Report: Photonics

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Report Module: Electromagnetic Lab

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Content

Abstract

The applications of the electromagnetic waves such as wireless energy transmission and wireless communication are getting more important nowadays as the electromagnetic waves is a type of clean and renewable energy. Most of the applications are based on their characteristics such as interference, diffraction and polarisation of electromagnetic waves.

The lab experiment identifies and classifies the phenomenon and explains the reasons for interference, diffraction and polarisation. The results from the lab experiment will be compared with derived equations and theoretical prediction to prove and explain the phenomenon even further. A simple structure of polariser between Wire Grid and Mesh will be chosen and clarified as a better polariser.

1. Introduction

The purpose of this lab experiment was to investigate the characteristics of Wave Propagation, for which Electromagnetic waves was applied during the lab experiment. It was aimed to determine 3 characteristics of the Electromagnetic waves including Interference, Diffraction and Polarization. Each characteristic was aimed to be identified and explained clearly with different experiment settings. Likewise, any relative expression was aimed to be derived.

The lab experiment was separated with 2 parts, each part has several questions which should be answered and analyzed. Part 1 was consisted of 7 questions which involve Interference of Waves, Measurement of Relative Permittivity of a Dielectric Material and Antenna Arrays with given experimental data. Part 2 was consisted of 4 questions which involve Diffraction and Polarisation. Therefore, software such as Matlab and Excel should be using for both Part 1 and Part 2 for comparing the data collection with theoretically predictions. While hardware such as wave emitter and wave detector with waveguide horn structure, multimeter and power supply should be used.

The lab report follows the order of the Questions begins from 1 to 11, the relevant theory and expression will be explained at the beginning. Then the possible procedure will be stated, followed by answer with fully analysis. Finally, a conclusion with further research will be discussed.

2. Part 1. Interference of Waves

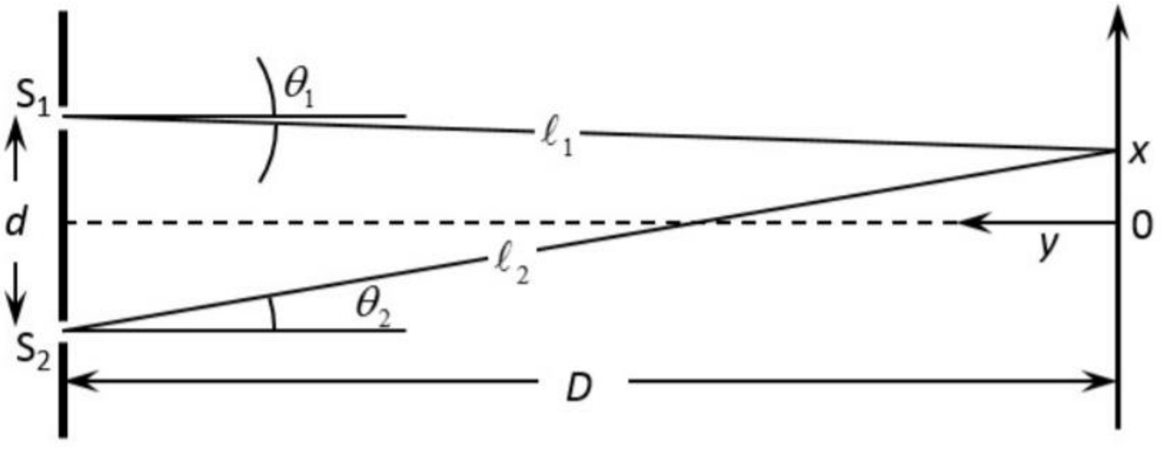


Figure.1 Two in-phase sources. S_1 and S_2, illuminating an observation plane ["Lab Script" 2020]

Interference of Waves occurs when two sources of wave with same frequency propagating, superposing and outputting the maxima and minima intensity pattern. This is due to constructive interference which two sources of waves are in phase and destructive interference which two sources of waves are 180° out of phase, respectively.

Experiment as shown in Figure.1 is Young's Double Slit experiment *["Young's Double Slit Experiment", 2017]*, however instead of using optical waves that Young had used, microwave is used in this experiment. This is because that the microwave has a relevant longer wavelength than optical waves which can provide reasonable higher accuracy when the interference pattern is measured using simple apparatus.

Using the set-up as shown in Figure.1, two sources, S_1 and S_2 with same amplitude and phase follows the properties of interference. They will output constructive interference when $l_1 - l_2 = n\lambda$, and destructive interference when $l_1 - l_2 = (2n+1)\lambda/2$, where l_1 and l_2 are distance that S_1 and S_2 travel from slit to screen, n is integer numbers that varies with magnitude of x which is the distance from central of the screen and $n > 0$. In order to measure the interference pattern, field (light) intensity, $|E_T|^2$ is required to be determined approximately.

Question 1

The standard and exact equation for E_t is shown:

$$E_T = \frac{e^{-jkl_1}}{l_1} + \frac{e^{-jkl_2}}{l_2} \tag{1}$$

Assumption is made:

$$l_1 \approx l_2 \approx D \tag{2}$$

Therefore, Approximation for E_t:

$$E_T = \frac{1}{D}(e^{-jkl_1} + e^{-jkl_2}) \tag{3}$$

Due to the small angle of θ_1 and θ_2 as shown in Figure.1, small angle approximation is assumed for sine function:

$$\sin\theta_1 \approx \theta_1 \approx (\frac{d}{2} - x)/l_1 \tag{4}$$

$$\sin\theta_2 \approx \theta_2 \approx (\frac{d}{2} + x)/l_2 \tag{5}$$

Apply first two terms of the Taylor Series for cosine function:

$$\cos\theta_1 = 1 - \frac{{\theta_1}^2}{2} = 1 - \frac{1}{2}[\frac{(\frac{d}{2}-x)}{D}]^2 \tag{6}$$

$$\cos\theta_2 = 1 - \frac{{\theta_2}^2}{2} = 1 - \frac{1}{2}[\frac{(\frac{d}{2}+x)}{D}]^2 \tag{7}$$

Based on assumption (2) and expressions (4), (5), (6), (7), the following expression for l_1 and l_2 can be derived:

$$l_1 = \frac{\left(\frac{d}{2}-x\right)^2}{D} + D - \frac{\left(\frac{d}{2}-x\right)^2}{2D} \tag{8}$$

$$l_2 = \frac{\left(\frac{d}{2}+x\right)^2}{D} + D - \frac{\left(\frac{d}{2}+x\right)^2}{2D} \tag{9}$$

Inserting expressions (8) and (9) into expression (3), for E_T:

$$E_T = \frac{1}{D}(e^{-jk[\frac{\left(\frac{d}{2}-x\right)^2}{D} + D - \frac{\left(\frac{d}{2}-x\right)^2}{2D}]} + e^{-jk[\frac{\left(\frac{d}{2}+x\right)^2}{D} + D - \frac{\left(\frac{d}{2}+x\right)^2}{2D}]}) \tag{10}$$

After derivation and rearrangements, E_T is:

$$E_T = \frac{1}{D} * 2\cos\left(\frac{kdx}{2D}\right) * e^{-jk(D + \frac{\frac{d^2}{4}+x^2}{2D})} \tag{11}$$

For absolute value, the term $e^{-jk\left(D+\frac{\frac{d^2}{4}+x^2}{2D}\right)}$, will become *sin² + cos² = 1*, therefore:

$$|E_T| = \frac{1}{D} * 2\cos\left(\frac{kdx}{2D}\right) \tag{12}$$

Therefore:

$$|\mathrm{E_T}|^2 = \frac{4}{\mathrm{D}^2} * \cos^2\left(\frac{\mathrm{kdx}}{2\mathrm{D}}\right) \tag{13}$$

When $|\mathrm{E_T}|^2$ reaches maximum,

$$|\mathrm{E_T}|^2 = \frac{4}{\mathrm{D}^2} \tag{14}$$

therefore,

$$\cos^2\left(\frac{\mathrm{kdx}}{2\mathrm{D}}\right) = 1,\ \cos\left(\frac{\mathrm{kdx}}{2\mathrm{D}}\right) = \pm 1 \tag{15}$$

$$\frac{\mathrm{kdx}}{2\mathrm{D}} = n\pi \tag{16}$$

$$x = \frac{2Dn\pi}{kd} \tag{17}$$

Where n is integer numbers and n > 0.

