Electric & Magnetic Fields (EE 204)
Lab Manual

September, 2017
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A. INTRODUCTION TO EE 204 LABORATORY

Laboratory Procedures and Report Writing

Laboratory Procedures
− Smoking, food, beverages and mobile phones are not allowed.
− Because of the limitations on experimental set-ups, no make-ups will be allowed.
− All equipment should be switched off upon completion of the experimental work. The workbench should be left as neat as possible, and all connection wires returned to their proper place.
− Experiments will be carried out in groups of four students (maximum). Groups are expected to remain the same throughout the semester. Each individual in a group is expected to participate in performing the experimental procedures. Most experiments have several parts, so, students should alternate in doing these parts.

Experimental Results
− Each group should present their results to the lab instructor before moving to a new part of the experiment.
− For each part of the experiment, the group should present the result in the form of a sketch. This way, a validation of the data taken is made if the sketch shows the expected characteristics.
− All experimental data taken and all sketches made should be produced using the blank page included in each experiment handout.

Performance in Lab
− Both group performance and individual performance will be evaluated.
− Group performance is based on (1) ability of the group to produce correct and accurate results and (2) ability of the group to independently carry out troubleshooting while conducting the experimental procedures.
− Individual performance is based on (1) attendance on time (2) participation in carrying out the experiment and (3) answer to questions given by lab instructor upon inspection of the results.

Report Writing
− Reports are due two days after the lab period (e.g., students of Saturday lab submit reports on Monday, Tuesday lab on Thursday, and so on).
− Each student is expected to produce his own report. Groups share experimental results only.
− Any copying of reports will be considered an act of cheating.
− In writing the report a student is supposed to follow the formal report writing studied in ENGL110.
− Evaluation of the reports is based on the quality of the following (1) correct format (2) Error analysis (3) Presentation of results and (4) Discussion and answer to questions.

Final Exam
− A combination of written and oral exams will be given in the last week of classes.
− Students will be allowed to bring along their reports to the written exam.
Both exams will test the experimental knowledge acquired by the student throughout the semester regarding (1) equipment (2) measurement methods and procedures and (3) basic concepts.

B. ELECTROMAGNETIC FIELDS SIMULATION

There are many opportunities for electromagnetic fields plotting, including design of structures for analysis of static electromagnetic fields and waves. The electromagnetic problems solved using this tool were solved using analytical equations and numerical methods (FDM, FEM, FDTD) but these methods are transparent to the user and their understanding is not necessary. Only the input and the output are visible to the user. The tool was written in Matlab and requires the user to run it under Matlab.

The various programs are intended to demonstrate concepts in electromagnetics. They are not intended for general purpose design or for computation of electromagnetic fields beyond that of demonstrations as no provisions have been made for accuracy and robustness. Nevertheless, they can give reasonable answers under the constraints described in this document. To simplify the use of the various programs, specific constraints on geometry (e.g. rectangular shapes, uniform distributions, etc.) have been used and are fully described in the document.

The software has two separate parts as follows:

a. Electromagnetic_Simulations
b. The_Smith_Chart

The Electromagnetic_Simulations part is further divided into the following components:
1 – Vector Addition
2 – Contour Lines - Gradient
3 – Electrostatic fields
   Point Charges
   Potential
4 – Electrical Current
5 – Magnetostatic fields
6 – Electromagnetic waves

The Smith_Chart part deals with chapter 15 of [1] and will be described separately below. It is different than part (a) in that it does not attempt to provide a general purpose Smith chart tool but rather to allow solution and display some examples. Nevertheless, the individual examples can be modified by user input and in this fashion used to solve other problems of the same general type. With care and perhaps by combining the use of more than one example, one can use this tool for almost any general problem and for problems in transmission lines and impedance matching techniques.

a. Electromagnetic_Simulations

Many of these components in this software are self explanatory, and for each there is a ready-made example that can be run to clarify its use. In some cases the variables of the example can be changed by the user. In these instances, the variables are entered with <space> between them and <Enter> after the variables have been entered (if more than oneline of
values is called for, type <Enter> at the end of each line. A <;> can be used instead of <Enter>.

1. – VECTOR ADDITION
This function is provided to help understand the meaning of vectors, with the possibility of plotting vectors in 2 and 3 dimensions and rotating them in space. It shows vectors and their projections on axes (in 2D) or on planes (in 3D). The system of coordinates is rectangular, with axes denoted as x, y and z.

