Instrumentation – DC Measurements

Section 1: Background reading – *Read before coming to the lab*

1.1 The Electronics Work Station and Equipment

Your workstation in the lab will look as in the following photograph and contains the following instruments:

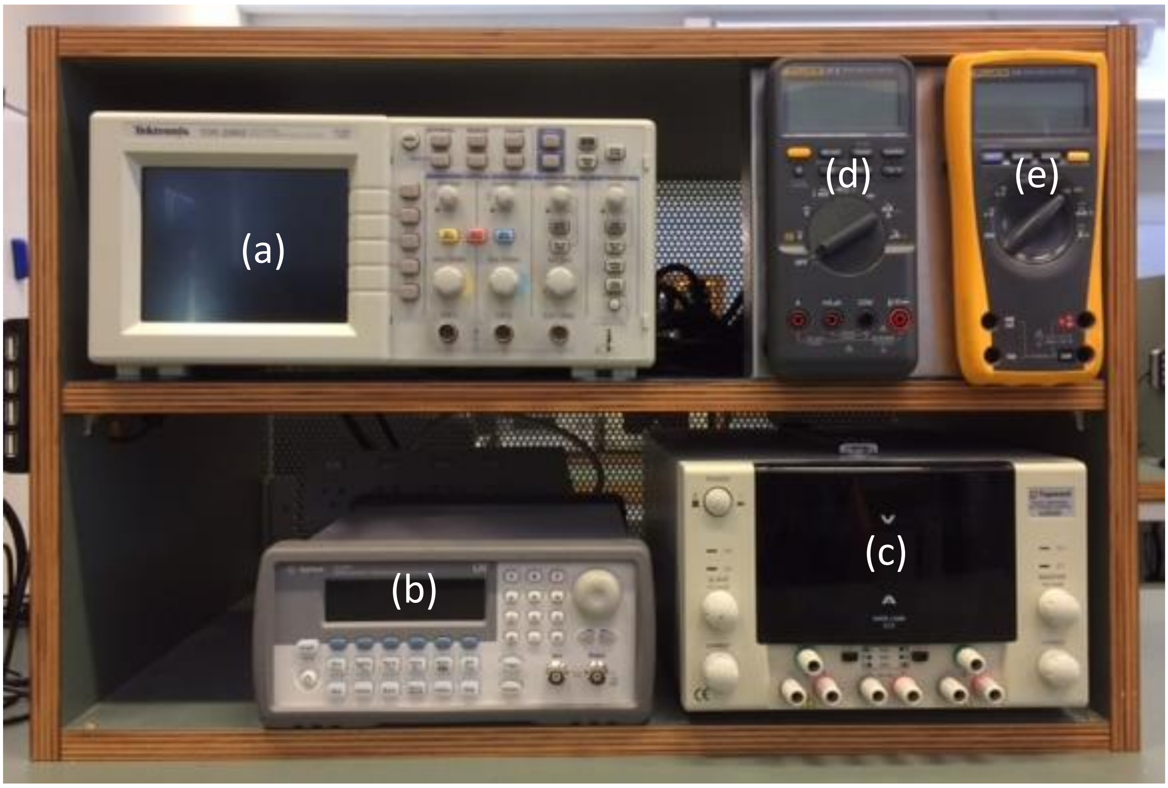


Figure 1: The electronics workstation in 200 level laboratories showing different instruments:
(a) A Tektronix TDS 2002 digital oscilloscope
(b) An Agilent 33220A Waveform generator
(c) A Topward 6303D dual power supply
(d) A Fluke 87 multimeter
(e) A Fluke 175 multimeter

All these instruments require a basic knowledge of their operation if we want to effectively use them in our laboratories and we gradually get familiar with the operation of each. In this lab we will concentrate on the use of the DC power supply and multimeter in measuring DC voltage and current as well as resistance measurements.

1.2 Digital multimeters

A **Digital Multimeter (DMM)** can be used to measure voltage, current and resistance and in the case of higher end meters may also be able to measure frequency or perform other measurement. It is based around an analog to digital converter that converts the analog input voltage a digital signal which is then displayed. It is also contains a range of internal resistances that enables it to be connected as either a voltmeter or as an ammeter. It uses an internal current source to enable the measurement of resistance. We may have to move the move the leads to different connection points depending on whether we are measuring current, voltage or resistance and we should also ensure that we have the correct AC vs DC setting for our measurement.

