of the dipole antenna was 115.5mm. Once this was extruded, an excitement was placed at the centre point of the length. Once the antenna was constructed, a solution was created and validated and a simulation run. Once the simulation was completed, the results were extracted into various formats.

2.2 – Results

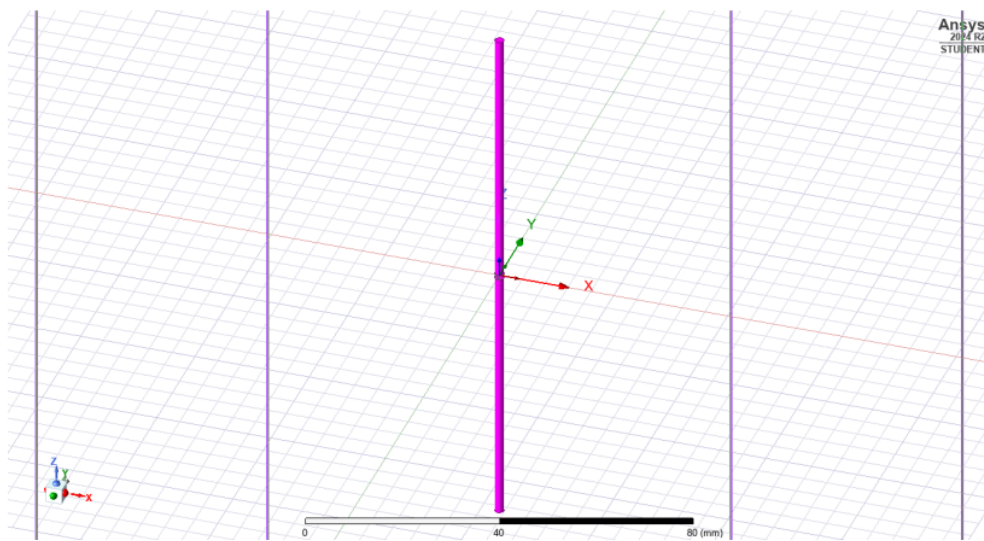


Figure 30 - Dipole Antenna being Constructed

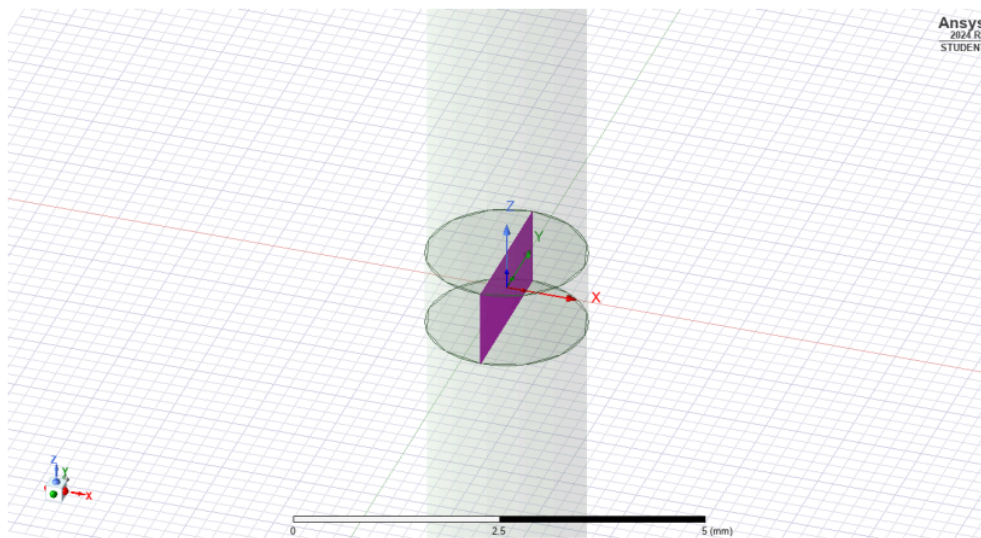


Figure 31 – Excitation being added

