

ACDD5009 - EMR - Final Coursework

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Design and Analysis of Electromagnetic systems

L5 Electromagnetic Radiation
ACDC5009
Embedded Electronics Systems
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Abstract

Within this report multiple different topics are covered ranging from looking into two separate waveguides. One Teflon and one Vacuum. Additionally, half wave antennas are researched to see how to create an optimal antenna. At the end principles of Radar and how they interreact with drones is covered in detail.

Task 1 – Rectangular waveguide model

1. Introduction

A rectangular waveguide guides Electromagnetic waves in a certain direction. Typically, these are hollow metallic tubes that act as a medium to transmit or transfer power [1]. An example of a waveguide would be a fibreoptic cable. There is 2 main different types of waveguide, these are rectangular and circular. This task will be focusing on rectangular waveguides.

The advantages of rectangular waveguides is that they are easy to make and highly efficient at specific frequencies depending on the dimensions of the waveguide. They are commonly used in Radars and satellite communications [2].

Some negatives of rectangular waveguides could be:

- They are rigid so not effective when flexibility is needed
- They are larger in size
- The manufacturing costs are high

2. Methodology

When designing a rectangular waveguide, the first main task is to simulate. To do this you have to decide what length and width you will need. This was decided by the university numbers, as mine is 2308344 and using the method to calculate what dimensions this would be; as in the assignment brief. The width x height will be 23mm x 4 mm.

The next stage is to design the waveguide in a simulation software. For this task the decision was taken to use Ansys. The simulation model of the rectangular waveguide can be seen below in figure 1.

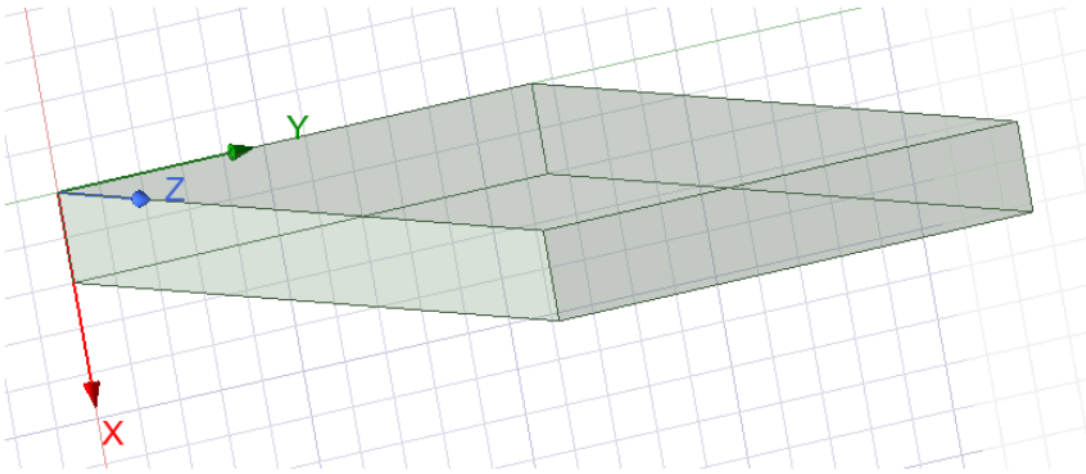


Figure 1 - An image of the rectangular waveguide design.

The next step is to run the simulation, this consisted of running frequencies from 2 GHz to 30 GHz. This then will be able to show us the nodes and cut off frequency within the waveguide. For this simulation 99 passes was decided, therefore it . will be cutting the sweep into 282 MHz chunks which for this simulation will be accurate enough to give us reliable results.

To have a theoretical understanding of what the cut off frequency a task within the method was to calculate the cut off frequency. This was done by using the equation:

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

Mode 1:

$$f_c = \frac{c}{2} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$
$$f_c = \frac{3 \times 10^8}{2} \sqrt{\left(\frac{1}{0.023}\right)^2 + \left(\frac{0}{4}\right)^2}$$
$$f_c = 1.5 \times 10^8 \sqrt{\frac{1}{529}}$$
$$f_c = 1.5 \times 10^8 \times \frac{1}{529}$$
$$f_c = 6.522 \text{ GHz (3dp)}$$

Mode 2:

$$f_c = \frac{c}{2} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$
$$f_c = \frac{3 \times 10^8}{2} \sqrt{\left(\frac{2}{0.023}\right)^2 + \left(\frac{0}{4}\right)^2}$$
$$f_c = 1.5 \times 10^8 \sqrt{\frac{2}{529}}$$
$$f_c = 1.5 \times 10^8 \times \frac{2}{529}$$
$$f_c = 9.223 \text{ GHz (3dp)}$$

Mode 3:

$$f_c = \frac{c}{2} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$
$$f_c = \frac{3 \times 10^8}{2} \sqrt{\left(\frac{3}{0.023}\right)^2 + \left(\frac{0}{4}\right)^2}$$
$$f_c = 1.5 \times 10^8 \sqrt{\frac{3}{529}}$$
$$f_c = 1.5 \times 10^8 \times \frac{3}{529}$$
$$f_c = 11.296 \text{ GHz (3dp)}$$

3. Results & Discussion for both Vacuum and Teflon

4.1 Vacuum waveguide

After running the Simulation, it was then time to look into the results. The first part of the results that was the cut off frequencies. The graph below in Figure 2 can show us the results.

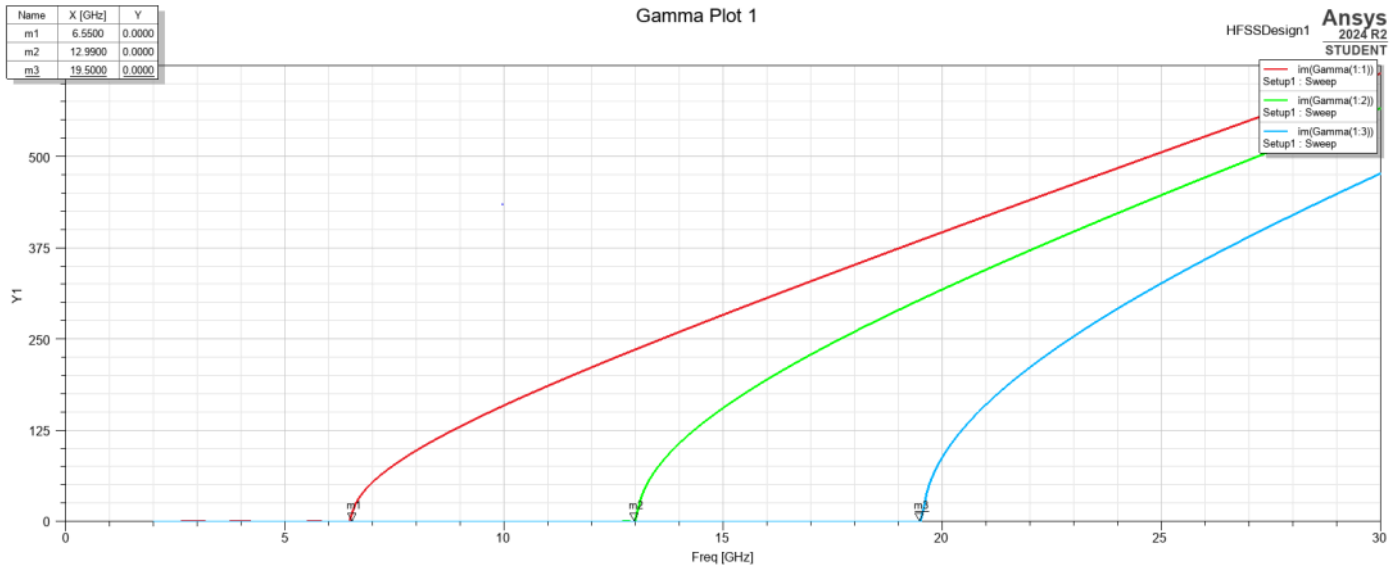


Figure 2 - A graph to show the cut off frequencies of the 3 modes

After doing the simulation the cut off frequency value for mode 1 can be seen as 6.55 GHz. If we compare this to the calculated value of 6.522 GHz. This is quite similar as it is only out by 30 MHz which in the grand scheme is very close and accurate. This is due to mode 1 looking at a lower frequency in comparison to mode 2 and mode 3. Typically, with electromagnetic waves accuracy decreases when frequency increases due to higher frequencies being harder to measure. Therefore, with modes 2 and 3 the accuracy starts to decrease and the calculated values will differ more from the measured values.

