Lab:
Equipotential and Field Mapping Experiments

(Read before coming to the lab)

Module: CAN102, Electromagnetism and Electromechanics

Lab Time: Week 7 Thursday for D1/2

Lab Room: IR112

Grouping: 4 students per team

Submission: **23:59 2024/04/16** for D1/2

ATTENDANCE in the laboratory is MANDATORY

You MUST have your attendance recorded to receive a mark.

Learning outcomes:

A. Apply basic principles related to electrostatics, magnetostatics, and electromagnetic induction.

B. Use the time-invariant Maxwell's equations in differential and integral form for engineering applications such as inductors and capacitors.

E. Understand the measurement of electromagnetic fields and analyse the results.

ACADEMIC INTEGRITY

Your assignment **must be entirely your team's own work**. **ALL team members are responsible for the entire submission**. Plagiarism, copying, collusion, or dishonest use of data will be penalised. Penalties ranging from capped scores to an award of zero can be applied. Please refer to the University's Academic Integrity Policy on E-bridge for guidance. You may also contact the Module Leaders if you have any confusion relating to academic integrity.

Be advised that more serious instances of academic infringement will be presented at exam boards, which can result in more serious actions.

LATE SUBMISSION POLICY

XJTLU policy is –5% per day up to a total of –25%. Work submitted more than five working days late will receive a grade of zero.

1. Equipment

- ✓ NI ELVIS III Kit
  - o DC power supply + cables
  - o Digital multimeter + cables
  - o Breadboard
- ✓ Conductive paper, no grid
- ✓ Carbon paper
- ✓ A4 paper, plain
- ✓ Corkboard working surface
- ✓ Aluminium push pins for attaching the paper to the board
- ✓ Conductive ink pen (copper /silver)
- ✓ Ruler and circle template for drawing the conductive paths

Self-Prepared Equipment (Bring these with you)

- ✓ Regular pencil and rubber
- ✓ Blue and purple pencils
- ✓ Set of compasses
- ✓ Ruler

2. Objectives:

To study the concept of an electric field and how it is defined.

To learn how to measure the electric field strength and how to identify regions of strong and weak electric fields from maps of electric field lines.

To illustrate typical types of electrode configurations and their accompanying electric field patterns.

To quantitatively estimate the magnitude and direction of an electric field using experimental voltage measurements.

3. Experimental Section

3.1 Introduction

Electrostatics, as implied by the constituent parts of the word relates to the influence and interaction of electric charges at rest. This influence is described in terms of a field of force in the vicinity of electric charges which constitutes an Electric Field ($\vec{E}$).

Formally, the strength of the electric field at a given point in space is defined as the force on a unit positive test charge placed at that point.

This experiment aims to identify the electric field distributions and equipotential lines in various scenarios. The methodology behind this experiment involves the use of a conducting paper plotting technique. It allows the voltage distribution to be assessed by analogy between the flow of a steady current in a resistive medium and the electrostatic field in a charge-free space. The voltage at a point in an electrostatic field, more correctly identified as the electrostatic potential at the point, is defined as the amount of work performed in bringing a unit positive charge from infinity to that point. Electric fields and potentials are closely related; and an electric field is expressed as the negative gradient of the corresponding potential.

The term gradient has a strict mathematical meaning when relating a vector quantity such as the $\vec{E}$-field, to a scalar quantity (the potential). It is useful to visualise these parameters by analogy with the presentation of contour lines and associated slopes on an ordinance survey map. The slope is perpendicular to the contour lines and represents the steepest descent at a given point. In the same way the $\vec{E}$-field is directed perpendicular to the lines of constant or equipotential and presents the maximum "slope" of potential at a point. In the case of a field directed uniquely along the direction x, the expression linking the magnitude of the field and its potential becomes:

$$\vec{E} = -\nabla V = -\frac{dV}{dx}$$

If a system is of high symmetry, Gauss's Law could be applied to find the relation of electric field and the number of enclosed charges. Gauss's Law states that the integral of the electric field (strictly the normal component) over a closed surface (S) is equal to the total charge Q contained by the closed surface, divided by the permittivity ε:

$$\oiint_S \vec{E} \cdot d\vec{s} = \frac{Q}{\varepsilon}$$

By forming the product of the $\vec{E}$-field and the permittivity, this equation can be expressed as:

$$\oiint_S \vec{D} \cdot d\vec{s} = Q$$

which links the electric flux density ($\vec{D}$) to the total charge contained by the closed surface.

