Experiment 261: Basic Electrical Measurements

Aim

To use a digital multimeter and oscilloscope to measure *dc* and *ac* voltage, *dc* and *ac* current, resistance, capacitance, time, frequency and phase. You may be unfamiliar with these instruments or the components measured. If so, *don't hesitate to ask a demonstrator for assistance.*

The Digital Multimeter (DMM)

The Fluke 77 Digital multimeter supplied measures *ac* and *dc* currents and voltages, and also resistance. This model by default is *auto-ranging*, that is, it adjusts its display to give the most accurate reading of the quantity measured, in 3 or 4 digits. The rotating *selector switch* selects the type of measurement. When not in use, always turn this to the left-most "off" position. The other switch positions, reading clockwise, are for measuring

- *ac* voltage,
- *dc* voltage,
- higher sensitivity *dc* voltage (300 mV maximum),
- resistance,
- circuit continuity (produces an audible signal if the resistance between the probes is $<\approx 100\Omega$),
- *ac* current,
- *dc* current.

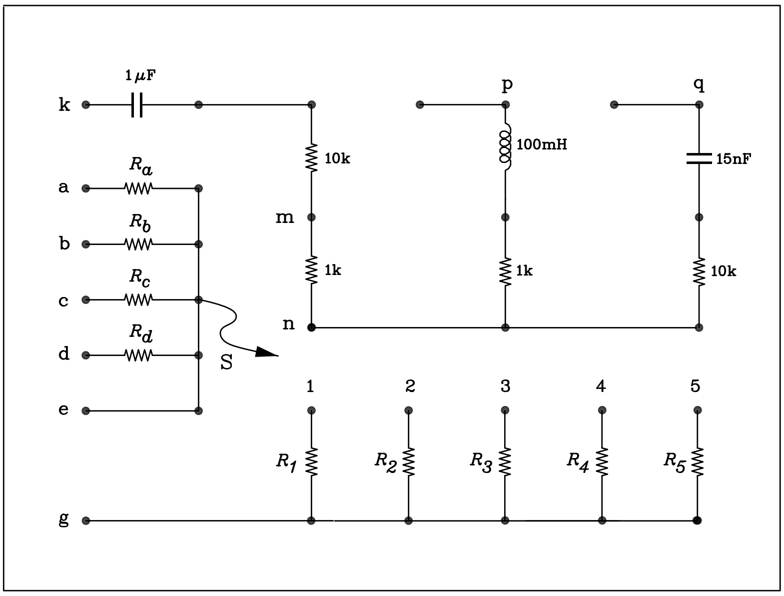
For *voltage* and *resistance* measurements, the probe leads must be plugged into the two right-hand sockets — black to bottom. For *current* measurements, the *red* lead is plugged into one of the two left-hand sockets.

> **Warning! Read this twice!** *Never* connect the leads of a meter configured to measure *current* directly across the terminals of a *dc* power supply, as this may blow the meter fuse or even destroy the meter.

Resistance Measurements

All components used in this experiment are mounted on a circuit board, shown schematically in Figure 1.

(1) Use the digital multimeter (DMM) to measure each of the resistances R_a to R_d and R_1 to R_5 on the circuit board provided (see Figure 1). Record, in an appropriate table, the measured values together with their nominal values, determined from the colour code of each resistor.



$R_a = 1\text{k}$	$R_b = 100$	$R_c = 1\text{M}$	$R_d = 10\text{M}$	
$R_1 = 270$	$R_2 = 680$	$R_3 = 1.5\text{k}$	$R_4 = 3.9\text{k}$	$R_5 = 1\text{M}$

Figure 1: Experimental set-up

D-C Voltage Source Measurements

The Phillips PE 4818 power supply used has an adjustable voltage range of 0 – 35 V, set with the left-hand knob. Pull this knob to turn the power supply on. *Current limiting* is provided to help protect equipment in case of inadvertant short circuits. The current limit is set with the right-hand knob. For this experiment, it can be set fully clockwise, as we do not wish the power supply to interact with the measurements we make. The left (negative) and right (positive) terminals supply the output voltage. The centre (ground) terminal connects to the case and is not used in this experiment.

