



DESIGN AND ANALYSIS OF ELECTROMAGNETIC SYSTEMS

Electromagnetic Radiation – ACDA5009

Jacob C
2420842@student.uwtsd.ac.uk

Contents

Table of Figures	3
Abstract.....	4
Introduction	4
Task 1	5
Task 1a.....	5
Modelling a Vacuum Core Waveguide	5
Port 1 – Modes.....	6
Port 2 – Modes.....	7
Cutoff Frequency Calculations	8
Task 1b.....	9
Modelling a Teflon Core Waveguide.....	9
Port 1 – Modes.....	10
Port 2 – Modes.....	11
Cutoff Frequency Calculations	12
Comparison of Results	12
Task 2	13
Design and Simulation	13
Gain Pattern	13
S-Parameter Plot.....	15
Discussion	15
Task 3	16
Introduction	16
Advanced Radar Technologies	16
Societal and Environmental Impacts	17
Societal Impacts	17
Ethical Impacts	17
Environmental implications.....	17
Conclusion.....	18
Appendix	18
Vacuum Waveguide.....	18
Mode 1	18
Mode 2	19
Teflon Waveguide	21

Mode 1	21
Mode 2	22
Bibliography.....	24

Table of Figures

Figure 1: Vacuum Filled Waveguide built in CST Studio	5
Figure 2: Port 1 of the Waveguide	5
Figure 3: Port 2 of the Waveguide	6
Figure 4: Port 1 - E Field Mode.....	6
Figure 5: Port 1 – H Field Mode	6
Figure 6: Port 2 – E Field Mode	7
Figure 7: Port 2 – H Field Mode	7
Figure 8: PTFE(Teflon) Filled waveguide built in CST Studio.....	9
Figure 9: PTFE(Teflon) Filled waveguide Port 1	9
Figure 10: PTFE(Teflon) Filled waveguide Port 2	9
Figure 11: Port 1 – E Field Mode.....	10
Figure 12: Port 1 – H Field Mode	10
Figure 13: Port 2 – E Field Mode.....	11
Figure 14: Port 2 – H Field Mode	11
Figure 15: The constructed Dipole antenna, featuring two poles are quarter wavelength and a 0.5mm Vacuum	13
Figure 16: A graph showing the change in gain vs frequency.....	14
Figure 17: The simulated directivity of propagation for the antenna at 2GHz.....	14
Figure 18: The simulated directivity of propagation for the antenna at 16GHz.....	14
Figure 19: The S-Parameter graph showing the optimum operating frequency for the simulated antenna	15
Figure 20: Mode 1, E Field Magnitude of Vacuum Waveguide at 8GHz	18
Figure 21: Mode 1, E Field Vector of Vacuum Waveguide at 8GHz	18
Figure 22: Mode 1, H Field Magnitude of Vacuum Waveguide at 8GHz	19
Figure 23: Mode 1, H Field Vector of Vacuum Waveguide at 8GHz.....	19
Figure 24: Mode 2, E Field Magnitude of Vacuum Waveguide at 8GHz	19
Figure 25: Mode 2, E Field Vector of Vacuum Waveguide at 8GHz	20
Figure 26: Mode 2, E Field Magnitude of Vacuum Waveguide at 8GHz	20
Figure 27: Mode 2, E Field Vector of Vacuum Waveguide at 8GHz	20
Figure 28: Mode 1, E Field Magnitude of Teflon Waveguide at 8GHz	21
Figure 29: Mode 1, E Field Vector of Teflon Waveguide at 8GHz	21
Figure 30: Mode 1, H Field Magnitude of Teflon Waveguide at 8GHz.....	21
Figure 31: Mode 1, H Field Vector of Teflon Waveguide at 8GHz	22
Figure 32: Mode 2, E Field Vector of Teflon Waveguide at 8GHz	22
Figure 33: Mode 2, E Field Magnitude of Teflon Waveguide at 8GHz	22
Figure 34: Mode 2, H Field Vector of Teflon Waveguide at 8GHz	23
Figure 35: Mode 2, H Field Magnitude of Teflon Waveguide at 8GHz.....	23

Abstract

The following report covers the design, simulation, testing and the results of vacuum and Teflon waveguides, as well as the design and analysis of a half-wave dipole antenna. Research into the radar technologies used in the tracking and detection of drones or UAVs, and the environmental and societal impacts of such technologies are also covered.

Introduction

This report is broken up into three tasks;

Task 1 a/b covers the simulation the calculations involved with Teflon and Vacuum cored, rectangular waveguides, detailing the modes, field plots, and the calculations involved in the process.

Task 2 focuses on the calculation, design and simulation of a half-wave dipole antenna, including the gain and field analysis.

Task 3 covers the research and analysis of radar systems used in the detection of UAV and Drone systems, also covering the environmental and societal impacts of such systems.

Task 1

Task 1 required the design and simulation of two waveguides, with dimensions directly tied to a student ID number. These two waveguides required one to have a vacuum core, and the other to have a Teflon core.

Task 1a

Modelling a Vacuum Core Waveguide

A waveguide with a vacuum core was created in CST-Studio, with the following parameters;

- $X = 24\text{mm}$
- $Y = 10$
- $Z = 50$
- Frequency Sweep: 2GHz – 30GHz

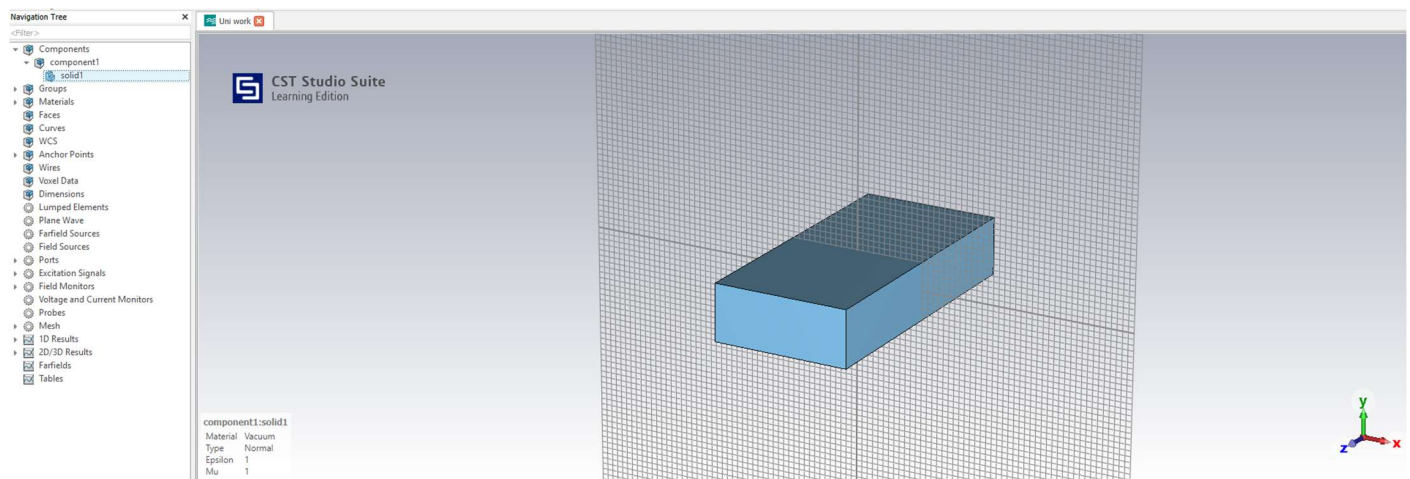


Figure 1: Vacuum Filled Waveguide built in CST Studio

The waveguide was created with two ports, placed at each end of the waveguide

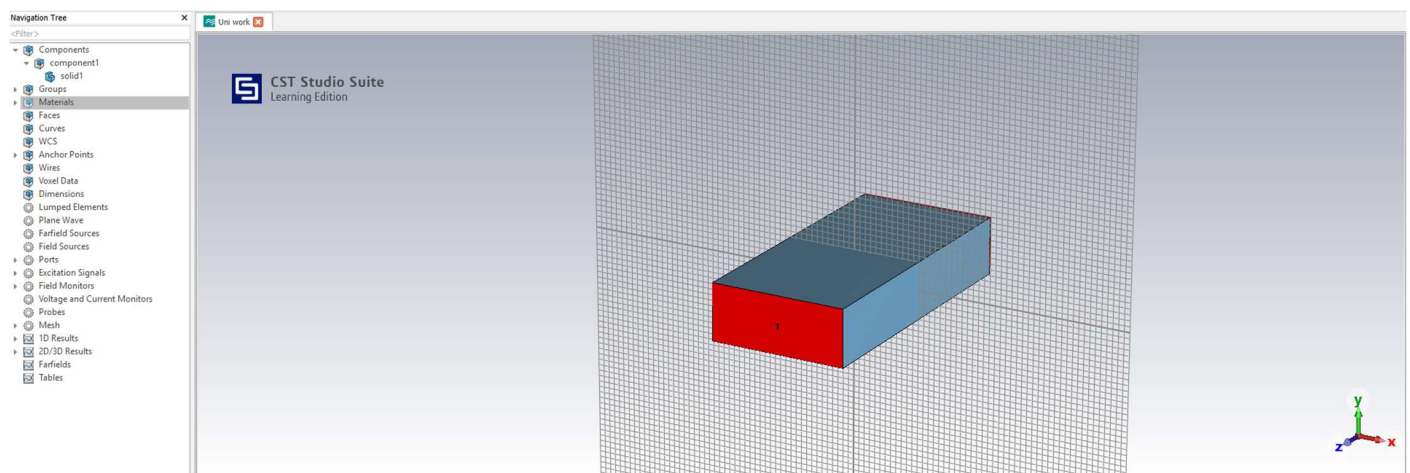


Figure 2: Port 1 of the Waveguide

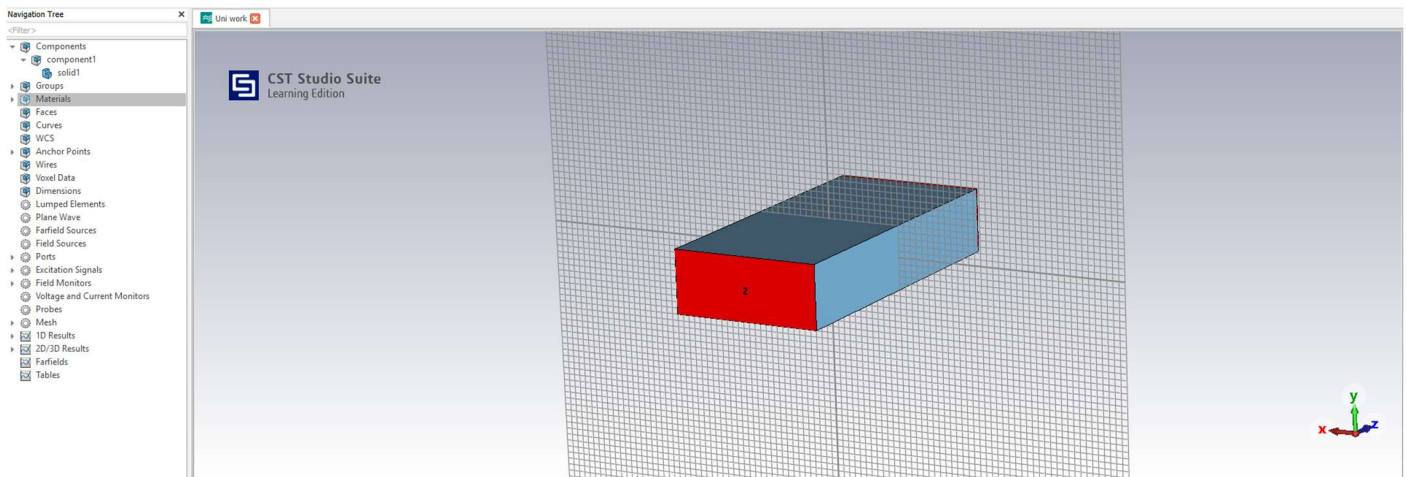


Figure 3: Port 2 of the Waveguide

Setting ports 1 and two like this allowed for the simulation software to understand the intended transmission length of the waveguide.