3.2 Equipment Setup

The conductive paper used in the experiment forms the conducting medium or space between a pair of electrodes. The resistance range is of 5-40 kΩ per square metre. The conductive ink pen in this experiment allows you to draw conductive ink electrodes on the conductive paper to form conductive paths. The ink consists of either copper or silver particles suspended in a liquid. As the ink dries, the copper or silver flakes settle on top of each other forming a conductive path (or conductive ink electrodes). The resistance of the ink is between 0.03 and 0.05 Ω/cm for a 1 mm wide line.

Due to the finite resistance of the paper, when a voltage is applied to the electrodes drawn on it a current will flow through it. As the current flows there will be a change in potential difference along the current path. The large difference between the ink's resistance and the resistance of the paper, means that for all practical purposes, the potential drop across within the electrodes may be considered negligible.

Step 1 – Preparing the conductive paper

You should prepare your conductive and blank paper prior to the laboratory by drawing a gird and creating the conductive electrodes. The conductive ink takes at least 30 min to dry sufficiently, but does not reach maximum conductivity until at least 24 hours after application.

Firstly, using a pencil, plot a 5mm × 5mm grid on the **black** side of each of the conductive papers you have been provided with and the same area of the blank A4 paper, see Figure 1. You can use the carbon paper to transfer the grid as you draw on the conductive paper through to the blank A4 paper. The grid will allow you to record your measurements more easily.

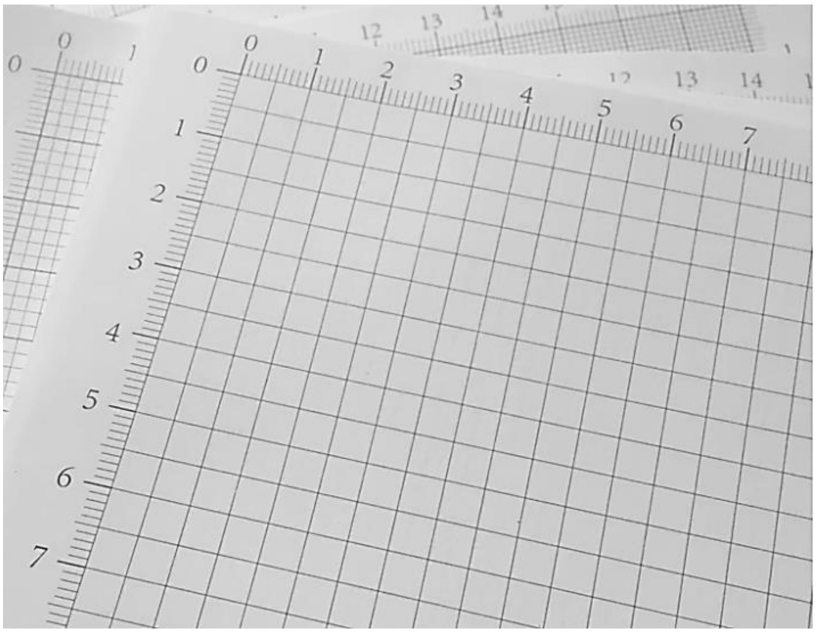


Figure 1. Example of plotting a 5mm × 5mm grid on a paper

Secondly, plan and sketch in pencil the two electrode layouts you have been assigned again on the **black** side of the conductive paper, take care to accurately copy the size, shape, and relative spacing of the electrodes.

Vigorously shake the conductive ink pen (with the cap on) for at least 30 seconds to adequately disperse the particle matter suspended in the ink (note that you should keep shaking the pen periodically during use). Remove the cap and colour in the electrodes as designed on the conductive paper. If the line becomes thin or spotty, draw over it again. A solid line is essential for good measurements.

NOTE: The copper/silver conductive ink reaches its maximum conductivity after

<u>24 hours</u> drying time. For optimal results, please prepare the paper the day before coming to the laboratory and plan the process for conducting the experiments wisely.

Please complete Step 1 before going to the lab.

Step 2 – Apparatus Set-Up

Mount the paper on the corkboard layered from top to bottom as: conductive paper, carbon paper, and A4 blank paper. Use the push pins in each corner to secure the paper to the corkboard. Place another push pin in each of the electrodes to act as conduits to connect the DC power supply to. Using the wires supplied with crocodile clips, connect the electrodes to the NI ELVIS III DC power supply (Figure 2).