Looking at mode 2, the cut off frequency is measured at 12.99 GHz this is largely different to the calculated value which was predicted to be 9.223 which has a difference of 3.767 GHz out of which is around 40% difference between the two values. There are many factors that could cause this, for example; the waveguide is made for specific frequencies and internal materials are not accounted for.

Mode 3 follows a similar path to mode 2 where the calculated and measured values have a large difference where the calculated value is 11.296 GHz and the measured is 19.5 GHz. Again, this could be factored in when looking into the materials and the design of the waveguide.

The next result to look at the Port field displays. Port field displays shows you the half wavelength which enter/exit the waveguide. For mode 1 this should be $\frac{1}{2} \lambda$. As you can see below in Figure 3 the red lines show the peak/trough of the wave therefore by looking at figure 3 you can see there is one peak which can prove that ad mode 1 there is one peak. This can validate that we are looking at the first mode due to being a half wave length.

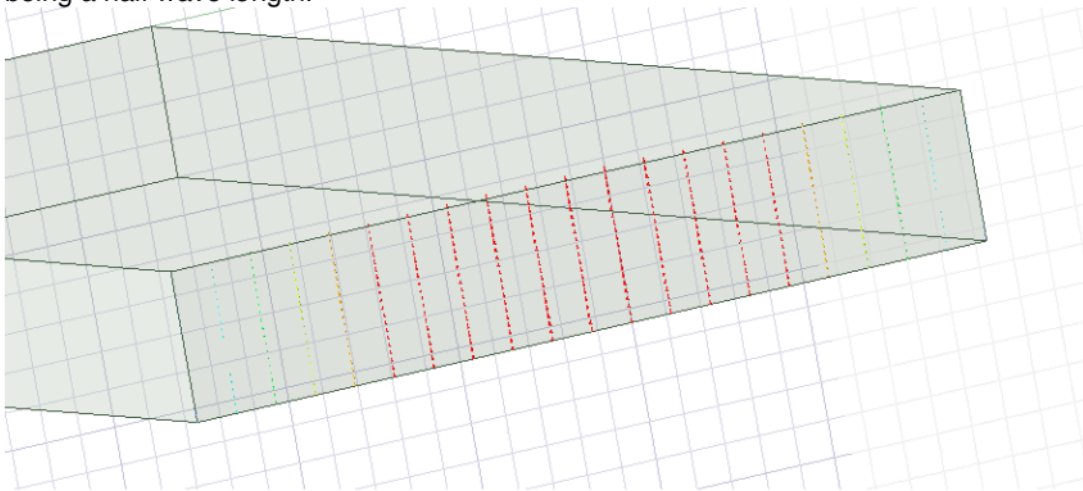


Figure 3 - Port Field display of mode 1

When looking at the figure above you can then infer that the wave entering the waveguide would look something like figure 4 below.

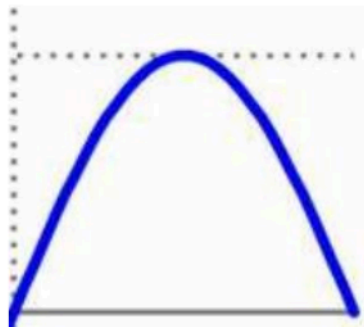


Figure 4 - An image of a half wavelength

For Mode 2, the wavelengths in the port will be 1λ . Therefore, within the port there will be 1 peak and 1 trough. Looking into figure 5 below you can see that there are 2 red sections with a peak at the left and trough at the right.

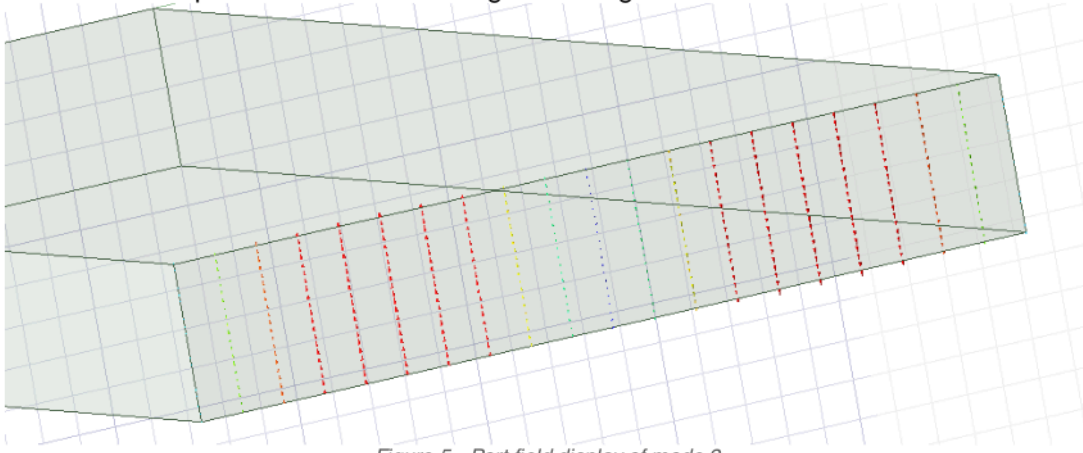


Figure 5 - Port field display of mode 2

From looking at Figure 5 you can then infer that the wave at the port will look very similar to 1 wavelength; similar to Figure 6 below.

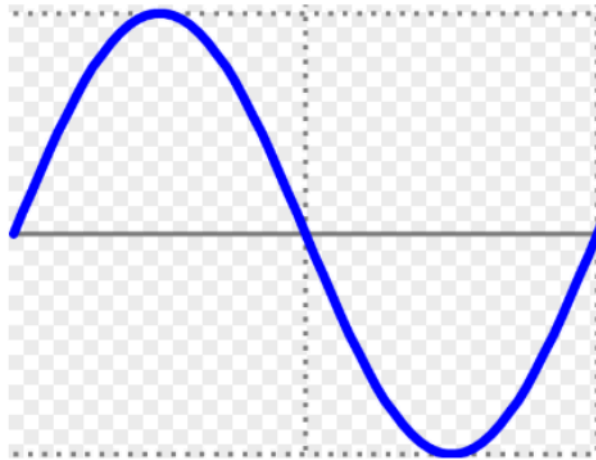


Figure 6 - Image of a full Wavelength

Finally, with mode 3 you can see, in figure 7, that there are 3 peaks/troughs. This can validate that this shows us the 3rd mode with wavelength of $\frac{3}{2} \lambda$.