(2) Connect the *dc* voltage source to terminals e and g (+ to e and − to g). Disconnect the jumper lead S. Set the DMM to read *dc* volts and connect it across the supply output voltage. Adjust this voltage to read exactly 10.0 V on the DMM (the power supply display may read slightly differently).

The circuit to the left of S, between points e and g (the power supply) can be considered to be an *ideal dc voltage source*. This means that its voltage should remain *absolutely constant* regardless of the current drawn from it.

Figure 2(a) shows how we will check this. The *load resistor*, R_L, is shown as *variable* (indicated by the arrow) so that it can be changed to draw different currents from the supply, while we measure the voltage across it. In practice, we will use discrete values of R_L, given by R_1 to R_5.

(3) For each value of load resistance from ∞ (open circuit) to 270 Ω, selected via S, measure the output voltage V_o, using the DMM. Using the resistance values measured earlier, calculate the current I_o flowing in each case. Record and tabulate the corresponding values of V_o and I_o.

(4) Plot a graph of V_o as a function of I_o. Does your graph confirm that the power supply is ideal?

Laboratory power supplies are hopefully always "ideal" in this sense. However cells, batteries, "plug-packs" etc. are usually not, in that their terminal voltage *decreases* with increasing current. Their observed current-voltage characteristic can usually be modelled fairly accurately however by assuming them to be an *ideal* voltage source in series with an *output resistance* (the *Thevenin equivalent circuit*).

(5) Connect the voltage source between terminals a and g so that the circuit to the left of S becomes a *non-ideal* voltage source, i.e. one having a *finite* internal resistance (= R_a).

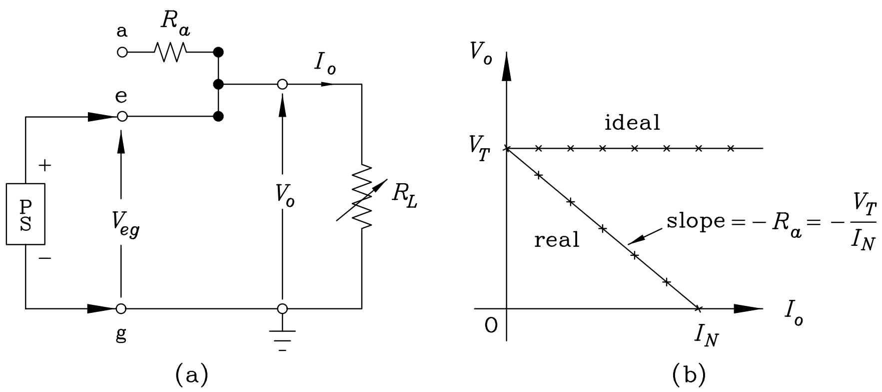


Figure 2: Illustrating the voltage source measurements.

(6) Repeat procedure (3).

(7) Using the same axes as for the earlier graph, plot V_o as a function of I_o. Confirm that the graph you have just plotted is what you would expect, i.e., the current-voltage characteristic of a voltage source having an internal resistance of R_a (Figure 2(b)). Your plot should be similar to the one shown as "real" in Figure 2(b).

(8) A non-ideal, linear voltage source may be represented by *either* the Thevenin (voltage source) equivalent circuit of Figure 3(a) *or* the Norton (current source) equivalent circuit of Figure 3(b)[1]. The resistances are called *internal resistances.*

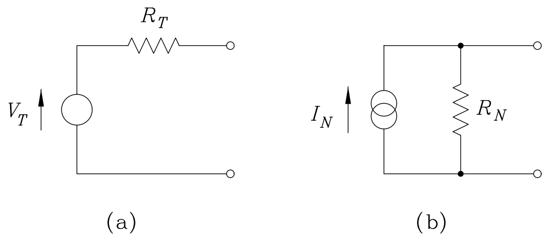


Figure 3: (a) Thevenin and (b) Norton representations of a non-ideal voltage source.

The "single circle" symbol represents an ideal *voltage* source. An "overlapping double circle" symbol represents an ideal *current* source. An ideal current source adjusts its terminal voltage to supply the same current regardless of the impedance across its terminals. This is a less intuitive concept than an ideal voltage source, but is useful for describing the properties of components such as transistors. Both symbols *must* be accompanied by an arrow showing the assumed direction of positive current flow from the source.

