**ELEC0019 Electromagnetic Theory:**

**Interference, Diffraction and Polarization of Electromagnetic Waves**

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Table of Contents

[Part 1 Interference of waves 2](#_Toc128445151)

[Experiment 1.1: Interference of waves 4](#_Toc128445152)

[Experiment 1.2 Measurement of relative permittivity of a dielectric material 7](#_Toc128445153)

[Exercise 1.3 Antenna Arrays 10](#_Toc128445154)

[Part 2 Diffraction and Polarisation 15](#_Toc128445155)

[Experiment 2.1: Diffraction of a wave by a conducting plane 17](#_Toc128445156)

[Polarisation of Electromagnetic Waves 19](#_Toc128445157)

[Experiment 2.2: Polarisation 21](#_Toc128445158)

# Part 1 Interference of waves

**Q1.** The square of the magnitude of the electric field is known as the intensity. Show that the approximations above lead to:

*ET* 2 ≈ 42 cos2 *kdx* (4) *D* 2*D*

From this expression, what is the distance between consecutive maxima or minima?

Showing procedure:

Diagram

Description automatically generated

Thus, distance between consecutive maxima or minima = .

**Q2.** Download and run the Matlab script Interference.m that calculates the intensity versus position *x* using eqn. (1) directly instead of using the approximate expression (4). Modify the script to include a calculation of the intensity as it varies with the displacement *x* of the observation point on the screen using eqn. (4) as well and plot this in the same figure as the results from eqn. (1). Comment on the approximations used in (1)-(4), compare the results and discuss and explain the differences



Figure 2.1

Comment and compare and explain the difference:

* Comment: generally, it is a good approximation from -50 to 50 cm, with similar value and shape to the accurate one.
* Compare:

1. the difference (error) between the accurate one and the approximated one is the smallest when x approaching 0, with they meet at point (0, 1).
2. However, as it goes further away from x = 0, the error becomes larger. It can be observed that the approximated one is always having constant maximum intensity, while the actual one starting to be attenuated as it goes away from x=0; Also, while the period of the approximated equation is always fixed, as it goes along from x = 0, the actual period becomes larger.

* Explain: To explain this,
  1. approximation of 'd is much larger than D', where we got 'l1 =l2 = D'. In this way, we underestimated the value of l1 and l2 to be D all the time, while D is their minimum value.
  2. approximation of ‘ approximately = 0’, where we got and the Taylor expansion of centred at .

## Experiment 1.1: Interference of waves

**Q3.** Explain the function of the detector diode. What is the frequency of the signal carried by the coaxial cable to the meter in the setup described in the figure above?

What is the relation between the electric field intensity received by the horn and the magnitude of the signal (current) coming from the detector through the coaxial cable? It happens that the output of the detector is proportional to |*E*|2 *i.e.*, is proportional to the field intensity; can you explain why?

Detector diode:

The detector diode (guessing a photodiode) is used for measuring the intensity distribution of the interference by the intensity of light received by itself.

Frequency:

According to ‘It generates a microwave signal of 10 GHz modulated in amplitude with a 5 kHz square wave signal.’,

**Q4.** From the Moodle site of the course, download the file Int1.txt containing measurements done using the setup shown in Fig. 2. The file has two columns: the first is the displacement *x* of the receiving horn in cm, where the origin is at the centre; that is, when the horn is aligned to the midpoint between the two sources. The second column is the reading in the meter, in mV.  
Write a Matlab program that loads the file Int1.txt, and plots the received voltage versus *x*. Explain the relation between this voltage and the received field intensity by the horn. Name the program: Pattern1.m and keep it in your records. The program should also plot the theoretical curve from eqn. (1) in the same figure. Compare the two curves and comment. **Hint.** In your program, normalise the intensity values calculated from the given readings to maximum value 1 before plotting and comparing with the theoretical results.

The relation between voltage and received field intensity is that, the received field intensity is proportional to the square of the voltage.



Do all the maxima have equal amplitude? Do all the minima have zero amplitude? Which of these, maxima or minima, will give a better, sharper definition of position? Comment on your observations and compare them with the theoretical results obtained for Fig.1 based on two point sources.

Comment:

* They are generally having the same period and thus frequency.
* For the experimental one, the maxima amplitude drops dramatically when it becomes further away from x = 0, and the amplitudes of all the minima are having a value above zero.
* Compared to the theoretical results, the theoretical amplitude of maxima drops slightly as going away from x = 0, while the amplitudes of all the minima are zero.
* The maxima would give a better, shaper definition of position, as the maxima has a shaper shapes compared to the minima, which means that the change of the relative intensity is more obvious here at the maxima.

Are the approximations in the theory justified? The theoretical description and derivations that follow Fig. 1 assume that the electric field is vertical, that is, along the *y*-axis and that is also the case of the experiment that produced the results in the file Int1.txt from the set-up in Fig. 2.

It is not that justified to assume the electric field is vertical with two point sources. (???)

Would there be any difference if the sources were transmitting waves with their electric fields in the *x-z* plane instead? If so, why?