A vector is defined by 2 points:

\[
\begin{align*}
\text{in 2D:} & \quad P_1(x_1, y_1) \quad \rightarrow \quad P_2(x_2, y_2); \\
\text{in 3D:} & \quad P_1(x_1, y_1, z_1) \quad \rightarrow \quad P_2(x_2, y_2, z_2).
\end{align*}
\]

After entering one or more vectors, one must press ENTER. The vectors will be plotted in blue. Each vector is held in memory; after that, one can use ADD to add to the previously entered vectors (new vectors will be plotted in red). The first vector is used as reference, so that all subsequent vectors are placed in the correct position with respect to this first vector. Pressing on the CLEAR field erases the memory. The vector component on the z axis in 3D will not have an arrow at its end, but rather a < + >. The projection of the vectors can be displayed by selecting the field Projections. In 2D the projection will be on de axes. In 3D, the projection will be shown on the planes xy, xz, yz. The vector projections are plotted in cyan.

2. CONTOUR LINES - GRADIENT

This function is intended to show how scalar functions (in three dimensions) look and how contour lines and gradients relate to the functions. Gradients are indicated as vectors (arrows). There are 4 different examples of functions starting from the simplest to the more complex. To run an example the field Run Example must be selected. Any function can be entered in the field Function z = f(x,y). The correct way to type the function is the same as that used in MATLAB©, a dot must be used before the symbols of multiplications, division, and exponential. The values used to calculate z (x and y) are assigned in the field xy Values (in the following way: start value: increment: end value. For example: -1:0.1:1 indicates the values starting with -1 at increments of 0.1 and ending with 1. One must pay attention not to allow the space increment to be zero at some point if the function divides by x or y (division by zero).

2. ELECTROSTATICS

POINT CHARGES

In this part of the software it is possible to see the interaction between point charges in free space (including forces between them) and near perfect conductors. Positive charges are plotted as red points, negative charges as blue points. The potential and field lines are shown as well. The individual forces between the charges are plotted in red and the total forces are plotted in black. The method of images is used to see the behavior of the electric field in the presence of perfect conductors.

The following simulations can be carried out:
Free Space 2D
1Q – One point charge, one can change the sign of the charge to see the fields.
2Q – You can enter the values of two point charges (the difference between de charge value is used). You can choose to see the arrows (vectors) in the plot.
NQ – One can enter any number of charges and their respective \( xy \) coordinates, in the following order: \( Q \ x \ y \ <\text{Enter}> \). You can choose to see the arrows (vectors) in the plot.

Capacitor – This is not an ideal capacitor, but it is a simulation of a capacitor using point charges over two parallel plates. One can choose the number of charges per plate (indicating charge density), the length of the plates and the distance between them. Positive charges are plotted as +, negative charges as points.

3D – the same, as in 2D.
1Q – one point charge over a perfect ground conductor. One can change the value of the charge and its height, and choose to see the image.
NQ – any number of charges over a perfect ground conductor, with their respective \( xy \) coordinates, in the following order \( Q \ x \ y \ <\text{Enter}> \)

Tilted planes – one can choose between different angles of perfect conductors and then entering the position of the charge and the charge value. The \( x \) and \( y \) coordinate of the charge must be inside of the plane section defined by the conducting planes, otherwise the software will change their value or indicate an error.

Metal Box – this function uses the method of images to calculate the electric field produced by a point charge inside a perfectly conducting metal box. One can change the value of the charge, position, length and height of the box. In this simulation only the first 4 image charges and the original charge are used. An exact solution would require an infinite number of image charges. Nevertheless, the result obtained, while approximate, is quite good. The metal box is assumed to be infinite in the dimension perpendicular to the display plane.

3.- ELECTRIC POTENTIAL
In this section of the software one can see the behavior of electrostatic fields when electric potentials are applied on conducting surfaces and different types of dielectric materials are placed between the conductors. The simulation relies on the finite difference method. Although a fairly complex method, its application in simple cases is fairly easy and is briefly explained next. The method requires geometrical modeling of the objects and space in which a solution is needed.

4– ELECTRICAL CURRENT
In this section one can see the magnetic field lines around parallel infinite conductors. In 2D it is also possible to calculate and display the force between the conductors. The red point indicates a current flowing out of the screen, the blue point indicates a current flowing into the screen. In 3D the field plot is a rough plot of the magnetic field lines. The values of the currents can be changed.