Port 1 – Modes

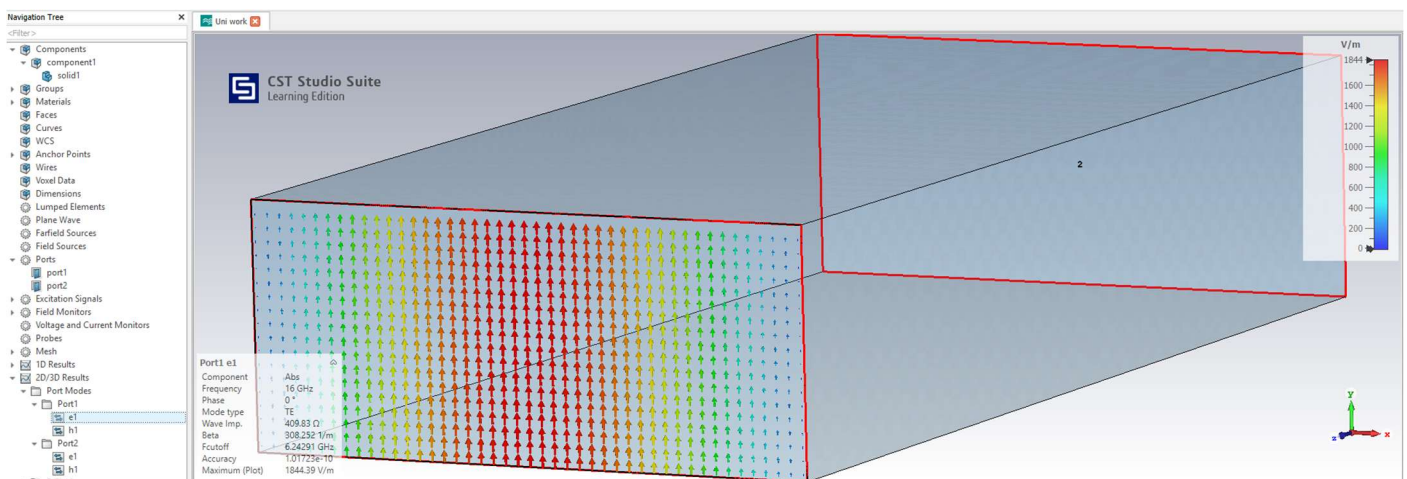


Figure 4: Port 1 - E Field Mode

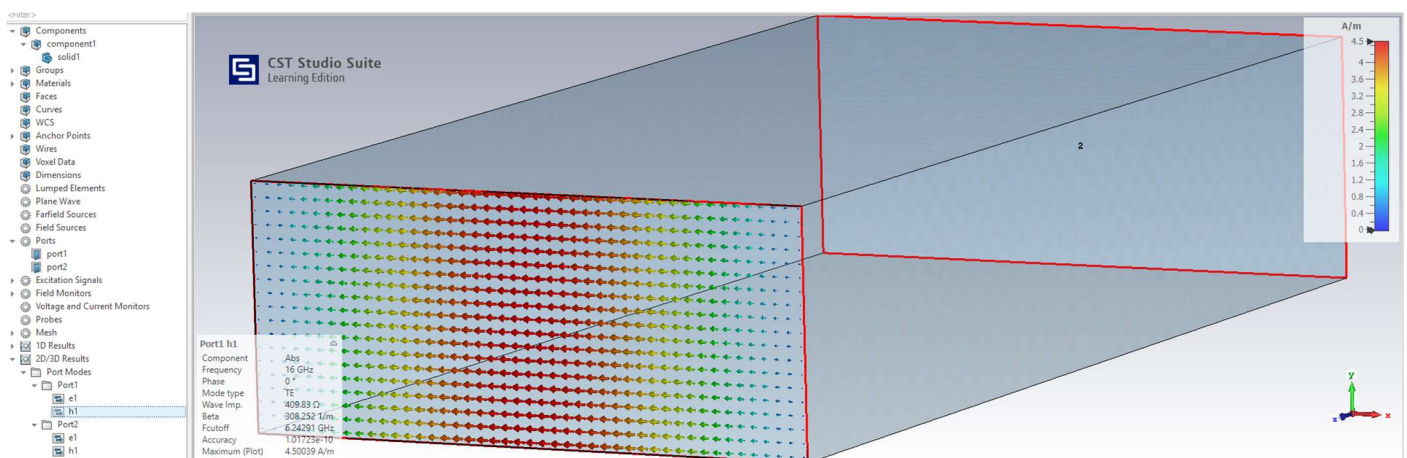


Figure 5: Port 1 – H Field Mode

Port 2 – Modes

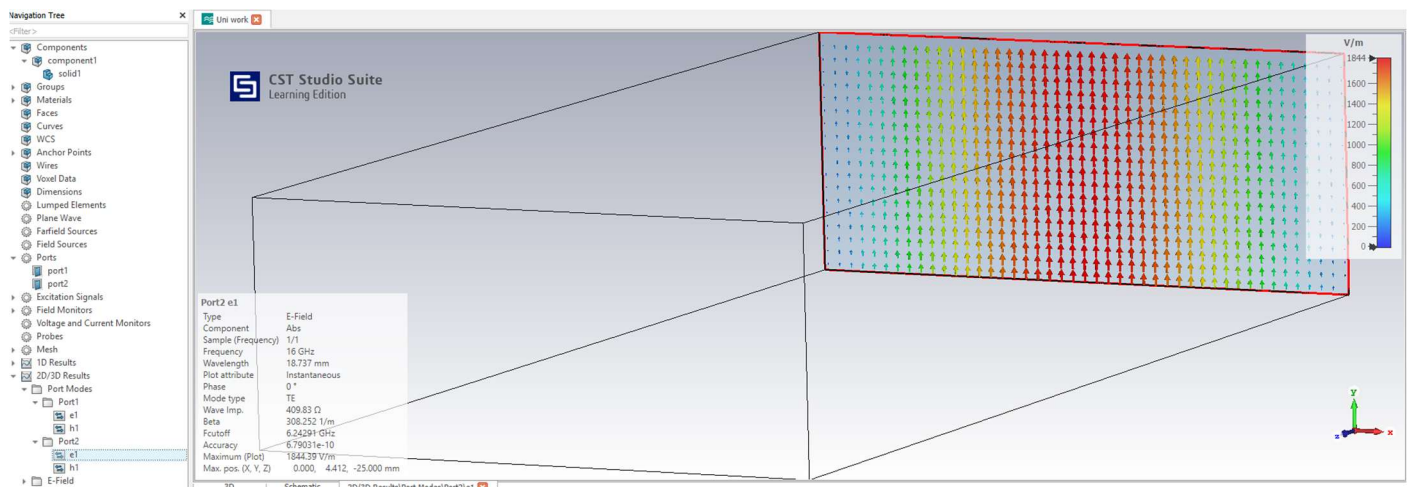


Figure 6: Port 2 – E Field Mode

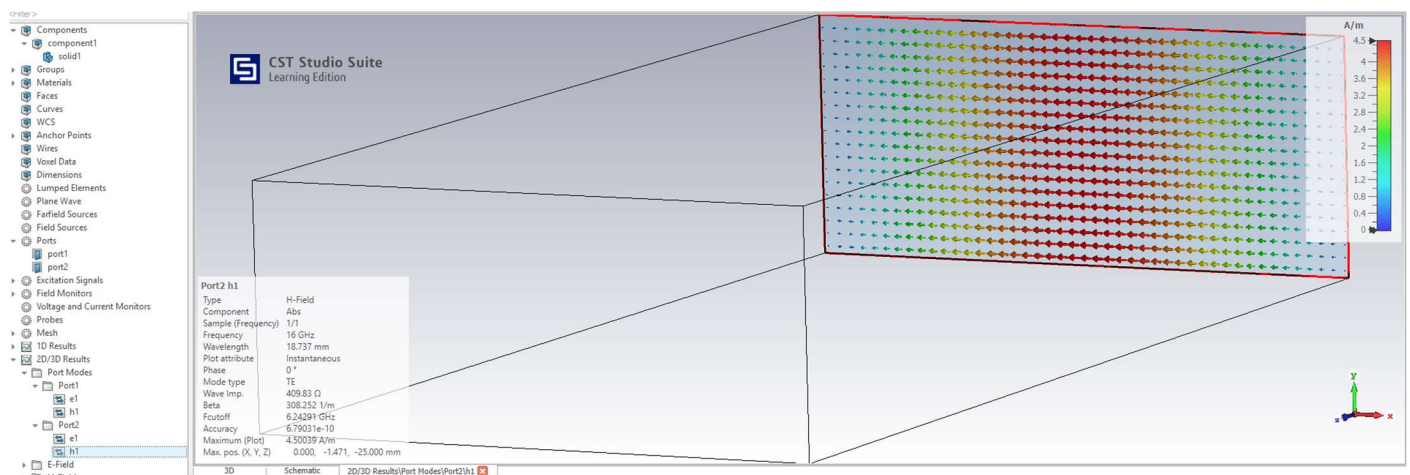


Figure 7: Port 2 – H Field Mode

(Please see figures 20 – 27 in appendix for vector and magnitude results)

Cutoff Frequency Calculations

The cut-off frequency was calculated using the following:

$$f_c = \frac{c}{2} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \quad (1.0)$$

[1]

Where;

c = Speed of light = 3×10^8

a = waveguide width = 0.024m

b = waveguide thickness = 0.01m

m/n = mode of propagation

Mode 1

The calculations for the mode 1;

$$a = 0.024m$$

$$b = 0.01$$

$$m = 1$$

$$n = 0$$

$$f_c = \frac{3 \times 10^8}{2} \sqrt{\left(\frac{1}{0.024}\right)^2 + \left(\frac{0}{0.01}\right)^2} \quad (1.1)$$

$$f_c = 6250000000$$

$$f_c = 6.25GHz$$

Mode 2

The calculations for mode 2;

