1EM1: Basic Electrical Measurements

OBJECTIVES

1. To become familiar with the basic methods of measuring voltage, current, and resistance.
2. To be acquainted with the use of an oscilloscope.

THEORY

Digital Storage Oscilloscope (DSO)
A digital oscilloscope (DSO) is a laboratory instrument used to display and analyse the waveform of electronic signals. We can use a DSO to measure various electrical signals, including voltage, current, frequency, and phase. ***In our experiment, the DSO shows you the voltage plot as a function of time of an AC current.***

Root Mean Square Voltage
In our experiment, an oscilloscope measures how voltage changes as time progresses. In other words, it detects the voltage as a function of time, $V(t)$. At home, you have many 3-pin sockets providing an AC voltage source. An AC voltage is typically varying like the sine curve; as time progresses,

$$V(t) = V_0 \sin(2\pi f t) \tag{1}$$

where V_0 is the amplitude, and f is the frequency of the signal. You can imagine this as a fluctuating voltage battery that could automatically change its terminal signs (+ or –), too!
A sine signal pattern repeats as time progresses, and each pattern cycle takes about T seconds. Therefore, the frequency of the signal is given by $f = 1/T$ Hz. Suppose that you randomly pick N numbers between 0 sec and T secs, i.e., $t_1, t_2, t_3, \dots, t_N$. With these, you can evaluate the corresponding values of voltages using Eq. (1), i.e.,

$$\begin{aligned} V_1 &= V_0 \sin(2\pi f t_1) \\ V_2 &= V_0 \sin(2\pi f t_2) \\ V_3 &= V_0 \sin(2\pi f t_3) \\ &\vdots \\ V_N &= V_0 \sin(2\pi f t_N) \end{aligned}$$

You can calculate the average using the standard formula,

$$\bar{V} = \frac{V_1 + V_2 + \cdots + V_N}{N} \tag{2}$$

Voila! You have estimated the average of the voltage function, $V(t)$, over the period T. However, the sine signal fluctuates above and below 0V. So, the average voltage in Eq. (2) will be zero, which is not meaningful. To get a meaningful result, we are interested in the average of the magnitudes, regardless of the voltage sign. To make it easy, we just take the squares of each $V(t_i)$, because squaring a positive or negative number will always return a positive number! Therefore,

$$\overline{V^2} = \frac{V_1^2 + V_2^2 + V_3^2 \dots + V_N^2}{N} \tag{3}$$

However, Eq. (3) is the average of the squared of V_i. That is too large; therefore, engineers take the square root,

$$V_{rms} = \sqrt{\frac{V_1^2 + V_2^2 + V_3^2 \dots + V_N^2}{N}} \tag{4}$$

If you generate many, many, many random numbers t_i, i.e., $N \to \infty$, then you have to use calculus,

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V^2 dt} \tag{5}$$

$$= \sqrt{\frac{1}{T}\int_0^T V_0^2 \sin^2(2\pi f t)\, dt}$$

$$V_{rms} = \frac{1}{\sqrt{2}} V_0$$

EQUIPMENT

1. Battery (6 V)
2. Ammeter (0–30 mA)
3. Voltmeter (0–10 V)
4. Digital storage oscilloscope (DSO)
5. Audio frequency generator
6. Digital multimeter (DMM)
7. 10-decade potentiometers

PROCEDURES

Week 1 (Part A): Measuring resistance using Ammeters and Voltmeters

In this part of the experiment, you will use three different methods to measure the unknown resistance, R_x : (A1) using a voltmeter and an ammeter, (A2) using a graphical method by varying resistance and noting the current.

Figure 5: Circuit for the ammeter/voltmeter method.

A1: Ohms Law Method

1. Using a DMM, obtain the resistance value after subtracting the lead resistance. Take this as your true value of resistance.
2. Set up the circuit shown in **Figure 2** and obtain the resistance using Ohm's law,

$$R = \frac{V}{I} \tag{6}$$

3. We can estimate the error of R using the Propagation of Error formula,

$$\Delta R = R\sqrt{\left(\frac{\Delta V}{V}\right)^2 + \left(\frac{\Delta \mathrm{I}}{I}\right)^2} \tag{7}$$

where ΔR, ΔV, and ΔI are the error of R, measured voltage, and measured current, respectively. Your final quote of R_x will be,