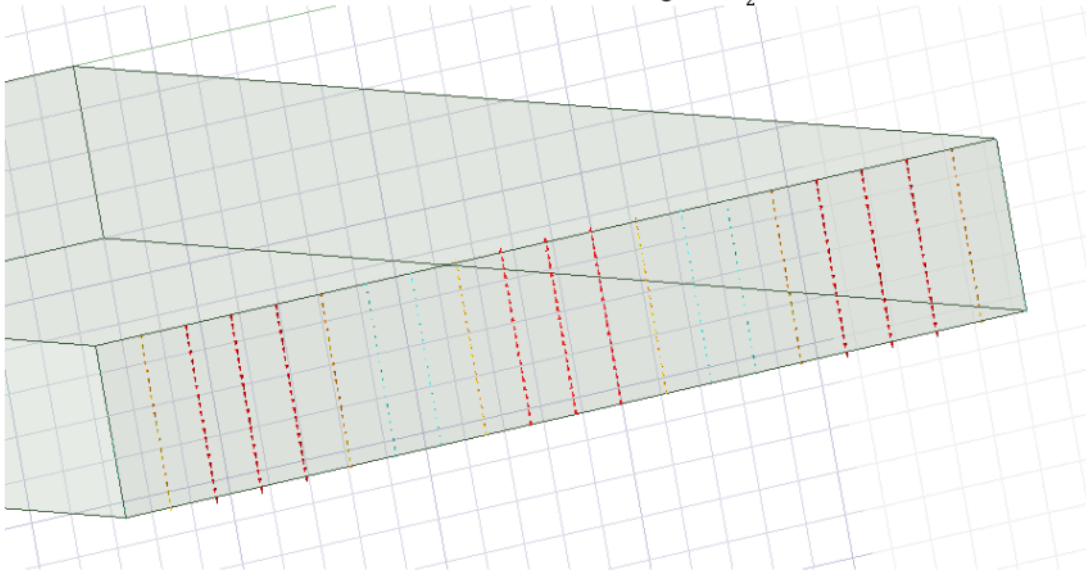


Figure 7 - Port field display of mode 3

Mode 3 at the port will look something similar to Figure 8 below.

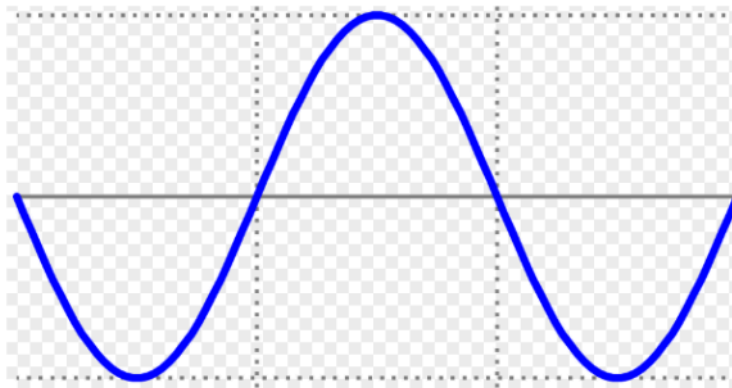


Figure 8 - An image of a wavelength of $\frac{3}{2} \lambda$

The next area of results to look into is the field overlays. the field overlays can show you the intensity of the Electric field. Working very similar to a heatmap you can see the intense spots (red) and the null spots (blue). There are two different types of field overlay. Vector and magnitude. The magnitude overlay can show you where the highest values lie and the vector overlay shows where the direction of the magnitude is going to better understand how the RF interreacts within the waveguide if you look below at the

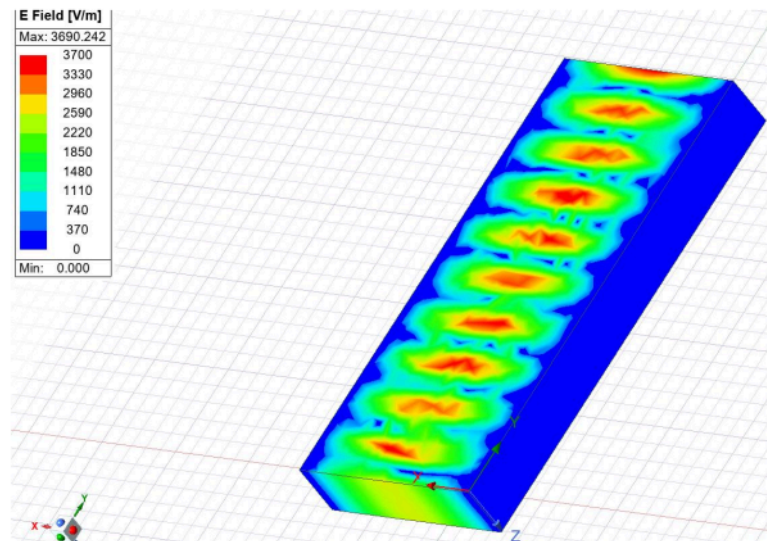


Figure 10 – Magnitude electric field overlay for mode 1

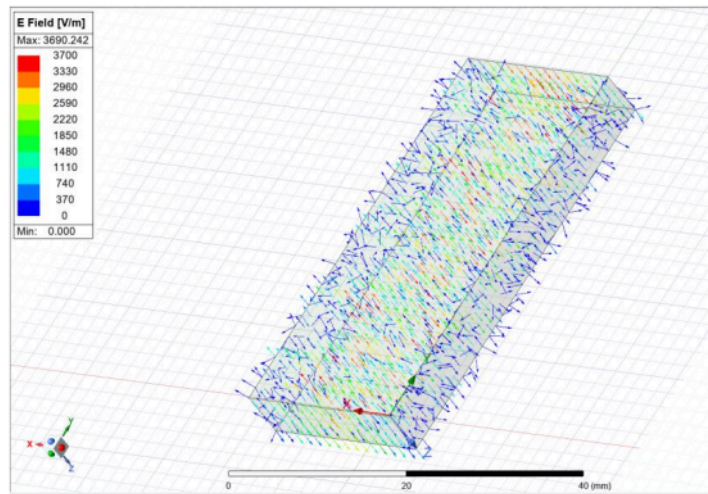


Figure 9 – Vector electric field overlay for mode 1

Figures 9-14 you can see the magnitude and vector overlays of the electric field for mode 1,2 and 3.