When n = 0 and n = 1, x = 0 and x = $\frac{2D\pi}{kd}$, where the central maxima and first maxima away from central are located, respectively. It could be concluded that the distance between consecutive maxima or minima is $\frac{2D\pi}{kd}$.

Question 2

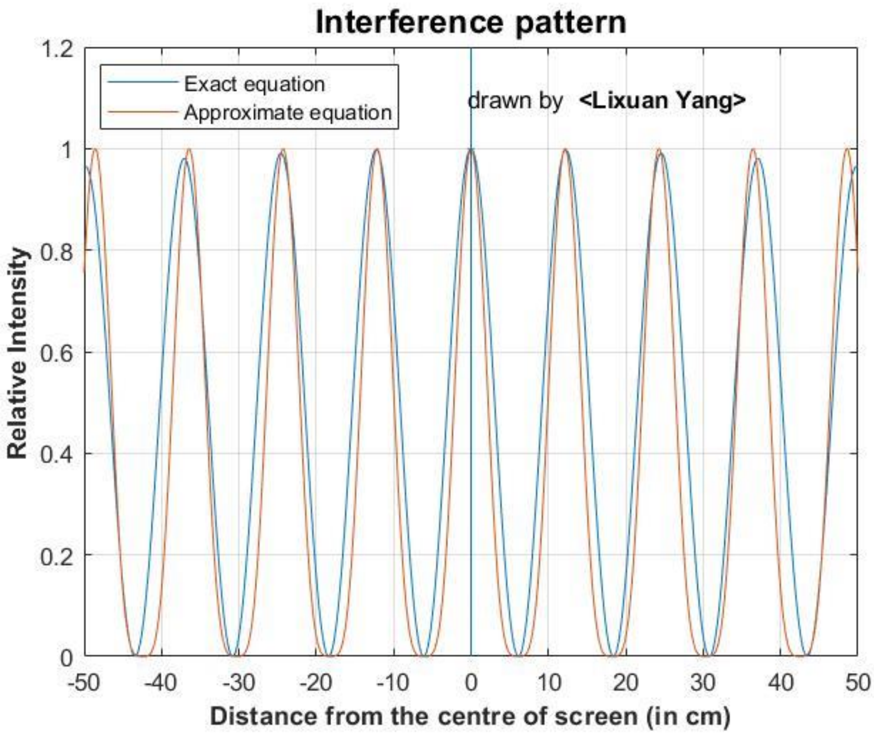


Figure.2 Interference pattern comparing Exact equation and Approximate equation

Figure.2 indicates Interference pattern of exact equation and approximate equation, plotted with Matlab using the code as shown in Appendix. As shown in the Figure.2 above, at original point, (0,0), the exact equation meets the approximate equation exactly. However, differences between two equations can also be clearly identified, firstly, phase shift occurs when the point is not at origin, also as magnitude of distance is rising, the phase shift between two equations is getting larger. Secondly, as the magnitude of distance is increasing, the exact equation tends to have a lower intensity gradually compare to approximation equation intensity.

The reason that cause phase shift may because of the application of Taylor series and small angle approximation during derivation of Approximation equation, as only first two terms of Taylor series was used, approximation would not accurate enough. Also, as the distance x is increasing, $\sin\theta_1 \neq \theta_1$ anymore, small angle approximation will not be valid for this situation. Likewise, to evaluate the reason that cause different intensity, this may because of the assumption $l_1 \approx l_2 \approx D$ as shown in expression (2) during the derivation. In reality and in majority cases, this has a very small chance to happen, especially when the distance x is increasing. Thus, the value of l_1 and l_2 will become larger as distance x is expanding which will break the assumption and lead to dropping of intensity.

Experiment 1.1: Interference of waves

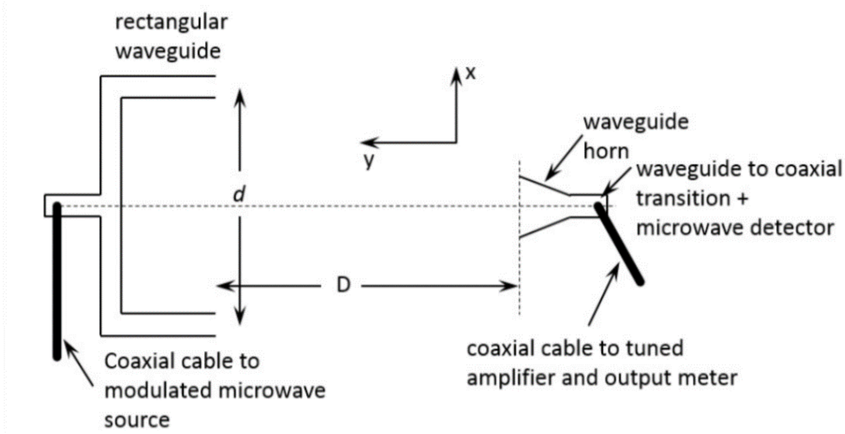


Figure.3 Experimental arrangement for the interference experiment. (in practice D>>d) ["Lab Script" 2020]

Figure.3 shows a better experiment to illustrate interference of wave compare to the previous experiment. Two equip-amplitude and in-phase microwave sources are supplied by the rectangular waveguide T-junction outputting at two equal open-ended lengths. The waveguide T-junction generates a microwave signal of 10GHz modulated in amplitude with 5kHz square wave signal. On the other end, a waveguide horn is set-up as receiver of the wave which is kept at y-axis and can be moved along x-axis. At the end of the receiver, there is a detector made by waveguide with a probe connected through a microwave diode. Also, an amplifier circuit is placed after the detector to amplify the signal to the meter. Finally, the intensity of the total field that waveguide horn received is required to measure when D = 255 cm and d = 63cm.

Question 3

Two functions of the detector diode that apply into this experiment could be defined, one of them is rectifying and the other one is low pass filtering. Before explaining the two functions, AM signal beforehand is needed to be explained. AM signal involves two signals that combine, one of the signals with lower frequency will be baseband signal and become signal envelope when two signals combine, while the one with higher frequency will be modulated in amplitude and become RF signal as shown in Figure.4 below. *["Amplitude Modulation, AM", 2018]*

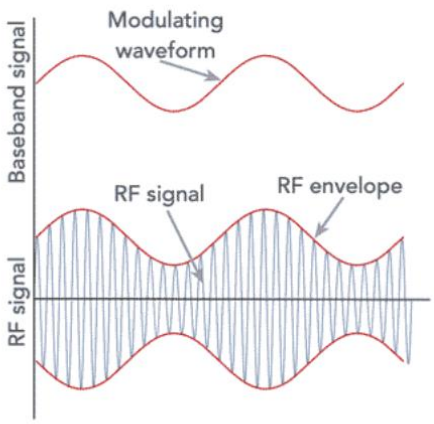


Figure.4 Amplitude Modulation, AM ["Amplitude Modulation, AM", 2018]

One of the functions that detector diode has which had been defined is rectifying, this is because as shown in Figure.5 and Figure. 6 below, the diode only allows current flow in one direction in the circuit, therefore, any negative signal applies through the diode will be rejected which leads to passing only positive half of the signal through diode. Thus, the function rectifying.