5 – MAGNETOSTATICS
In this section the Finite Element Method is used in a fashion similar to that used above
for the electrical potential. Therefore the mesh and the parameters entered are similar. The material properties and the boundary conditions are entered in the same way as for the electrical potential.

One can use two kinds of FEM calculations for static magnetic fields; one uses the scalar potential (voltage) and the other the vector potential. There are 4 examples for vector potential and one for scalar potential that can be run. For these examples a number in the name of the example, e. g. [2M] means that 2 material properties can be changed in the permeability field. The order is from top to bottom, that is, from material 1 to material 5. To run an example the field Run Example must be selected. After that the values used will appear in the properties and boundary conditions fields and can be seen on the screen. It is still possible to change values over the boundary and properties fields, but in this case the Run Example must not be pressed again.

6–WAVES

In this section one can see the interaction between electromagnetic waves and matter including potential and current in transmission lines. Electromagnetic propagation in two dimensions is shown. This is calculated using the Finite Difference Time Domain (FDTD) algorithm. Although the FDTD is used, the user has no interaction with the model: the model is internal and any change in parameters are handled by the program as inputs. Thus the details of the FDTD method are not important.

Reflection and Transmission

In this section, the reflection and transmission of a plane wave in different media is explored. The first option, Metallic Walls, is an example of a Gaussian pulse hitting metallic walls; the reflection of the electric and magnetic fields can be seen as they occur. The number of iterations can be changed to suit. In the next part, one can see a sinusoidal planar wave (electric field) crossing different types of media. There are 3 possibilities (1, 2 and 3 media); the electric properties of each medium can be assigned at will. Length [P] is the length of the medium in periods of excitation. Time [P] is the number of excitation periods to simulate. Freq. [Hz] is the frequency of the excitation in Hertz. In the plot option one can choose what waves to plot, transmitted (red), reflected (green) and total (blue).

7.- TRANSMISSION LINES

Here one can see the electric potential, current, and input impedance on a transmission line, the potential, input impedance and current at the load are also shown. The phase shown for the load current is the angle assuming zero phase angle for potential at the load. The transmitted fields are plotted in red, the reflected fields in green and the total fields in blue.

The parameters are:

- \( V_{\text{source}} \) = potential of the source [Volts];
- \( Z_{\text{source}} \) = impedance of the source, must be \( a + bi \), where \( i \) means imaginary number;
- \( Z_{\text{line}} \) = impedance of the transmission line;
- \( \text{Attenuation} \) = attenuation over the line in Nepers/meter [Np/m];
- \( \text{Phase} \) = phase constant [Rad/m];
- \( \text{Length} \) = length of the transmission line in meters;
$Z_{load} =$ impedance of the load;  
Freq. = frequency of the source in Hertz;  
Time $[P]$ = number of periods of excitation.  

It is also possible to calculate the input impedance $Z_{in}$ at any point on the transmission line, where $Z_{in} \rightarrow x/m$ means the distance from the source, so at 0 one has the full length of the transmission line. At the full length the $Z_{in}$ is equal $Z_{load}$. When this function is used a figure is generated showing the input impedance on the line (magnitude and angle).

**The Smith Chart**

The second part of the software deals with the Smith Chart and. This is structured somewhat differently than the first par. However, the software can be used to solve other problems as long as they are structured in the form of one of the examples in the text book or can be brought to this form by additional calculations. The purpose is not to provide a general purpose Smith Chart tool but rather to allow better understanding of the examples given and in the process better understand the material. The Smith Chart menu screen (see section on download and installation) is divided into 7 section. Each section addresses one example although some data is common to more than one example.

There are a number of options in the simulations

1. Run the examples indicated on the screen. To do so, one selects the example number by clicking in the appropriate circle followed by selection of the Run button. Two things happen. First, the appropriate sections are filled with the computed data for the specific example. Second, the Smith chart with all appropriate indications is displayed (and can be printed).

2. Instead of selecting to run the example, another example of the same type but different data may be run by changing the data on the left upper corner of the screen and any specific data in the given example that can be changed (such as distances between stubs, location of load, etc.) and then selecting the Run button (without selecting the example number).