$$a = 0.024m$$

$$b = 0.01$$

$$m = 2$$

$$n = 0$$

Task 1b

Modelling a Teflon Core Waveguide

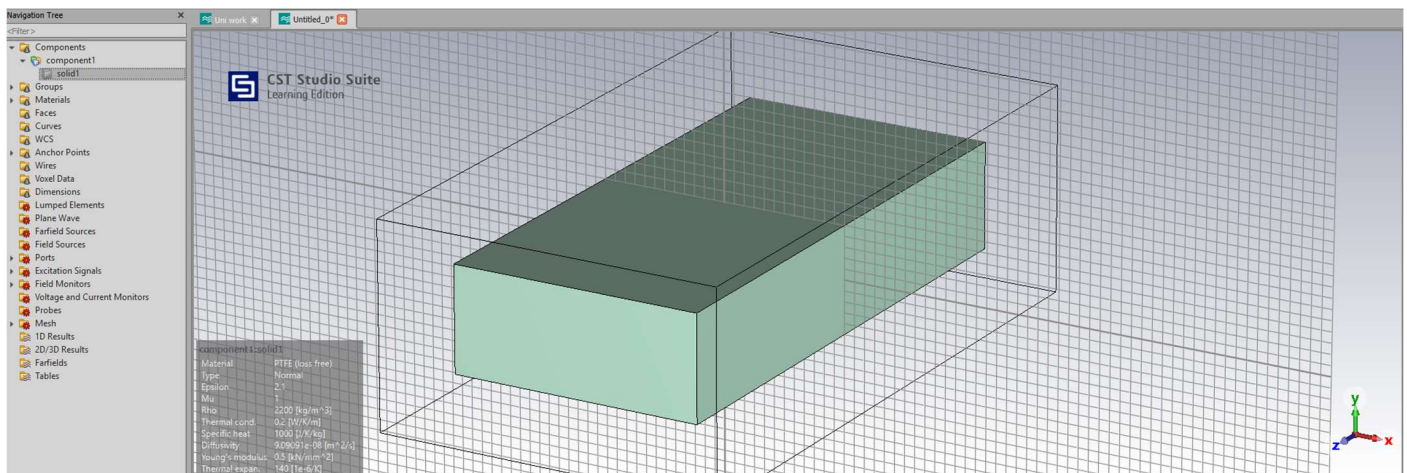


Figure 8: PTFE(Teflon) Filled waveguide built in CST Studio

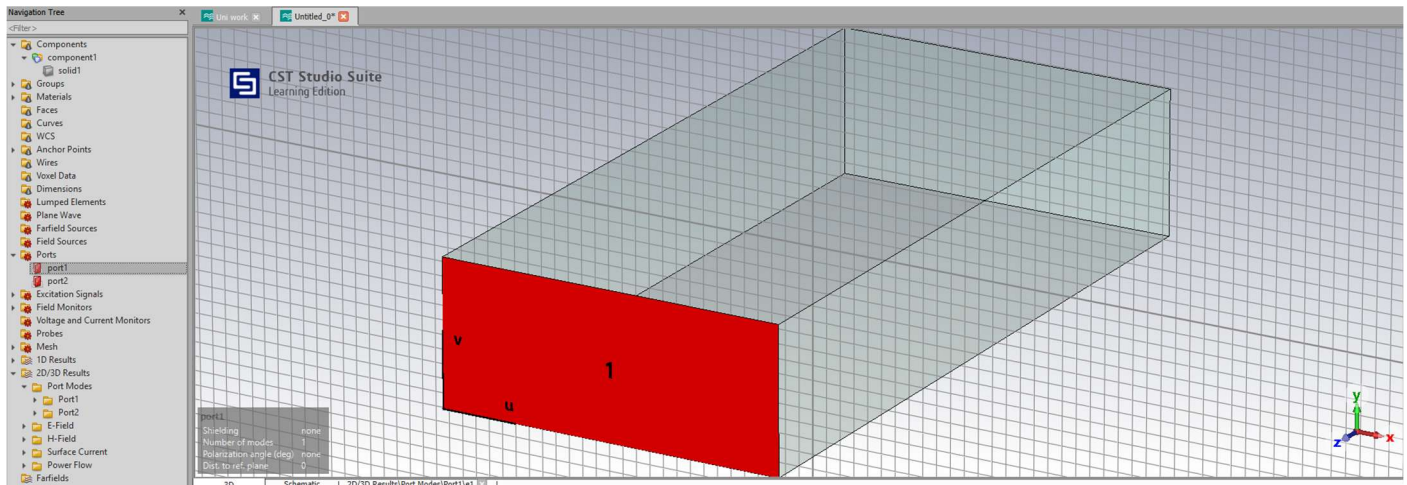


Figure 9: PTFE(Teflon) Filled waveguide Port 1

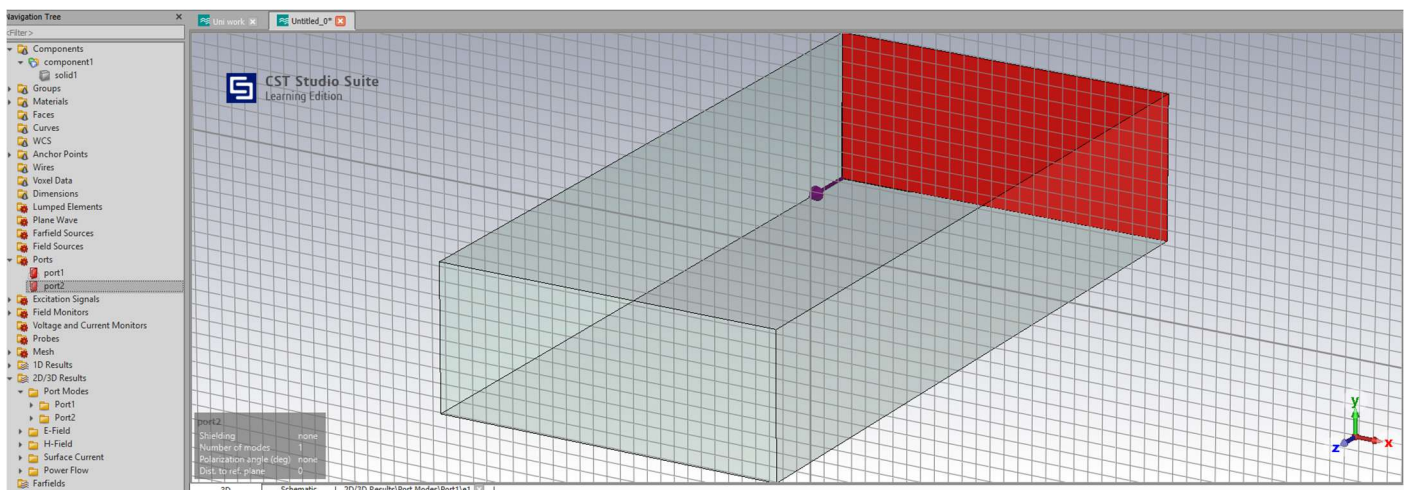


Figure 10: PTFE(Teflon) Filled waveguide Port 2

Port 1 – Modes

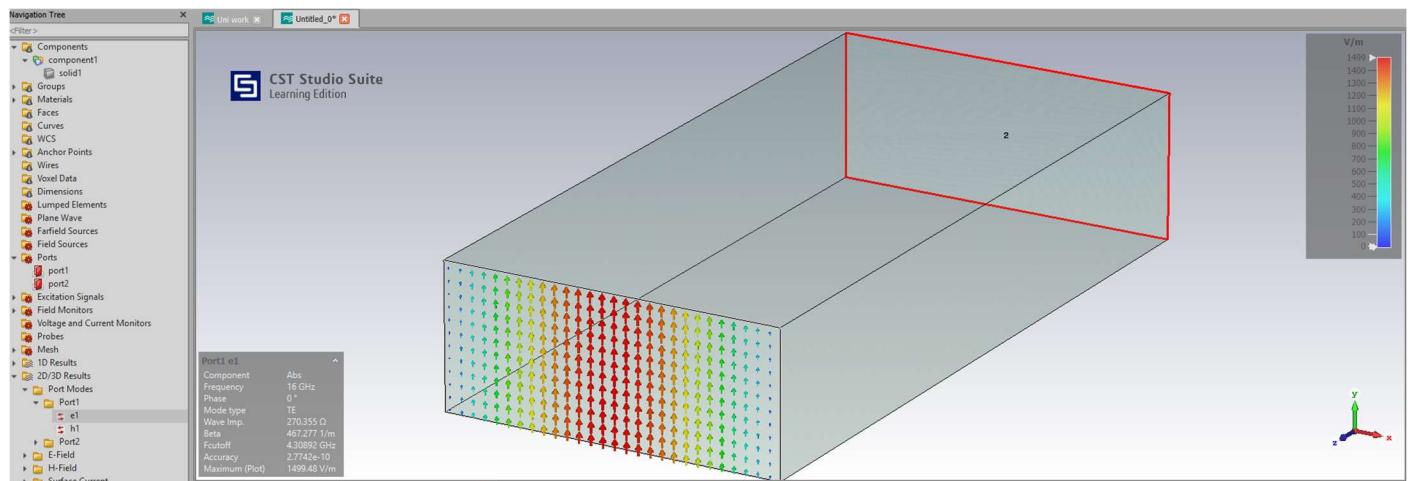


Figure 11: Port 1 – E Field Mode

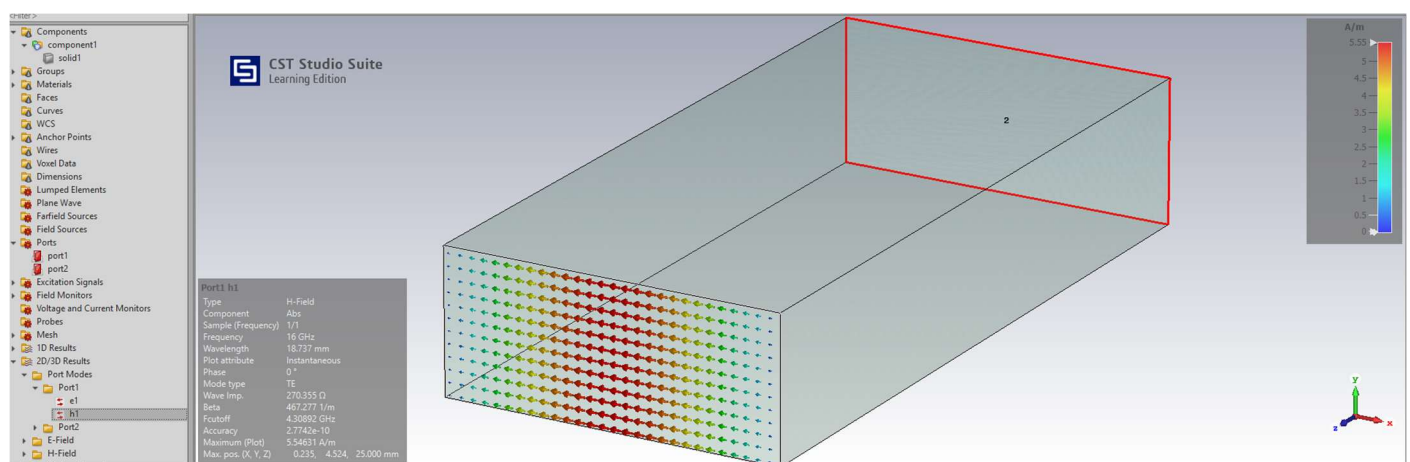


Figure 12: Port 1 – H Field Mode

Port 2 – Modes

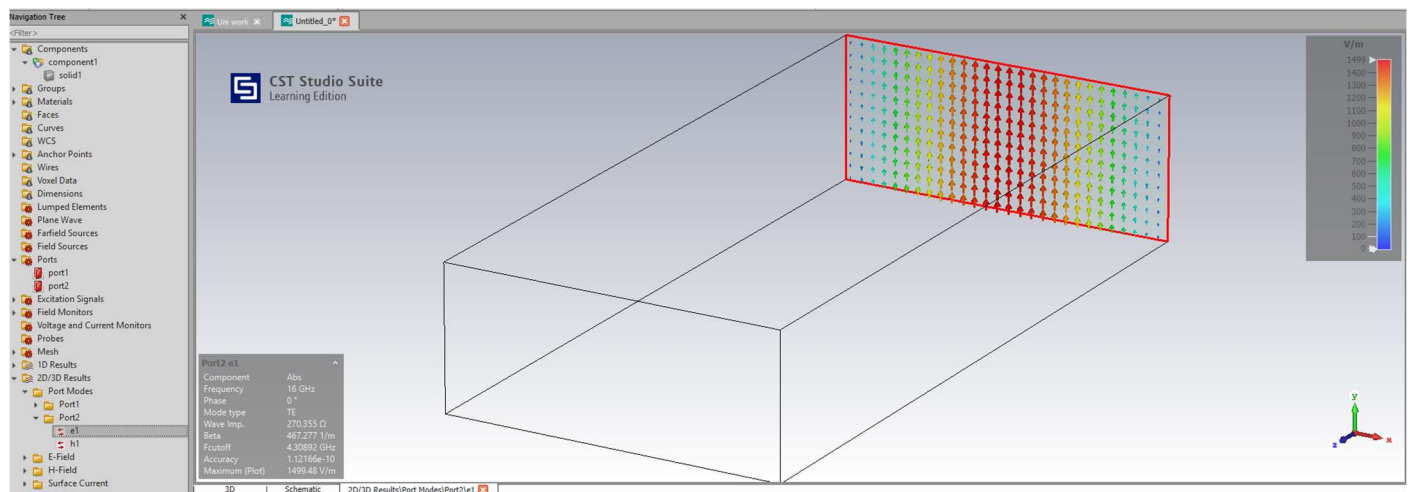


Figure 13: Port 2 – E Field Mode

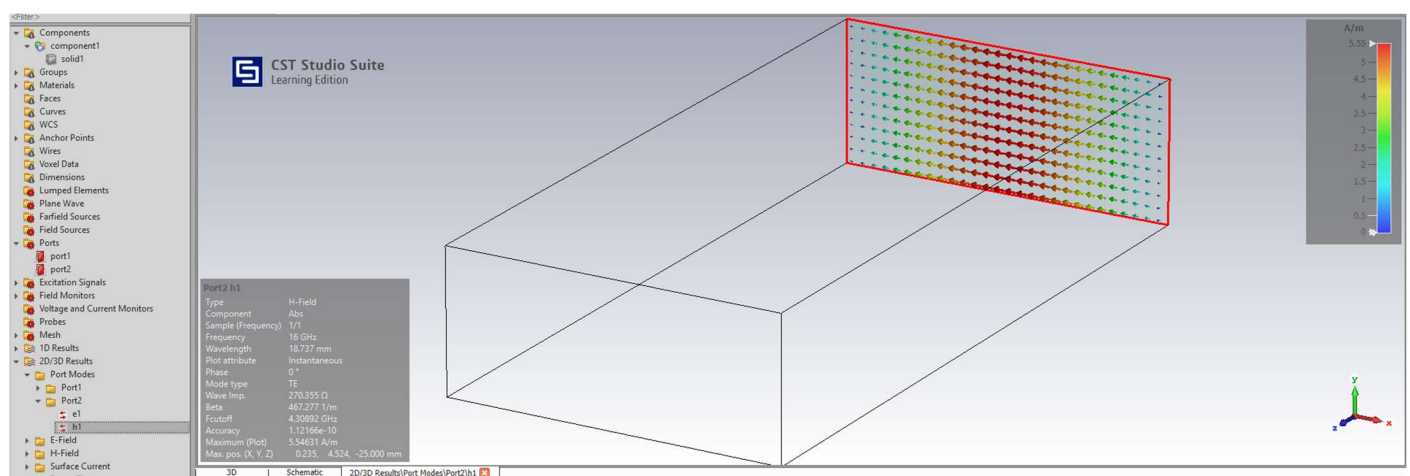


Figure 14: Port 2 – H Field Mode

(Please see figures 28 – 35 in appendix for vector and magnitude results)

Cutoff Frequency Calculations

The cut-off frequency was calculated using the following:

[1]

Where;

a = waveguide width = 0.024m

b = waveguide thickness = 0.01m

m/n = mode of propagation

Mode 1

The calculations for the mode 1;

$a = 0.024m$

$b = 0.01$

$m = 1$

$n = 0$

Mode 2

The calculations for mode 2;

$a = 0.024m$

$b = 0.01$

$m = 2$

$n = 0$

Comparison of Results

Upon calculation the cut-off frequencies for each waveguide were entered into the table below;

Mode	Vacuum Waveguide cut-off frequency (GHz)	Teflon Waveguide cut-off frequency (GHz)
Mode 1	6.25	5.558
Mode 2	12.5	11.116

Table 1: A table of results showing the calculated cutoff frequencies for each waveguide mode

The Table illustrates the cut-off frequencies for each waveguide, and the changes in behaviour that can be observed with the addition of a Teflon core as opposed to a free vacuum. This change in behaviour is due to the relative permittivity of the Teflon, and the other dielectric properties of the materials compared to what would be observed within a vacuum, with a relative permittivity of 2.1 and 0 respectively.

