2. Meter Measurements and Loading Effects in Resistance Circuits

2.1. Purpose

1. To measure and predict the affects of multimeter(s) on a circuit when measuring electrical quantities.
2. To make use of Ohm's Law to predict values of voltage, current and resistance.
3. To compare different types of multimeters and determine some of their limitations for providing accurate measurements.
4. To quantify the error involved in a multimeter measurement using the specifications.

2.2. Equipment

digital multimeter (DMM), analog multimeter, breadboard, various resistors, DC power supply (CVCC).

2.3. Safety

Please read the notes on electrical safety on page 8.

2.4. Voltage and Current being measured

The purpose of a voltage measurement is to determine the potential difference between two points in a circuit. A multimeter can be set to measure voltage and then the two leads a placed at the points of interest without changing the circuit's connections. The displayed reading is the potential difference expressed on volts [V]. The type of volts measured for the reading must stated: DC or AC.

The purpose of a current measurement is to determine the rate of charge flow in any branch of a circuit. The multimeter is set to measure current and the circuit opened (or broken) so that the meter can be inserted in series with the other circuit devices. A current reading will then be determined in amps [A]. The type of amps measured for the reading must stated: DC or AC.

In both the above cases, the circuit is altered by the meter's presence. Thus the readings obtained are for a new circuit (the one with a meter included), not the original circuit. Meters are designed to minimize this problem, but it is important to be aware of the issue and to account for its affects when the influence of the meter is significant. This affect is called "meter loading".

2.4.1. Meter Loading

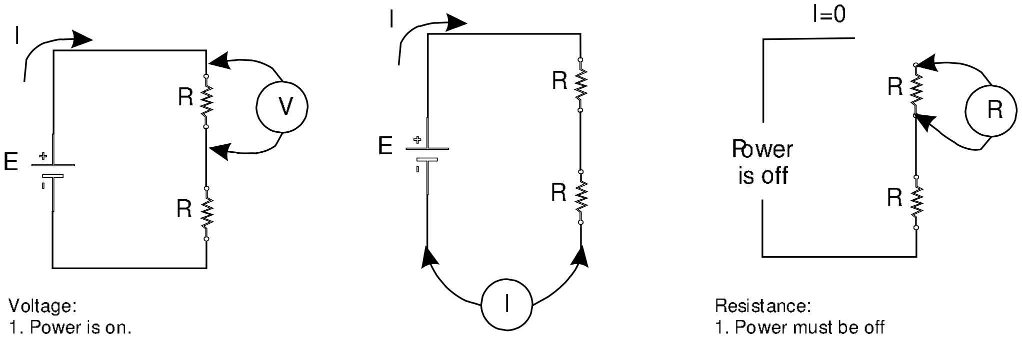
Meter loading is due to the resistance value of the meter presents between its leads when configured as a voltmeter or ammeter, which is not ideal. In both cases below, the value being measured is altered when the meter is connected to the circuit.

1. In the case of a voltage measurement, a perfect voltmeter's resistance would be infinite. It high, but not infinite.
2. In the case of current measurement, an ideal ammeter's resistance would be zero. It is low, but not zero.

Neither ideal is achievable, and getting close increases cost. Fortunately, given the meter's resistance, we can compensate for meter loading when it is a problem. Also the affects are negligible in many measurement situations.

2.5. Electrical Connections

Figure 2.1 shows the proper connection technique voltage, current and resistance readings. To measure a voltage, follow the steps of the left diagram.



NB: In all cases, make sure the meter's function switch is adjusted to the correct setting before applying the leads to the circuit. Failing to do this can result in damage to the meter.

Voltage:
1. Power is on.
2. Circuit is left intact
3. Choose appropriate scale if meter is not autoranging.
4. Place leads on either side of component of interest.

Current:
1. Turn power off and open circuit.
2. Choose appropriate scale if meter is not auto-ranging.
3. Insert meter so current goes through the meter.
4. Turn power on

Resistance:
1. Power must be off
2. Make sure there isno other paths around the component ie nothing in parallel.
4. Attach leads across component.

Figure 2.1.: Meter measurement connections.