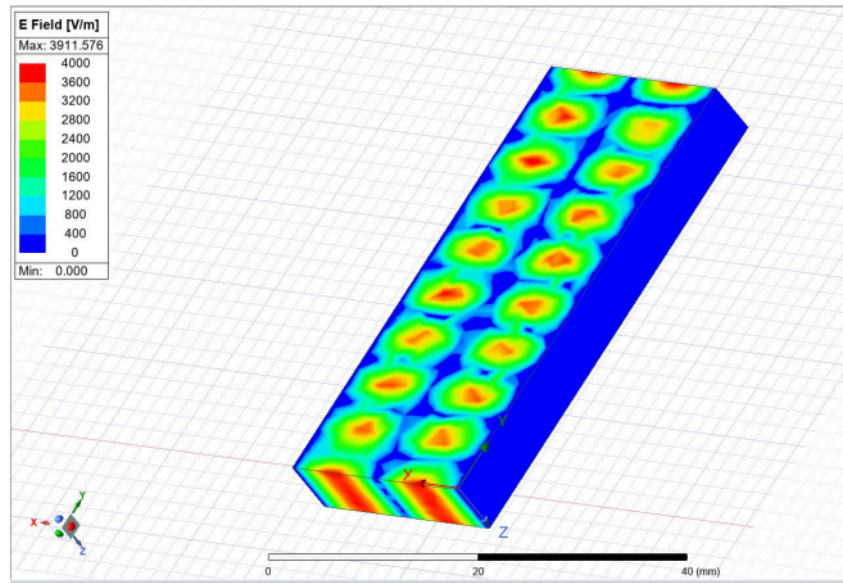


Figure 12 – Magnitude electric field overlay for mode 2

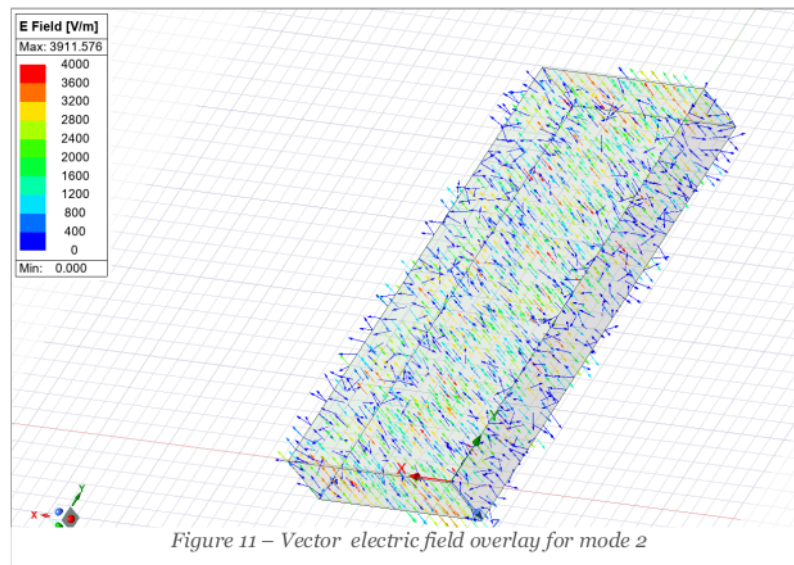


Figure 11 – Vector electric field overlay for mode 2

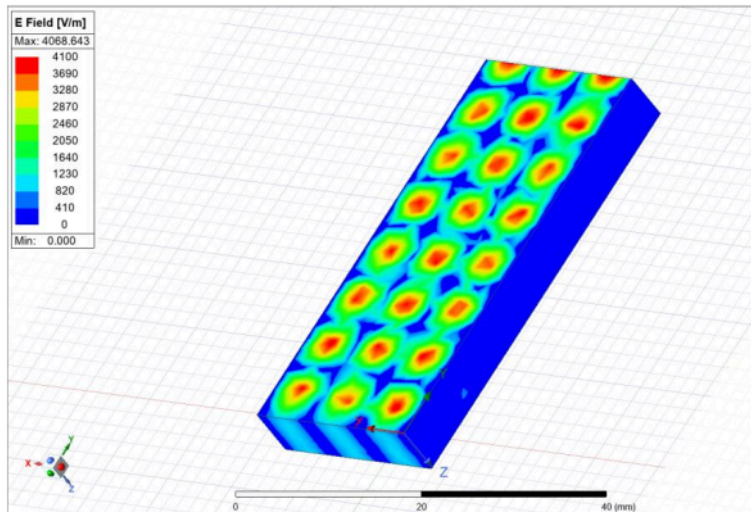


Figure 13 – Magnitude electric field overlay for mode 3

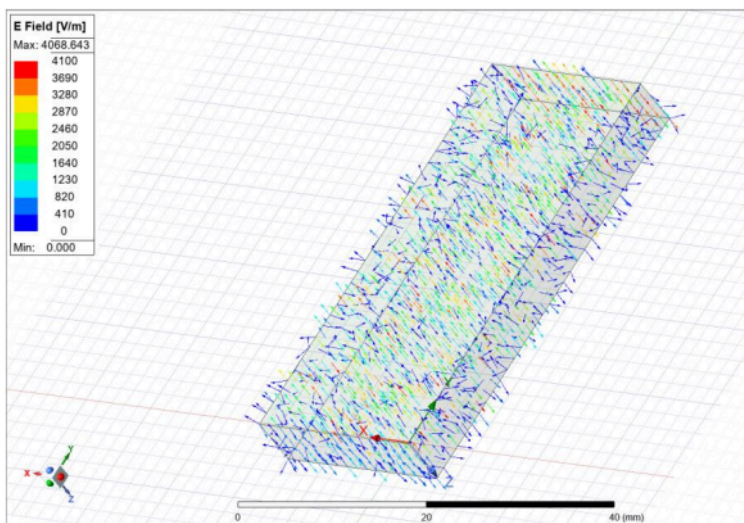


Figure 14 - Vector electric field overlay for mode 3

Additionally to electric fields, you can also look into the magnetic field overlays, the principles of the diagrams is the same with the main difference is that it shows you magnetic field strength not the electric field strength. As seen below in figures 15-20.