Another function that detector has is low pass filtering, which removes the high frequency in the circuit. This is because the capacitor, C1 in the circuit stores the voltage and therefore the voltage at resistor only output the highest amplitude of the signal as shown in Figure.7 *["Diode Detector", 2018]*. It could also be concluded that the frequency in the case of experiment will have a 5kHz frequency of the signal.

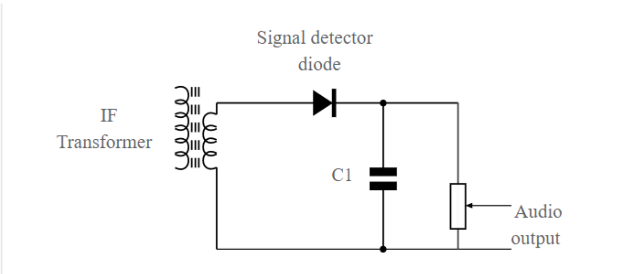


Figure.5 Circuit for an envelope detector as used in an AM radio receiver

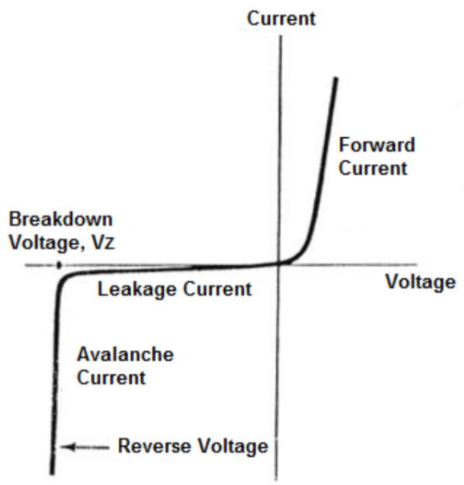


Figure.6 Diode I-V Characteristics Curve

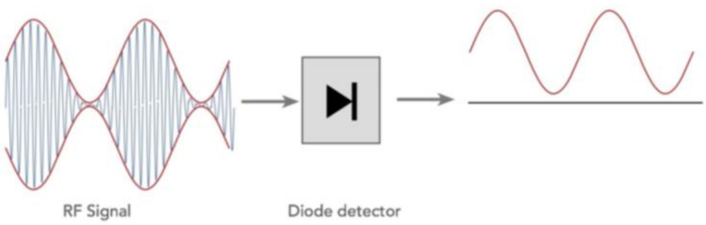


Figure.7 AM Diode envelope detection process

As in the experiment, the signal passing the detector before the amplifier will be small, this means only a small amount of voltage will pass through diode. As shown in Figure.6, when the voltage apply through diode is low, the current through the diode will equal to the square of the voltage. Since voltage is proportional to electric field, E_T. Therefore, the current is proportional to the filed intensity, $|E_T|^2$.

Question 4

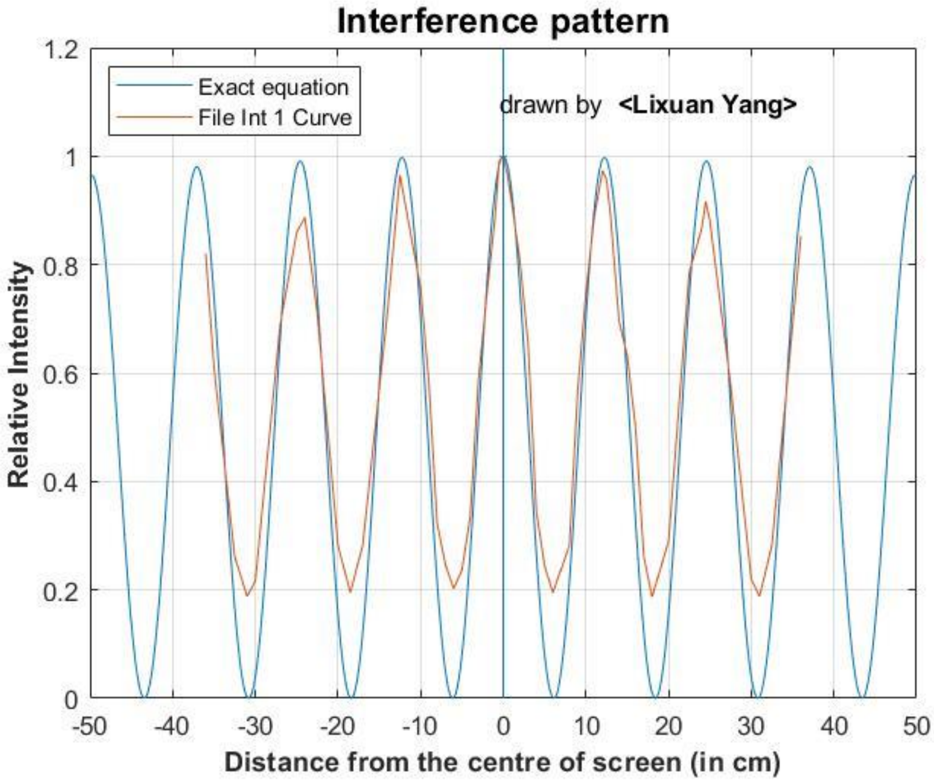


Figure.8 Interference pattern comparing File Int 1 Curve with Exact Curve

As shown in the Figure.8 which compare the File Int 1 Curve with Exact Curve (Matlab Code shown in Appendix), there are several differences could be identified. Firstly, for the File Int 1 Curve, the minima do not reach 0 relative intensity, instead the minima have around 0.2 relative intensity. This is because of the fact that the aperture of the collecting point is finite, which means there could not be a perfect point that can only detect and collect one intensity that has fully been cancelled out and reach 0 relative intensity. Thus, the aperture will receive multiple intensities and could only have minima around 0.2 relative intensity. Secondly, the amplitude of the maxima of the File Int 1Curve has lower value compare to the exact equation especially while the distance, x is increasing. This is because in practical, as the distance that microwave travels gets longer, the more particle collision is likely to happen, which will be resistance for the microwave to travel to the receiver. Thus, the light intensity loss become larger as the distance x increase in reality, therefore, the lower amplitude of the maxima will be observed for File Int 1 Curve.

It is believed that the maxima will give a better, sharper definition of position, as the maxima shows a better feature of trend of the Exact Equation, also, the maxima obtain a almost exact origin to the Exact Equation compare to the minima.

As the wave source are transmitting with their electric field in the x-y plane instead, most of the wave will be blocked and not received by the waveguide horn and thus, there will be barely any reading on the meter. This is because, the electric field of the microwave that travels are along z-axis which is vertical to the x-y plane, which means the microwave is only polarised in z-axis that the waveguide horn can be fully received the signal.

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

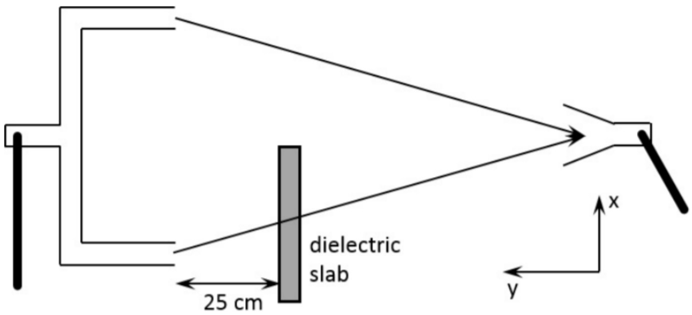


Figure.9 Experimental arrangement for measurement of relative permeability of a dielectric sheet

Using the similar set-up as Figure.3, inserting a dielectric slab between the regular waveguide and waveguide horn, and is 25 cm away from regular waveguide as shown in Figure. 8. The dielectric slab will cause an effect of phase for one of the sources and affect the interference pattern in the observation plane. Question 5 requires deriving the relative permittivity.