Determine values for V_T, R_T, I_N, and R_N of the Thevenin and Norton sources that would best reproduce the data you plotted in Procedure (7). **Note:** The rules for transforming between equivalent voltage and current sources are:

- The value of the internal resistance is the same for both (that is, $R_T = R_N$).
- The values of the ideal voltage and ideal current sources are related by Ohm's Law (i.e $I_N = V_T/R_T$).

[1]see Bold and Earnshaw, *Linear Steady-state Network Theory*, page 43

Measuring Instrument Loading Effects

(9) Up till now we have assumed that the DMM has no effect on the voltages it is used to measure. This will only be true if its terminal resistance is infinite, or alternatively, it draws no current from the circuit. However, *all* voltage measuring devices have a finite terminal impedance, although so far component values have been chosen to make the effect of the DMM imperceptible.

The equivalent circuit of a voltmeter is shown in Figure 4, inside the dashed box. R_M is the internal resistance, and the circle symbol represents an *ideal galvanometer*, which has *zero* resistance. Thus, the resistance seen between the voltmeter terminals is just R_M, and the voltage indicated by the meter is that developed across R_M.

We use the DMM to measure its *own* terminal resistance R_M, as follows (see Figure 4).

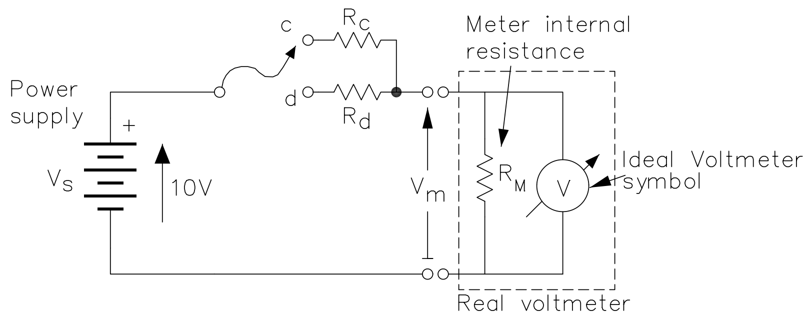


Figure 4: Measuring the internal resistance of the voltmeter.

(10) The voltmeter is connected between g and e. The power supply (shown as a battery having a voltage V_s) is connected between g and the left-hand end of resistors R_c and R_d in turn. Adjust its output voltage to a convenient value, say 10 volt, as shown. Assume that resistor R_c is in the circuit. Then, by the voltage division theorem,

$$V_M = V_s \frac{R_M}{R_M + R_c}$$

whence

$$R_M = R_c \frac{V_M}{V_s - V_M}$$

Theory shows that the optimum value of R_c (that giving the smallest percentage error in the estimate of R_M) is obtained when the series resistor (R_c or R_d) is equal to R_M, which gives $V_M = V_0/2$. You should find that one of the resistors specified approximately satisfies this condition. Calculate and note the value of R_M.

(11) An oscilloscope can similarly be used to measure its own terminal (input) resistance R_{in} in the same way. Replace the meter in Figure (4) with the oscilloscope.

Set the oscilloscope trigger mode to "AUTO" so that a line-trace appears on the screen. Arrange for the Y_1 amplifier (Channel 1) to measure *dc* with a sensitivity of 2 V/Div and use the vertical displacement of the line-trace from the zero position to measure voltage. Repeat the measurements in procedure (10) to estimate the best value of the oscilloscope input resistance. Calculate and note this value.

(12) Set up the circuit of Figure 5 using resistors R_c and R_5 and record the value of V_o as measured by the DMM and then by the oscilloscope. What is the reason for the different values obtained?

(13) Calculate the value of V_o

(a) under open circuit conditions

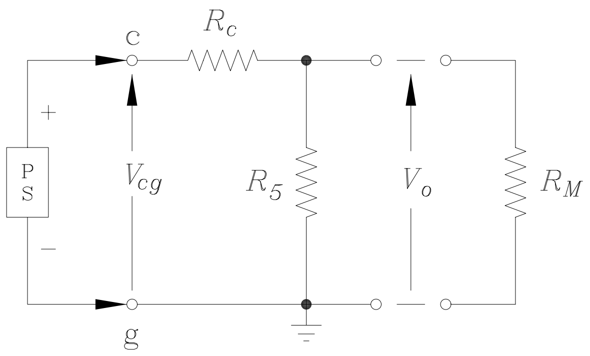


Figure 5: Measuring the same voltage with the DMM and the oscilloscope.