This causes the transmitted wave to propagate at a slower rate within the Teflon core as opposed to within a vacuum, which would allow a signal to transmit freely. This affects all of the modes within the waveguide.

Task 2

For task 2, a half-wave dipole antenna was created with the following dimensions and parameters;

$Radius=1mm$

$\lambda = 242mm$

$Frequency\ Sweep=2GHz-30\ GHz$

From these figures, it was then possible to calculate the values for the dimensions and predicted frequency of the antenna;

$Frequency= 1239669421\ Hz$

$Frequency= 1.239669421\ GHz$

Design and Simulation

The antenna was designed in line with the specifications outlined in the brief wherein;

- A second cylinder was created at the end of the cylinder, with a length of 0.5mm, and was assigned the material of a vacuum.
- A third cylinder, identical to the first, was created at the end of the second cylinder
- Finally, a discrete port was created across the vacuum, and was assigned an impedance of 50Ω

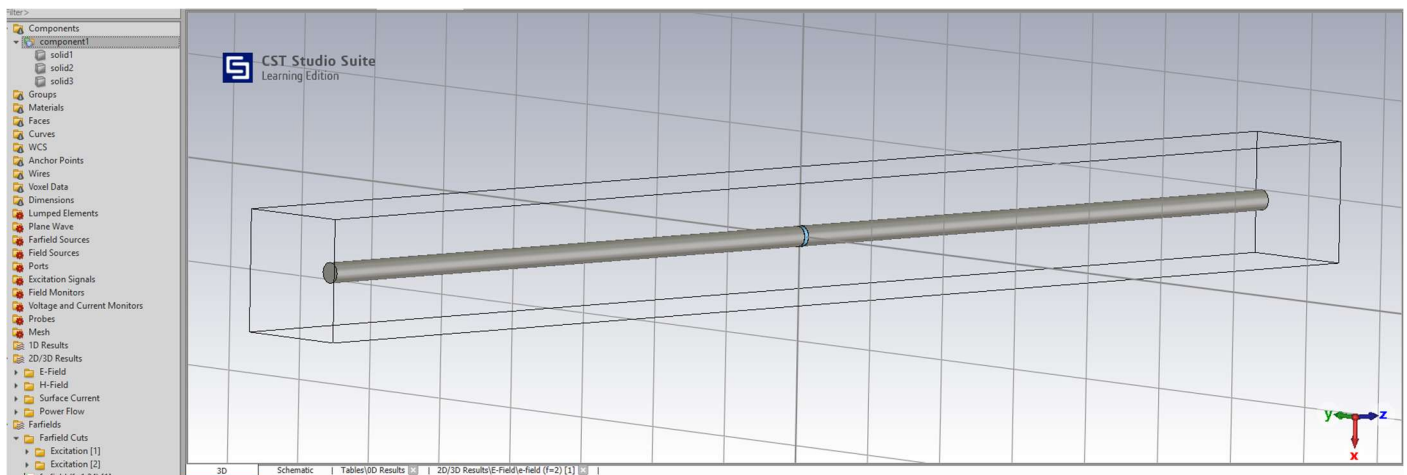


Figure 15: The constructed Dipole antenna, featuring two poles are quarter wavelength and a 0.5mm Vacuum

Gain Pattern

Once the antenna was constructed, a broadband field monitor was setup within the software with a sample rate of 30, in order to gain an accurate representation of the antennas gain across the desired frequency band. This was then output to a 3D polar plot.

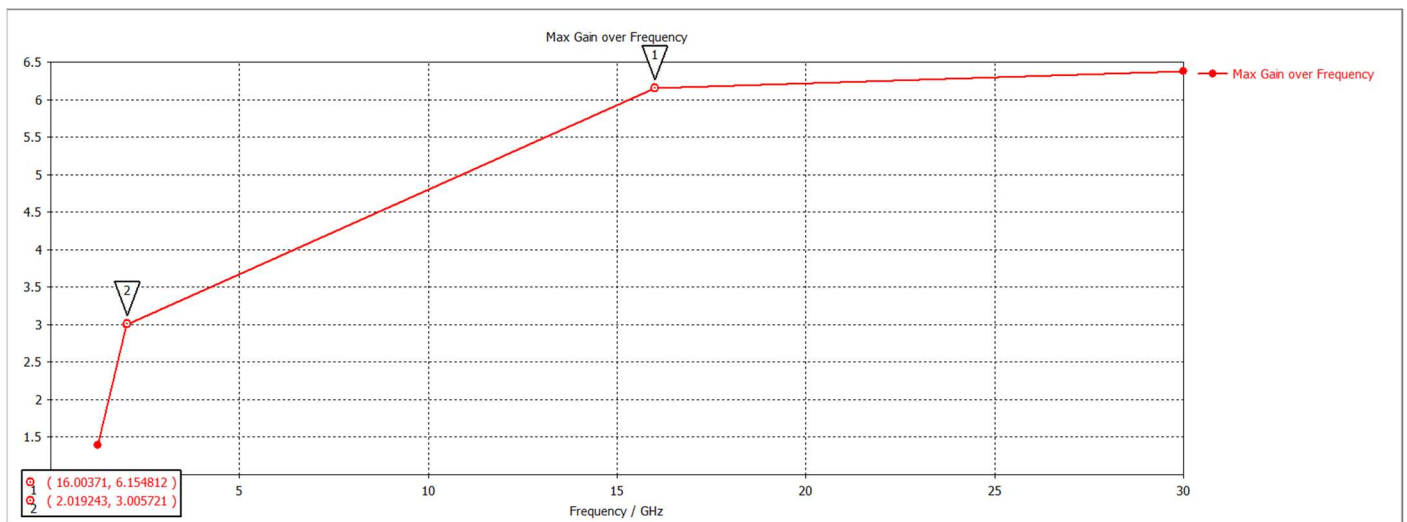


Figure 16: A graph showing the change in gain vs frequency

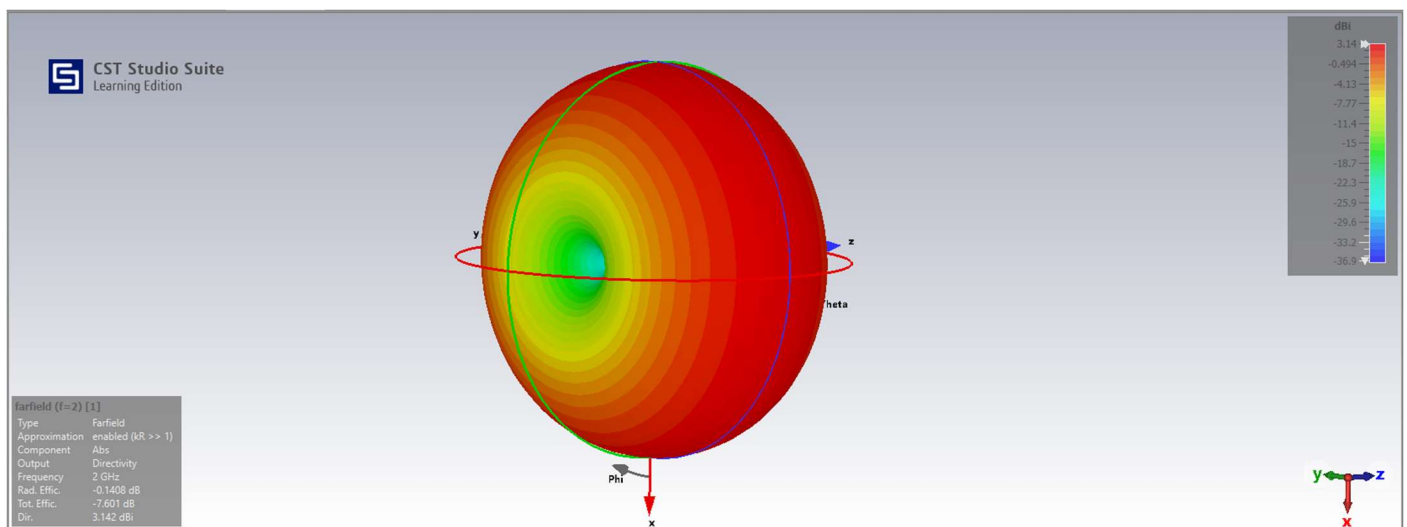


Figure 17: The simulated directivity of propagation for the antenna at 2GHz

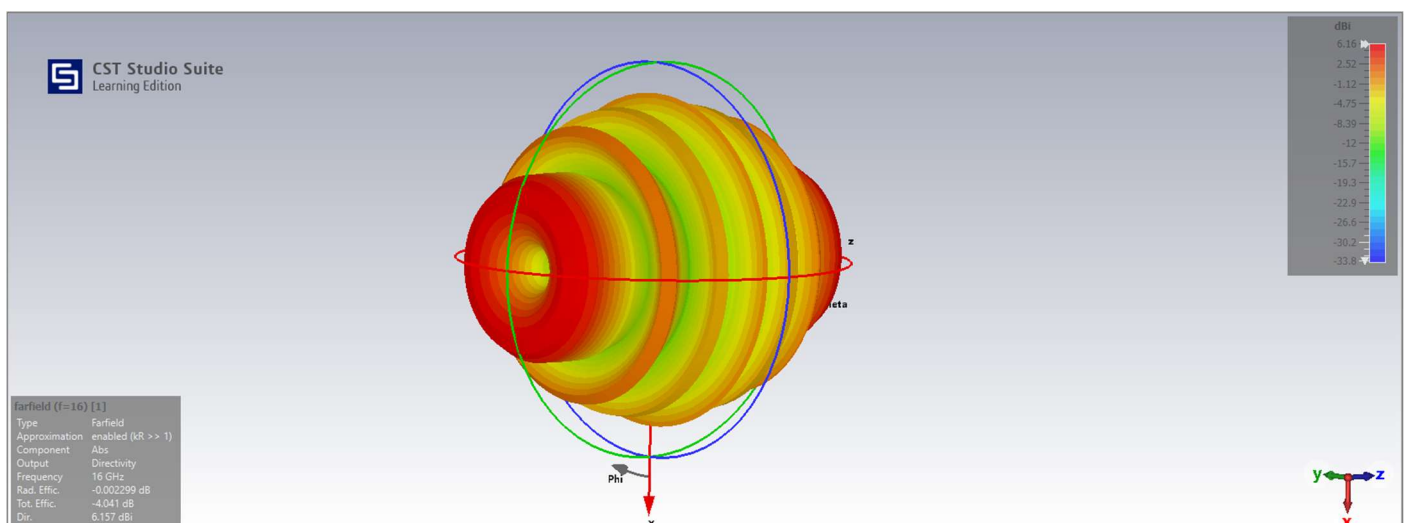


Figure 18: The simulated directivity of propagation for the antenna at 16GHz

S-Parameter Plot

The S-Parameter for the antenna was plotted on a rectangular graph showing the peak operating frequency of the dipole antenna from the simulation.