In this case, the wave is transmitted in the x-y plane with the electric field in the z direction, perpendicular to the x-y plane. However, if the electric fields are changed in the x-y plane instead, the wave would propagate in the z direction. Thus, the horn would not receive any signal since it does not stay in the plane where the wave propagates.

At the observation plane the total field is measured using a horn receiver with a finite aperture. Does this introduce any complication?

When replacing the horn as a finite aperture, more background signal and the signal at the other point might be detected, introducing uncertainties to the system.

The finite aperture in the horn receiver does introduce to complication as it has been stated above that there will be multiple intensities being received at the receiver which will reduce the accuracy of the exact intensity and will cause different conclusion between practical and reality.

## Experiment 1.2 Measurement of relative permittivity of a dielectric material

**Q5.** Using simple theory, show that the relative permittivity of the sheet is given by:

where ∆*s* is the shift of the central maximum along the *x-*axis, and δ is the thickness of the dielectric sheet.  
**Hint**. Consider the phase shift introduced by the thickness δ of the dielectric sheet and the corresponding shift in the position of the minima (or maxima). Since you know the phase difference that corresponds to the distance between minima (or maxima) on the screen, you can determine the corresponding value of refractive index.

Fig. 3 is not at scale and the angle between the propagation direction and the normal to the slab is actually very small so it is safe to assume normal incidence on the dielectric slab.

Clearly state any assumptions you make in deriving this expression.

**Q6.** Download the file Int2.txt that contains the new measurements of intensity versus *x.* This file has the same format as Int1.txt and the second column lists the readings of the instrument in mV. Create a new Matlab program modifying your Pattern1.m, to read this file and plot both the original and the shifted interference pattern in the same plot. Name this program ShiftedPattern.m and keep it in your records.



From the plots and the data files, determine the shift as accurately as you can, explaining your procedure and calculate the relative permittivity of the dielectric slab if its thickness is δ = 1.2 cm.

**Text

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**From those calculations in MATLAB command shown in figure above, I used max() function to first find the maxima, then used find() function to get its index, followed by finding out its corresponding x-coordinate, and then comparing and getting the value of shift.**

**After calculation, the shift of each maxima is 4cm, 2.5cm, 3cm, 2.5cm respectively, and the average shift can be calculated which is 2.917 cm. The value of the relative permittivity of the slab with = 1.2 cm can be calculated use :**

Would this method be suitable for (a) thick sheets (b) high permittivity sheets? If not, what would be the problem? Is the position of the dielectric sheet between the source and the screen important or relevant? Does it need to be 25 cm as shown in the figure? Discuss.

**This method won’t be suitable for either thick sheets or high permittivity sheets, as larger errors could be introduced with large or large . By looking at the figure below, with the black arrow representing the actual path, with the identical incident light, we can see that when is smaller than , is smaller than . And, if is smaller than , is smaller than .**

Chart, line chart

Description automatically generated**Chart, line chart

Description automatically generated**

Does it need to be 25 cm as shown in the figure? Discuss.

**The distance from the waveguide source and the dielectric doesn’t need to be 25 cm as in the figure, as we have the assumption that D >> d, the path difference produced by the slab won’t change with the change of position of the slab.**

## Exercise 1.3 Antenna Arrays

**Q7.** Starting from equation (6), find an expression for the absolute value of the far field as a function of the angle θ.

The final expression will have the form:  
*E*(*r*,θ) = *F*(θ) (7)

*r*where the factor *F*(θ) is called the radiation pattern of the array, or more properly, the Array

Factor.  
Write a Matlab program and name it Array.m, to calculate the array factor of this array as a

function of the antenna separation *d*, the phase difference between the antennas, φ and the inclination angle θ. Use the Matlab command “polarplot” to plot the normalised array factor versus θ for the cases: (a) *d* = λ/2 and φ = 0, (b) *d* = λ/2 and φ = 90, (c) *d* = λ/2 and φ = 180, (d) *d* = λ/4 and φ = 0, (e) *d* = λ/4 and φ = 90 and (f) *d* = λ/4 and φ = 180. Keep all these plots and the program Array.m in your records.

Text, letter

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1. **, = 0**

图表, 雷达图

描述已自动生成

1. **, = 90**

图表, 雷达图

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1. **, = 180**

图表, 雷达图

描述已自动生成

1. **, = 0**

图表, 雷达图

描述已自动生成

1. **, = 90**

图表, 雷达图

描述已自动生成

1. **, = 180**

图表, 雷达图

描述已自动生成

**Q8.** Write down the complete derivation of eqn. (8).

**Text, letter

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# Part 2 Diffraction and Polarisation

**Q9.** Consult the references indicated for the Fresnel and Fraunhofer diffraction theories and/or any other source of information you may find and keep in your records a brief summary description in your own words of the theory of diffraction, in particular concerning the diffraction by a screen as in Experiment 2.1.

**Note:** When using material taken from a book, journal, webpage or any other source, textual reproduction (or very similar) is not permissible. Read and understand the material and summarise it using your own words and explanations and quote the corresponding source using one of the standard formats to cite references.

**Q10.** What is the difference between refraction and diffraction? Comment on the effect of diffraction in microwave communications systems. Explain in detail the use of a grating in a device that can separate light with a narrow band of wavelengths from a white source (monochromator).

