Lab 2: Measurement of DC voltages and currents

1. Objectives.

1) Familiarization with bar-code resistor marking. Measurement of resistance using the DMM.
2) Setting up the DC power supply for operation as a voltage source and for operation as a current source. Selection of a ground node.
3) Measurement of voltages and currents using DMM. Measurement of I-V characteristics.

2. Introduction.

There is no such thing as a perfect measurement. Each measurement contains a degree of uncertainty due to either fundamental reasons or, more often, due to limitations of the methodologies, instruments and the people using them.

Random error present in the results of the measurement can be minimized by averaging over multiple measurements. Assuming normally distributed data, the error bars for the results of measurements of R using ohmmeter can be calculated based on standard deviation σ_R.

$$\sigma_R = \sqrt{\frac{\sum_{i=1}^{N}\left(R_i - \overline{R}\right)^2}{N-1}}, \qquad \overline{R} = \frac{\sum_{i=1}^{N} R_i}{N}, \tag{1}$$

where N is number of measurements (for instance, the number of times you measure the same resistance using ohmmeter). Each time you might get slightly different value R_i. After averaging over N (ideally N should be rather big number) experiments one can calculate an average value $\overline{R}$ and the actual value of the resistance will be with 68% of certainty in the range from $\overline{R} - \sigma_R$ to $\overline{R} + \sigma_R$. There is 95% likelihood that the actual value is within range from $\overline{R} - 2\cdot\sigma_R$ to $\overline{R} + 2\cdot\sigma_R$. From equation (1) one can see that precision of measurement improves as square root of number of experiments. Hence, in order to minimize the contribution of the random noise it is advised to perform multiple measurements and average the results.

There is also systematic errors that can affect the accuracy of the measurements (precision can be improved by averaging but final result could still be not accurate since the errors are not necessarily come in the form of random noise). Good example of the systematic error are offset voltages and currents, i.e. when R is calculated based on I and V there is constant shift in either one or even in both of these parameters, hence averaging alone could not improve the accuracy. One way to deal with this is to use known functional dependences of one parameter on another. For instance in case of I and V for resistor R we know that they are supposed to follow Ohm's law, i.e. I=V/R. Hence one can obtain the plot of I on V from measurements and perform a linear fit. The linear fit is usually obtained by least-square regression method (can be done in Excel or in any other spreadsheet analysis software package) that minimizes the sum of the squares of deviation from the best fit.

For current and voltage measurements one would obtain I_i for each V_i applied. This dependence can be fitted with least-square method to obtain I* for each V_i according to the expression: $I^* = \frac{1}{R}\cdot V_i + I_0$. The least-square method performs minimization of the sum $\sum_{i=1}^{N}\left(I_i - I^*\right)^2$ in order to find R and I_0. The parameter 1/R can be expressed as:

$$\frac{1}{R} = \frac{N \cdot \sum_{i=1}^{N} (I_i \cdot V_i) - \left(\sum_{i=1}^{N} I_i\right) \cdot \left(\sum_{i=1}^{N} V_i\right)}{N \cdot \sum_{i=1}^{N} V_i^2 - \left(\sum_{i=1}^{N} V_i\right)^2}. \tag{2}$$

Nonzero value of parameter I_0 in this particular experiment originates from measurement error.

In this lab you will compare the results of measurements of resistance R using an ohmmeter with data obtained from the linear fit of resistor current-voltage (IV) characteristic.

3. Preliminary lab.

1. Resistors in the lab kit have 200 V voltage rating and ¼ W power rating. Calculate the maximum voltage and current values for resistors with R = 10Ω, 1 kΩ, 100 kΩ, 10 MΩ. Present data in a table.

2. Consider a resistive circuit in Figure 1. Using Kirchhoff's current law (nodal analysis) calculate the voltage at node 1 with respect to the ground for two voltage functions V1 = 5 V and 15 V. Using Kirchhoff's voltage law (mesh analysis) calculate the currents through resistors R1 and R2, then find the voltage at node 1. Make sure both methods give identical results.

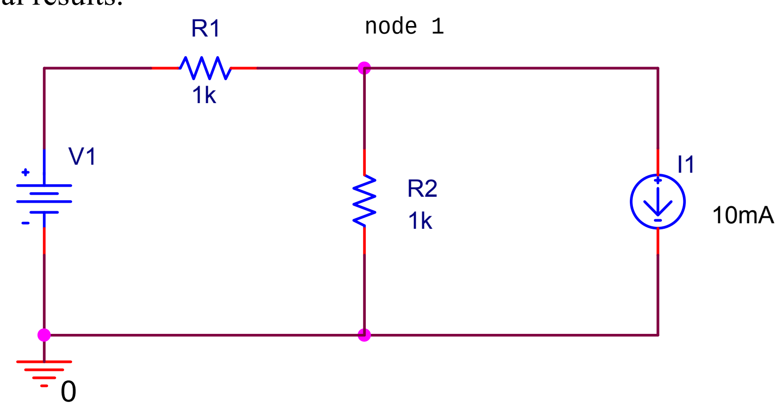

Figure 1.