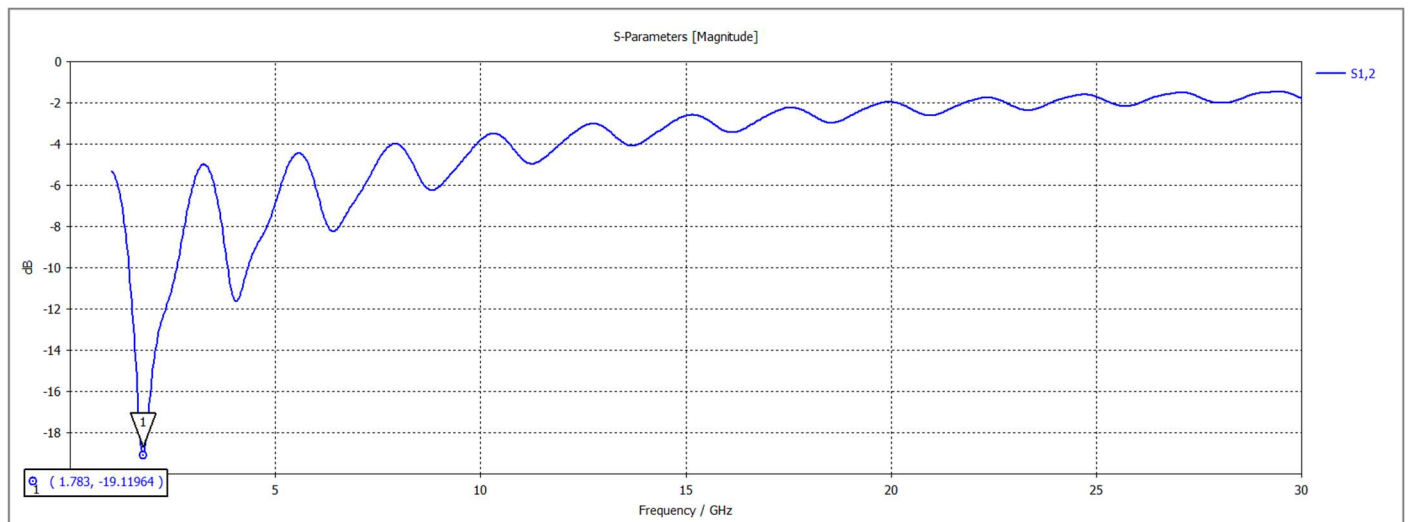


Figure 19: The S-Parameter graph showing the optimum operating frequency for the simulated antenna

Discussion

Comparing the results from the S parameter plot and the calculations drawn prior to designing the antenna, it is notable that a discrepancy is present between the results of the two sets of data.

Whilst the initial calculations stated that the peak operating frequency for the antenna would be approximately 1.24GHz, the simulation showed that the moment of peak operation was shown to be at approximately 1.78GHz.

Potential causes of this discrepancy could be due to self-interference between the poles of the antenna, not initially accounted for within the calculations, caused by differences in phase within the transmitted waveform causing destructive interference within the antenna, affecting the overall point of resonance. [2]

Another potential cause could lie within parasitic resonances, which can occur due to stray capacitances found within the material itself, which can lead to shifts within resonance, affecting the point of peak performance. [3]

Task 3

Introduction

Task 3 Covers the research and evaluation of the use of radar and detection systems to identify drones and UAV(Unmanned Aerial Vehicles), and the potential societal and environmental implications that may be caused as a result.

Advanced Radar Technologies

Radar-based UAV detection has emerged as the most capable approach for identifying and tracking unmanned aerial vehicles, across wide areas and in challenging conditions [4]. Among the various traditional perimeter security and UAV detection methods, radar-based detection holds the greatest potential for military and security applications, owing its ability to cover maximum airspace and adapt to geographically fluid operational environments [5].

Modern counter-drone radar systems primarily exploit two operating principles: Full Modulated Continuous Wave (FMCW) radar, and pulse-Doppler radar. FMCW has become the preferred architecture for tactical and commercial counter-drone systems, transmitting a continuous frequency-swept signal and measuring the difference between transmitted and received frequencies to determine both range and velocity simultaneously, with no minimum detection range, making it particularly suited for perimeter defence scenarios [6].

The key technological breakthrough that enabled radar to distinguish drones from other airborne objects is micro-doppler analysis [7]. Spinning propellor blades create time-varying doppler shifts, appearing as unique sidebands around the main radar return, allowing for the classification of targets based on their rotational characteristics [6]. Research has demonstrated that deep-learning-based classification of radar micro-doppler signatures can achieve recognition accuracies of 99.4% using continuous wave radar sensors [8].

Radar frequency band selection is also a critical design parameter. Studies using multi-band micro-doppler data across short-wave bands(2-4GHz), compromise bands(4-8 GHz), and millimetre-wave bands(75-110GHz), have achieved a mean payload classification accuracy of up to 86.05% in the millimetre-wave band, enabling systems to estimate both drone type and whether said drone is carrying a payload [9]. More recently, cognitive and multi-band radar systems have been developed to address increasingly sophisticated threats, with systems supporting multi-band switching that automatically optimises operating frequencies based on the target characteristics and environmental conditions [10]. Additionally, passive radar approaches leverage existing ambient electromagnetic emissions, such as TV broadcasts, cellular networks, and satellite transmissions, to detect and track drones without requiring active tracking solutions [11].

Societal and Environmental Impacts

Societal Impacts

The widespread deployment of counter-drone radar systems raises significant societal concerns, particularly around privacy and civil liberties [12]. The proliferation of drone infrastructure enables monitoring with minimal visibility, causing some people to alter behaviours out of fear of observation and surveillance [12]. From a regulatory perspective, one major challenge is the absence of well-defined legal frameworks governing AI-powered UAV Surveillance, with many countries lacking comprehensive regulations on data retention and consent requirements [13]. The question of civilian airspace also presents legal tensions with the general public; with the US military reporting 420 drone incursions between 2024 and 2025, however FAA rules and regulations protecting civilian airspace can mean that authorities can sometimes lack the necessary powers required to act on potential unlawful drone use [11].

Ethical Impacts

The ethical debate surrounding radar-enabled drone systems extends beyond detection and into automated response and autonomous engagement [14], [15]. Autonomous weapon systems decouple lethal actions from human agency, creating responsibility gaps where harm occurs without identifiable moral agents, creating a scenario that undermines established deterrence models that rely on contextual interpretation of an adversary's intentions [14]. At the international governance level, in December 2024 the UN General Assembly passed a resolution on lethal autonomous weapons systems with 166 votes in favour, reflecting growing global concern, though the US department of defence continues to favour adaptive regulation over prohibition [16]. For civilian deployments specifically, the ethical case for maintaining meaningful human control over any counter-drone response remains compelling, with ongoing regulatory updates considered essential for ensuring counter-drone technology remains both effective and ethically sound [15], [16].

Environmental implications

Counter-drone systems contribute heavily to the growing electromagnetic interference across the radio frequency spectrum [17]. High levels of electromagnetic interference from radar systems can disrupt the performance of adjacent RF equipment, increasing the false positive rates and degrading detection accuracy [18]. This is particularly relevant for neutralisation technologies; wherein high-power microwave devices carry a significant risk of unintentionally disrupting communications or destroying electronic devices within range [10]. The collateral electromagnetic impact on civilian communications infrastructure is an ongoing concern, requiring careful frequency management [17]. Further research has demonstrated that drone electronics operating at frequencies within the 2-3GHz band are particularly susceptible to EMI-induced motor failure [18], highlighting a potential risk to the general civilian population in the event of an unintentional drone failure due to detection infrastructure.

Conclusion

To conclude, the battle against drones remains an ongoing issue, with a variety of factors to consider when detecting drones using radar and the implementation of AI within drone detection systems. Highlighting that whilst there are significant benefits to these systems, there are also real tangible issues with such systems, both legally, ethically and within society as a while, and these considerations must be taken into account prior to the implementation of any drone detection systems to ensure a safe and non-intrusive environment.