(b) with the DMM connected

(c) with the oscilloscope connected.

Use your measured values of R_M and R_{in} in the calculations.

Hint: If you have covered network theorems in the 453.240 course, use Thevenin's theorem to simplify the calculations.[2]

Compare your measured and calculated values of V_o.

Superposition of A-C and D-C

(14) Construct the circuit illustrated in Figure 6, using both the *ac* signal generator supplied and the *dc* power supply. Connect the oscilloscope to observe the voltage shown. Make the following initial settings where Y_1 denotes Channel 1 and Y_2 denotes Channel 2:

Oscilloscope Y_1 & Y_2 Amplifiers	1V/Div
AC-Gnd-DC Selector	DC
Zero Trace Position	1 Div from lowest graticule line
Oscilloscope Time Base	0.5ms/Div
D-C Power Supply	10V (set by DMM)
Signal Source	1V p-p triangular waveform at 1 kHz

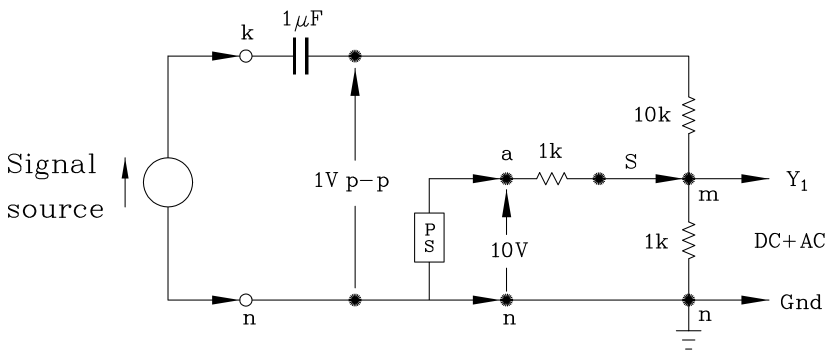


Figure 6: Superposition of *ac* and *dc*

(15) Calculate the *dc* and *ac* components of the voltage measured by the oscilloscope.
(Hint: By superposition, these can be calculated separately. If you have not covered this in the 453.240

[2] Bold and Earnshaw, *Linear Steady-state Network Theory*, page 44.

course, seek help from a demonstrator). Observe this voltage using the Y_1 trace. Attempt to measure the amplitude of both components with the sensitivity set at 1V/Div. Increase the sensitivity to 500mV/Div and observe the trace disappear off the top of the screen. Now switch the AC-Gnd-DC selector to AC. Note that the *dc* component of the observed voltage is *removed* and the *ac* component may be measured quite easily by increasing the sensitivity to 10mV/Div.

A-C Amplitude and Phase Measurements

(16) Connect up the circuit illustrated in Figure 7(a) and make the following initial settings:

Oscilloscope Y_1 and Y_2 Amplifiers	1V/Div
AC-Gnd-DC Selector	AC
Oscilloscope Time Base	0.2ms/Div
Signal Source	8V p-p sinusoidal waveform at 1kHz

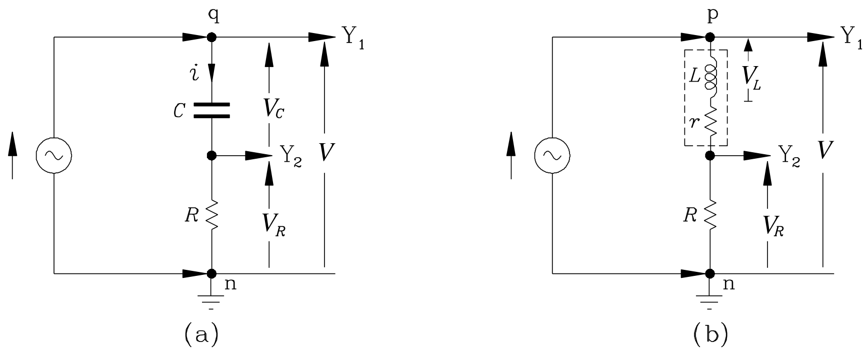


Figure 7: Measuring phase shifts in RC and RL circuits

(17) To check that both oscilloscope channels have identical gain and phase shift, connect both Y_1 and Y_2 oscilloscope probes between q and n. Set the y gain of both channels at the same value. Superimpose the two traces on the screen. They should be identical. If they are greatly different, ask a demonstrator for help.