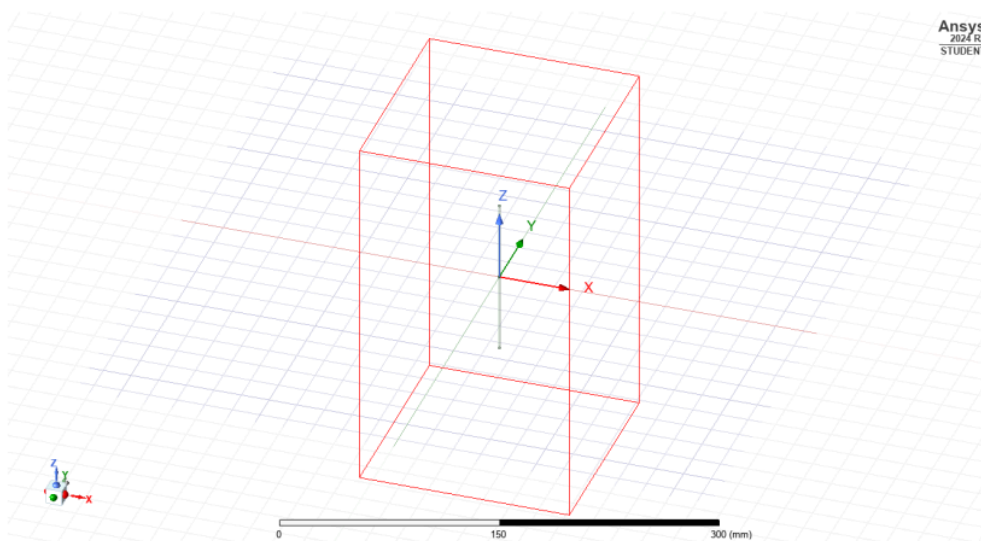


Figure 32 - Scope of the simulation

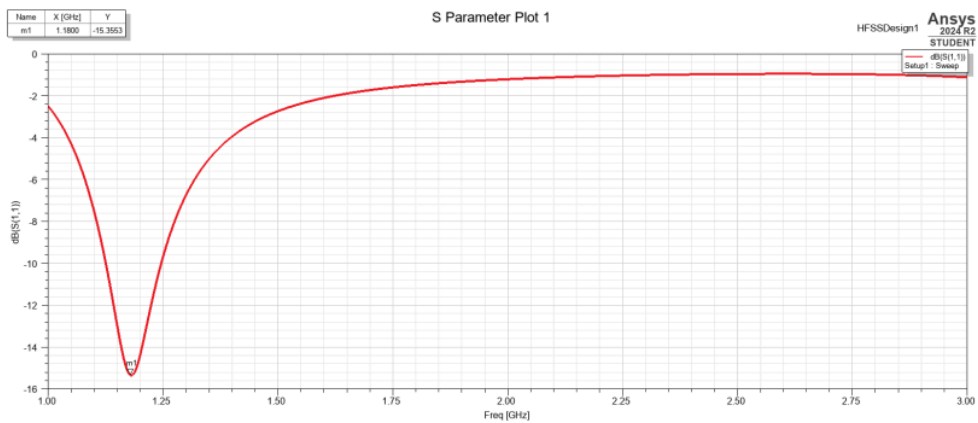


Figure 33 - S Parameter Plot

This S parameter plot suggests that operating frequency will be **1.18 GHz (2.d.p)**.

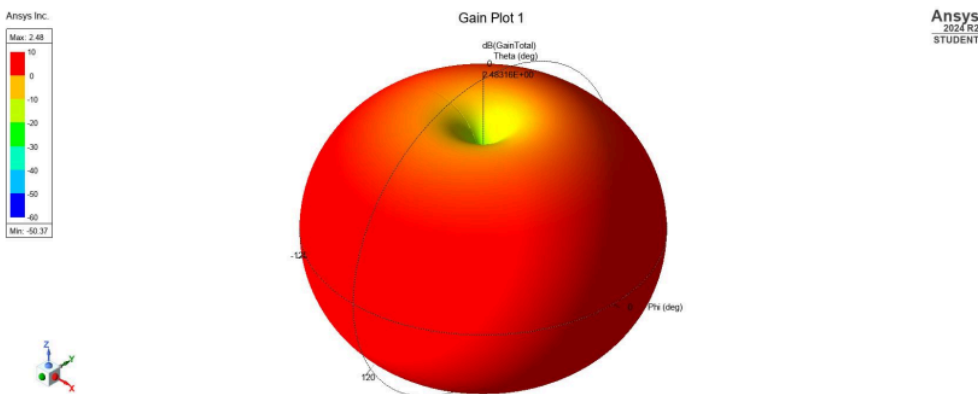


Figure 34 - Graphical representation of emission

2.3 – Calculations

As the length of the dipole is one half wavelength, the operating frequency can be calculated as follows:

$$f = c / \lambda$$

Equation 3 - Frequency, Speed, Wavelength

$$\lambda = 231 \times 10^{-3} \text{ m}$$

$$c = 3 \times 10^8 \text{ ms}^{-1}$$

$f = 1298701299 \text{ Hz} = 1.30 \text{ GHz (2.d.p)}$

2.4 – Conclusions

In conclusion, the dipole antenna will operate at a frequency of 1.18-1.30 GHz and will extend 57.75mm either side of the emitter. The discrepancy in the simulated value and the theoretically worked out value for operating frequency may be attributed to an insufficient simulation. The emission it produces will be cylindrical with uniform emission in a ring around the length with a null at either end.

References

[N. Marcuvitz, in *Waveguide Handbook*, McGraw Hill, 1951.

1

]

[M. R. a. A. B. Abdul Qadir Khan, "Various Types of Antenna with Respect to their
2 Applications: A Review," *INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY*
] *SCIENCES AND ENGINEERING*, vol. 7, no. 3, 2016.

[A. Ishimaru, in *Electromagnetic Wave Propagation, Radiation, and Scattering:*
3 *From Fundamentals to Applications*, John Wiley & Sons, 2017.

]

[S. C. R. a. S. P. Robert Kingman, An experimental observation of Faraday's law of
4 induction, Berrien Springs, Michigan : American, 2000.

]

["The Engineering Tool Box," [Online]. Available:
5 https://www.engineeringtoolbox.com/relative-permittivity-d_1660.html. [Accessed
] 25 04 2025].

[M. Steer, "LibreTexts Engineering," NICE CXone Expert, [Online]. Available:
6 [https://eng.libretexts.org/Bookshelves/Electrical_Engineering/Electronics/Microwa
\] ve_and_RF_Design_II_-
_Transmission_Lines_%28Steer%29/06%3A_Waveguides/6.04%3A_Rectangula
r_Waveguide?utm_source=chatgpt.com](https://eng.libretexts.org/Bookshelves/Electrical_Engineering/Electronics/Microwave_and_RF_Design_II_-_Transmission_Lines_%28Steer%29/06%3A_Waveguides/6.04%3A_Rectangular_Waveguide?utm_source=chatgpt.com). [Accessed 25 04 2025].

EMR Lab Report Final

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

67 /100

PAGE 1

PAGE 2

PAGE 3



Comment 1

Good work

PAGE 4



Comment 2

A page left blank

PAGE 5



Comment 3

Good work

PAGE 6

PAGE 7

PAGE 8

PAGE 9



Comment 4

It is better to number each heading

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

PAGE 21

PAGE 22

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

PAGE 28

PAGE 29

PAGE 30

PAGE 31

PAGE 32

PAGE 33

PAGE 34

PAGE 35

PAGE 36

PAGE 37



Comment 5

It is better to have a conclusion for waveguide together

PAGE 38

PAGE 39

PAGE 40

PAGE 41

PAGE 42

GRADING FORM: EMR-MAY 2025 OME

JAMES CAWTE

67

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.



Engagement with an appropriate range of literature, including sources retrieved independently. References include foundational

5

texts. Referencing shows minor inaccuracies or inconsistencies. Citations are rarely used within the text. Each paragraph discussing a concept or definition should be supported with a citation. Use modern engineering articles or IEEE papers to enhance technical credibility and demonstrate engagement with current research.

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 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.

17.5

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 sound critical evaluation and analysis of key concepts. Simulated and theoretical results

are compared reasonably well, demonstrating effective analytical thinking through valid explanations for discrepancies. However, the analysis is brief and somewhat generalised. To improve, include more discussion of simulation limitations, such as mesh size, boundary effects, or assumptions related to lumped ports. Additionally, calculating and comparing percentage errors between theoretical and simulated results would add further depth.

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.

14.5



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.

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..



Can communicate well, consistently in a suitable medium for the audience. Report is mostly well-organised, with clear sectioning and logical flow. The conclusion is overly list, and doesn't synthesise findings or propose real-world applications. It would have been better if the conclusion for both the waveguide is combined. Proper alignment and uniform font. Conduct a full proofread for clarity.

13