Appendix

Vacuum Waveguide

Mode 1

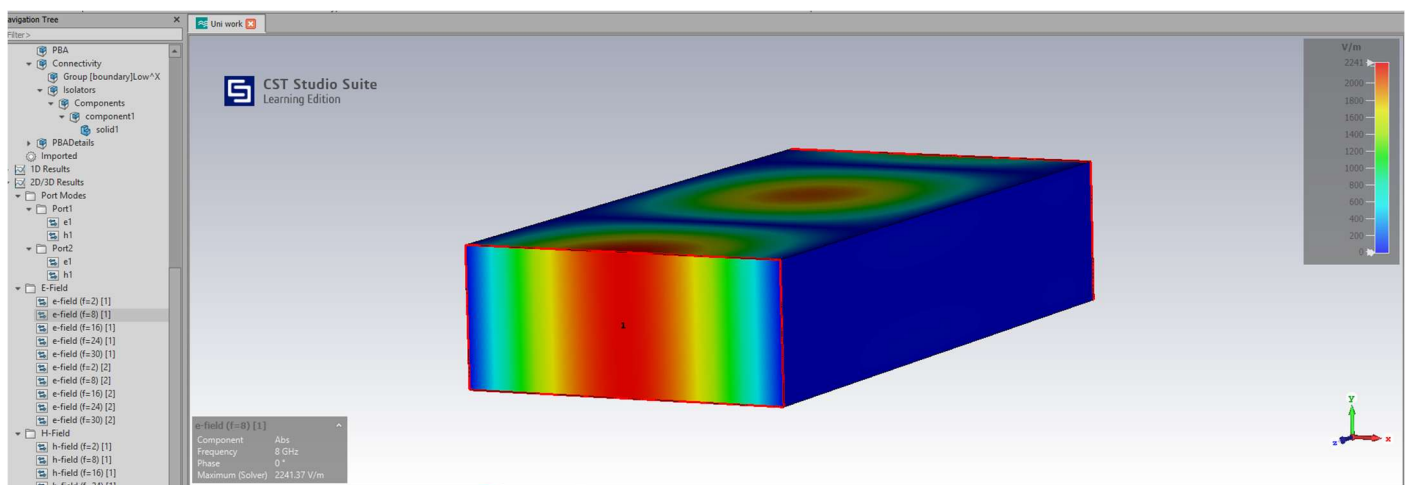


Figure 20: Mode 1, E Field Magnitude of Vacuum Waveguide at 8GHz

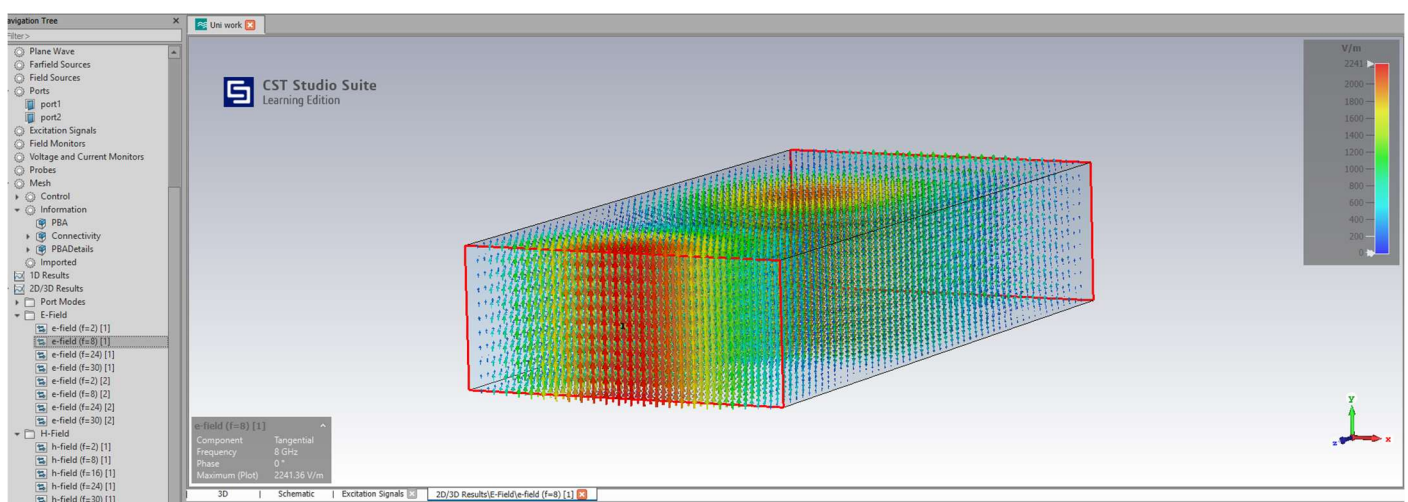


Figure 21: Mode 1, E Field Vector of Vacuum Waveguide at 8GHz

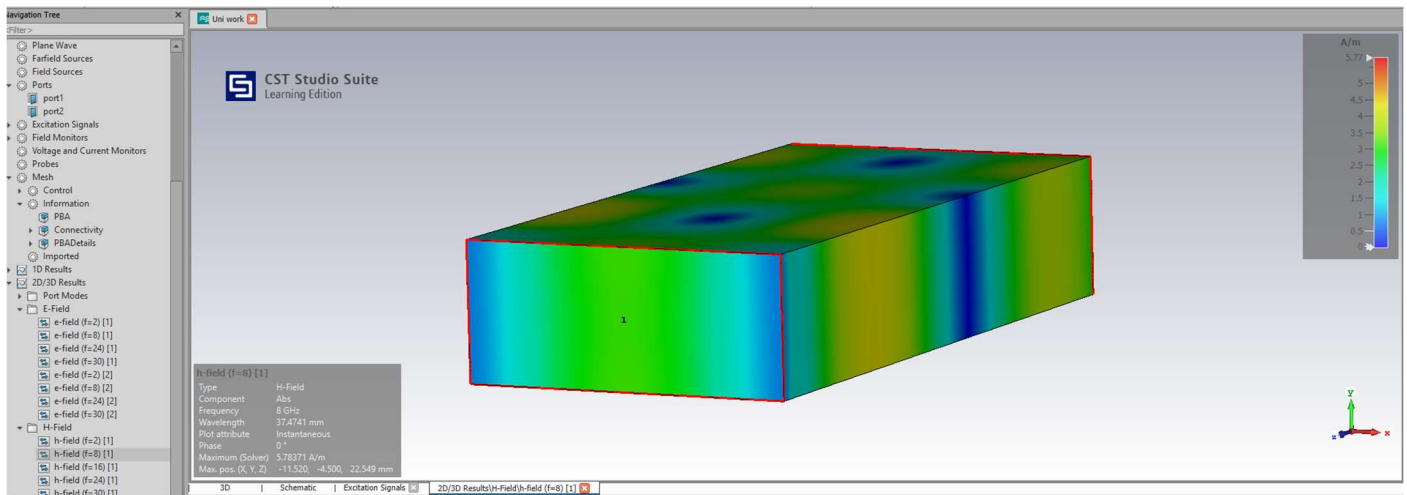


Figure 22: Mode 1, H Field Magnitude of Vacuum Waveguide at 8GHz

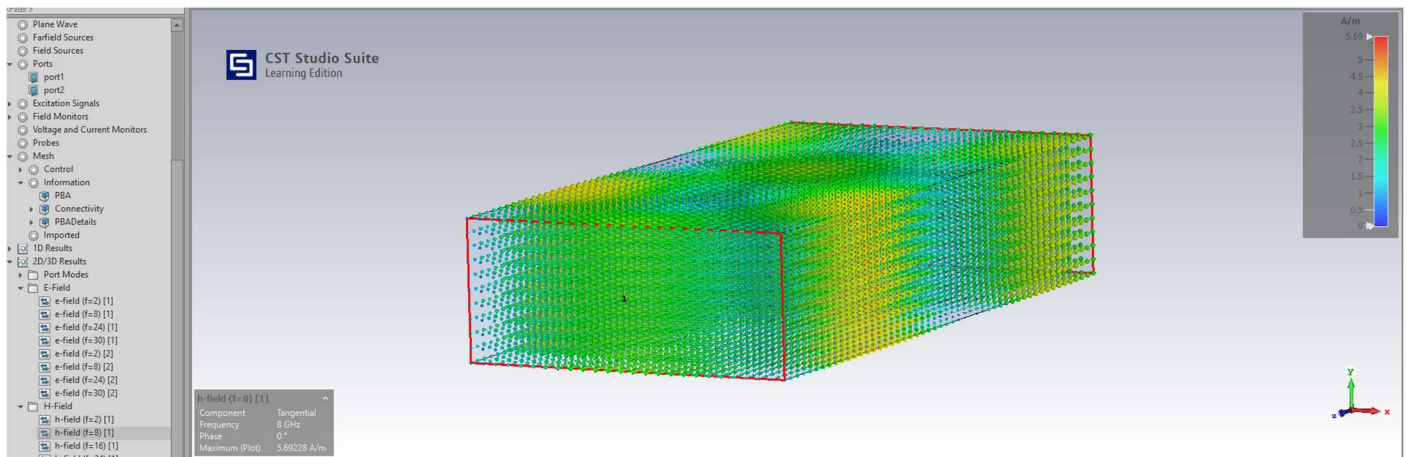


Figure 23: Mode 1, H Field Vector of Vacuum Waveguide at 8GHz

Mode 2

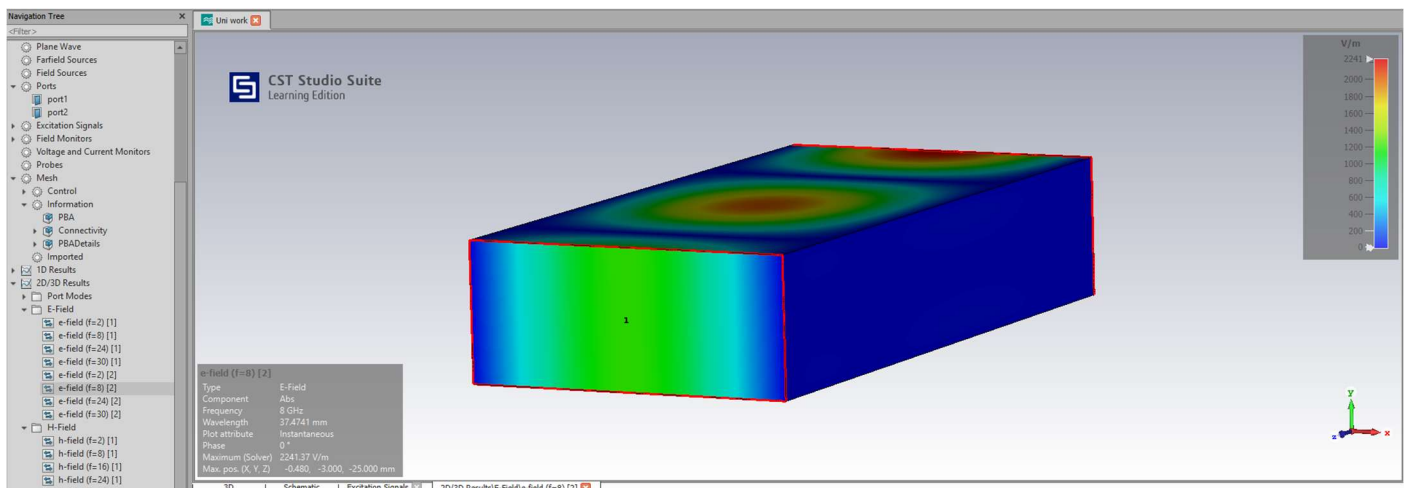


Figure 24: Mode 2, E Field Magnitude of Vacuum Waveguide at 8GHz

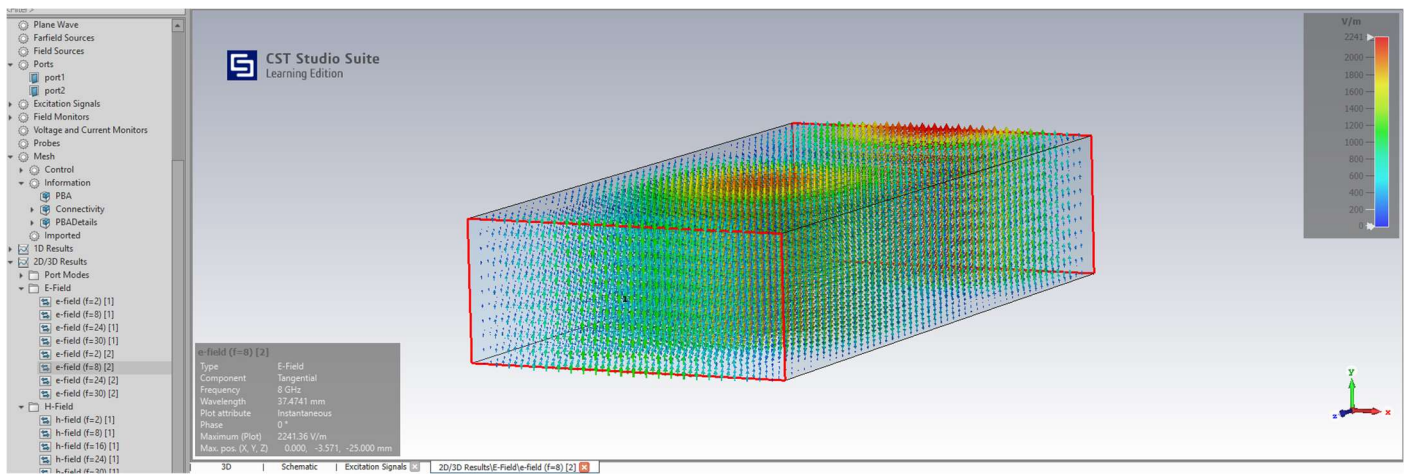


Figure 25: Mode 2, E Field Vector of Vacuum Waveguide at 8GHz

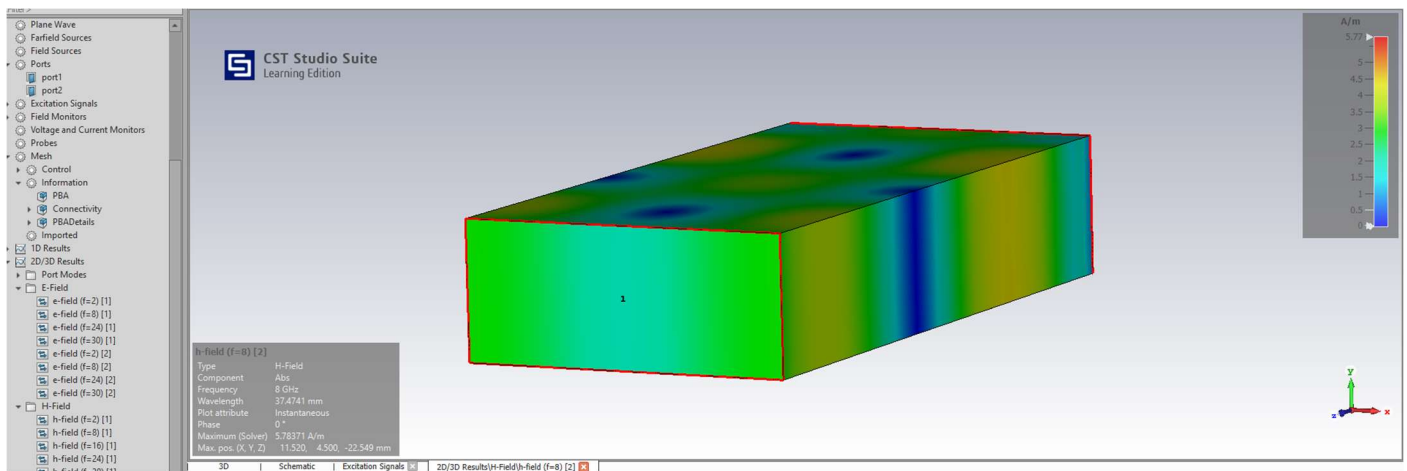


Figure 26: Mode 2, E Field Magnitude of Vacuum Waveguide at 8GHz

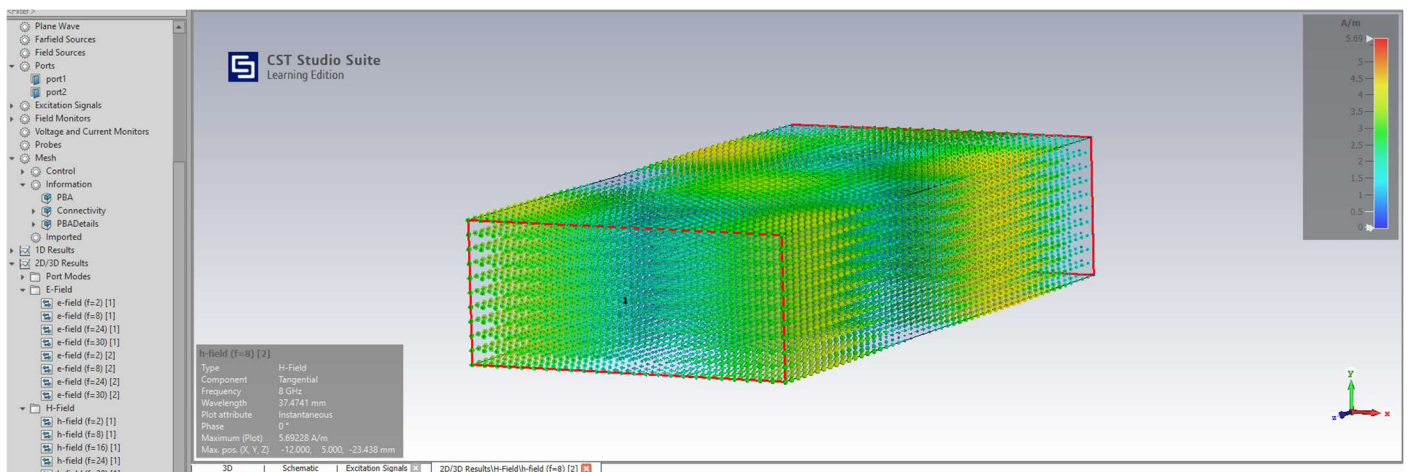


Figure 27: Mode 2, E Field Vector of Vacuum Waveguide at 8GHz

Teflon Waveguide

Mode 1

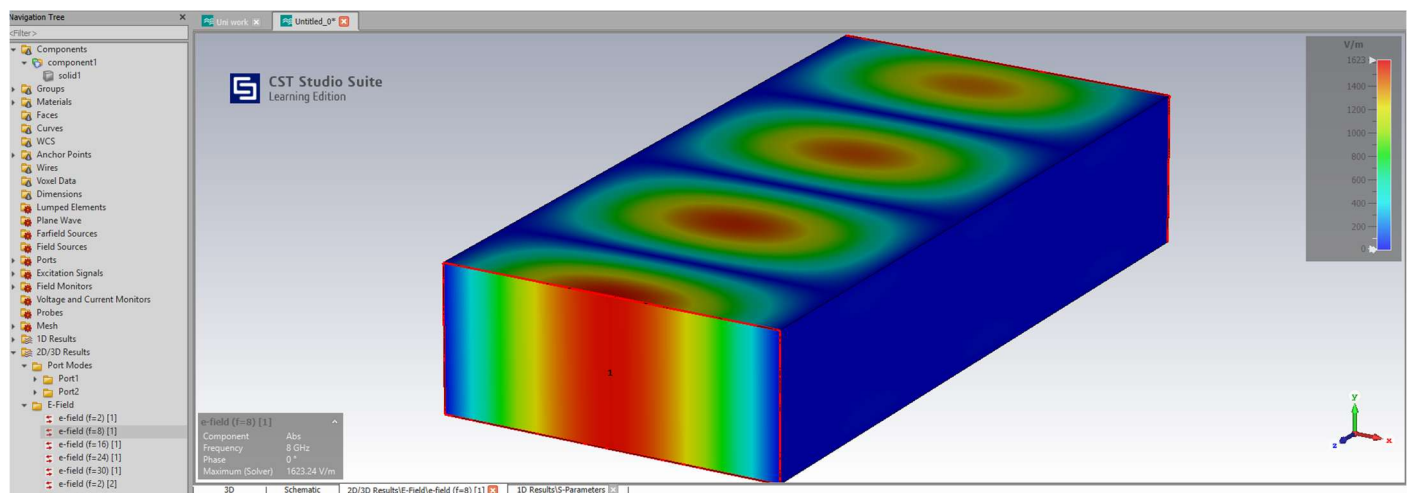


Figure 28: Mode 1, E Field Magnitude of Teflon Waveguide at 8GHz

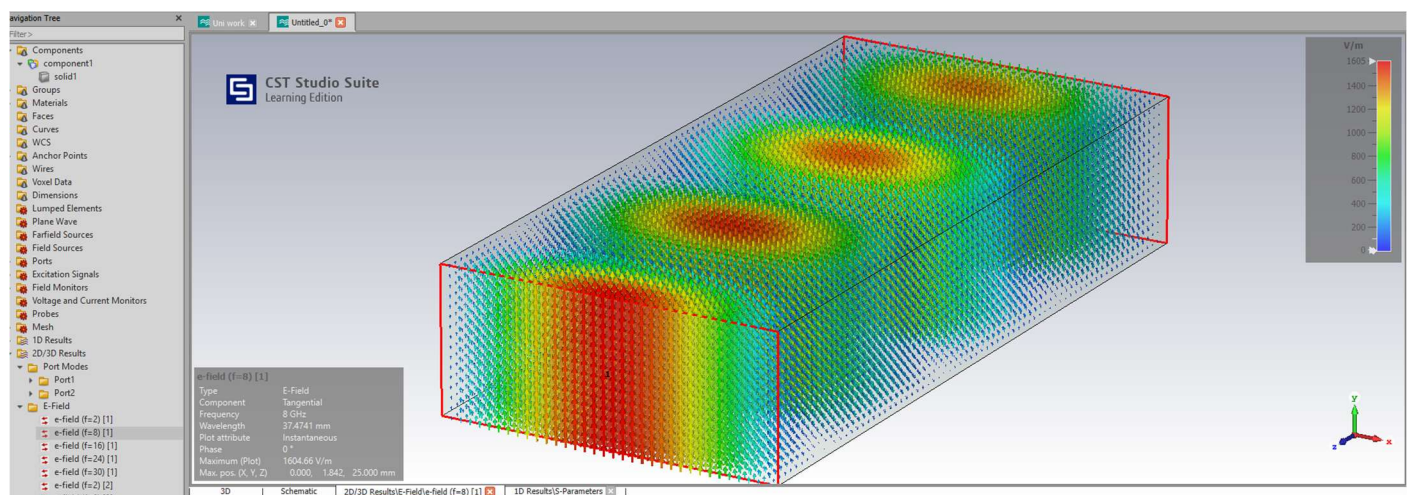


Figure 29: Mode 1, E Field Vector of Teflon Waveguide at 8GHz

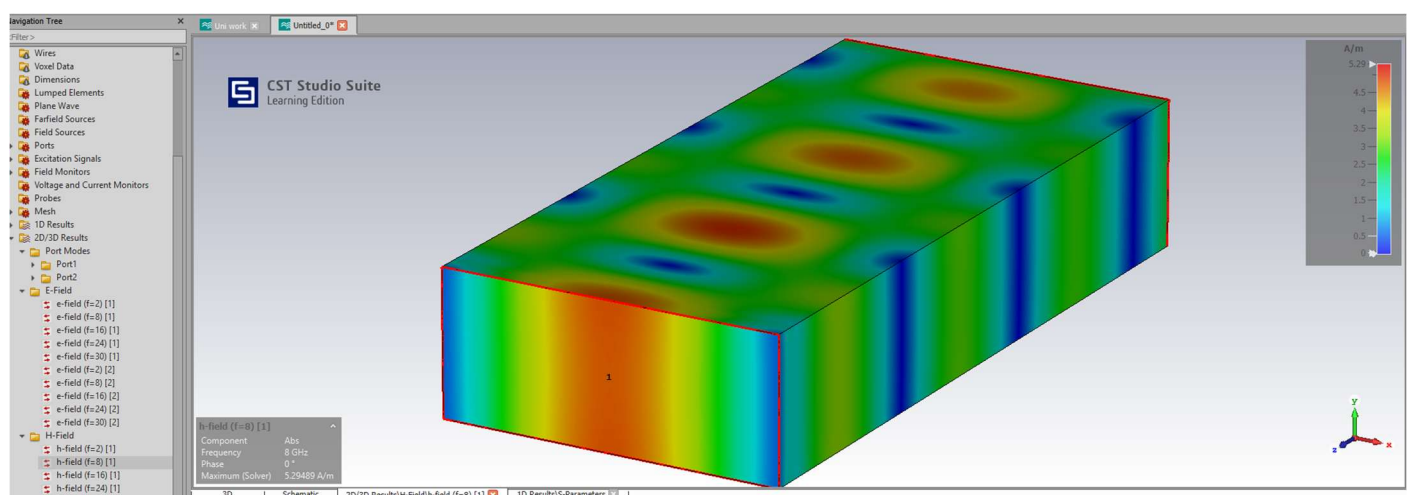


Figure 30: Mode 1, H Field Magnitude of Teflon Waveguide at 8GHz

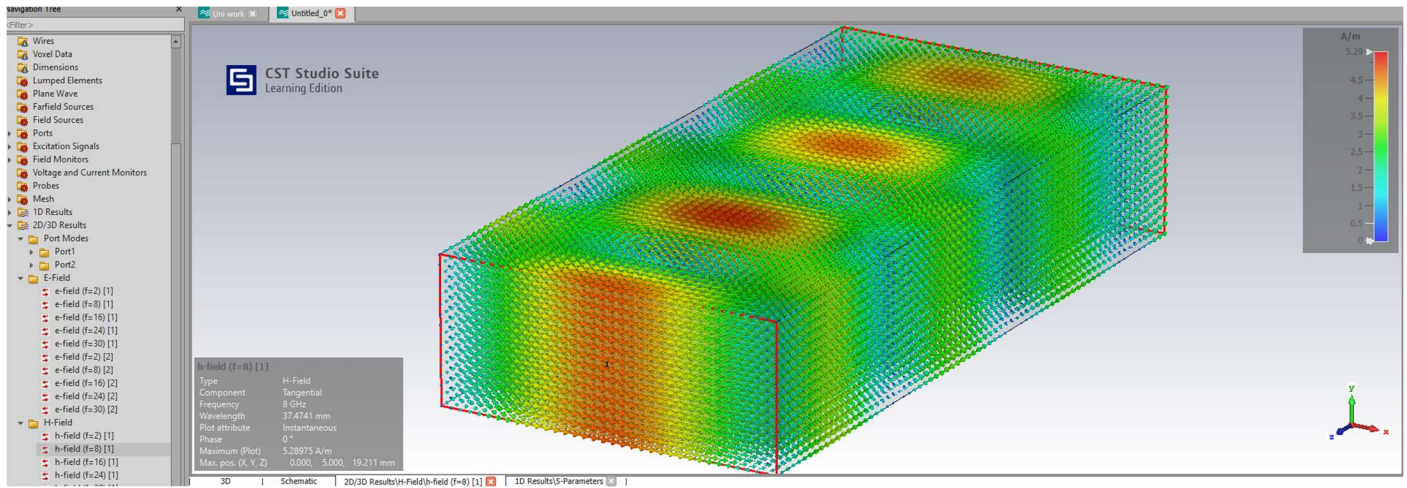


Figure 31: Mode 1, H Field Vector of Teflon Waveguide at 8GHz

Mode 2

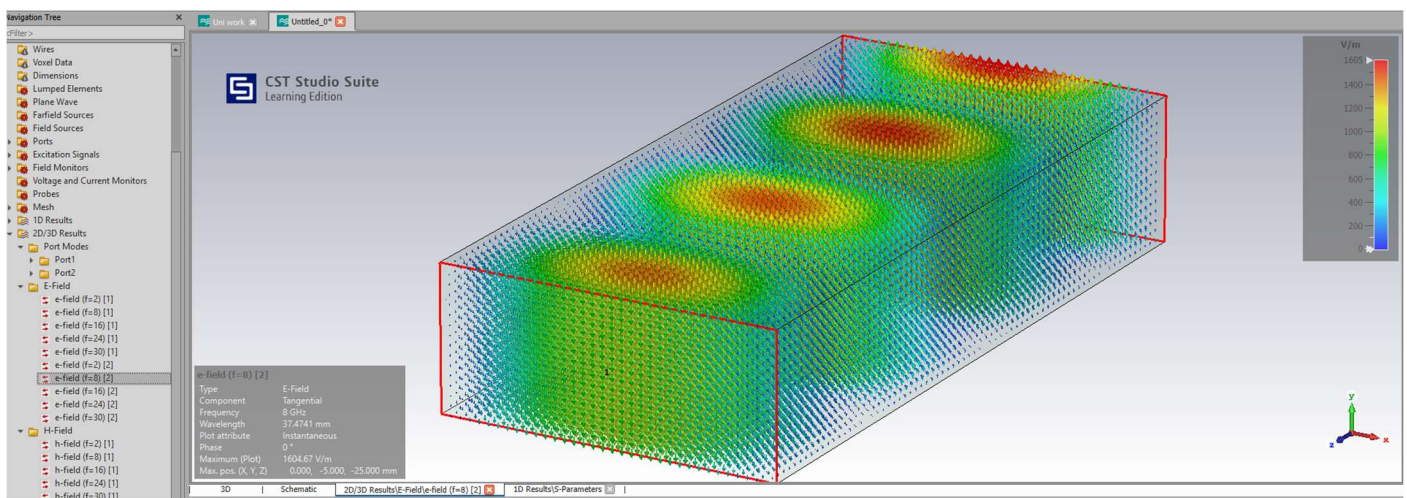


Figure 32: Mode 2, E Field Vector of Teflon Waveguide at 8GHz

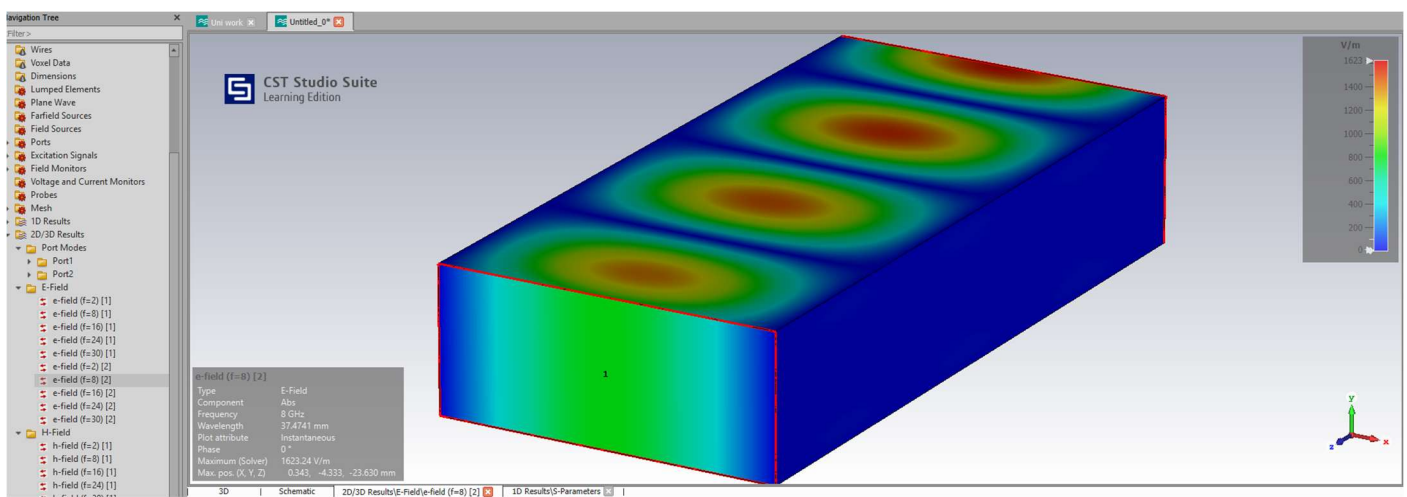


Figure 33: Mode 2, E Field Magnitude of Teflon Waveguide at 8GHz

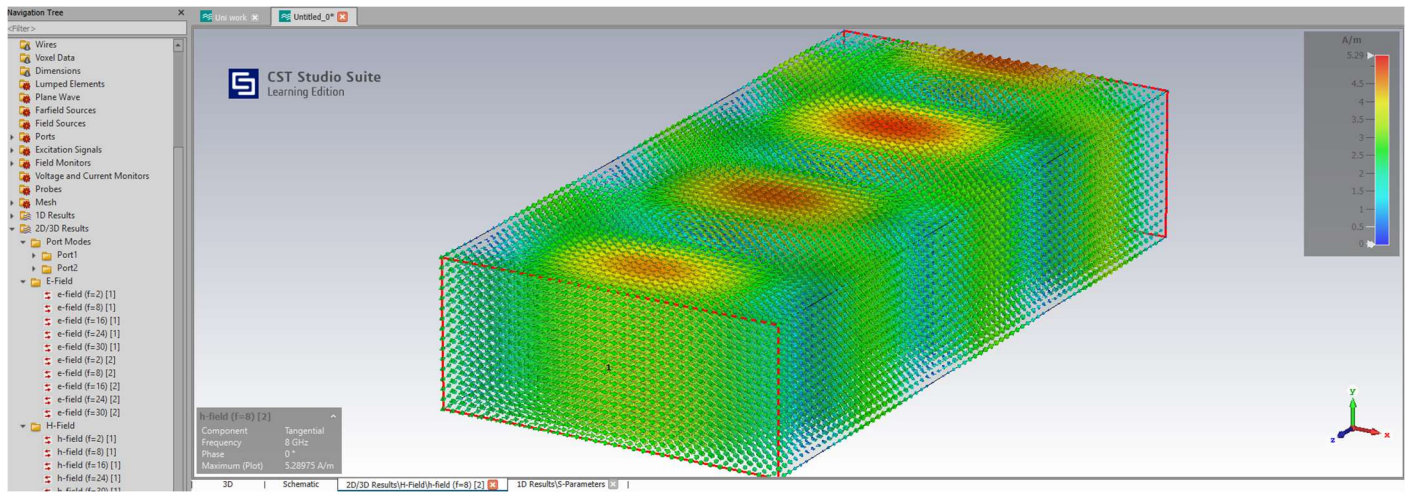


Figure 34: Mode 2, H Field Vector of Teflon Waveguide at 8GHz

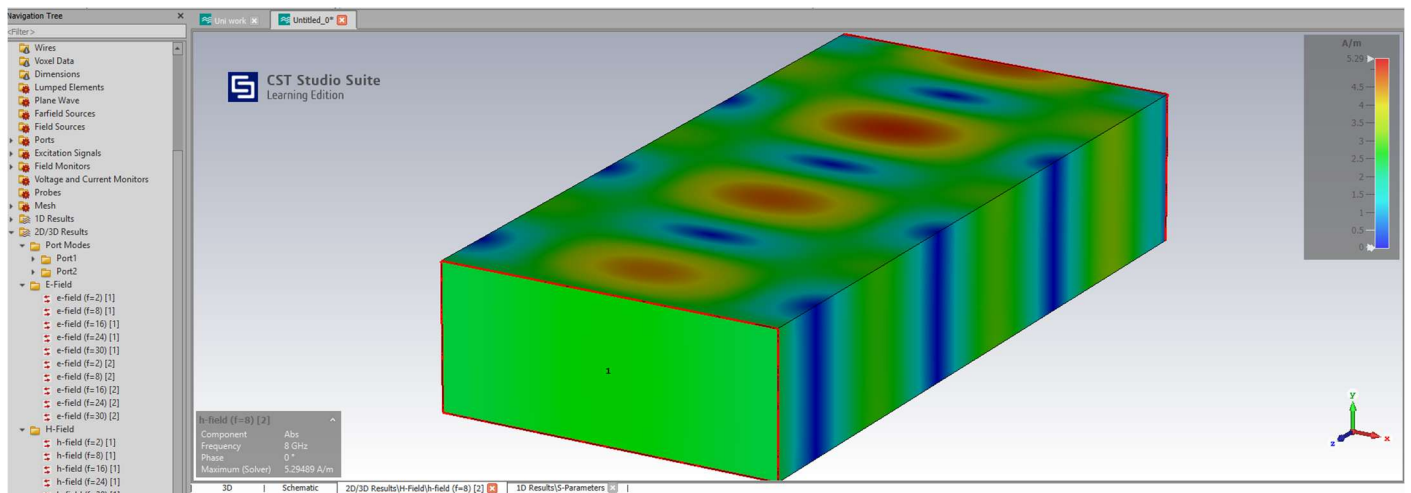


Figure 35: Mode 2, H Field Magnitude of Teflon Waveguide at 8GHz

Bibliography