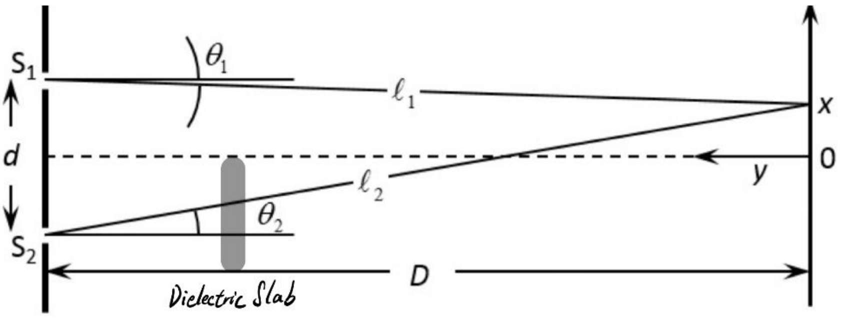


Figure.10 Sketch Diagram for Question 5 Derivation

Question 5

Based on the Sketch Diagram shown in Figure.10, the implementation and assumption as Question 1 as expressions (2), (8), (9):

$$l_1 \approx l_2 \approx D \tag{2}$$

$$l_1 = \frac{\left(\frac{d}{2}-x\right)^2}{D} + D - \frac{\left(\frac{d}{2}-x\right)^2}{2D} \tag{8}$$

$$l_2 = \frac{\left(\frac{d}{2}+x\right)^2}{D} + D - \frac{\left(\frac{d}{2}+x\right)^2}{2D} \tag{9}$$

Therefore:

$$l_1{}^2 = D^2 + \left(\frac{d}{2} - x\right)^2 \tag{18}$$

$$l_2{}^2 = D^2 + \left(\frac{d}{2} + x\right)^2 \tag{19}$$

The phase difference is the length difference between l_1 and l_2:

$$l_2 - l_1 = \frac{{l_2}^2 - {l_1}^2}{l_2 + l_1} = \frac{2dx}{2D} = \frac{dx}{D} \tag{20}$$

The phase difference when passing the Dielectric Slab can be defined as:

$$l_{slab} = \mu_r * \delta - \delta = (\mu_r - 1) * \delta \tag{21}$$

where μ_r is the relative index of the Dielectric Slab and δ is the thickness of the Dielectric Slab.

Therefore, the total phase difference in the path is, (assumed at maxima point):

$$l_{total} = n\lambda = (\mu_r - 1) * \delta + \frac{dx}{D} \tag{22}$$

$$x = \frac{D[n\lambda - (\mu_r - 1) * \delta]}{d} \tag{23}$$

The shift from central maxima Δs can be defined:

$$\Delta s = x - x_p = \frac{D[n\lambda - (\mu_r - 1) * \delta]}{d} - \frac{n\lambda D}{d} = -\frac{(\mu_r - 1) * \delta * D}{d} \tag{24}$$

The relative index, μ_r will be:

$$\mu_r = 1 + \frac{\Delta s}{\delta} * \frac{d}{D} \tag{25}$$

As relative permittivity, ε_r, is proportional to the square of relative index, μ_r:

$$\varepsilon_r = {\mu_r}^2 = [1 + \frac{\Delta s}{\delta} * \frac{d}{D}]^2 \tag{26}$$

Question 6

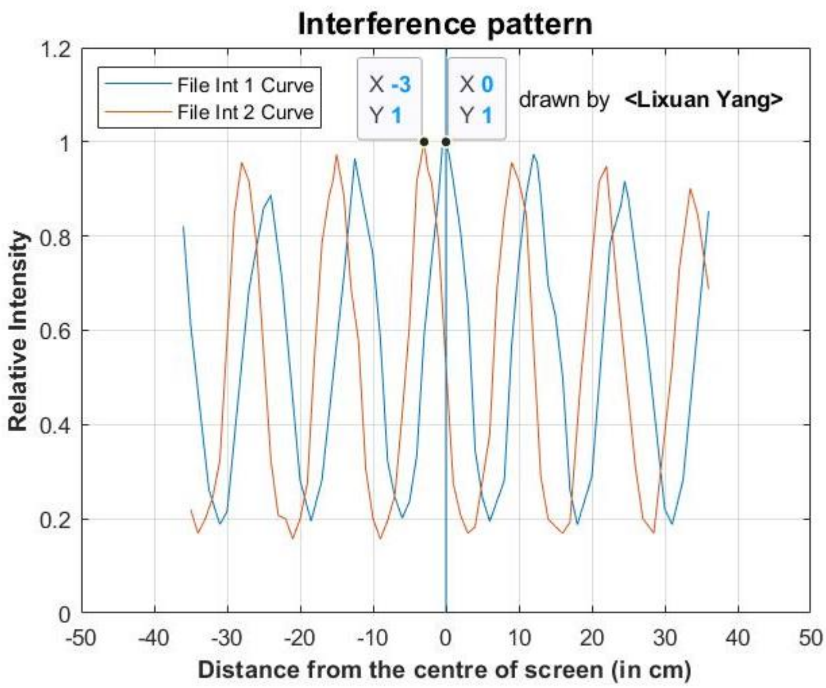


Figure.11 Interference pattern comparing File Int 1 Curve with File Int 2

As it is shown in Figure.11 (Matlab Code shown in Appendix), the shift of the central maximum along x-axis can be determined as 3 cm. Therefore, when the dielectric thickness, δ is 1.2 cm, the relative permittivity of the dielectric slab after calculation using expression (26) will be around 2.63 (estimate into 2 decimal places).

The method is not suitable if the dielectric slab become thicker. As when the wave passes through the Dielectric Slab, the speed of the wave will be reduced for the wave travel at l_2. When the thickness increases, the duration of the reduction of the speed will be longer, this will lead to more phase difference between l_2 and l_1. Thus, the central maximum will be shifted further away from the central point x = 0 and cause harder detection for the central maxima intensity. Also, the same effect happens for the situation when the Dielectric Slab has higher permittivity. This also expand the time that the reduction of speed happens and therefore, induce more phase difference. The shift of the central maxima will be moved away from the central point x = 0 and provoke difficulties to determine the central maxima intensity.

The position of the Dielectric Slab will not affect the pattern at screen effectively. This is because the pattern is only affected by wavelength of the output wave and the intensity. However, the Dielectric Slab should not be put too close to the waveguide T-junction, as this may cause all the wave being blocked; nether the Dielectric Slab should be put too close to the receiver horn, as this may cause incomplete diffraction of the waves. Thus, the position of the Dielectric Slab does not need to be at 25 cm as shown in Figure.10.

Experiment 1.3: Antenna Arrays

As it is shown in Figure.12, the distance d, which is the distance between two antennas can vary the interference pattern which antenna generates if distance d changes. Also, the interference pattern can be affected by the amplitude and phase of individual excitations of antennas.

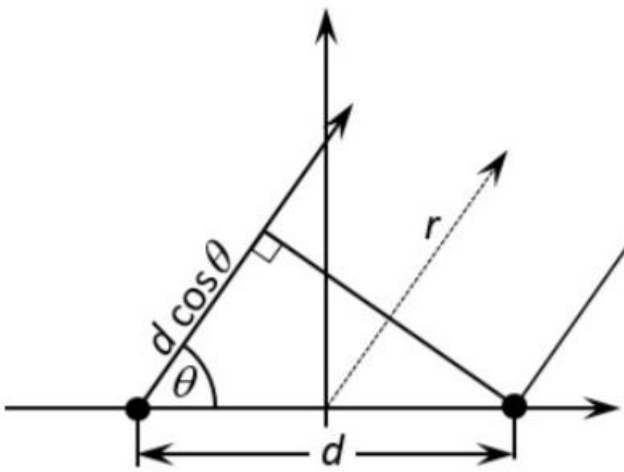


Figure.12 An array of two-point antennas

Assume that excitation of two antennas have value 1 and $e^{j\varphi}$, the magnitude of two antennas are equal and the phase difference is φ. Because of the large distance, the ray from each antenna to the observation point is parallel to each other, the distance of the ray will be equal to r in the amplitude aspect based on these. Therefore, the field can be expressed as:

$$E(r,\theta) = \frac{e^{-jk[r+dcos\left(\frac{\theta}{2}\right)]}}{r} + \frac{e^{j\varphi}e^{-jk[r-dcos\left(\frac{\theta}{2}\right)]}}{r} \tag{27}$$

The radiation pattern of the array, also known as Array Factor, has form of:

$$|E(r,\theta)| = \frac{F(\theta)}{r} \tag{28}$$

Question 7 requires determining $F(\theta)$.