$$R_x = R \pm \Delta R \text{ Ohms}$$

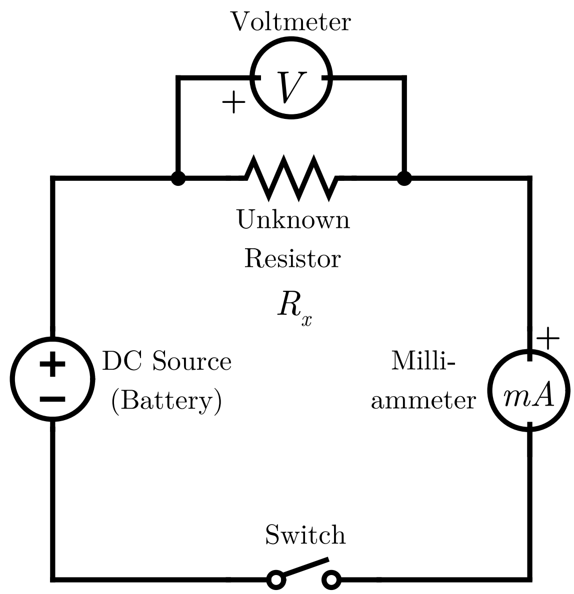

Figure 2: Circuit for the ammeter/voltmeter method.

A2: Empirical Method

In this part of the experiment, you will obtain the unknown resistance, R_x, using a plot of known resistance, $R(I)$, against the measured current.

1. Set the circuit as shown in **Figure 3**.
2. Set both R_0 and R_1 into 0 Ω.
3. Adjust R_0 so that the milli-ammeter reading stays at 10 mA.
4. Notice that now $R_1 = 0\ \Omega$ due to Step 2. Record the milli-ammeter reading, and this corresponds to $I(0)$.
5. Now, repeat Step 4, but adjust R_1 into other values and record corresponding ammeter readings for $R_1 = 100\Omega, 200\Omega, \dots, 1000\Omega$.

6. Prepare a table like in Table 1. For each row, calculate a_i,

$$a_i = -\frac{1}{R_i}\ln\left(\frac{I_i}{10}\right) \tag{8}$$

Table 1

$R_1\,(\Omega)$	I_i (mA)	a_i
0	10.0	–
100	$I_1 \pm \Delta I$	a_1
200	$I_2 \pm \Delta I$	a_2
:	:	:
1000	$I_{10} \pm \Delta I$	a_{10}

7. Make a plot of current vs. resistance recorded in the above table. Obtain

$$\alpha = \frac{a_1 + a_2 + \cdots + a_{10}}{10} \tag{9}$$

8. Replace R_1 with R_x. Obtain the milli-ammeter reading, I_x. Obtain R_x using Eq. (3),

$$I_x = 10e^{-\alpha R_x} \tag{10}$$

where α is the value that you have obtained in Step 7.

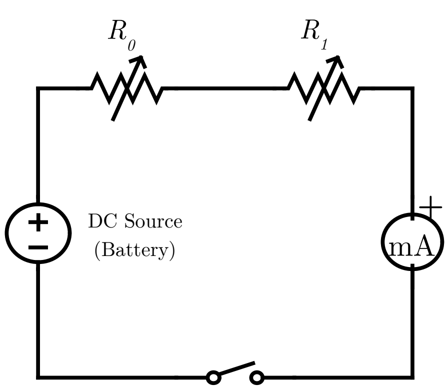

Figure 3: Circuit for the graphical method.

Part B: Using an Oscilloscope

In this part, you will use the DSO to measure (a) measure the amplitude and frequency of an AC Voltage and (b) verify that, $V_{\mathrm{rms}} = \frac{1}{\sqrt{2}} V_0$, where V_{rms} is the root mean square voltage, and V_0 is the amplitude of the AC voltage.

Setting up the AC Source

1. Turn on the AC source power.
2. Toggle the attenuation knob to 0 dB.
3. Adjust the output level knob to the middle position.
4. Adjust the frequency level knob to any value. You can use the dial on the AC source as a guide.

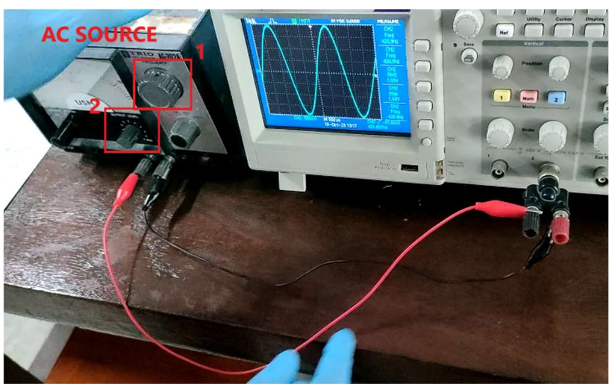

Figure 4: The connection for Part B. (1) The *frequency level* knob. (2) The *output level* knob.

Setting up the Oscilloscope.

1. Set up the circuit connection as in Figure 1. You don't have to worry about polarity (+ or – signs).
2. Turn on the oscilloscope and press the *Autoset* button (Figure 5). Please wait for it to set up.
3. If the display is frustrating, adjust the output level knob and repeat step 2.