3. Any of the above can be run step by step by selecting the Step by Step button in the right-lower corner of the screen. With this option the process can be followed as it occurs. This can be done by selecting the appropriate button on the right lower corner of the screen.

4. Problems that do not fit any of the given examples, may still be solved but may require additional computation to bring them into the format needed to be solved using one of the examples shown. As mentioned, this is not a general purpose Smith Chart tool. Such tools exist and may be found on the Internet either as free software or for purchase. A quick search will show many and varied software tools of all types. The main value of the present tool is the close linkage with the examples in the textbook.
C. VIRTUAL LABORATORY

The following topics will be explained using graphics and animations of a virtual lab package:

1. Charged particles
2. Oscilloscope
3. Electrostatic induction and electrometer
4. Moving coil
5. Electrical bell
6. Faraday’s law (Transformer, Generator and Motor)
7. Longitudinal and transverse waves
8. Waves diffraction and Interferences
D. ELECTROMAGNETIC FIELDS AND WAVES MEASUREMENTS

The following experiments will be performed:

1. Electric Field and Potential Inside the Parallel Plate Capacitor
2. Magnetic Field Outside a Straight Conductor
3. Magnetic Induction
4. E.M Wave Radiation and Propagation
5. E.M Wave Transmission and Reflection
6. Capacitance and Inductance of a transmission line
Experiment#1: Electric Field and Potential Inside the Parallel Plate Capacitor

OBJECTIVE
To verify the relationship between the voltage, the electric field and the spacing of a parallel plate capacitor.

EQUIPMENT
1. Capacitor plate (two).
2. Electric field meter (1 KV/m = 1mA).
3. Power supply DC 12V and 250V (variable).
4. Multi-meters (two).
5. Plastic ruler (100 cm).
6. Plastic and wooden sheets.

INTRODUCTION
Assume one of the capacitor plates is placed in the y-z plane while the other is parallel to it at distance d as shown in Figure 1. The effect of the boundary disturbance due to the finite extent of the plates is negligible. In this case, the electric field intensity E is uniform and directed in x-direction. Since the field is irrotational ( \(0 = \nabla \times E\)), it can be represented as the gradient of a scalar field V.

EXPERIMENTAL SETUP AND PROCEDURE
1. The experimental setup is as shown in Figure 2. Adjust the plate spacing to \(d=10\) cm. The electric field meter should be zero-balanced with a voltage of zero.
2. Measure the electric field strength at various voltages ranging from 0 to 250 Volts for \(d=10\) cm and summarize the results in a table. Choose a suitable voltage step to produce a smooth curve.
3. Plot a graph of the data of step (2). On the same graph paper, plot the theoretical graph based on equation (2) and compare the theoretical and experimental graphs.
4. Adjust the potential \(V_A\) to 200V. Measure the electric field strength as the plate separation is varied from \(d=2\) cm to \(d=12\) cm. Summarize your results in a table.
5. Plot a graph of the data of step (4). On the same graph paper, plot the theoretical graph based on equation (2) and compare the theoretical and experimental graphs.
6. With a different medium (sheet) inserted between the plates, measure the electric field strength at various voltages ranging from 0 to 30V. The separation between the plates is fixed at \(d=1\) cm. Repeat for all sheets.

QUESTIONS FOR DISCUSSION
1. What are the assumptions and simplifications in this experiment? Discuss their effects on experimental results.
2. Plot theoretical relation between the potential and distance (equation 4) inside a parallel plate capacitor with \(d=10\) cm and \(V_A=100V\).
Figure 1: A parallel plate capacitor placed in the yz-plane

Figure 2: Experimental set-up
Experiment#2: Magnetic Field Outside a Straight Conductor

OBJECTIVE
To obtain the magnetic field due to current in a straight conductor as a function of the current and as a function of the normal distance from the conductor. Also the magnetic field due to current passing through two straight conductors is to be obtained.

WARNING
THIS EXPERIMENT INVOLVES HIGH CURRENT (100A) AND HIGH TEMPERATURE. DO NOT TOUCH THE CONDUCTOR OR THE TRANSFORMER.

EQUIPMENT REQUIRED
1. A straight conductor.
2. Teslameter with an axial probe.
3. Ammeter.
4. Multimeter.
5. Transformer.
6. Current transformer (100:1 ratio).
7. Power supply.