Question 7

Rearrange the field expression:

$$E(r,\theta) = [e^{-jk\left(r+\frac{dcos\theta}{2}+\frac{\varphi}{2k}\right)} + e^{-jk\left(r-\frac{dcos\theta}{2}-\frac{\varphi}{2k}\right)}] \tag{29}$$

Assume P = $\frac{dcos\theta}{2} + \frac{\varphi}{2k}$:

$$\begin{aligned} E(r,\theta) &= \frac{e^{\frac{j\varphi}{2}}}{r} * [e^{-jk(r+P)} + e^{-jk(r-P)}] \\ &= \frac{e^{\frac{j\varphi}{2}}}{r}[\cos(kr+kp) - jsin(kr+kP) + \cos(kr-kP) - jsin(kr+kP)] \\ &= \frac{e^{\frac{j\varphi}{2}}}{r}[2\cos(kr)\cos(kP) - 2jsin(kr)\cos(kP) \\ &= \frac{e^{\frac{j\varphi}{2}}}{r}\{2\cos(kP) * [\cos(kr) - jsin(kr)]\} \end{aligned} \tag{30}$$

When squaring the field, the term $\cos(kr) - jsin(kr)$ become 1, therefore:

$$E^2(r,\theta) = \frac{1}{r^2}[2\cos(kP)]^2 \tag{31}$$

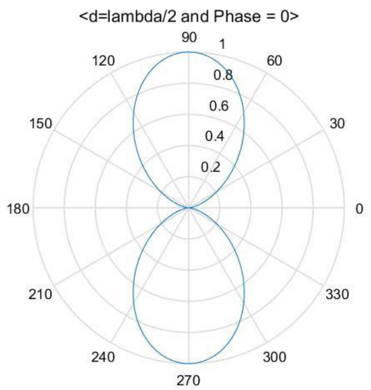
$$|E(r,\theta)| = \frac{1}{r}[2\cos(kP)] \tag{32}$$

Express P, we get:

$$|E(r,\theta)| = \frac{1}{r}[2\cos\left(\frac{\varphi+kdcos\theta}{2}\right)] \tag{33}$$

Thus, the Array Factor is:

$$F(\theta) = [2\cos\left(\frac{\varphi+kdcos\theta}{2}\right)] \tag{34}$$



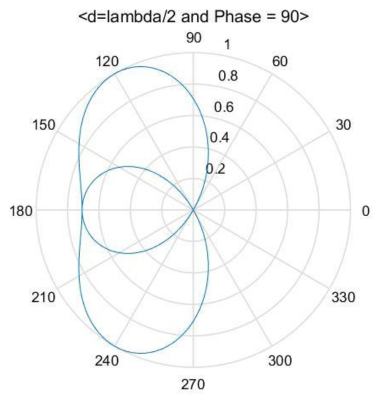


Figure.13 radiation pattern d=λ/2 and phase = 0   Figure.14 radiation pattern d=λ/2 and phase = 90

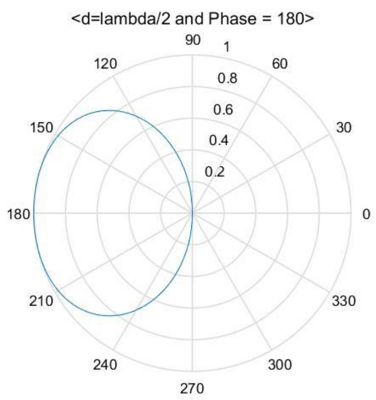


Figure.15 radiation pattern d=λ/2 and phase = 180

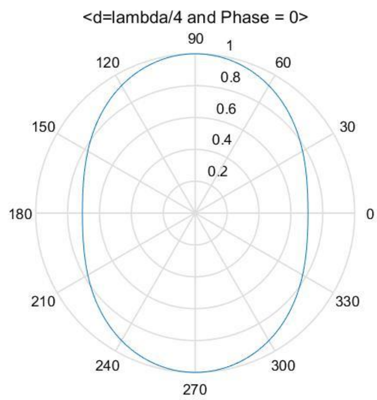


Figure.16 radiation pattern d=λ/4 and phase = 0

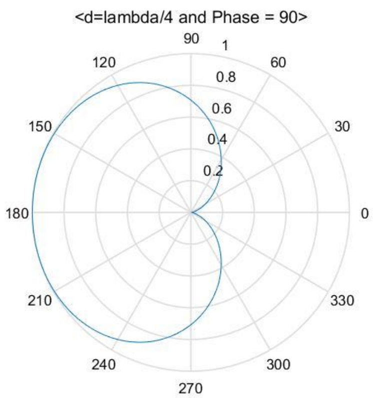


Figure.17 radiation pattern d=λ/4 and phase = 90

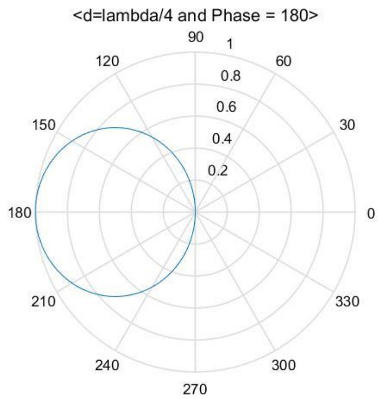


Figure.18 radiation pattern d=λ/4 and phase = 180

3. Part 2. Diffraction and Polarisation

Diffraction occurs when the waves are partially obstructed by boundary which affect the speed of wave due to the particle property of the wave. Polarisation occurs when the waves are blocked when propagating at different dimension due to the its electromagnetic wave property. Experiments that prove these two phenomena were done separately in this part during the lab experiment, then results and analysis will be displayed in the latter section.

Question 8

As it is mentioned above, diffraction occurs when the waves are partially obstructed by the obstacle, where some of the wave will be bent. This will lead to change of direction or speed reduction for some wave propagating, which will cause phase or amplitude difference for them and interfere with other unaffected wave. This then will cause multiple interference diffraction pattern on the output. The phenomenon can be explained using Huygen's Principle which assumed that as a wave is propagating from a single source through space, each wavefront can be considered as multiples individual secondary wavefronts. *["Fresnel Diffraction", 2014]*

The phenomenon can also be explained by Fresnel's theory as Fresnel's diffraction occurs when the distance from the emitter to the obstacle or the distance from the obstacle to the receiver is finite and with similar length compare to the pnstruction. *["Fresnel Diffraction", 2014]*, i.e. the distance is finite also known as near-field diffraction. It assumed that each wavefront propagate secondary waves continuously, and the resultant effect will be combination of all secondary effect as the waves reach the receiver. *["Fresnel's Theory of Diffraction", 2016]*

Referring to another type of diffraction, Fraunhofer's diffraction, which occur when the distance when the distance is infinite, also know as far-field diffraction, this is not considerable in practical as infinite distance is not valid.