Ideal measuring instruments should not affect the parameter being measured. This means that voltmeters and ammeters connected into a circuit should not change the voltages and currents within the circuit (i.e they should not *load* the circuit). This is achieved by ensuring that:

(a) voltmeters have internal resistances that are much higher than the circuit values they are connected across; and

(b) ammeters have small internal resistances relative to the circuit components.

(c) In the case of measuring resistance, the DMM uses an internal constant current source to drive a known current through the test resistor, then measures the voltage drop over the current source and use a calculation of Ohms Law to calculate the resistance.

Figure 2: The two DMMS in more detail; left the Fluke 175 and right the Fluke 87.

It is a good idea to spend some time handling each of these instruments and have a look at their user manuals so that you become familiar with their operation.

1.3 DC Power Supply

Each work station is supplied with a Topward dual channel power supply, consisting of two variable (0 -20 V) supplies
that have individual controls for varying the voltages and setting upper current limits. The supplies may be used independently or as a combined bipolar supply (+, earth or ground, -). Note that power for this unit is derived from the ac mains so there will always be some ac 'ripple' or noise present (if you look hard enough). In many applications this noise is minimi sed by ensuring that one terminal of the supply is earthed but care should be taken when mak ing measurements with earthed instruments (e.g. the oscilloscope).

1.4 Breadboard for prototyping

We will be using breadboards such as the one in the photo below for prototyping our circuit. This allows us to quickly construct a circuit without any soldering. We can then experiment with the circuit the circuit on breadboard and before we solder it on stripboard or fabricate a printed circuit board (PCB)

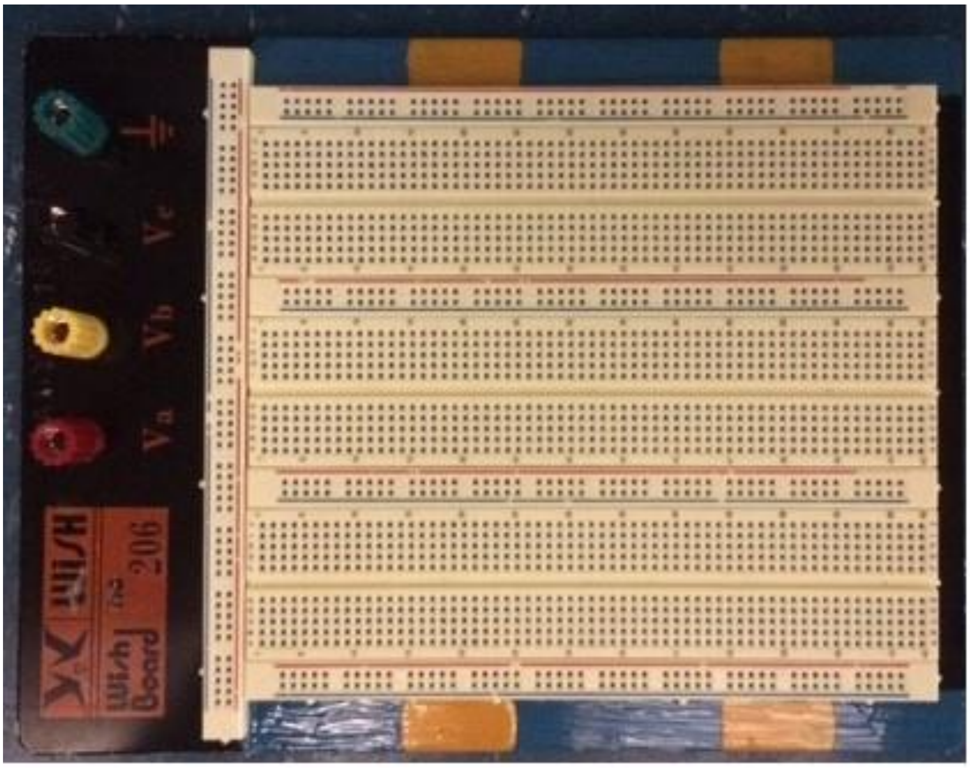


Figure 3: Breadboard for prototyping

1.5 Resistors and other components

The components that are needed for each lab will normally be available in a small bin at the work station. In addition, have containers of additional components at the back and side of the class.

Resistors are colour coded with bands to indicate both the resistor value as well as the precision of the value that can be expected.