Sdfs

Sf

## Experiment 2.1: Diffraction of a wave by a conducting plane

**Q11.** Plot the received intensity against the position of the screen edge using the data collected in the file *diffraction.xlsx*. make a special note of the value at *x*=0 and give a theoretical value and explanation for it. Does the result agree with this? Compare the results with published results for an opaque semi-infinite diffracting screen. Comment on the differences due to the use of an excitation different to a plane wave. How could the set-up be changed to approximate better the case of a plane wave?

**图表, 折线图

描述已自动生成**

As shown in plot above, the special note is made on x = 0 point, where the y value is around 0.25. In theory, a plane wave will be partially blocked if there’s a opaque screen thus producing shadows. As I  **(**the magnitude of intensity proportional to the square of the amplitude of signal), if the screen occludes ½ the wave, its intensity I will become (½)^2 = ¼ the original value, which is equal to 0.25. Thus, the result agrees with the theorical value.

**The result from *Fresnel diffraction on a semi-infinite opaque screen* written by *Loenen, S.J.H.* in 2015 [9] shows a similar conclusion which is shown in *Figure 6*.**

**Chart, line chart, histogram

Description automatically generated**

**Q12.** Does this case correspond to a Fresnel or Fraunhofer diffraction? Does a conducting screen really correspond to an opaque screen? Would the experimental results differ if an orthogonal polarisation were incident on the screen? In the experiment the screen was moved. Suppose the screen was fixed and the receiving horn moved instead. Would the results be different? What do the terms ‘near field’ and ‘far field’ mean?

## Polarisation of Electromagnetic Waves

**Q13.** Explain briefly what is polarisation of an electromagnetic wave. What is a polariser?

Polarizers are films made by artificial methods. Polarizers could make an unpolarized wave polarize obviously in some specific forms. Polarization could attenuate and block high-energy light and minimize the effect of reflected lights.

Light is reflected when it hits a smooth surface, causing glare. The lens of the anti-glare sunglasses contains a layer of polarizer which could reduce the intensity of the incident light by polarizing the light and absorb the reflected light. This is because reflected light is polarized in horizontal. However, the lens of sunglasses is a kind of vertical polarizer. Thus, the orientations of the light and lens are perpendicular to each other, and hence, reducing glare.

When there is a polarizer between a source emitting a polarized file and a receiver, the signal would only remain the components in the same direction with the orientation of the polarizer after passing through the polarizer. When rotating the polarizer from 0 to 180°, the intensity of the light would vary from the maximum when the direction of the vibration of the photons in the same direction of the polarizer (i.e., when θ=0) to zero when the direction of the vibration of the photons is perpendicular to that of the polarizer (i.e., when θ=90°), then return to the maximum when the direction of the vibration of the photons back to the same direction of the polarizer (i.e., when θ=180°). The same process would repeat when the polarizer rotates in the following half cycle (i.e., from 180° to 360°).

The relationship between the detected amplitude (indicate as A) and the angle θ is A=A\_0 cosθ, where A\_0 is the amplitude of the polarized light. Since there is a relationship between the intensity (indicated as I) and the amplitude I∝A^2, the expression above could be rewritten as I=I\_0sx(cosθ)^2.

By assuming the value of I\_0 is 0.5, a graph of intensity against angle could be drawn:

图表, 折线图

描述已自动生成

## Experiment 2.2: Polarisation

**Q14**. Since the excitation comes from a rectangular waveguide and its longer side is horizontal, what do you think the polarisation of the emitted wave should be and why? From the orientation of the grid and the corresponding received intensity shown in the table above, what is the polarisation of the source: horizontal or vertical and why? Does this coincide with your expectations for this source? Give a full explanation of the blocking mechanism. Which of the two types of screen is more effective as a polariser? Why?

For the case of the wire grid, deduce the expression that relates the intensity received versus the angle that the wires form with the horizontal (wires horizontal: angle = 0 and vertical:  
angle = 90°).

From the table provided in the question, the horizontal components of the received signal for both screens are much larger than the vertical components of the received signal for both. Therefore, the polarization of the received signal is horizontal. However, the orientation of the received signal after the wire grid is perpendicular to that of the source signal. Thus, the polarization of the source signal is vertical. The result does not coincide my expectation for this source. This is because that the wire grid works in an opposite way compared with the normal polarizer.

The electrons inside the wire would absorb energy from the electromagnetic wave. When the electric field component is parallel with the screen, the energy would be absorbed.

The wire grid screen would provide more efficiency compared with the performance of the wire mesh screen. This is because the wire in the wire grid screen has signal direction while that in the wire mesh screen has two directions. The orientation of the wire would define the polarization of the output wave.

When there is a polarizer between a source emitting a polarized file and a receiver, the signal would only remain the components in the same direction with the orientation of the polarizer after passing through the polarizer. When rotating the polarizer, the intensity of the light would change, from the maximum when the direction of the vibration of the photons in the same direction of the polarizer to zero when the direction of the vibration of the photons is perpendicular to that of the polarizer.