INTRODUCTION
It is known that the current passing through a long straight conductor (see Figure 1) produces a magnetic flux density, given by:

\[
\mathbf{B} = \frac{\mu_0 I}{2\pi r}
\]  

(1)

It can also be easily shown that \( \mathbf{B} \) due to current in two long and parallel straight conductors is given by:

\[
\mathbf{B} = \frac{\mu_0 I}{2\pi x} + \frac{\mu_0 I}{2\pi (x - a)}
\]  

(2)

\[
\mathbf{B} = \frac{\mu_0 I}{2\pi x} - \frac{\mu_0 I}{2\pi (x - a)}
\]  

(3)

where \( a \) is the distance between the conductors. Equation (2) applies to the case when the currents flow in the same direction and equation (3) applies when the currents flow in opposite directions as shown in Figure 2 (a) and (b), respectively.
EXPERIMENTAL SETUP AND PROCEDURE
The experimental set up is shown in Figure 3. The magnetic field readings will be taken from the voltmeter which is connected to the Teslameter with appropriate relation. The Teslameter must first be calibrated. For calibration it does not matter if a magnetic field is present or not. The calibration procedure is as follows:

a) Adjust the multimeter knob to the 3V position (choose AC).
b) Push the DC button of the Teslameter.
c) Push the “Eichen” button of the Teslameter.
d) Turn the “Eichen” knob until the multimeter reads exactly 3 volts.
e) Release the “Eichen” button. The Teslameter is now calibrated.

Turn the knob of the Teslameter to the 3 mT position and keep it set at this position throughout the experiment. This makes 3 mT equivalent to 3 V or 1 mT = 1 V. Push the AC button of the Teslameter.

The power supply output (0…15 V, 5 A) is connected to the upper most and lower most ports of the transformer for maximum power output.

1. Fix the distance between the tip of the probe and the conductor to 1 cm (keep the probe tip near the middle of the vertical conductor). Change the current through the conductor and measure the resulting \( B \) field. (Keep the tip of the probe in the plane of the conducting loop. Also keep the probe perpendicular to the plane of the loop throughout this experiment).

2. Fix the current to 100 A and change the distance between the probe and the conductor. Record the magnetic field at several distances to produce a smooth curve.

QUESTIONS FOR DISCUSSION
1. Plot a graph of the experimental relation between the current in the wire and the resulting magnetic field. Compare with the theoretical results based on equation (1). (Note: plot both results on top of each other).
2. Plot a graph of the experimental relation between the magnetic field of the wire and distance. Compare with the theoretical results based on equation (1). (Note: plot both results on top of each other).
3. Based on your experimental curve for a single wire, sketch the expected field from the structures in Figure 2 (a) and (b).
4. How can you experimentally determine the direction of the magnetic field due to
the straight line?

Figure 3: Experimental set-up
Experiment #3 Magnetic Induction

OBJECTIVE
To verify Faraday's law of induction. The induced voltage in the secondary circuit is measured as a function of the amplitude and frequency of the current in the primary circuit. The variation of the induced voltage with the number of turns and the cross-sectional area of the secondary circuit is also studied.

EQUIPMENT REQUIRED
1. Frequency counter.
2. Function generator.
3. Digital multimeter.
4. Analog multimeter.
5. Voltage transformers 125/220 (two).
6. Field coil 485 turns/meter, 750 mm long.
7. Induction coil, 300 turns, 41 mm diameter.
8. Induction coil, 300 turns, 33 mm diameter.
9. Induction coil, 300 turns, 26 mm diameter.
10. Induction coil, 200 turns, 41 mm diameter.
11. Induction coil, 100 turns, 41 mm diameter.

INTRODUCTION
According to Faraday's law of induction, voltage can be induced in a circuit due to current passing through a nearby circuit. In this experiment, a large solenoidal field coil (item 6 in the equipment list) is used to generate a time-varying magnetic field by passing an AC current \( I_1 \) through it. Smaller coils (items 7-11 in the equipment list) are used for induction (see Figure 1). The AC current \( I_1 \) passing through the field coil produces a time-varying magnetic field given by:

\[
\vec{B} = \mu_0 n I_1 \]

where \( n \) is the turns density (turns/meter) of the coil. If the current \( I_1 \) is sinusoidal and given by:

\[
I_1 = I_o \cos(\omega t) \]

then, the induced voltage \( v \) in the induction coil is given by:

\[
v = \mu_0 n \pi a^2 N \omega I_o \sin(\omega t) \]

where \( a \) and \( N \) are the radius and the number of turns of the induction coil, respectively.