Resistors are (in theory !) purely dissipative electrical element (cannot store any electrical energy) that provides a specific resistance to the flow of electrical current. Resistors come in all shapes and sizes, but the following points should be kept in mind when using them:

- The value of the resistor is normally provided by a four or five band colour scheme on the body of the resistor. Shown below is a resistor with a four band colour scheme, where the first two bands indicate the first two digits in the resistance value and the third band indicate the multiplier. See in the sketch below how the colour of the band indicate the numeric value.

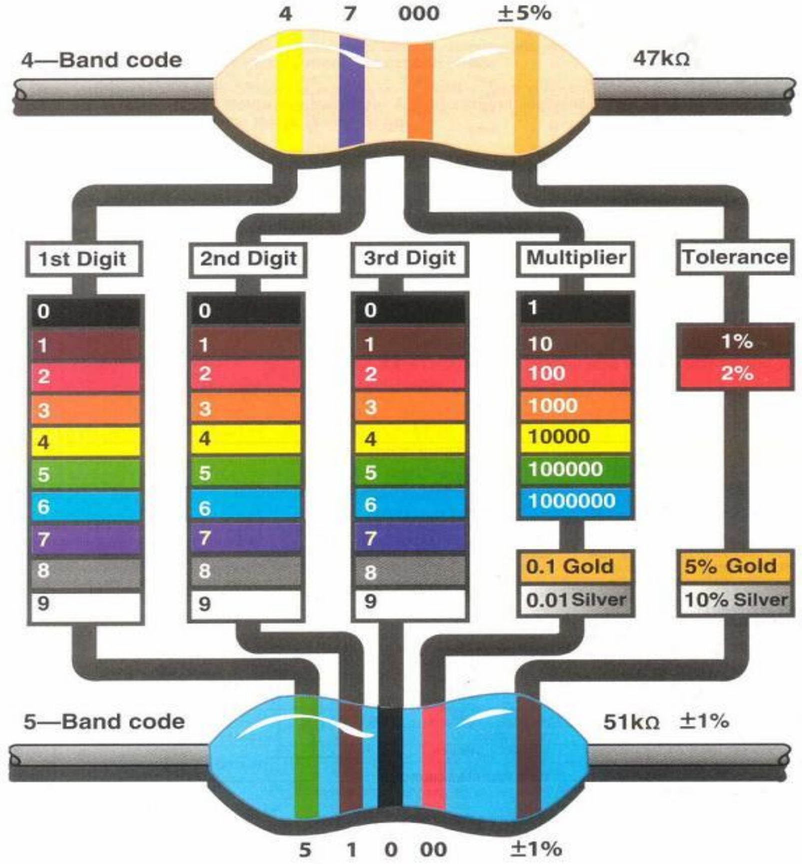


Figure 4: Resistor values as based on colour codes

- Every decade of resistor values (0.1 to 1 Ω, 1 to 10 Ω, 10 to 100 Ω……) should contain 12 resistor values. For example the decade from 1 kΩ to 10 kΩ should contain the following resistor values: 1) 1.0 kΩ 2) 1.2 kΩ 3) 1.5 kΩ 4) 1.8 kΩ 5) 2.2 kΩ 6) 2.7 kΩ 7) 3.3 kΩ 8) 3.9 kΩ 9) 4.7 kΩ 10) 5.6 kΩ 11) 6.8 kΩ 12 8.2 kΩ follows by 10 kΩ which will be the first resistor in the next decade.
- The last band (4^{th} or 5^{th}) will indicate the tolerance in the resistor value that can be expected. A silver band will then indicate that the real value of the resistor should be within ±10% of the marked value.
- Every resistor (as is true for every electronic component!) will also have a maximum power rating, indicating the maximum power that is should be able to dissipate before starting to overheat. The size of a resistor is a good indication of the amount of power it can dissipate, with larger resistors being able to handle larger powers. The lab resistors we use are normally ¼ W resistors, meaning we should stay below 0.25 W unless we want to run into problems.

1.6 Resistance measurement with a DMM

Figure 5 below illustrates how a DMM operates when it makes a resistance measurement. An internal current source applies a constant current to the resistor under test, and the voltage drop is measured internally, with the resistance calculated from these current and voltage readings.