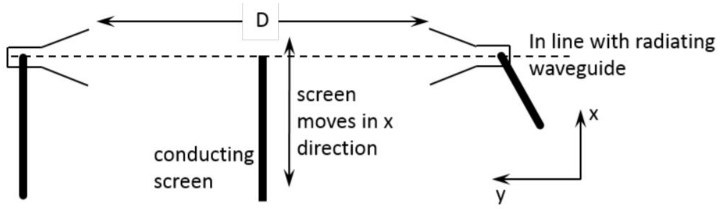


Figure.19 Experimental arrangement for diffraction experiment

For the experiment in Question 9, it is assumed that x = 0 when the screen is at the place as shown in Figure.19. When the screen moves upwards in x-axis, the x value which is the displacement that the screen move is negative; when the screen move downward in x-axis, the x value will be positive. If x is negative, the screen will block all the signal propagating from emitter to receiver gradually, therefore, the data at the receiver will tends to 0 as x tends to negative infinity. On the other hand, if x is positive, the screen will partially block the emitter first then at some point will not obstruct the emitter at all. Based on the diffraction properties and wave assumptions as shown above, the data at receiver will take maxima and minima intensity with amplitude decreases continuously as the screen moves and the data received become constant as the screen is totally not obstructed the emitter. Figure. 20 shows the prediction of the result in Question.9.

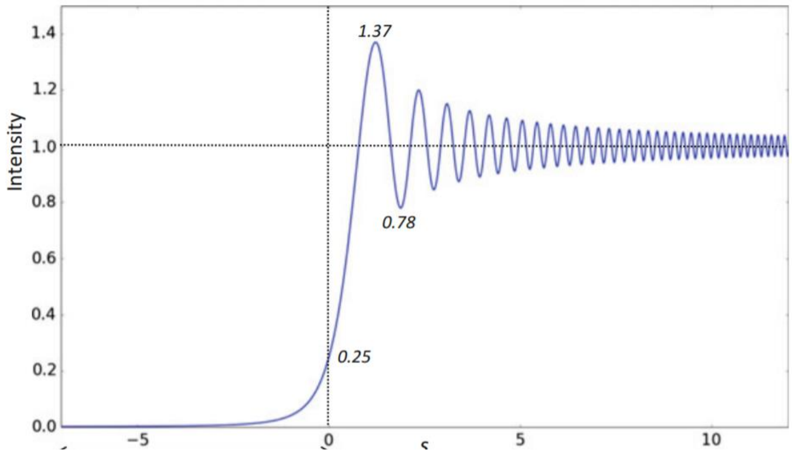


Figure.20 Prediction for the result in Question .9

Experiment 2.1 Diffraction of a wave by a conducting plane

The lab experiment is set-up as shown in Figure.19. Firstly, it is crucial to set the screen at original point, where x is set to 0 which is located at 92cm of the meter ruler, i.e the point where the displacement is zero. It is required to place a long wire in the middle of emitter and receiver which the edge of the screen should just be touched. The metal screen then is asked to slide along the rail in both directions of x-axis , so that the receiver could draw data in three scenarios: fully exposed directly by the source; partially obstructed the wave from the source and fully blocked of the source. Record the value from the reader in these three scenarios with appropriate displacement intervals. Finally plot the results using Matlab.

Question 9

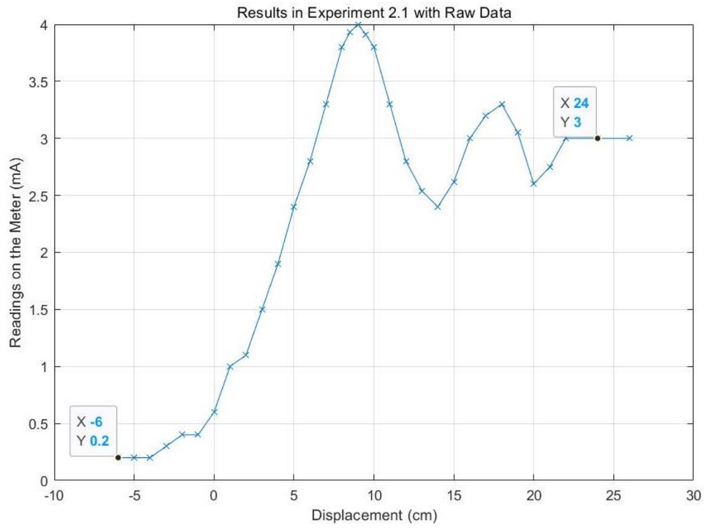


Figure.21 Result in Experiment 2.1 with Raw Data

The result is shown as above in Figure.21 (the recorded data is listed in appendix), as it can be identified the that as the displacement exceed 24 cm, the reading on the Meter become constant which is 3mA. Similarly, when the displacement is less than -6 cm, the reading on the Meter become constant which is 0.2 mA. The graph cannot be compared with the prediction as it needs to be normalised with the value of 3mA, in order to get relative intensity.

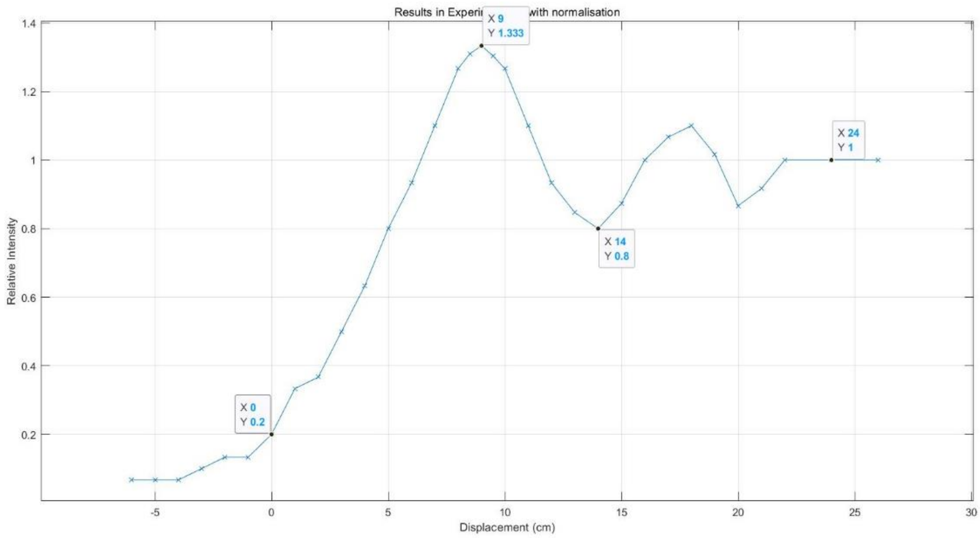


Figure.22 Result in Experiment 2.1 with Normalisation

Figure.22 shows the result with normalised data. Comparing to the prediction as shown in Figure.20, they are similar in pattern aspect, also the values between prediction and practical of relative intensity at 0 displacement and at peak are very similar, 0.25 compares to 0.2, 1.37 compares to 1.33, respectively. The difference between prediction and practical could be caused by the absorbing of the conducting screen of the waves instead of diffraction them, as the waves are electromagnetic waves. Also, as the scale of the Meter is quite large, human error may involve during reading the data. Moreover, the output of the wave from the emitter comes from an antenna at a finite distance from the screen, therefore, the equivalent wavelets cannot be considered as equal amplitude and phase. This leads to incomplete obstruction of the waves from the conducting screen as the waves are considered in 'spherical' form as shown in Figure.23. Therefore, the relative intensity in practical will be lower than the prediction which meets the results.

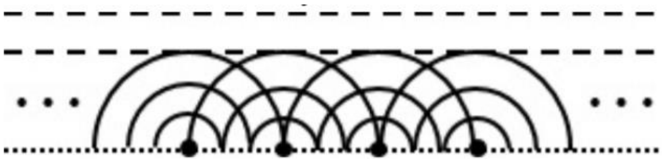


Figure.23 Wavelets being generated which will interference with each other

The set-up could be improved by placing the screen and receiver far from the emitter which could reduce the fact of wavelets. Also, the conducting screen should be changed with non-conducting screen to prevent absorption of the electromagnetic wave.