PROCEDURE
RARTA: Induced voltage vs. current
1. Connect the function generator to the field coil and to the frequency counter.
2. Adjust the frequency to 10.7 kHz.
3. Measure the amplitude of \( I_1 \), using the analog multimeter.
4. Insert the 300-turn, 41 mm diameter coil into the field coil. Insure that the coil is well into the field coil. Measure the induced voltage in the coil using the digital multimeter.
5. Repeat for a range of \( I_1 \) from 0 to 30mA.

PART B: Induced voltage vs. number of turns
1. Fix the current \( I_1 \) to 30mA and the frequency to 10.7 kHz. Measure the induced voltage across the 300-turn, 41 mm diameter coil.
2. Repeat step (1) for the 200-turn, 41 mm diameter and the 100-turn, 41 mm diameter
3. Repeat step (1) for a 400-turn, 41 mm diameter coil (not provided but a combination can be used).
4. Repeat step (1) for a 500-turn, 41 mm diameter coil.

**PART C: Induced voltage vs. coil diameter**
1. Fix the current $I_1$ to 30mA and the frequency to 10.7kHz. Measure the induced voltage across the 300-turn, 41 mm diameter coil.
2. Repeat step (1) for the 300-turn coils of diameters 33 mm and 26 mm.

**PART D: Induced voltage vs. frequency**
1. Fix the current $I_1$ to 30mA and the frequency to 1 kHz. Measure the induced voltage across the 300-turn, 41 mm diameter coil.
2. Repeat step (1) for a frequency range from 1 to 12 kHz (make sure that the current is maintained at 30mA each time you change the frequency).

**QUESTIONS FOR DISCUSSION**
1. Plot the experimental and the theoretical relations between the induced voltage and current, number of turns, coil diameter and frequency.
2. From your experimental curves, find the induced voltage for the case: $N=350$, $a=15$ mm, $I_1=10mA$ and $f=10$ kHz.
3. Use equation (3) to find a theoretical value of the induced voltage for the case in question (2). Compare with your answer of question (2). This is a good measure of the accuracy of your experimental results.
Experiment #4 E.M Wave Radiation and Propagation

OBJECTIVE
To acquaint the students with the idea of polarization of electromagnetic (EM) waves and to introduce some microwave components. Also, the radiation patterns of a horn antenna will be measured.

EQUIPMENT REQUIRED
1. Microwave oscillator.
2. Attenuator.
3. Horn radiators (two).
4. Oscilloscope.

INTRODUCTION
Linearly polarized waves are radiated by a waveguide horn antenna, the direction of polarization being parallel to the narrow dimension of the waveguide feeding the antenna. The reason is that the waveguide field has only one electric field component parallel to the narrow wall of the guide. Because of this and by virtue of the principle of reciprocity such a horn can only receive waves of the same polarization as that it radiates, and so if the incident field is arbitrarily polarized the horn selects the components of the field aligned with its direction of polarization. If the only field component is perpendicular to the horn's direction of polarization, then the horn does not receive the incident field.

PROCEDURE

PART A: Demonstration of microwave components and EM wave radiation
1. The instructor will explain the different components of a microwave transmission and receiving components. This includes the oscillator, the attenuator, the waveguide, the horn antenna and the detector.
2. The instructor will also explain the basic concept of polarization.

PART B: EM wave polarization
1. Connect the circuit shown in Figure 1.
2. Align the two antennas for maximum reception. Adjust the received power to maximum reading on the meter.
3. Rotate the receiving antenna about its center (Figure 2) from −90 degrees to +90 degrees in steps of 10 degrees. In each setting, read the received power from the meter or the oscilloscope. *(Note: The oscilloscope may provide a finer resolution).*
4. Readjust the receiving antenna for maximum reception and repeat step (3) using the polarizing screen.