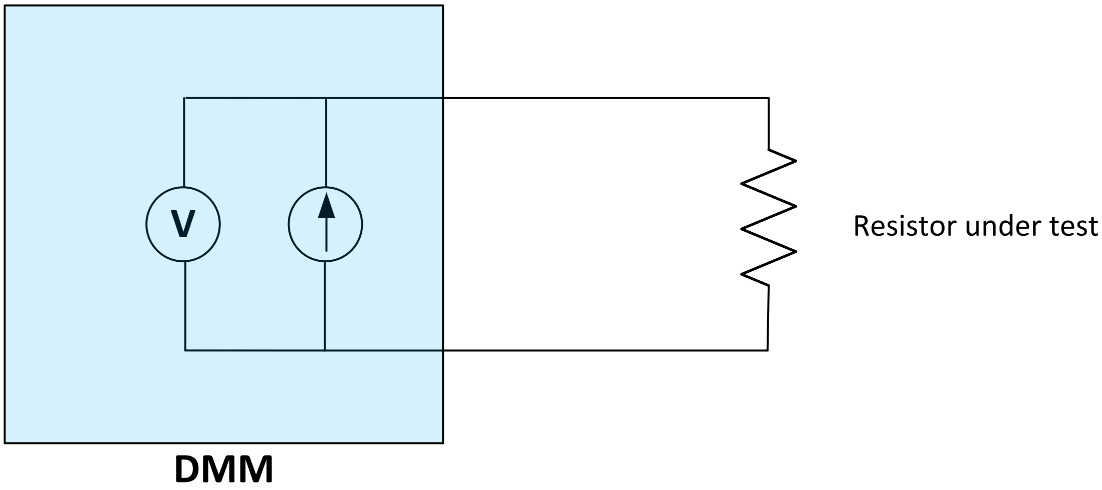


Figure 5: A normal two-wire resistance measurement

However, this picture is a simplification, because we will always have at least two other potential sources of resistance present in the circuit:

- The leads of the ohmmeter will have a small but non-negligible resistance, typically in the order of ~ 1Ω depending on the quality of the leads.
- The contact between the probes and the resistor leads will lead to a contact resistance.

The more accurate model of this measurement will thus look as below in Figure 6:

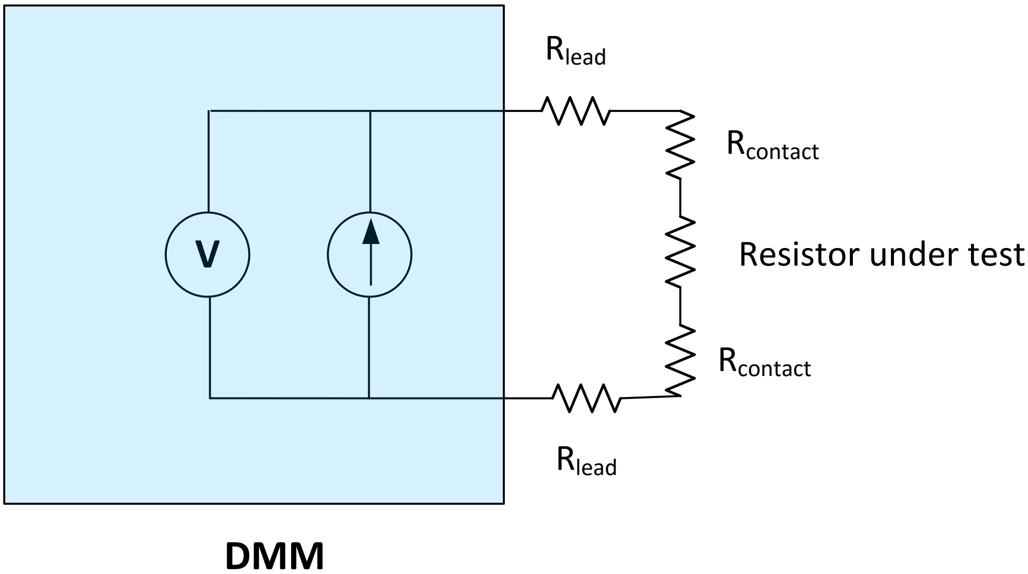


Figure 6: More accurate model of resistances during a two-wire resistance measurement

These additional resistances are not of great influence if the resistor under test is significantly greater than the parasitic resistances, but in the case where we need to measure a small resistance (< 1 Ω), the value obtained will be strongly influenced by the parasitic contributions.