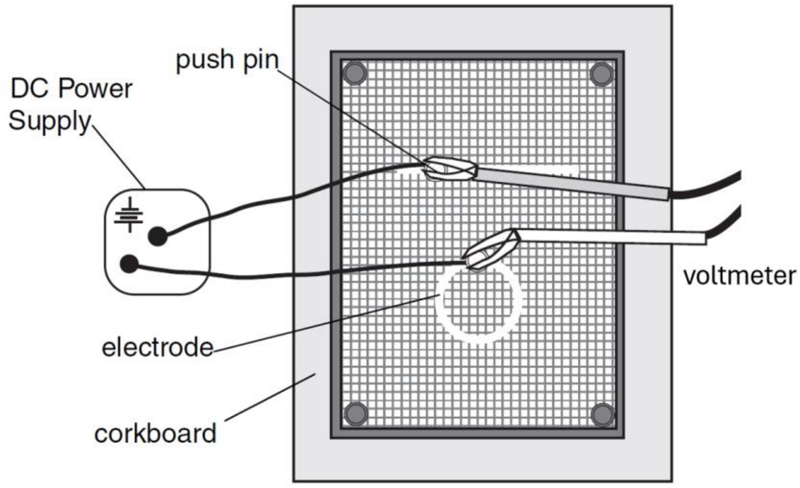


Figure 2. Example of connecting electrodes to a power supply and voltmeter

Step 3 – Measurement Set-Up and Electrical Connections

Start the “Measurements Live” Software and select “Measure” (see Figure 3).

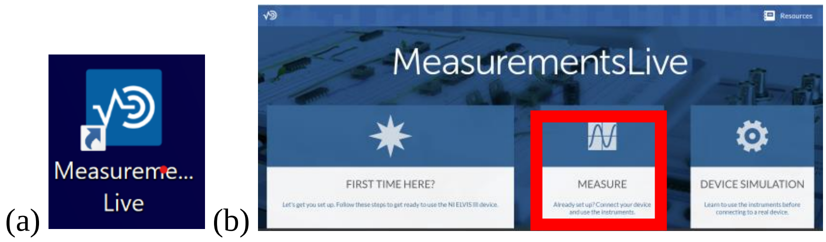
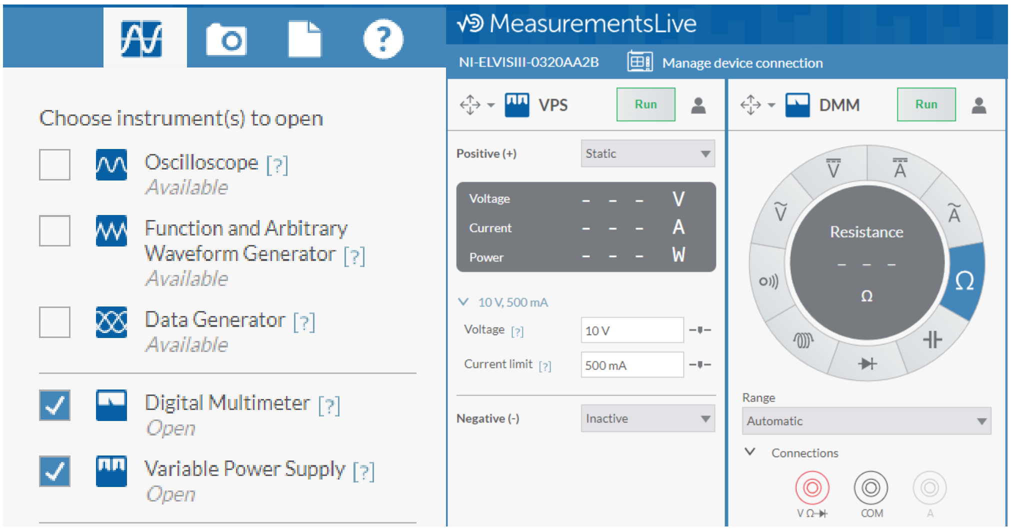


Figure 3: (a) Software shortcut (b) Measure application

From the instrument menu, shown in Figure 4(a), select the “Variable Power Supply” (VPS) and the “Digital Multimeter” (DMM) as indicated and shown in Figure 4(b) and (c).