2.6. D'Arsonval Movement

The heart of an analog multimeter is the coil and permanent magnet of the D'Arsonval movement as shown in figure 2.2. The needle deflection is produced when a current goes through the floating or moving coil. This current is DC and its maximum value is an important property of the meter. Typically it is is called I_{FSD} for $I_{Full\,Scale\,Deflection}$ and ranges between $30\mu A$ and $50\mu A$. Due to this tiny maximum current, precautions must be taken. Melting a coil is quite easily achieved. Fortunately a fuse in series will protect the meter from most mistakes.

The current being measured passes through the coil so that a magnetic field is produced. This field and the field of the permanent magnet try to align to minimize the system's energy. Thus a torque is produced on the moving coil and needle, so a rotation of the needle occurs. This rotation is proportional to the current

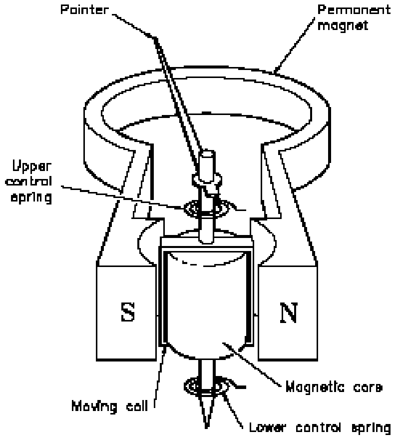


Figure 2.2.: d'Arsonval movement.

being measured due to the linearity of the restoring force which the spring produces against the needle's movement.

When the current is interrupted, the coil's field collapses and the needle returns to its resting position of zero deflection due to the action of the restraining springs.

A common variation of the D'Arsonval movement is the Weston movement, which uses the same principle built into a more rugged design and employing jeweled supports for the core and heavier windings.

2.7. Analog Meter Design: Voltmeter, Ammeter, Ohmmeter

Since the current I_{FSD} is fixed, the D'Arsonval movement is limited in the range of current it can measure. The meters range of application can be expanded by introducing shunt and series resistances to limit the current sent through the coil. Other important specifications of the coil are its resistance R_{coil} and its full-scale voltage deflection V_{FSD}. These parameters are related by Ohm's law for the coil by itself as shown in equation 2.1.

$$V_{FSD} = I_{FSD} \cdot R_{coil} \tag{2.1}$$

2.7.1. DC Voltmeter.

A series resistor R_{series} is placed as shown in figure 2.3. The value of resistor can be found from Ohm's law and equation 2.2.

$$R_{series} = \frac{V_{max} - V_{FSD}}{I_{FSD}} \tag{2.2}$$

This allows the measurement of a DC voltage of V_{max}. Commonly several series resistances are implemented to make the meter more flexible as in figure 2.3.

2.7.1.1. Questions:

1. Calculate the proper values of RA, RB, and RC in figure 2.3, so that the meter moves to full-scale deflection when the meter leads are connected to 2.5V, 25V, and 250V.

2. Explain what you would add to the DC voltmeter design to allow it to be used for AC measurements.

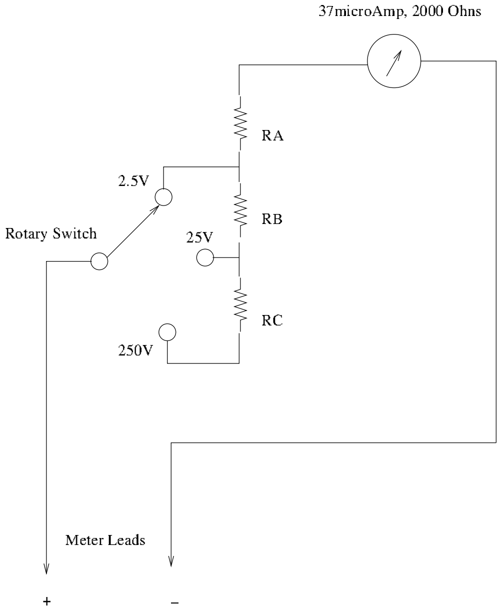


Figure 2.3.: Voltmeter configuration.

2.7.2. DC Ammeter

To protect the coil from high currents and increase the useful range of measurement a shunt resistance R_{shunt} is used in analog ammeter design. Such a design is shown in figure 2.4. Consideration of the power dissipation ($P = I^2R$) of the shunt resistor must also be made. With a shunt resistor in place the test current is split and the coil will only see I_{FSD} at most.

Consult the center diagram of figure 2.1 for ammeter connection instructions.