To solve this problem, most high end (benchtop) multimeter will have the capability to perform a so-called four-wire resistance measurement. This allows a second set of leads and probes to be used, separating the current leads from the voltage measurement leads as shown in Figure 7.

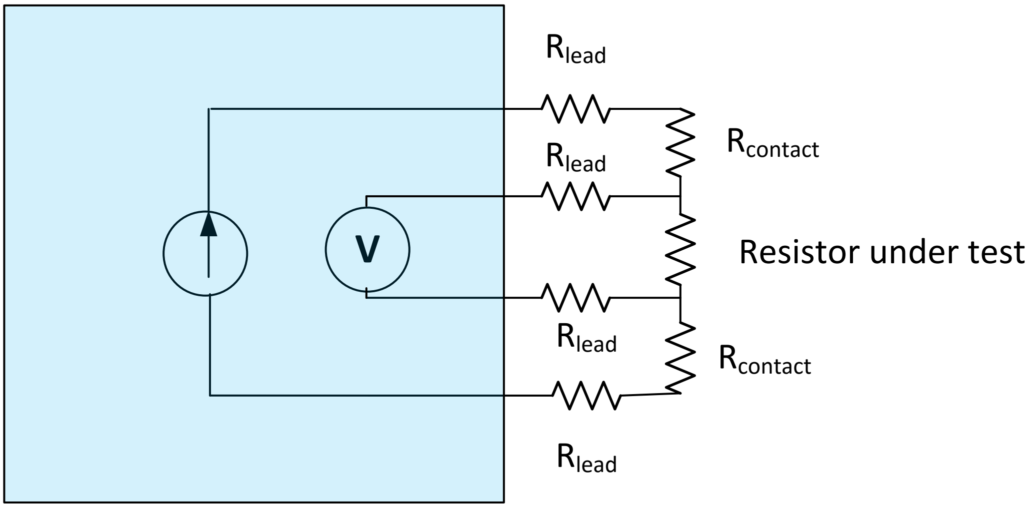


Figure 7: A four-wire resistance measurement

At first glance it looks like we have simply introduced more leads with more lead resistances into the measurement. However, keep in mind that the voltmeter has a very high resistance so that very little (~no !) current will flow in these voltmeter leads and the only voltage drop that will be measured will be across the resistor under test.

Using this method we can make very accurate resistance measurements, particularly at low resistance. Unfortunately our hand held DMMs are not equipped with this function and a high end benchtop DMM with this function will be illustrated in the lab.

1.7 Other equipment

The other equipment (oscilloscope, waveform generator) will be described in more detail in following laboratories.

Section 2. Pre-lab calculations

2.1 Current, voltage and power dissipated in a circuit.

For the circuit below, calculate the expected values of the currents (I_1 to I_3) through each resistor and the voltages (V_1 to V_3) over the resistors that will be observed in the circuit. Also calculate the power dissipation in each of the resistors to check that we are within the 0.25 W limit of the resistors.

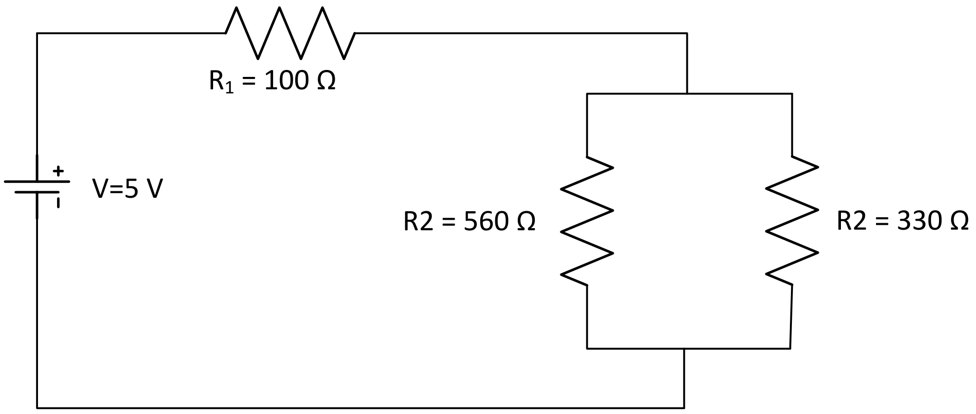


Figure 8: Basic circuit for section B2

Complete the following table with calculated values of currents and voltages in Figure 8:

I_1 (mA)	I_2 (mA)	I_3 (mA)	V_1 (V)	V_2 (V)	V_3 (V)	P_1 (mW)	P_2 (mW)	P_3 (mW)

2.2 Voltage divider circuits

The circuit in Figure 10 below acts as a voltage divider and divides the applied voltage from the power supply according to the resistance ratio between the two resistors.