The conducting screen does not really coincidewith an opaque screen, as it is mentioned above, the conducting screen will absorb some of the electromagnetic wave being generated from emitter instead of reflect back the wave as what ideally should be done by the opaque screen.

When the orthogonal polarisation was used in the experiment, the results may be different depend on the direction of horn of the receiver. If the direction of the horn does not match the wave propagation direction, the waves will be eliminated by the horn and thus no reading at the receiver. If the direction of the horn partially matches the wave propagation direction, the reading at the receiver will be lower in a proportion which means the results in Figure.22 will be different but the result in Figure.23 will be the same. If the direction of the horn totally matches the wave propagation direction, the results will be shown as Figure.22 and Figure.23

In the situation when the screen is fixed at point of origin, the receiving horn is moving instead, the result will be different. The result will be opposite using the same displacement regard to the receiving horn, as when the receiver moving downward in x-axis shown in Figure.19 which the displacement is positive, the waves are blocked by the conducting screen, and when the receiver is moving upward in x-axis which the displacement is negative, the waves are partially blocked at beginning, then being not obstructed as the displacement increases. This shows an opposite phenomenon with the previous exam; thus, the result will be different.

'Near field' can be referred to the Fresnel's Diffraction Theory and can be explained due to the assumption. Firstly, the distance between screen and the receiver is not finite. Then in the 'near field', the electric field decrease rapidly as distance increases. Also, the relationship between electrical field and magnetic field is complicated which involves more mathematically complexity. Finally, the wave is propagated without limitation *["Near Field and Far Field Regions of an Antenna", 2018]*.

'Far field' can be referred to the Fraunhofer's Diffraction Theory and can be explained due to the assumption. Firstly, the distance between screen and the receiver is considered as infinite. This lead equality between electric field and magnetic field in 'far field'. Then unlike 'near field', the wave is propagated regularly with specific pattern *["Near Field and Far Field Regions of an Antenna", 2018]*.

The wave propagation difference can be shown as Figure.24.

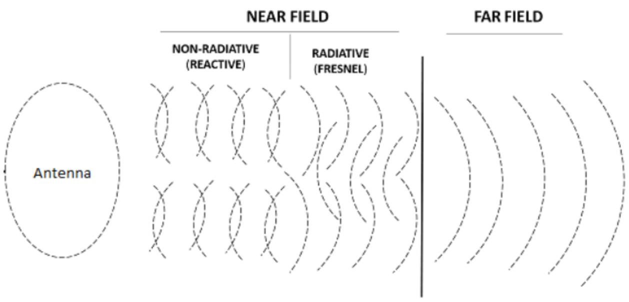


Figure.24 Wave Propagation in Near Field Region and Far Field Region ["Near Field and Far Field Regions of an Antenna", 2018]

Question 10

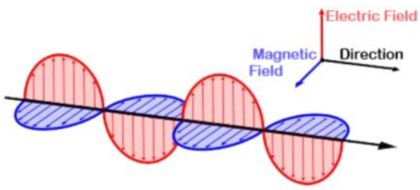


Figure.25 Electromagnetic Field ["Relationship between electromagnetic wave and photon", 2017]

Electromagnetic wave contains two types of field, electric field and magnetic field. Both fields are propagating in the same direction but perpendicularly as shown in Figure.25. The polarisation of an electromagnetic wave illustrate the characteristic of the oscillating electric field, as the polarisation involves, the electric field oscillate perpendicular to the propagation of the wave in one direction. *["Polarization of an Electromagnetic Wave", 2012]*

A polariser is a kind of optical filter which passes specific wave through with polarisation properties. Polarisation is important in anti-glare sun-glasses as polarisation reduces light intensity by blocking electromagnetic waves with longer wavelength and mismatching of the direction of electric field. The reduction of the light then could protect people from glare caused by sunlight.

If a polariser is put between a source emitter that emits polarised field and a receiver, depends on the angle of the polariser is put, the polarised field may be totally blocked, partially blocked or not blocked at all. The intensity data received by the receiver will vary when the polariser is rotating, as if at the beginning when the polariser is placed, there is no reading at receiver at all, when the polariser starts to rotate, the reading starts climbing and reach its maximum when the polariser is rotated to exact 90° compare to the beginning. As the rotation continues, the reading become smaller again and become 0 when the polariser is rotated to exact 180° compare to the beginning.

Experiment 2.2 Polarisation

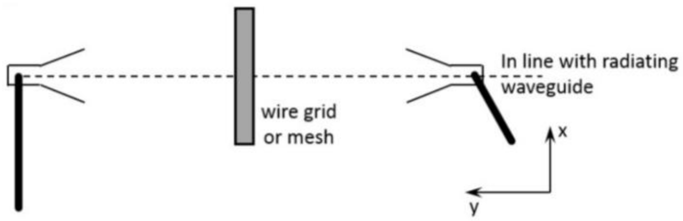


Figure.26 Showing use of wire grid or mesh to block transmission of a polarised wave

The set-up for this experiment is shown in Figure.26 which is like the previous experiment. Compare to the previous one, the conducting screen is replaced with a wire grid or mesh. The aim of this experiment to observe the variation of the received intensity when the grid or mesh is rotated.

Question 11

Since the excitation comes from a rectangular waveguide, with longer edge in horizontal aspect, the wave will have better vibrated amplitude horizontally. Therefore, the emitting waves should be horizontal polarised

In this experiment, the wire gird and mesh are used with pattern as shown below as Figure.27 and 28:

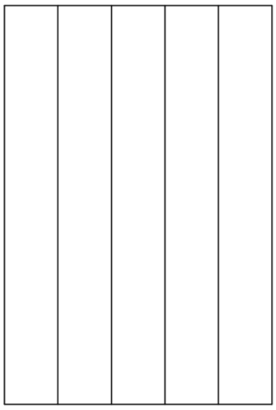


Figure.27 Wire Grid

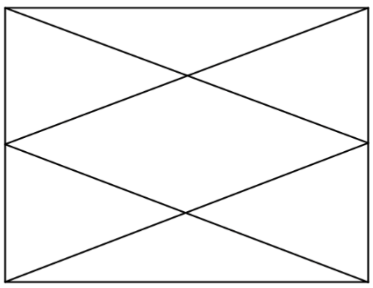


Figure.28 Mesh

At the beginning of the experiment, when there is nothing put between the emitter and the receiver, the reading taken from the meter is 3.0mA. When the Wire Grid is placed between the emitter and the receiver at the direction as shown in Figure.27, the reading from the meter is 0.2mA which shows the same minimum value as shown in Figure.21, thus, no wave passes the Wire Grid. Then the Wire Grid is rotating to 90^o, the reading from the meter is 3.0mA which has the same value as non-blocking situation, this shows all the waves pass the Wire Grid. When the Mesh is placed between the emitter and the receiver at the direction as shown in Figure.28, the reading from the meter is 1.6mA which shows that only part of the waves passes through the Mesh. When the Mesh is rotated to 90^o, the reading from the meter is 0.2mA which shows the minimum value, thus, no wave passes the Mesh. The observation above describe a horizontal polarised characteristic.

The experiment results coincide with the expectations which the source is horizontal polarised.

As the result for the Wire Grid when it is rotating 90^o, all the wave passes through the Wire Grid. Also, comparing the situation when the Mesh is placed as shown in Figure.28, and after it is rotating 90^o, the previous situation shows a higher value of reading. This is because in previous situation, the Mesh has a longer horizontal length. These show that the source is horizontal polarised.