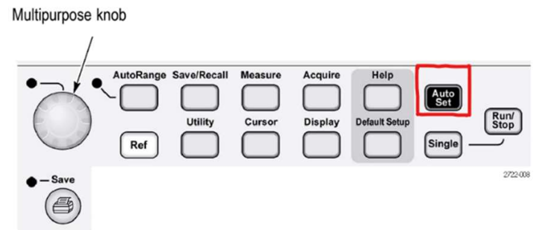

Figure 5: The Autoset button.

Verifying the relationship between root mean square voltage, V_{rms} and amplitude, V_0.

In this part, you will plot the peak voltage versus the RMS voltage of the sine wave. Refer to Figure 6.

1. Push the *Measure* button (1) to see the Measure Menu.
2. Push the topmost option button (2); then the Measure 1 menu appears.
3. Push *Source* ► CH2 (depends on which terminal you connect the AC source).
4. Push Type ► Max.
5. Push the *Back* option button.
6. Push the second option button (3) from the top; the Measure 2 Menu appears.
7. Push Source ► CH2 (depends on which terminal you connect the AC source).
8. Push Type ► Cyc RMS.
9. Push the *Back* option button.
10. From the oscilloscope screen (next to each corresponding option button), obtain the V_{max} and the corresponding V_{rms}.
11. Repeat this for the various V_{max} values (adjust using the *output level* knob of the AC source) and record the $(V_{\mathrm{max}}, V_{\mathrm{rms}})$ pair in Table 2 of your worksheet (Part B).
12. Follow the remaining instructions in the worksheet.

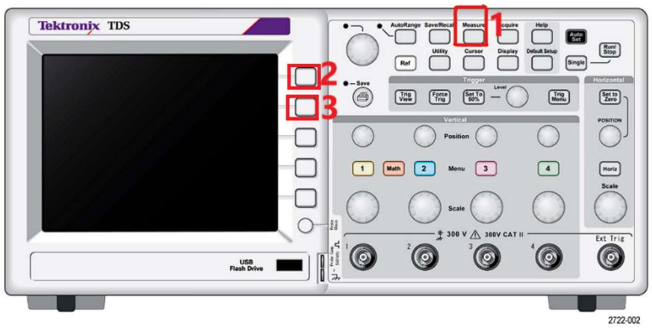

Figure 6: Oscilloscope buttons. (1) The measure button. (2) First option button, topmost. (3) Second option button.

Last Updated: 23 March 2024 (MRO)

BASIC ELECTRICAL MEASUREMENTS WORKSHEET

Instructions: Please **submit this worksheet at the end of the second session** of your experiment.

Name : ________________________
Group : ________________________
Partner's Name : ________________________
Marks : ________________________

DATA

Part A1: Ammeter / Voltmeter Method

1. The true value of resistance (measured using a digital multimeter (DMM):
   First measurement (R_1): ____________ Ω
   Second measurement (R_2): ____________ Ω
   Third measurement (R_3)t: ____________ Ω

   Average: ____________

2. Value of resistance using Ohm's Law (show your workings below):
   a) Current (I): ____________ ± ____________
   b) Voltage (V): ____________ ± ____________
   c) Resistance (R) using Eqs. (6) & (7): ____________ ± ____________

Part A2: Empirical Method

Table 1: Resistance versus current.

Resistance, R (Ω)	**Current, I (mA)**	a_i
0	±	-
100	±	
200	±	
300	±	
400	±	
500	±	
600	±	
700	±	
800	±	
900	±	
1000	±	
	Average of a_i (α)	
R_x	±	

From Eq. (10), the value of R_x is given by ____________ Ω.

Calculate the percentage discrepancy between the measurement made using (1) the digital multimeter (DMM) and (2) the multimeter with the value of resistance obtained through the colour code:

DISCUSSION & CONCLUSION (PART A)

Safety Precautions:

Potential Sources of Error:

Comments about your findings:

Conclusions:

-------The End of Part A (Week 1)-----

Part B2: Measurement of AC Voltage

Table 2: Peak voltage versus the RMS voltage.

Peak Voltage (V_p)	**RMS Voltage (V_{RMS})**	$m = \frac{V_{RMS}}{V_0}$
Average of m:		

From the above result (average of m), obtain the slope of the straight line and compare this value with the theoretical value, $\frac{1}{\sqrt{2}}$. Calculate its percentage discrepancy.

DISCUSSION AND CONCLUSION (PART B)

Safety Precautions:

Potential Sources of Error:

Comments about your findings:

Conclusions:

-------*The End of Part B (Week 2)*-----