# EM Theory Lab

## Part 1

**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 process on Good Notes.

Interval =

**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



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 .

**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.

**It** could be seen from Figure 3 that the magnitude of the shift for each maximum value is **, , , and . And the magnitude of the mean shift is which is quite close to the shift of the center (the magnitude of which is ).**

**In order to calculate the value of the relative permittivity of the dielectric slab with , we would use with all the parameters (i.e., , , and ) in .**

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 would not be suitable for thick sheets and same for high permittivity sheets. *Figure 4* illustrates the difference. This is because larger or larger wound introduce more errors to the final result. This could be explained in the following figures. With same incident light, when , , where black arrows represent for actual path while green arrows represent for the path without sheet. With same incident light, when , , where black arrows represent for actual path while green arrows represent for the path without sheet.**

Chart, line chart

Description automatically generated**Chart, line chart

Description automatically generated**

**The distance between the slab and one of the terminals of the rectangle terminal does not affect the final pattern, which means it does not need to be exactly . This is because the path difference caused by the slab does not change no matter where it is as long as it meets the requirement that which is stated in *Q5*.**

***Exercise 1.3 Antenna Arrays***