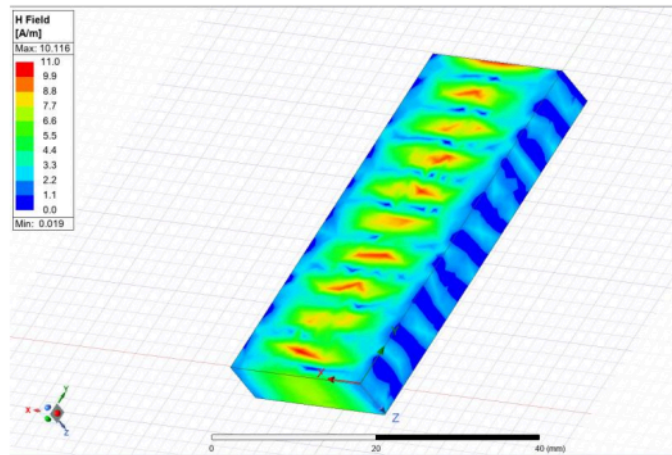


Figure 15 – Magnitude magnetic field overlay for mode 1

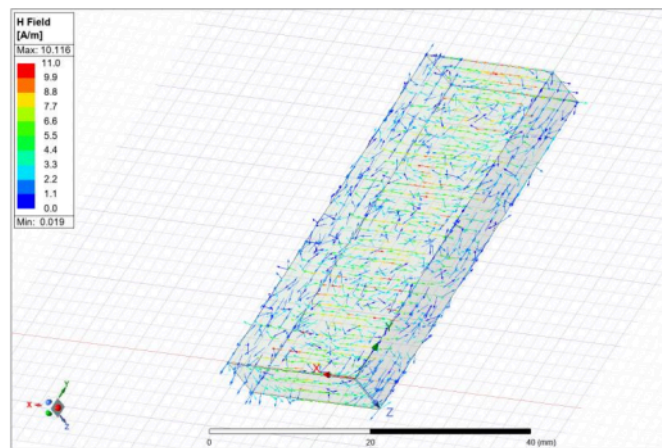


Figure 16 –Vector magnetic field overlay for mode 1

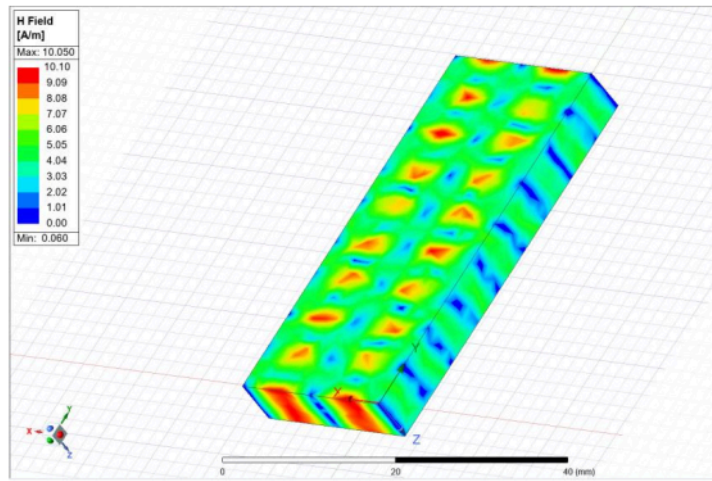


Figure 17 – Magnitude magnetic field overlay for mode 2

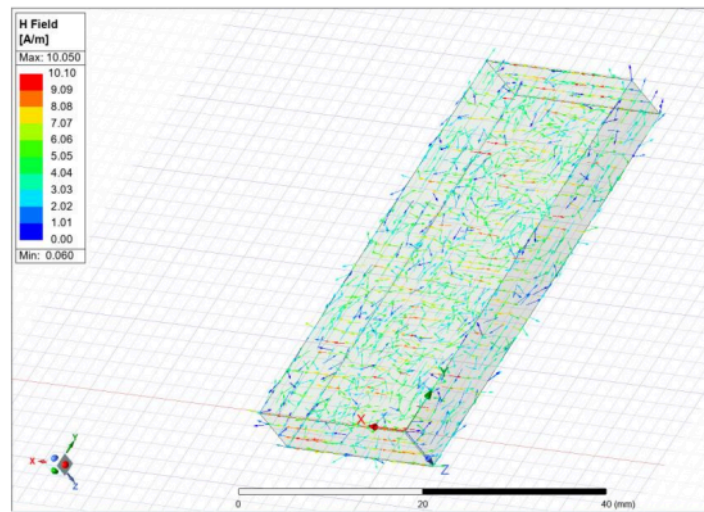


Figure 18 –Vector magnetic field overlay for mode 2

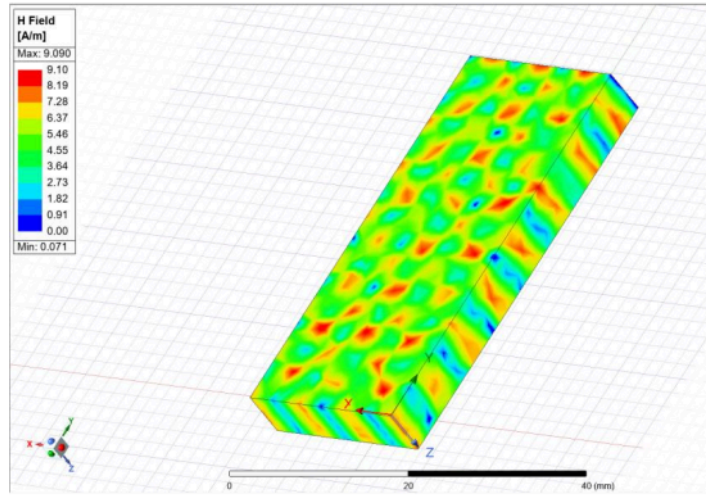


Figure 19 – Magnitude magnetic field overlay for mode 3

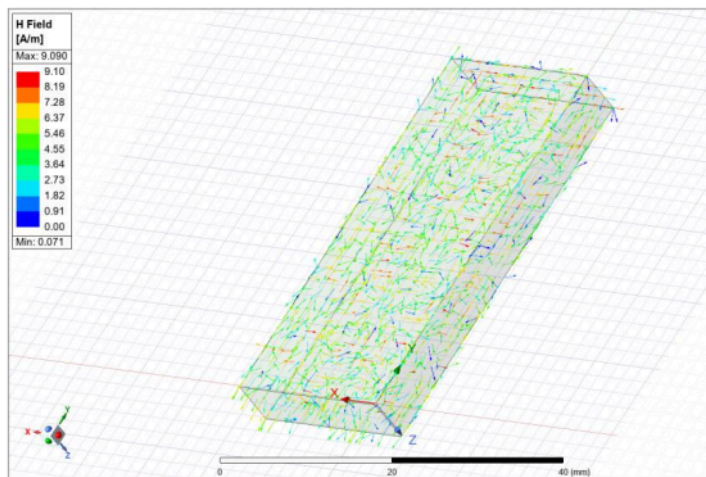
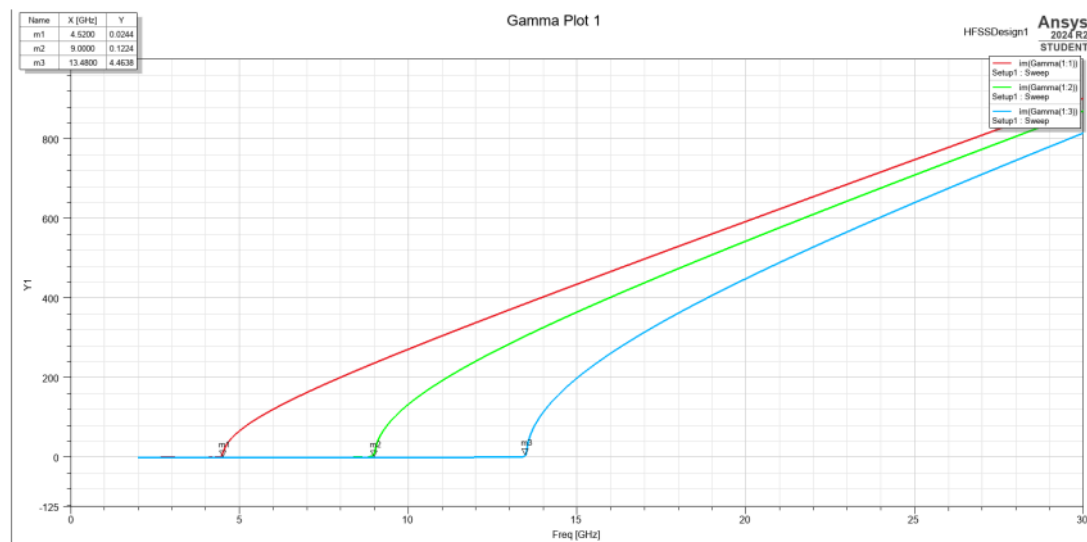


Figure 20 – Vector magnetic field overlay for mode 3

Teflon Waveguide

After looking at the results for the vacuum waveguide it was then time to look into a waveguide with a different internal material. To do this the vacuum centre was changed out for a Teflon centre. Theoretically the main difference between the two would be the cut off frequencies due to different materials having different properties.

As you can see below the cut off frequencies are much lower therefore the waveguide would only work up to a smaller frequency. Again, this is a different value to the calculated. This could be due to the calculation did not consider the materials used within the waveguide.



With regards to the port field displays. Both the Teflon and Vacuum waveguides have near identical displays. This is most likely due to the material not affecting the ports. As you can see in figures 22-24 below.

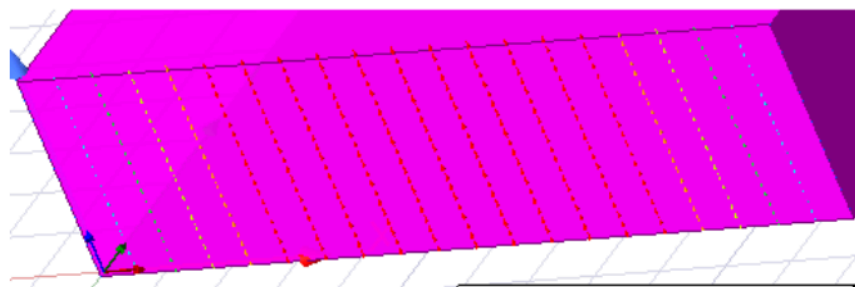


Figure 22 - Port Field display of mode 1 for Teflon

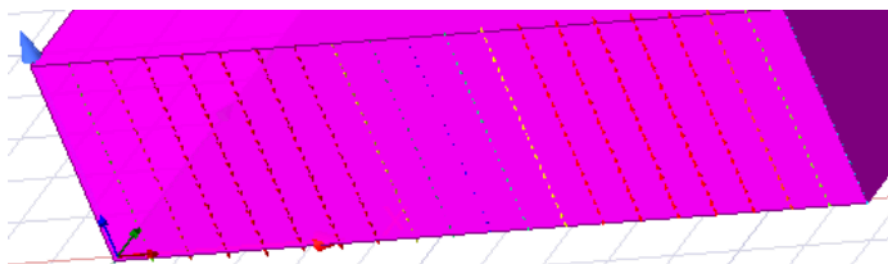


Figure 23 - Port Field display of mode 2 for Teflon

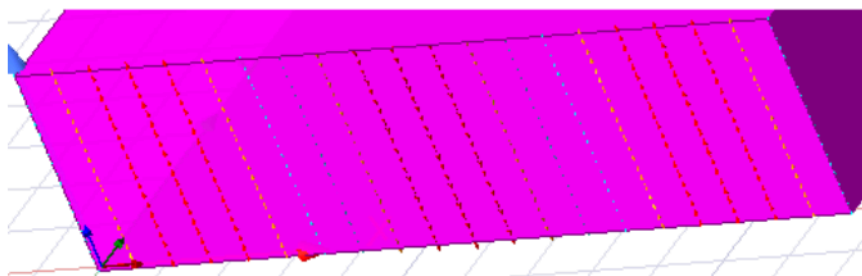


Figure 24 - Port Field display of mode 3 for Teflon

The magnetic and electronic field overlays of the Teflon waveguide are very similar in looks to the vacuum waveguide. The main difference is the intensity where the electric and magnetic field within the Teflon is much weaker than in the vacuum. As you can see in figures 25-36