- [1] Cadence Systems Analysis, "The Rectangular Waveguide Cut-Off Frequency," Cadence, [Online]. Available: <https://resources.system-analysis.cadence.com/blog/msa2021-the-rectangular-waveguide-cut-off-frequency>. [Accessed 25 05 2026].
- [2] C. D. Y. J. Y. L. Yuenian Chen, "Antenna/Propagation Domain Self-Interference Cancellation (SIC) for In-Band Full-Duplex Wireless Communication Systems," *Sensors*, vol. 22, no. 5, p. 1699, 2022.
- [3] P. M. D. N. D. A. R. H. N. C. Jack Bush, "Very Long, Variable Frequency, Dipole Antenna for Ground Penetrating Radar Science with Tethered Rovers," Nasa, California, 2019.
- [4] A. S. H. W. J.-M. (. P. R. G. Alireza Famili, "Securing your airspace: detection of drones trespassing protected areas," *Sensors*, vol. 24, no. 7, p. 2028, 2024.
- [5] N. N. Rao, *Elements of Engineering*, 6th edition, London: Pearson, 2004.
- [6] Airsight, "Drone Detection Radar: How It Works, Costs & Types," Airsight, [Online]. Available: <https://www.air sight.com/blog/drone-detection-radar-guide>. [Accessed 25 05 2026].
- [7] F. L. S.-S. H. H. W. VICTOR C. CHEN, "Micro-Doppler Effect in Radar: Phenomenon, Model, and Simulation Study," *IEEE TRANSACTIONS ON AEROSPACE AND ELECTRONIC SYSTEMS*, vol. 42, no. 1, 2006.
- [8] L. I. K. T. N. S. E. T. M. Ulzhalgas Seidaliev, "Advances and Challenges in Drone Detection and Classification Techniques: A State-of-the-Art Review," *Sensors*, vol. 24, no. 1, p. 125, 2024.
- [9] N. P. C. H. P. B. M. R. Dilan Dhulashia, "Multi-Frequency Radar Micro-Doppler Based Classification of Micro-Drone Payload Weight," *Frontiers in Signal Processing*, vol. 1, 2021.
- [10] Robin Radar Systems, "10 types of counter-drone technology to detect and stop drones today," Robin Radar Systems, [Online]. Available: <https://www.robinradar.com/resources/10-counter-drone-technologies-to-detect-and-stop-drones-today>. [Accessed 25 05 2026].