PART C: Radiation patterns
1. Connect the circuit shown in Figure (1).
2. Align the two antennas for maximum reception. Adjust the received power to maximum reading on the meter.
3. Rotate the receiving antenna about its axis (Figure 2) from −90 degrees to +90 degrees in steps of 10 degrees. In each setting, read the received power from the meter or the oscilloscope. *(Note: The oscilloscope may provide a finer resolution).*
4. Move the receiving antenna in a semicircle around the transmitting antenna from −90 degrees to +90 degrees in steps of 10 degrees. In each setting, obtain maximum reception and read the received power from the meter or the oscilloscope. *(Note: The oscilloscope may provide a finer resolution).*
QUESTIONS FOR DISCUSSION
1. Draw a normalized curve of your results in PART B on a polar plot (provided). Explain the results with relation to polarization.
2. Draw normalized radiation patterns of the antenna using your results in PART C on a polar plot (provided). Discuss these curves.

Figure 1: Experimental setup

Figure 2: Front view of the receiving horn antenna
Polar Plots for the Questions

EE 204 Lab Manual, Professor/ Mohamed Eleiwa, Sept. 2017
Experiment #5 E.M Wave Transmission and Reflection

OBJECTIVE
To demonstrate the phenomena of reflection and transmission of electromagnetic fields.

EQUIPMENT REQUIRED
1. Signal Generator, with square wave modulation.
2. Directional Coupler and matched termination.
3. Oscilloscope.
4. Detectors (two).
5. Horn antennas (two).
6. Waveguide sections.
7. Several sheets of different materials.

INTRODUCTION
When a time-varying electromagnetic wave propagating in one medium encounters another medium of different electric parameters, part of the energy will reflect back at the interface and part will continue to propagate. Further, some of the field characteristics may change (for example, the direction of the power flow, the field polarization, etc.). These changes in the field characteristics and the ratio of the reflected field to the incident field (the reflection coefficient) depend on the electromagnetic parameters of the materials ($\mu$ and $\varepsilon$). In this experiment, the effect of $\mu$ and $\varepsilon$ on the value of the reflection coefficient and the transmission coefficient will be studied for the case of normal incidence. The reflection and transmission coefficients are related to the material parameters in the case of normal incidence by the following relations:

\[
\text{Reflection coefficient} = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \tag{1}
\]

\[
\text{Transmission coefficient} = \frac{2\eta_3}{\eta_2 + \eta_1} \tag{2}
\]

where $\eta_1$ and $\eta_2$ are the characteristic impedances of the media at the interface.

PROCEDURE

PART A: Demonstration of microwave components
The instructor will explain the function of some microwave components used in this experiment. This include the directional coupler and matched termination. The instructor will also explain the basic concept of reflection and transmission.

PART B: EM wave reflection and transmission
1. Bring the transmitting and the receiving antennas in close proximity with a separation small enough to insert a sheet between them.
2. Align the two antennas for maximum reception. Adjust the received power to maximum reading on the meter. Record this value.
3. Insert a sheet between the two antennas and adjust it such that best transmission can be obtained. Record the transmitted value.
4. Repeat step (3) for different sheets (A mix between dielectric and metallic sheets).

QUESTIONS FOR DISCUSSION
1. From the results of PART B obtain a rough estimate of the permittivity of the material of the dielectric sheets (Note: $\mu_r = 1$ and $\sigma \approx 0$ for most dielectric)
materials). Compare with textbook values.
2. What is the main reason for the discrepancy in the answers of question (1)?
3. Suggest another method to measure reflection and transmission coefficients.
Experiment # 6 Capacitance and Inductance of a transmission line

OBJECTIVE
The capacitance and inductance per unit length of commonly used transmission lines are measured and compared to the theoretically calculated values and to manufacturer's supplied data.

EQUIPMENT
1. LCR meter (Digital).
2. A length of coaxial transmission line.
3. A length of twin-wire transmission line.
5. Meter stick.

INTRODUCTION
The two types of transmission lines to be studied in this experiment are the coaxial and the twin-wire transmission lines. The cross-section of these transmission lines are shown in Figure 1-(a) and 1-(b), respectively. The value of the capacitance $C$ of any given structure can be analytically obtained by solving Laplace's equation. For the inductance $L$, analytical relations are obtained by calculating the magnetic flux linkage. For the coaxial transmission line, the capacitance per unit length and the inductance per unit length are given, respectively, by:

$$ C/l = \frac{2\pi \varepsilon}{\ln \left( \frac{b}{a} \right)} \quad (1) $$

$$ L/l = \frac{\mu}{2\pi} \ln \left( \frac{b}{a} \right) \quad (2) $$

For the twin-wire transmission line:

$$ C/l = \frac{\pi \varepsilon}{\ln \left( \frac{b}{a} + \sqrt{\frac{h^2}{a^2} - 1} \right)} \quad (3) $$

$$ L/l = \frac{\mu}{\pi} \ln \left( \frac{2h}{a} \right) \quad (4) $$

where $l$ is the total length of the line and $a$, $b$, and $h$ are as shown in Figure 1. The constants $\varepsilon$ and $\mu$ are the permittivity and the permeability, of the material of the line, respectively.