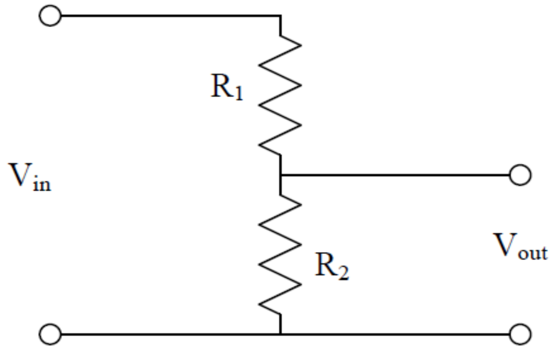


Figure 9: A simple voltage divider

(a) Write an expression for the voltage that will be observed over R_2 in terms of R_1, R_2 and the supply voltage V_{in}.

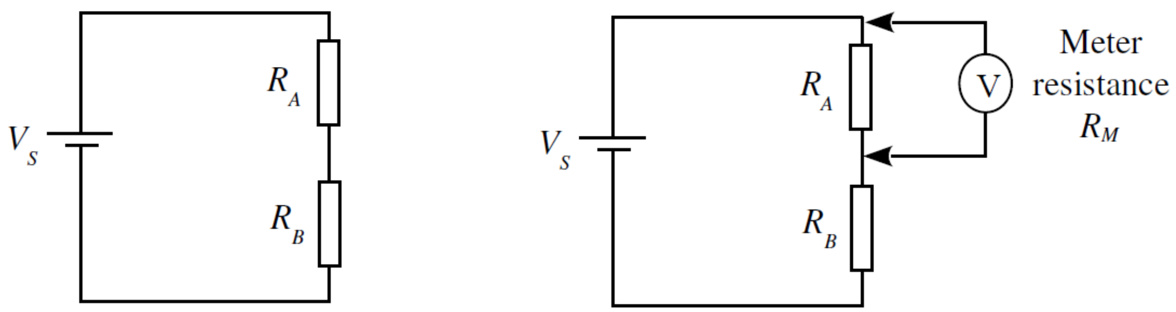
(b) You must now design a voltage divider similar to the circuit above (Figure 9) so that $V_{out} = 0.33V_{in}$ (±10%). Choose the values of R_1 and R_2 so that $R_1 + R_2$ is equal to 5 kΩ (±10%). You may use combinations of resistors to form R_1 and R_2 in order to achieve these objectives. Write the values chosen for your design in the table below:

R_1 value	
Resistor combination to achieve R_1	
R_2 value	
Resistor combination to achieve R_2	
Expected V_{out}/V_{in}	

Do you expect your circuit to meet all the design requirements ?

2.3 Internal resistance of ammeter and voltmeter.

One of the reasons for uncertainty in our measurements may be due to our measurement instruments not meeting the required conditions for use as an ammeter (resistance ~ 0 Ω) or as a voltmeter (resistance ~ ∞ Ω). We would like to obtain an estimate of how any non-ideal values of the meters will influence our measurements and we would also like to check what these values really are. To do this we will consider the effect of a measurement performed with a voltmeter where $R_{voltmeter}$ is not the infinite resistance we expect.



(a) (b)

Figure 13: Circuits for investigating the effect of voltmeter loading.

(a) Assume that we have a simple circuit with resistors R_A and R_B in series as shown below and you want to measure the voltage drop across R_B. Work out expressions for what you would expect the voltages across R_A and R_B to be for the circuit in Fig. 1a. If V_S = 3V what would the voltages across R_A and R_B be for the cases of (i) R_A = 1 kΩ, R_B = 10 kΩ; (ii) R_A = 100 kΩ, R_B = 1 MΩ?

(b) Now suppose that you measure these voltages using a voltmeter which has a resistance R_M associated with it as shown in Figure 9(b). Derive an expression for the actual voltage which would be measured across R_A and R_B using this meter. (Hint: first work out the resistance of the parallel combination of R_A (or R_B) and the meter in parallel, and then the resulting current in the circuit.)