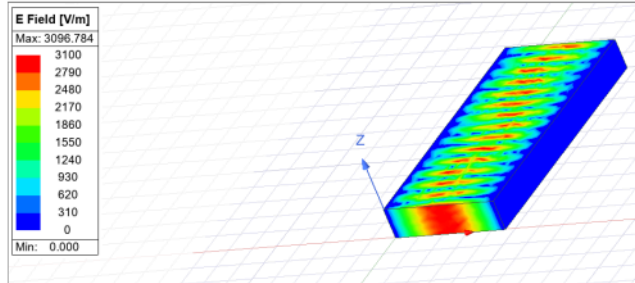


Figure 26 – Magnitude electric field overlay for mode 1 for Teflon

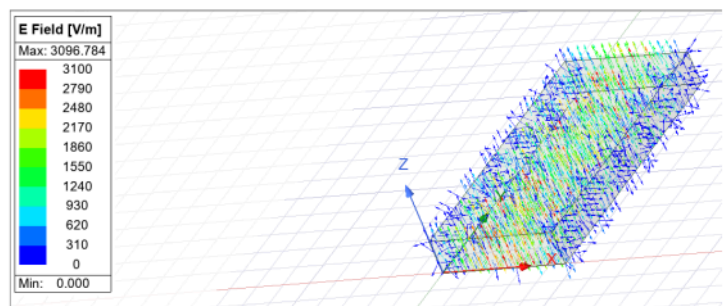


Figure 25 – Vector electric field overlay for mode 1 for Teflon

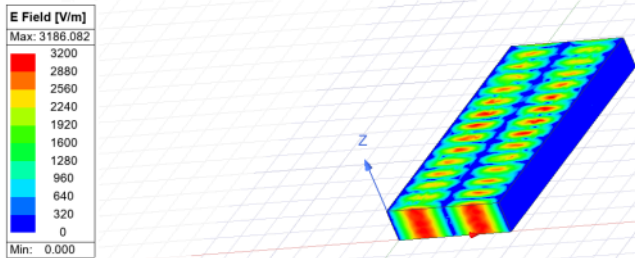


Figure 30 – Magnitude electric field overlay for mode 2 for Teflon

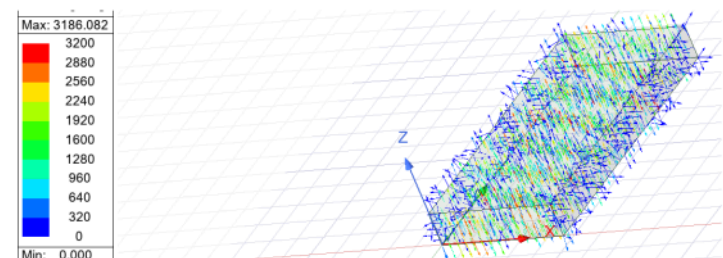


Figure 29 – Vector electric field overlay for mode 2 for Teflon

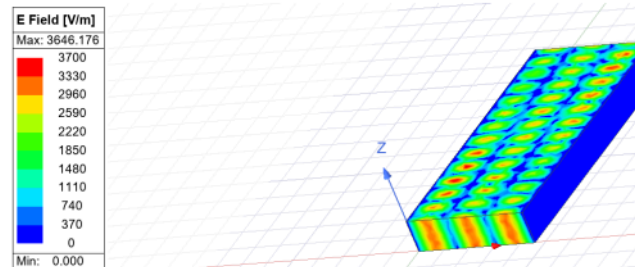


Figure 28 – Magnitude electric field overlay for mode 3 for Teflon

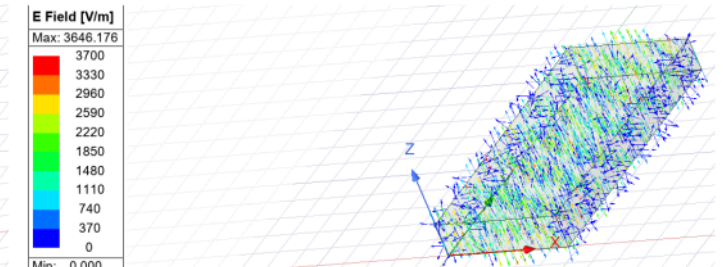


Figure 27 – Vector electric field overlay for mode 3 for Teflon

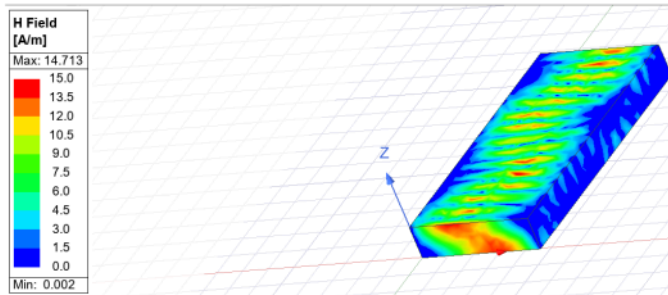


Figure 35 – Magnitude magnetic field overlay for mode 1 for Teflon

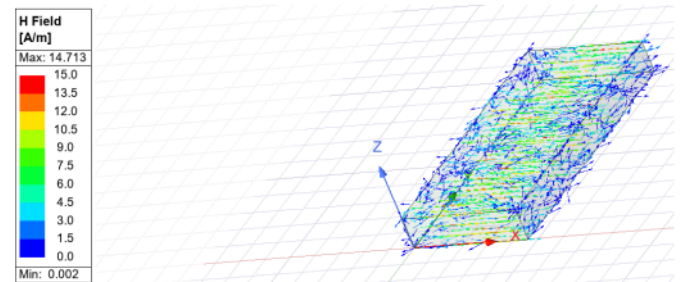


Figure 32 –Vector magnetic field overlay for mode 1 for Teflon

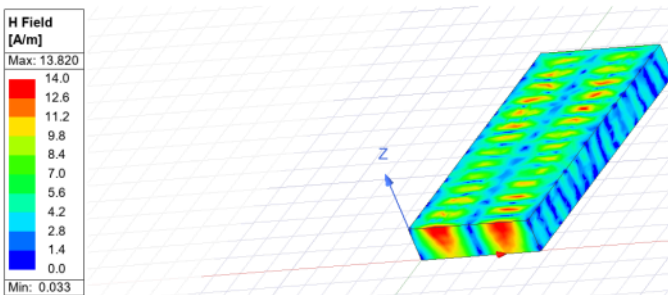


Figure 36 – Magnitude magnetic field overlay for mode 2 for Teflon

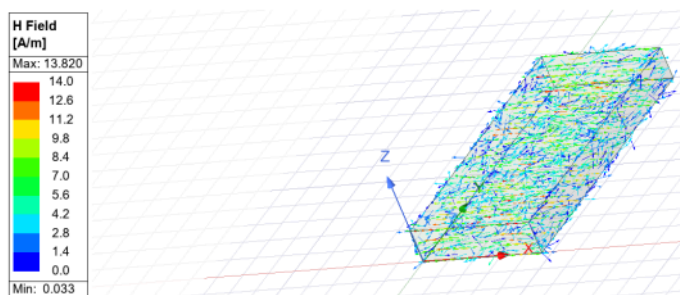


Figure 31 –Vector magnetic field overlay for mode 2 for Teflon

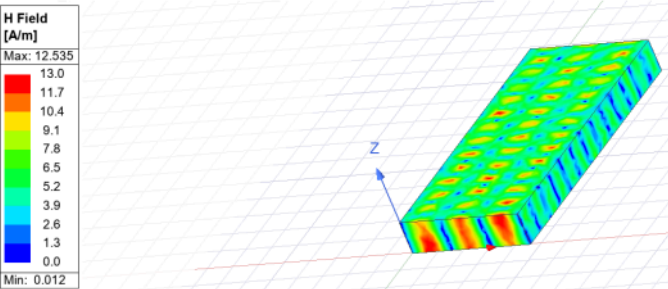


Figure 34 – Magnitude magnetic field overlay for mode 3 for Teflon

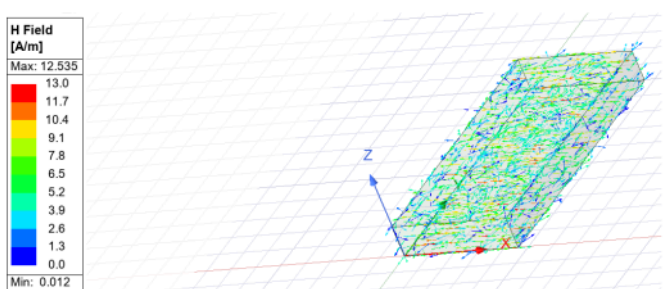


Figure 33 –Vector magnetic field overlay for mode 3 for Teflon

4. Conclusion

In summary the Teflon and Vacuum waveguides act very similar. The Vacuum waveguide is more effective as a waveguide but it can pose as a challenge to create in the real world as making vacuum dielectrics is difficult.

After looking into the field overlays and the cut off frequencies you can also see that theory and practical results can be more different due to real world errors such as there being no such thing as a perfect vacuum.

Task 2 – Halfwave dipole Antenna

1. Introduction

The next task within this report is to create a halfwave dipole antenna with an operating wavelength of the first 3 digits of our student numbers for the antenna in this report it will be a wavelength of 230λ . To calculate the length of the antenna you will need to divide this number by two as it uses a halfwave. Therefore, the length of the antenna would be 115 m. this will be using a Perfect Electrical Conductor (PEC).

2. Methodology

The first task is to calculate the operating frequency, to calculate this you can use the equation:

$$c = f\lambda$$

$$f = \frac{c}{\lambda}$$

$$f = \frac{3 \times 10^8}{115 \times 10^{-3}}$$

$$f = 2.61 \text{ GHz}$$

The next stage was designing the antenna on the Ansys simulation software, to do this the values calculated for the antenna length will need to be used. To create the antenna as seen below in Figure 37.