When the Wire Grid is not rotating as in position shown in Figure.27 the Wire Grid blocks the wave. This is because the intensity in this situation is almost zero. As it is shown in Figure.27, the wire is arranged vertically with relative small gap horizontally, as the electromagnetic wave pass through, since the wave vibrates most horizontally, the electric field in this case is in horizontal and magnetic field is in vertical. Base on the arrangement, most of the electric field can not pass through the Wire Grid, this cause that even magnetic field has passed, current will not be induced for detection of intensity due to lack of electric field.

Wire Grid is more effective as a polariser, as it blocks the wave in only one direction, this met the characteristic of polariser which only allow specific wave to pass through. Unlike Mesh none of the specific wave can pass through it fully.

4. Conclusion

During the lab experiment, 3 characteristics of the Electromagnetics waves including Interference, Diffraction, and Polarisation had been determined with clear explanation. Also relative expression was derived.

In Part 1 of the lab experiment, interference of the waves was explained and proved with Young's Double Slit experiment by comparing the pattern of prediction from derived expression and practical data. Also, the relative permittivity of dielectric material is measured for which also determine the characteristic of interference of the waves when the speed of waves varies. Finally, the phenomenon in application such as antenna arrays consolidate the characteristic even further.

In Part 2 of the lab experiment, diffraction and polarisation of the waves was explained with two separate but similar experiments. Conducting screen was used in the first experiment to determine the diffraction by the phenomenon observed which match the prediction based on the theory. Wire Grid and Mesh were used for the second experiment to determine the polarisation by the observation when rotating the Wire Grid and Mesh which also match the prediction based on the theory. It was also concluded that Wire Grid is a better polariser than Mesh.

Overall, recalling all the process had been done and the result from the lab experiment, all the aims and objects had been clarified fully. Thus, the lab experiment was successful.

Reference

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Appendix

Question 2:

```
d=0.63;                    % separation between the sources (in m)
D=2.55;                     % distance from sources to screen (in m)
lambda=0.03;               % wavelength (in m)
k=2*pi/lambda;
x=-0.5:0.001:0.5;      % to cover 50 cm at either side of the centre
theta1=atan((d/2-x)/D);
theta2=atan((d/2+x)/D);
l1=D./cos(theta1);
l2=D./cos(theta2);
j=0+i;
Et=exp(-j*k*l1)./l1+exp(-j*k*l2)./l2;
Et=Et.*conj(Et)/(max(Et)^2);
Et4= (4/(D^2)).*(cos((k*d*x)/(2*D)).^2);
```

```
Et4=Et4.*conj(Et4)/(max(Et4)^2);
%
y=x*100;                        % converting to cm
plot(y,abs(Et))
axis([-50 50 0 1.2]);
hold on
grid on
plot(y,abs(Et4));
set(gca,'XTick',[-50:10:50])
title('{\bfInterference pattern}','FontSize',14)
xlabel('{\bfDistance from the centre of screen (in cm)}')
ylabel('{\bfRelative Intensity}')
line([0 0],[0 1.2])
line([-0.5 0.5],[1 1],'linestyle',':')
text(-0.48, 1.1,'drawn by {\bf <Lixuan Yang> }')
legend('Exact equation', 'Approximate equation');
```

Question 4:

```
d=0.63;                        % separation between the sources (in m)
D=2.55;                         % distance from sources to screen (in m)
lambda=0.03;                   % wavelength (in m)
k=2*pi/lambda;
%
x=-0.5:0.001:0.5;      % to cover 50 cm at either side of the centre
theta1=atan((d/2-x)/D);
theta2=atan((d/2+x)/D);
l1=D./cos(theta1);
l2=D./cos(theta2);
j=0+i;
Et=exp(-j*k*l1)./l1+exp(-j*k*l2)./l2;
Et=Et.*conj(Et)/(max(Et)^2);
I = load('Int1.txt');
x1 = I(:,1);
v = I(:,2);
v=v./max(v);
y=x*100;
% converting to cm
plot(y,abs(Et));
axis([-50 50 0 1.2]);
hold on
grid on
plot(x1,v);
set(gca,'XTick',[-50:10:50])
title('{\bfInterference pattern}','FontSize',14)
```

```
xlabel('{\bfDistance from the centre of screen (in cm)}')
ylabel('{\bfRelative Intensity}')
line([0 0],[0 1.2])
line([-0.5 0.5],[1 1],'linestyle',':')
text(-0.48, 1.1,'drawn by {\bf <Lixuan Yang> }')
legend('Exact equation', 'File Int 1 Curve');
```

Question 6

```
I = load('Int1.txt');
x1 = I(:,1);
v = I(:,2);
v=v./max(v);
J = load('Int2.txt');
mInt2 = J(:,1);
v2 = J(:,2);
v2=v2./max(v2);
plot(x1,v);
axis([-50 50 0 1.2]);
hold on
grid on
plot(mInt2,v2);
set(gca,'XTick',[-50:10:50])
title('{\bfInterference pattern}','FontSize',14)
xlabel('{\bfDistance from the centre of screen (in cm)}')
ylabel('{\bfRelative Intensity}')
line([0 0],[0 1.2])
line([-0.5 0.5],[1 1],'linestyle',':')
text(-0.48, 1.1,'drawn by {\bf <Lixuan Yang> }')
legend('File Int 1 Curve', 'File Int 2 Curve');
```

Question 7

```
lambda=0.03;
k=(2*pi)/lambda;
d1=lambda/2;
d2=lambda/4;
phase1=0;
phase2=pi/2;
phase3=pi;
theta=0:pi/100:2*pi;

%%Expression for each graph.
P1= (2*cos(0.5*(k*d1*cos(theta)+phase1)));
P1 =P1/max(P1);
P2 = (2*cos(0.5*(k*d1*cos(theta)+phase2)));
P2 = P2/max(P2);
```

```
p3 = (2*cos(0.5*(k*d1*cos(theta)+phase3)));
p3 = p3/max(p3);
P4 = (2*cos(0.5*(k*d2*cos(theta)+phase1)));
P4 = P4/max(P4);
P5 = (2*cos(0.5*(k*d2*cos(theta)+phase2)));
P5 = P5/max(P5);
P6 = (2*cos(0.5*(k*d2*cos(theta)+phase3)));
P6 = P6/max(P6);

%%Plotting the equations
figure(1);
polar(theta, P1);
title('<d=lambda/2 and Phase = 0>','FontSize',12);
box off;
figure(2);
polar(theta, P2);
title('<d=lambda/2 and Phase = 90>','FontSize',12);
box off;
figure(3);
polar(theta, p3);
title('<d=lambda/2 and Phase = 180>','FontSize',12);
box off;
figure(4);
polar(theta, P4);
title('<d=lambda/4 and Phase = 0>','FontSize',12);
box off;
figure(5);
polar(theta, P5);
title('<d=lambda/4 and Phase = 90>','FontSize',12);
box off;
figure(6);
polar(theta, P6);
title('<d=lambda/4 and Phase = 180>','FontSize',12);
box off;
```

Data Collected for Question 9

Ruler Scale (cm)	*Displacement (cm)*	*Reading at Meter (mA)*
98	-6	0.2
97	-5	0.2
96	-4	0.2
95	-3	0.3
94	-2	0.4
93	-1	0.4
92	0	0.6

91	1	1
90	2	1.1
89	3	1.5
88	4	1..9
87	5	2.4
86	6	2.8
85	7	3.3
84	8	3.8
83.5	8.5	3.93
83	9	4.0
82.5	9.5	3.91
82	10	3.8
81	11	3.3
80	12	2.8
79	13	2.54
78	14	2.4
77	15	2.62
76	16	3.0
75	17	3.2
74	18	3.3
73	19	3.05
72	20	2.6
71	21	2.75
70	22	3.0
68	24	3.0
66	26	3.0