(a) (b) (c)

Figure 4: (a) Instrument Menu (b) VPS Instrument Panel (c) DMM Instrument panel

The VPS is effectively a DC power supply. As indicated in Figures 4(b) and (c):

1. Set the voltage value of the VPS to **+10 V** for **D1/2**.
2. Set the digital multimeter (DMM) to measure resistance "Ω".

Connect the appropriate wires to the output sockets for the VPS and input sockets for the DMM on the ELVIS III unit as shown in Figure 5.

NOTE: Double check the supplied voltage before activating the VPS by clicking run. Any accidents occurring due to use of the wrong power supply settings will result in the immediate termination of the experiment and an award of zero for the coursework for the whole group.

Figure 5: NI ELVIS III connections

Step 4 – Test the electrodes

To check the electrodes for proper conductivity, measure their resistance at various points. Select Run on the DMM interface in Measurements Live and place one lead at one end of an electrode and touch the second lead to other points along the length of the same electrode. If the electrode has been properly drawn, the maximum resistance shown should be less than 100 Ω. If the resistance measured is greater than this then remove the conductive paper from the corkboard and draw over the electrodes one more time with the conductive ink pen.

When you finish testing, "Stop" the DMM on interface in Measurements Live.

Step 5 – Connect to the Electrodes

Push a metal push pin through the central region of the electrode. This does not need to be exactly central but should be placed carefully to ensure a good connection. Make certain the pin holds firmly to the electrode.

NOTE: Check to see that the push pin is clean as a dirty pin may result in a bad contact.

Connect the clips on the VPS wires to one push pin each, such that the voltage is applied between the two electrodes (Figure 6).

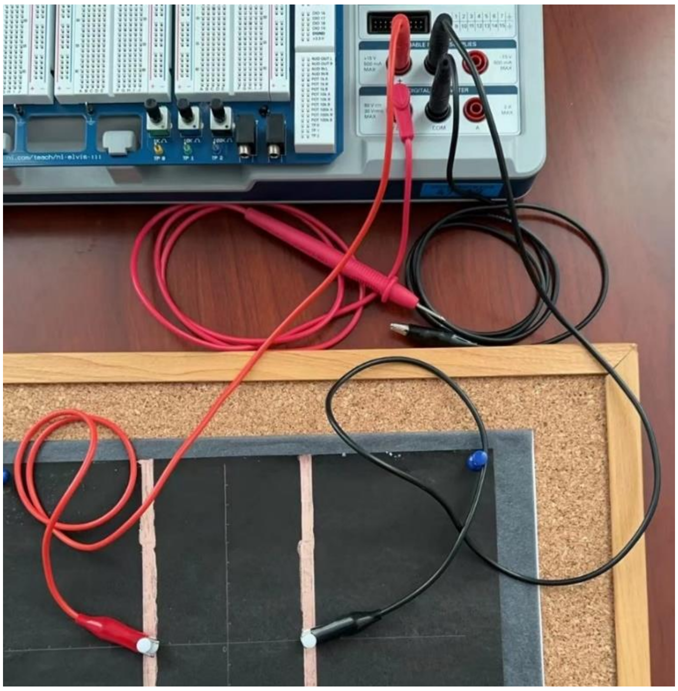
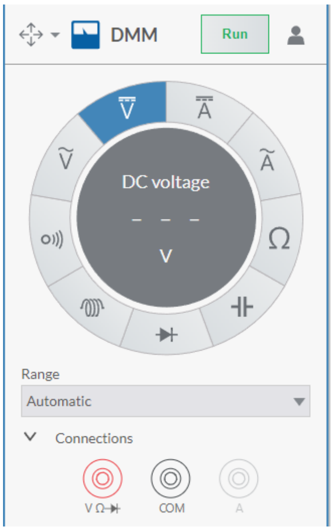
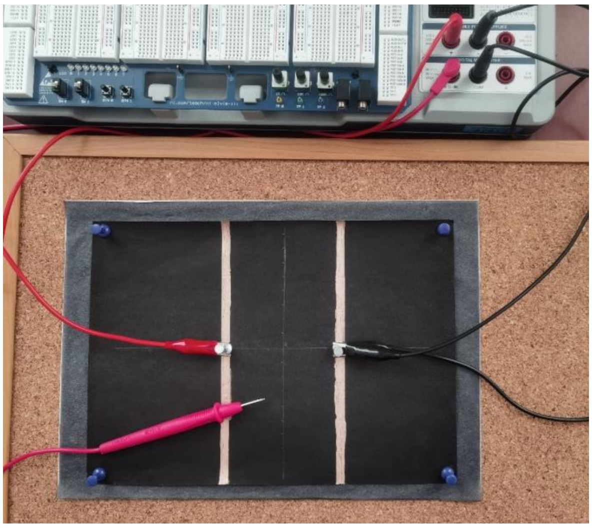