(c) What voltages would you expect across R_A and R_B to be for the circuit in Fig. 9 (for both cases (i) R_A = 1 kΩ, R_B = 10 kΩ; (ii) R_A = 100 kΩ, R_B = 1 MΩ) if the measurement is done with a voltmeter of an internal resistance of (i) R_M = 10 kΩ , (ιι) R_M = 1 MΩ (iii) R_M = 10 MΩ.

(d) How does the accuracy of the measurements depend upon the relationship between R_M and R_A and R_B? What value of R_M is necessary for the measured voltage to be accurate? Explain the influence of R_M in obtaining accurate measurements.

The above effect is called meter loading and may be a major source on inaccurate measurements in some circuits.

Section 3: In the Lab - Experimental

3.1 Continuity measurement with the DMM

One function of the DMM that is not so obvious but is extremely useful, is the use as a continuity indicator. In this function it emits an audible signal when a low resistance path is encountered and is ideal for fault finding on a circuit board, as the signal can be used to find open circuit connections on the board.

Set one of your DMMs to the continuity function and use leads with crocodile clips and short pieces of hookup wire to probe the connection on the breadboard. Sketch the basic breadboard connection patterns and use your continuity test results to indicate the internal connections of the breadboard.

3.2 Current and voltage measurements

(a) Construct the circuit in Figure 8 on your breadboard. Decide how you should employ your two multimeters as part of the circuit in order to perform the required measurements of current through each resistor and the voltage over each resistor. Sketch an example of the circuit showing the multimeters and show your circuit diagram to the lab demonstrator. Double check all connections and power up the circuit from one channel of your Topward power supply. Perform the required current and voltage measurements and tabulate your results.

Complete the table with measured values of currents and voltages in Figure 8.

I_1 (mA)	I_2 (mA)	I_3 (mA)	V_1 (V)	V_2 (V)	V_3 (V)	P_1 (mW)	P_2 (mW)	P_3 (mW)

(b) How does the calculated values of current, voltage and power from Section 2.2.1 compare to the measured values above ? List the % difference between the two values in the table below:

I_1 (mA)	I_2 (mA)	I_3 (mA)	V_1 (V)	V_2 (V)	V_3 (V)	P_1 (mW)	P_2 (mW)	P_3 (mW)

Can you explain why the observed values would differ from the calculated values ?

3.3 Voltage divider circuits

(a) Construct your voltage divider design from Section 2.2. Now use different values of V_{in} = 1, 2, 3, 4. 5 V and each time measure the value of V_{out} and express as a percentage of V_S.

V_{in} (V)	1	2	3	4	5
V_{out} (V)					
V_{in}/V_{out} %					

(b) We are sometimes temped to use this output voltage as a "stable" input voltage into the next stage of a circuit – often with disastrous result. Simulate the next stage of the circuit by adding a load resistor R_L over V_{out}. Keep V_S constant at 3 V and use different values of R_L (100 Ω, 500 Ω, 1 kΩ, 5 kΩ, 10 kΩ, 50 kΩ, 100 kΩ) and for each value of R_L measure the value of V_{out} and show in a table. How stable is the value of Vout = $0.33V_S$ (required) when adding different load resistance ? Explain.

R_L	100 Ω	500 Ω	1 kΩ	5 kΩ	10 kΩ	50 kΩ	100 kΩ
V_{out} (V)							

3.4 Resistor series measurements

Use your DMM to measure the resistance of a range of resistors from ~1 Ω to 1 MΩ (do one resistor from each decade) and compare the observed value to the value expected from the colour band. Express the difference as a percentage and check if it is within the expected tolerance of the resistor.

Stated resistor value	1 Ω	10 Ω	100 Ω	1 kΩ	10 kΩ	100 kΩ	1 MΩ
Measured resistor value							
% Difference							

3.5 Measurements on low resistances

Your previous measurements included some resistors that were getting very low in values (1 Ω). How do this value compare to your lead resistances ? Can this introduce errors ?

Now measure the resistance of a low resistance sample (supplied in the lab) with your multimeter. Does this value make any sense ? Also use the four wire resistance measurement option of the benchtop multimeter to measure this resistance.

Section 4: Report

Now complete the report by answering the questions from the associated report sheet. This must be handed in at the start of the next laboratory session (typically one week after completion of the laboratory).