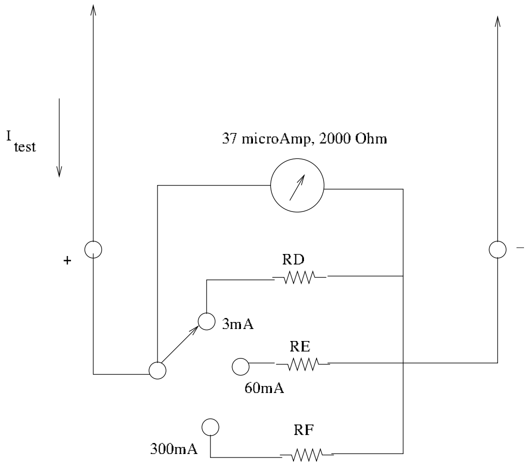


Figure 2.4.: Ammeter configuration.

2.7.2.1. Question:

1. What flaw is present in the ammeter design? Hint: Think what happens when you change ranges with the switch.

2.7.3. Series Ohmmeter

The basic design is called the Series Ohmmeter as the unknown resistance is placed in series with the meter components. Figure 2.5 shows the series ohmmeter configuration. It is quite different from the ammeter and voltmeter designs. First an internal supply is used. Secondly, zero ohms is indicated by a full-scaled deflection of the D'Arsonval movement. Consult the right-hand diagram of figure 2.1 for connection instructions.

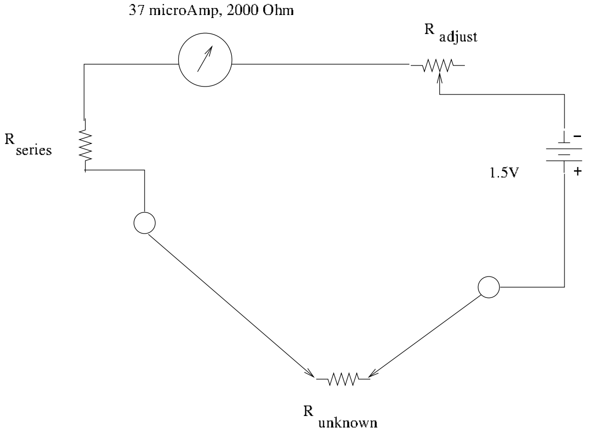


Figure 2.5.: Ohmmeter configuration.

A 1.5 volt battery is mounted inside the meter. An adjustable resistor R_{adjust} is available to compensate for voltage changes in the battery supply. The leads are shorted together to produce a full-scale deflection and R_{adjust} altered to produce this condition. When the meter leads are not connected to an unknown resistance $R_{unknown}$ this simulated infinite resistance and the deflection is zero.

With the meter leads shorted, R_{series} is chosen to give I_{FSD} through the coil with R_{adjust} set to the center of its travel. Thus its value can be found using equation 2.3.

$$I_{FSD} = \frac{1.5V}{R_{series} + R_{coil} + \frac{R_{adjust}}{2}} \tag{2.3}$$

If an unknown resistance is placed between the leads, a deflection of less than full-scale will occur due to a current $I_{unknown}$flowing through the coil. The value of R_{unkown} can be shown equation 2.4.

$$R_{unknown} = \left(\frac{I_{FSD}}{I_{unknown}} - 1\right)\left(R_{coil} + R_{series} + \frac{R_{adjust}}{2}\right) \tag{2.4}$$

2.8. Ohms per volt Rating of a Voltmeter

A figure of merit for analog meters is the $\frac{Ohms}{volt}$ rating S. The higher it is, the better. Common analog meters have $20\frac{k\Omega}{volt}$ ratings for DC voltage scales and $10\frac{k\Omega}{volt}$ ratings for AC measurements. This rating is used to calculate the meter's resistance using equation 2.5. Thus the meter loading can be calculated and if necessary properly accounted for.

$$R_{meter} = S \cdot V_{FSD} \tag{2.5}$$

2.9. EXPERIMENT: Meter loading tests

2.9.1. Circuit

A suggested table layout is shown in Table 2.1.