Figure 6: Connecting the VPS to the electrodes via the metal push pins

Set the DMM to measure DC voltage (See Figure 7(a). Connect the clip on the black cable for the DMM to the push pin connected to the ground side of the VPS (i.e. the black cable) Figure 7(b).





(a) (b)

Figure 7: (a) DC voltage measurement on DMM (b) DMM connections

Step 6 - Measurements

Equipotential lines are plotted using the probe connected to the positive side of the DMM to measure the voltage between the reference point (the grounded side) and any other point on the conductive paper by simply touching the probe and reading the voltage.

To map an equipotential, select "**Run**" on both instruments in Measurements Live and move the probe until the desired potential is indicated on the voltmeter. Continue to move the probe, but only in a direction which maintains the voltmeter at the same reading. You can mark all points with same potential by pressing the probe hard on the paper. The carbon paper will transfer the point onto the A4 blank paper helping you to record the points.

All points on the A4 grid paper should be represented by a symbol of your choice (such as a small × or o). Connect the points with a **smooth** line (Don't just connect the dots with straight line segments!) and **label** this line with its voltage value (such as 1 V).

Once the equipotential lines are found, the electric field can be deduced by constructing lines at right angles to the equipotential lines.

NOTE: You should decide the number of points to be measured and recorded to accurately represent the equipotential lines and electric field lines.

Step 7 – Straighten up the lab station

Once you have completed the experiment, make sure to "stop" the instruments from running on measurements live and tidy up your bench.

3.3 Overview of electrode layouts

D1/2: Parallel plate capacitor without/with floating insulator

Draw the schematics below (Figure 8) with silver ink conductive pen and go through steps 1-7. above and then complete all tasks in the document 'D12_ Assignment.pdf' on Core. Values for each parameter will be released on Core in Week 6 Friday.

NOTE: Only power supply connections are shown in the following schematics.

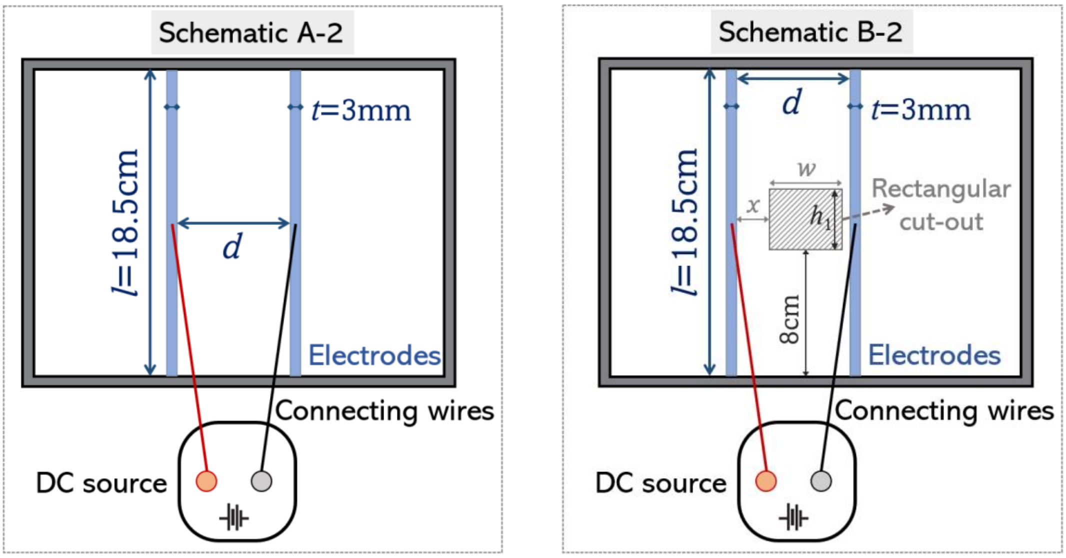


Figure 8: Electrode layout for parallel plate capacitor with/without floating insulator