3. Based on the passive sign convention determine if the power is supplied by the sources or being delivered to them for both voltage functions V1= 5 and 15 V. Calculate the power values and present the data in a table.

4. Experiment.

1. Read the bar code of the resistors in the lab kit and select two of them with nominal values of 100 Ω and 1 MΩ. Use DMM in an ohmmeter mode to measure the actual resistance values, record the data. Express difference of the measured value from the nominal one in percents and check if it is within the marked tolerance.

2. Warm up one of the resistors holding it between the finger tips and observe change of the resistance with temperature. The effect of temperature is characterized by a thermal resistance coefficient (TRC) in ppm/C. What sign of the TRC do you observe?

3. Set up the experiment for I-V measurements.

You will need in a power source to bias the resistor. The lab power supply has two independent sources that can work in voltage mode or current mode depending on the selected voltage or current compliances and the circuit load. In this part of the lab you will vary the voltage generated by the power source and perform measurements of pairs of voltages and currents in the resistor using DMM. To avoid possible burning of the resistor, set compliance for the current calculated from the resistor power rating of ¼ W. As you know, measurement of voltage is performed by placing the voltmeter in parallel to a circuit element, while measurement of current requires breaking the circuit and incorporation of the ammeter in series with the element. We will use a convenient feature in the DMM – the ability to perform two simultaneous measurements. To set up the DMM into that mode, assemble the testing circuit according to Figure 2 and select voltage and current measurement to be shown on the main display and the 2nd display respectively. As the DMM has a COMMON (reference) node shared by the voltmeter and the ammeter, it has to be the circuit ground node. Consequently, the DC voltage source should be left "floating", i.e. its middle (ground) terminal should NOT be connected to any node.

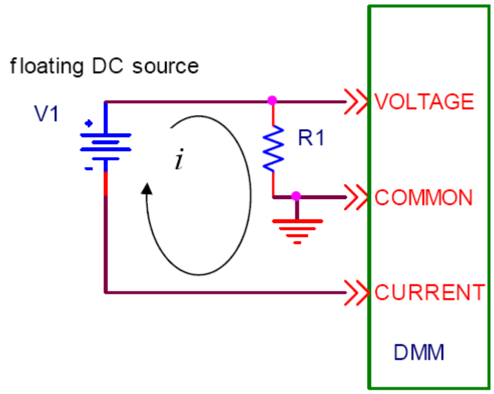

Figure 2.

4. Perform the measurements of the IV-characteristics for R=100Ω and 1MΩ for ten (10) positive and ten (10) negative voltages more or less uniformly distributed over the range of voltages permitted by power rating. We will perform "manual" measurements this time, i.e. voltages will be set manually and readings will taken by writing the values of Vi and Ii in your lab book. In future, when you are more acquainted with lab equipment we will perform automatic experiments when signal/power generator parameters are set and data are taken by PC using data acquisition software.

Present data in table.

Number of measurement, i	Vi	Ii	Vi*Ii	Vi^2
1				
2				
…				
N				
sum				

5. Calculate the value of the resistance according to equation 2. You can compare the result of your calculation with the value predicted by linear fit feature of the "Excel" or any other spreadsheet analysis software.

6. Assemble the circuit in Figure 1. Set up the 6V source to operate as a positive source connecting the circuit ground terminal to (-) of the power supply 6V section. Set the voltage at 5V and the current compliance at the sufficiently high value of 100mA so that the source will operate in the voltage mode for the given circuit. Set up the maximum voltage of 25 V in the second source and select the current compliance at 10mA level. The source loaded with the circuit will operate as a 10-mA current source. If you disconnect it from the circuit, the source will switch back to the voltage mode. The current flows from positive to negative terminals, so that to have the correct current direction, connect the circuit ground to the positive terminal of the 25 V source.

Breaking the circuit for current measurements is not convenient. In practice the current values are often being calculated from the results of voltage measurements using Ohm law, KVL and KCL. Perform measurement of the voltage at node 1 at V1 = 5V compare it with the results of calculations. Calculate the currents in resistors R1 and R2.

5. Report.

The report is due at the beginning of lab 3. It should include the work goals, a short description of what have been done, the original data, the I-V plot, and a conclusion. Be creative; try to find something interesting to comment on.

** Details of error analysis can be found in:*
P.R. Bevington, D.K. Robinson, "Data Reduction and Error Analysis in the Physical Sciences", 2nd ed. New York: McGraw-Hill, 1992.

**Resistor color codes*

Precision Resistor Color Codes						
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
Color	1st Digit	2nd Digit	3rd Digit	Multiplier	Tolerance	Reliability
Black		0	0	1		
Brown	1	1	1	10	1%	1%
Red	2	2	2	100	2%	0.1%
Orange	3	3	3	1,000	3%	0.01%
Yellow	4	4	4	10,000		0.001%
Green	5	5	5	100,000		
Blue	6	6	6	1,000,000		
Violet	7	7	7	10,000,000		
Gray	8	8	8	100,000,000		
White	9	9	9	1,000,000,000		
Gold				x 0.1	5%	
Silver				x 0.01	10%	

The reliability of a resistor indicates the failure rate of a resistor when run at its rated power dissipation for 1000 hours.