The characteristic impedance $Z_0$ is related to $L$ and $C$ by

$$ Z_0 = \sqrt{\frac{L}{C}} \quad (5) $$

EXPERIMENTAL SETUP AND PROCEDURE
The available transmission lines are the following:
Coaxial line:
Type RG 59 B/U
Characteristic impedance 75 $\Omega$
Capacitance/meter 68 $pF/m$
Maximum voltage 6 $kV$
Twin-wire line:
Characteristic impedance 300 Ω
Capacitance/meter 13.2 pF/m
In all of the measurements, make sure the lines are fully extended (no loops). Also, avoid areas of electromagnetic interference inside the lab.
1. Measure the capacitance of the coaxial transmission line using the universal bridge. The far end of the line should be open-circuited.
2. Measure the length of the coaxial line, then find the capacitance per unit length \((C/l)\) of the line.
3. Measure the relevant dimensions of the coaxial line using the caliper.
4. Repeat steps (1)-(3) for the inductance \((L/l)\) of the coaxial transmission line. In this case, the far end of the line should be short-circuited.
5. Repeat all previous steps for the twin-wire line.

QUESTIONS FOR DISCUSSION
1. Calculate \((C/l)\) using equation (1). The dielectric occupying the space between the conductors of the coaxial line is made of polyethylene \((\varepsilon=2.3\varepsilon_0, \mu=\mu_0)\).
2. Compare the theoretical, experimental and the manufacturer's data values of \((C/l)\).
3. Calculate \(Z_o\) of the coaxial line from the experimental values of \(L\) and \(C\) and compare to theoretical and manufacturer's values.
4. Repeat for the twin-wire line.
5. What is the effect on the characteristic impedance of the transmission line when it is not fully extended?
6. Explain the dependence of your measurements on frequency.

![Figure 1: Structure of (a) coaxial transmission line and (b) twin-wire transmission line](image-url)
E. APPENDIX A (FORMAL REPORT GUIDELINES)

APPENDIX A

Guidelines for Formal Report Writing

A formal report is expected to include the following sections

Cover Page
Contains experiment number and title, student name, partners’ names, date and abstract.

Abstract
A few statements that summarize the work done in the experiment, the general procedure and results and observations.

Introduction
A brief summary of the theoretical background needed to understand the experiment. This background may include laws and formulas, models, equivalent circuits, block diagrams, etc. A clear statement of objective should also be included in this section.

Procedure
A list of steps done in the experiment. Each step should be briefly explained and outlined. The circuit connections, block diagram and/or modifications to the handout procedure should be included in the appropriate step. All components in the circuit connections should be marked clearly. (Do not copy the lab manual; write your own statements)

Results
The experimental results obtained from each of the steps in the procedure. All data should be tabulated.

Discussion of Results
A comprehensive evaluation of the results. This evaluation includes the following:
- Calculation of theoretical values.
- Plots of experimental and theoretical values.
- Error analysis (calculation of % error associated with each data set).
- Discussion of errors and ways to reduce them.
- Any specific observations and comments.

Conclusions
A few statements discussing the following:
- A general statement about the experiment and how close it accomplishes the objectives. Problems and Conclusions of the experiment regarding procedure, equipment, accuracy, learning benefits, etc.
- Answer to questions (those in the lab manual and those given by instructor).

Important notes
- Submitting identical or even similar reports will be considered as act of cheating.
- All pages should be numbered.
- All figures (including circuits diagrams, plots, block diagrams, etc.) should be numbered and given meaningful captions and legends (see examples on next page).
- Tables should be numbered and given meaningful captions (see examples on next page).
- Landscape figures or tables should be oriented correctly.
- Report grade will be based on the quality of the above sections and on correct format.
- Use of computers in word setting and plotting is highly encouraged.