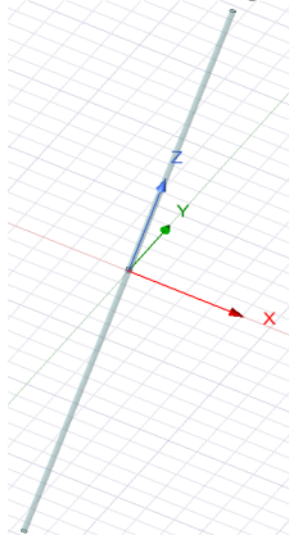


Figure 37 - An image of the simulation antenna

After creating the simulation, it was then time to run the simulation so that the radiation pattern and S-parameters can be calculated.

3. Results & Discussion

After running the simulation, it was then time to look into the results. The first section of results to look into is the S-Parameters. For this we will look into S11 parameters, this is due to it being able to show the return loss over a frequency range. As seen below in Figure 38.

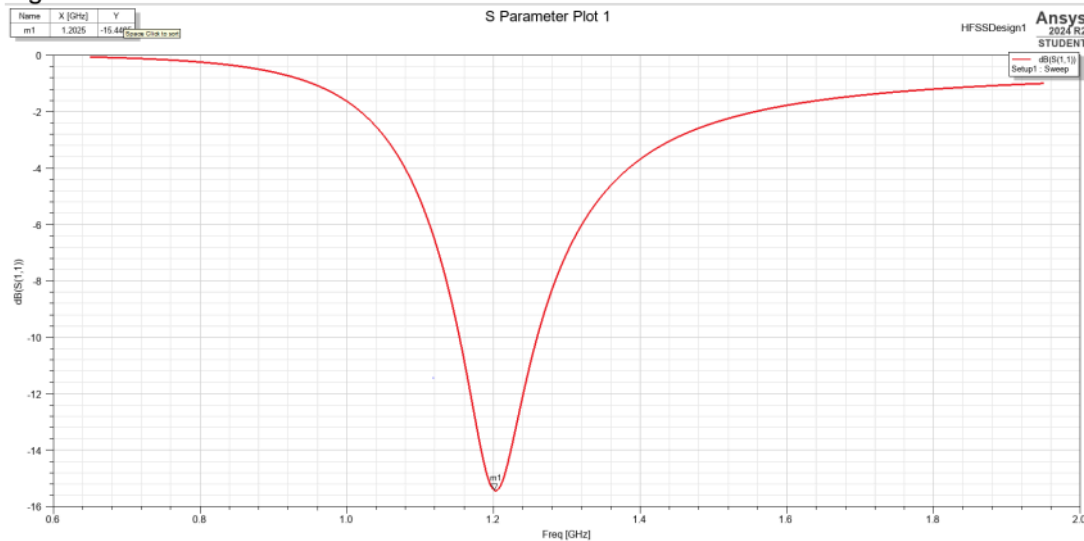


Figure 38 - S11 Parameters for the halfwave dipole antenna

If you look at the S11 Parameter the minimum is at 1.2 GHz this frequency is where the antenna will radiate the best. This isn't the same as the intended 2.61 GHz. This is due to a theory called impedance matching as this then will ensure that maximum power is being transferred at the correct frequencies. The optimal impedance for this antenna would be 73Ω instead.

The next part of the results is looking at the radiation pattern. As seen below in figure 39.

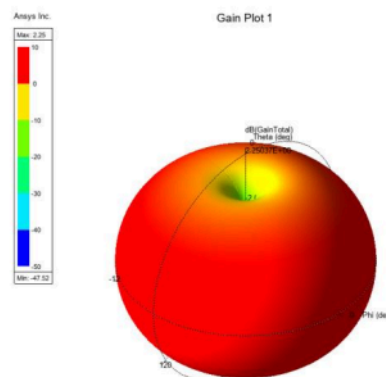


Figure 39 - Radiation pattern of the antenna

If you look at the pattern you can see it is a perfect sphere. This is due to the simulation running a perfect antenna plot. In the real world the pattern will not look like this due to factors such as physical objects in the way and manufacturing errors. There is a null at the top and bottom end due to a lack of radiation at the top and bottom end of the antenna.

4. Conclusion

In conclusion the antenna in the simulation radiates perfectly due to it being a simulation although the frequency is not correct due to impedance matching. For future designs this can be considered to ensure that an optimal antenna is created.

Task 3 – Detecting UAV's with Radar

1. What is a Radar?

A radar is an electromagnetic sensor that is used to detect, locate, track and recognise objects. [1] In simple terms a Radar will send out an electromagnetic wave which will then reflect off a specific object and be received back at the Radar. This signal will then be displayed on the screen. Radars can be used to detect where an object is and even more modern Radar can also detect the speed and direction of a vehicle by using Doppler shift. Doppler shift is the change in frequency or wavelength to an observer moving relative to the source of the wave. [2] therefore if the electromagnetic wavelength is decreased the vehicle will be travelling towards you.