Adjust the amplitude control of the signal source so that its output voltage $v(t)$ (as observed on the oscilloscope traces) is 8 V peak-to-peak.

Comment: We would like to measure $v_R(t)$ *and* $v_C(t)$ simultaneously. However, *one* lead of each oscilloscope input pair must *always* be grounded and so this is not possible. What we can measure, though, is $v_R(t)$ and the *total* output voltage $v(t)$. We will deduce $v_C(t)$ using simple trigometry.

(18) Display both $v(t)$ and $v_R(t)$ waveforms symmetrically about the horizontal centre-line of the screen as shown in Figure 8. Carefully measure the peak-peak amplitudes of, and the phase between, $v(t)$ and $v_R(t)$. Note whether $v(t)$ is leading or lagging $v_R(t)$[3] Record the frequency of the signal source.

(19) The series resistance of the capacitor is extremely small and may be neglected. Thus the phasor diagram for this circuit is as shown in Figure 9.

From the phasor diagram, it is clear that the voltage across the capacitor is given by:

$$V_C = \sqrt{V^2 - V_R^2}$$

and the phase angle δ by

$$\delta = \cos^{-1}\left(\frac{V_R}{V}\right)$$

[3]See *Bold and Earnshaw*, p. 2, for an illustration of "leading" and "lagging".

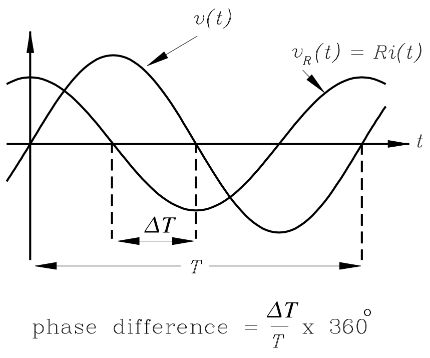


Figure 8: Measuring phase difference with the oscilloscope

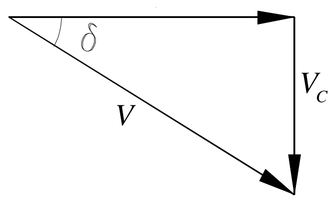


Figure 9: Phasor diagram for the CR circuit

Compare the theoretical and measured values of δ. You should find that they agree to within a few percent. Use the definition of capacitive reactance X_C and the calculated value of v_C to determine the value of the capacitance C. Use the colour code value of R in your calculations.

(20) Repeat procedures (18) and (19) for the inductor circuit of Figure 7(b).

The series resistance r of the inductor is *not* negligible and hence the voltage drop v_r *must* be included in your phasor diagram. Draw a phasor diagram for this circuit and use it to show that

$$V_r = V \cos \delta - V_R$$

and

$$V_L^2 = V^2 - (V_R + V_r)^2$$

Using the definition of inductive reactance and the calculated value for V_L, find the inductance L of the inductor. Find the value of the series resistance r of the inductor. Again, use the colour code value of R in your calculations.

(21) Take your circuit board to the RCL (left-hand rear wall of the laboratory) meter and measure the series inductance and series resistance of the inductor, and the series capacitance of the capacitor. (You may try to measure the series resistance of the capacitor, but you should find that it is extremely small indeed). If you are unfamiliar with this meter, ask a demonstrator. Record these values alongside those deduced experimentally. They should be within 10% of each other (resistance values vary a bit).

List of Equipment

1. 1 x Circuit Board Housing with circuit board
2. 1 x Fluke Digital Multimeter (model 77)
3. 1 x D-C Variable Power Supply (Phillips type PE 48418)

4. 1 x Newtronics Pulse/Function Generator (model 200PC or 200MSPC)
5. 1 x Hitachi Dual-Channel Oscilloscope (type V-212 or V-552)
6. 2 x Oscilloscope ($\times 1/\times 10$) probes
7. 1 x Coaxial Cable - BNC to alligator clips
8. 2 x Wire pair - Banana plugs to alligator clips

Gary E.J. Bold

L.R. Watkins

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