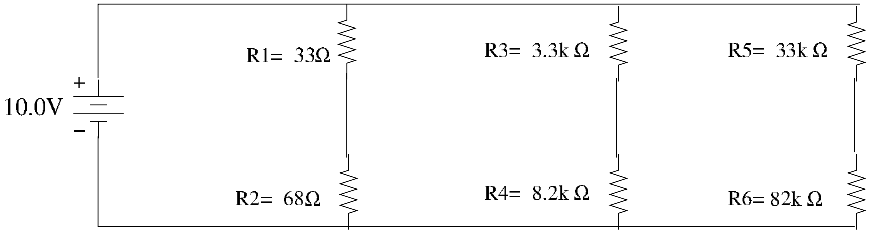


Figure 2.6.: meter loading test circuit

Value	spec (R's) ± error or I,V calculated	digital multimeter	analog multimeter	%difference DMM	%difference analog
R_1				X	X
R_2				X	X
R_3				X	X
R_4				X	X
R_5				X	X
R_6				X	X
I_1		±			
I_2		±			
I_3		±			
V_{R1}		±			
V_{R2}		±			
V_{R3}		±			
V_{R4}		±			
V_{R5}		±			
V_{R6}		±			

Table 2.1.: Multimeter experiment: suggested data table. ***All measurements must have units.*** The %differences can be calculated as $\frac{measured-calculated}{calculated} \times 100\%$.

2.9.2. Data and Measurements

1. Record type of manufacturer and model for each meter. See Section 11 for specifications including errors.

2. Do not build the circuit yet.

3. Record the manufacturer's value for each resistor in column one of Table 2.1.

4. Put each resistor's legs into holes on the breadboard without making connections to other resistors.

5. Use the digital meter to measure all resistor values and record these in Table 2.1. Repeat this using the analog meter.

6. Calculate all voltage drops and currents present in figure 2.6. These calculations are the "no meter present" predictions and go in the first open column of Table 2.1.

7. Now build the circuit shown in Figure 2.6.

8. Use the Digital Multimeter (DMM) to set the power supply output to $10.0 V_{DC}$. This will help remove any discrepancies between the calculations and measurements which could be due to the supply voltage being different from the value used for the calculations.

9. Use the digital multimeter to measure all voltages present in figure 2.6. Tabulate the values as V_{R1}, V_{R2}, etc.

10. Use the digital meter to measure the three currents as illustrated in Figure 14. Record these values to the table.

11. Repeat all measurements with the analog meter. Set the range switch to a high range if in doubt of how far the needle will deflect. Apply the leads for a positive deflection of the needle. Be aware that results disagreeing with the results of steps 15 and 15 are expected. However the errant values from the analog are not random, they are predictable.

12. Record the analog meter's sensitivity value S. It may be on the meter's scale in one of the corners. Look of Ω/V or $k\Omega/V$.

13. Switch the digital meter to measure resistance. Set the analog meter to the largest DC voltage measuring scales. Using the digital meter, measure the resistance of the analog voltmeter the ranges requested in Table 2.1.

2.9.3. Analysis

1. Calculate the % difference between the measured and predicted voltages (no meter) for each resistor. Repeat for both the analog and digital meter readings. Use the last columns of Table 2.1 to record the % values.

2. Calculate the voltmeter's resistance using the $\frac{ohms}{volt}$ rating S. Compare these predictions to the measured resistances for each voltmeter scale setting in Table 2.2.

3. What conclusions can you make about the analog and digital meter's performance and application to measuring circuit current, resistance and DC voltage?

4. Predict the V_{R6} reading with the analog meter by incorporating the meter's resistance.

Table 2.2.: Measurements and calculations of the analog voltmeter's resistance

S rating of analog meter = ____________________		
Full Scale DC voltage setting	Measured voltmeter resistance	Calculated voltmeter resistance
2.5V		
10V		
50V		

2.10. Report

Lab submission details TBA. Use LyX to generate the report. [1]

Include the following items. Please label them using sections/subsections so the marker can tell what is being presented.

1. your data/calculation tables 2.1, 2.2 and 2.3.
2. answers to the analysis section 2.9.3.
3. a sample calculation of I_{R1} and V_{R1}using measured (DMM) values of the resistor or resistors.
4. A table with the following information available from online at `hogan53.net/meter_specs.html` or from this manual, see Chapter 11.

Table 2.3.: meter uncertainties

type of measurement	All-Sun analog meter	Your digital meter and range
current DC		40mA
voltage DC		4V
resistance		40k-ohm

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[1] Document Class set to REVteX V. 4 (not 4.1), no/uncheck predefined class options, custom class options needs to have prl,aps specified.