2. Practical Applications of Radar

There is plenty of applications of Radar, including:

- Weather
- Space
- Air traffic control
- Biological research
- Space
- Military capability

This isn't every use of Radar as there is a surplus of uses. But this can show us that improving the modern technology on Radar is vital for the enhancement of science and technology. Without Radar the Air and space travel will never be accessible as it would be unsafe and dangerous to the public due to not having situational awareness of what is around you.

Radar is not just used for Aircraft, it can also be used to track animals and wildlife. This can help biologists track and record where animals are travelling and nesting to better understand the lifecycle of specific animals and also help endangered animals by ensuring that they are recorded and tracked to keep them safe.

3. Current Challenges with Radar

One key issue with Radar is within the airspace domain. With modern advancements to Aerial Systems; radars can be forgotten about and not improved to keep up with these technological advancements. Therefore, one thing that is vital in science and technology is to continue the development of all radar to keep up with the modern airspace.

One big threat is Unmanned Aerial Systems (UAS). The proliferation of UAS technology has made Counter UAS (C-UAS) a ubiquitous weapon in UAS conflicts. [3] UAS can be a major challenge to Radar due to its Radar Cross Section (RCS) being so small this can mean that the current Radars used may not be able to pick up a system as small as a drone.

On top of this some of the future UAS has an AI driven system which has the ability to counter Radar using real time adaptations [4]. As symmetrical warfare continues to increase in the real world so does the use of AI and high-level technology. Therefore, meaning that warfare continues to become a game of who can create a device which can counter the other. So therefore, it is vital that as a country we enhance our detection and countermeasure techniques.

UAS systems typically use low-power Radio Frequency (RF) for signal and communication which leads to these signals being a challenge to detect due to blending in with the array of electronic noise in public and on the battlefield.

UAS systems are light and fast which can lead to Radars struggling to keep up and track their movements. Therefore, posing a bigger risk to people. And leading to an increase in the duty cycle of a radar. Which leads to radars having to be upgraded and improved constantly.

With all of these requirements to assist with tracking drones there also can be some physical challenges with Radar, for example to increase the effectiveness of a radar. You will also need to increase its physical size to account for all of the internal technology. This can pose a challenge specifically to military due to size and weight being a key factor into the transferability of the asset.

4. Technological advancements in Radar

All of the challenges raised above have been comprehended by radar experts and have already been looked into to allow for the detection of drones. And already there is commercial assets which can detect drones. An example of this would be the Robin Radar [5].



Figure 40 - Robin Radar

The Robin Radar can detect up to speeds of 100 Km/Hr with 360° and 60° elevation. This uses Deep Neural Network (DNN). This is an AI network which can solve trivial tasks with a network outline. Consisting of 2 or more layers with each layer consisting of nodes which can operate together [6]. DNN Technology allows the Radar to detect lades and rotating parts which allows the radar to detect the difference between a bird and a UAS.

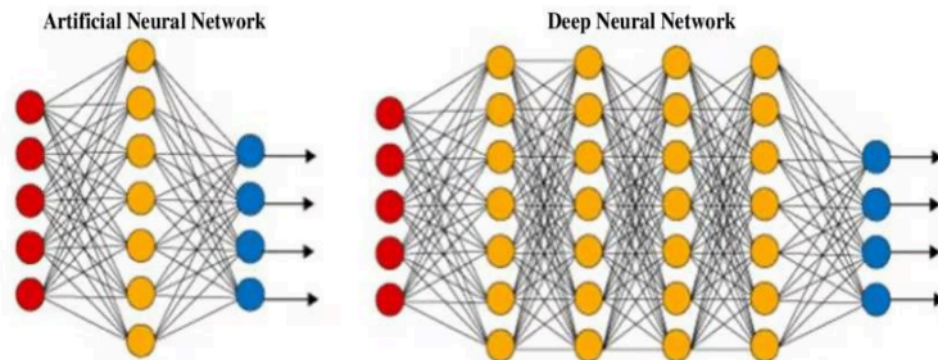


Figure 41 - An image to show Artificial Neural Network vs Deep Neural Networks

High resolution Radar in current use have the ability to characterise drones. This is using a previously stored database which therefore reduces the chance of false positive detection of a UAV [7].

5. Conclusion

In summary, Radars work by sending and receiving electromagnetic waves which can be a challenge when you are trying to detect smaller objects such as UAV's therefore technological advancements need to be worked on to ensure that they can keep up with the air domains technology. This is already being done; for example, with the Robin Radar. Although there is still areas that need improvement to ensure that all UAV's can be detected it is still a correct step in the correct direction.

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ACDD5009 - EMR - Final Coursework

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

70/100

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Comment 1

Calculation is wrong

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GRADING FORM: EMR MAY

SAM PEPPARD

69.50

ENGAGEMENT WITH LITERATURE

The report should demonstrate the use of relevant, high-quality academic and professional sources. Comprehensive research incorporating recent journal articles, textbooks, and reliable sources should be evident. The credibility of each source should be evaluated, favouring peer-reviewed materials. All references must follow IEEE format, with consistent in-text citations.



Demonstrates engagement with a wide range of literature including independently sourced materials. Credible set of sources is used. References include textbooks, journal articles, and online resources. In-text referencing is consistently applied and relevant to the context. The number of peer-reviewed academic journal articles remains limited. HFSS/Ansys were not referred.

6

KNOWLEDGE AND UNDERSTANDING

The report must exhibit sound knowledge of RF principles, waveguides, and antenna theories. Theoretical concepts such as wave modes and propagation should be clearly explained. Concepts should be related meaningfully to practical contexts. The report should demonstrate how this knowledge informed the design decisions.



Excellent and detailed understanding of waveguide behaviour, TE modes, cut-off frequency, antenna radiation, wave propagation, mode identification, and material impacts on cut-off frequency. Formulas are accurate and clearly explained. The dominant mode is identified. Include more theoretical validation of field plots. It

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would have been better with proper calculation of cutoff frequency of waveguide and operating frequency of antenna.

COGNITIVE AND INTELLECTUAL

The report should present a critical analysis of simulation results and theoretical data. Findings must be discussed with evidence, leading to logical and valid conclusions. Comparisons between theoretical and simulation results should be presented. Discussions should include implications, limitations, and alternative solutions.



Provides critical evaluation and analysis of key concepts. Simulated and theoretical results are compared reasonably well for antenna design. To improve, include more discussion of simulation limitations, such as mesh size, boundary effects, or assumptions related to lumped ports. Additionally, a table comparing theoretical and simulated values with percentage error should have been better. Designed effective waveguide and antenna systems with commercial awareness. Radar analysis addressed privacy, safety, and environmental concerns. Applied advanced technology for innovation.

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PRACTICAL SKILLS

Appropriate engineering software and methodologies should be applied to design waveguides and antennas. The simulation process and parameters should be documented clearly, with justifications for methods used. Results should be presented with neat plots and

visuals. Problem-solving skills should be demonstrated through analysis and design refinements.



An advanced application of a range of established methods, materials, tools, and techniques.

Excellent use of HFSS simulations, including the port field display, field magnitudes, vector plots, S-parameters, and radiation patterns. The application context is well considered and insightful. To improve further, specify the boundary conditions used and the solver settings.

14.5

TRANSFERABLE SKILLS FOR LIFE

The report should be clear and well-structured for technical and non-technical readers. Complex ideas must be communicated effectively, with appropriate terminology and visual aids. A logical flow from introduction to conclusion should be maintained. Professional presentation elements such as clear headings, subheadings, and a well-organised reference list should be included.



Communicates well in a suitable format, with clear structure and logical flow. Academic language is appropriate, and the presentation is professional. However, alignment and clarity should be improved. Figures are appropriately referenced in the text. The conclusion of the report would have been better. A thorough proofreading is recommended to enhance the overall quality.

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