- [11] C. Mcfadden, "US military tests new tech to tackle rising drone threat over American airspace," *Interesting Engineering*, 12 10 2025. [Online]. Available: <https://interestingengineering.com/innovation/us-military-new-counter-drone-tech>. [Accessed 25 05 2026].
- [12] "Drones Surveillance," Privacy International, [Online]. Available: <https://privacyinternational.org/learn/drones-surveillance>. [Accessed 25 05 2026].

- [13] D. Alsadie, "Cybersecurity and Artificial Intelligence in Unmanned Aerial Vehicles: Emerging Challenges and Advanced Countermeasures," *IET Information Security*, vol. 2025, no. 1, p. 2046868, 2025.
- [14] S. Miller, "Lethal autonomous weapon systems (LAWS): meaningful human Control, collective moral responsibility and institutional design," *Ethics and Information Technology*, vol. 27, no. 4, 2025.
- [15] A. Blanchard, "The road less travelled: ethics in the international regulatory debate on autonomous weapon systems," *Humanitarian Law & Policy*, 25 04 2024. [Online]. Available: <https://blogs.icrc.org/law-and-policy/2024/04/25/the-road-less-travelled-ethics-in-the-international-regulatory-debate-on-autonomous-weapon-systems/>. [Accessed 25 05 2026].
- [16] S. A. Qubaisi, "Governing Lethal Autonomous Weapons in a New Era of Military AI," *Trends Research & Advisory*, 03 08 2025. [Online]. Available: <https://trendsresearch.org/insight/governing-lethal-autonomous-weapons-the-future-of-warfare-and-military-ai/>. [Accessed 25 05 2026].
- [17] J. Harper, "Pentagon to test whether counter-drone systems can operate effectively under electronic attack," *DefenceScoop*, 25 07 2024. [Online]. Available: <https://defensescoop.com/2024/07/25/pentagon-test-counter-drone-systems-operate-electromagnetic-environment/>. [Accessed 25 05 2026].
- [18] S. M. H. A. S. J. G. & V. M. Peyman Hasani, "Characteristic mode analysis of electromagnetic interference susceptibility in motor driven unmanned drones for enhanced design and performance," *Scientific Reports*, vol. 15, 2025.