ET 304A
Electric Circuits Laboratory
Lab 4
Voltage Measurements and Meter Loading Effects

PURPOSE: Use different types of laboratory instruments to measure the voltage in a simple dc circuit. These instruments are the digital multimeter, the analog multimeter and the oscilloscope. Determine the effects of adding a meter to a circuit under test. Observe the effect on measurement accuracy when the circuit resistance changes relative to the meter resistance.

Theoretical Background

Introducing a measuring instrument into any electric circuit causes a loading error. This loading error is due to the internal resistance of the instrument's circuits. This resistance can have a fixed value or depend on the range setting of the instrument. Voltage measurement places the internal resistance of the instrument in parallel with the circuit element. Figure 1 shows a voltmeter with an internal resistance of R_m measuring the voltage in a voltage divider circuit.

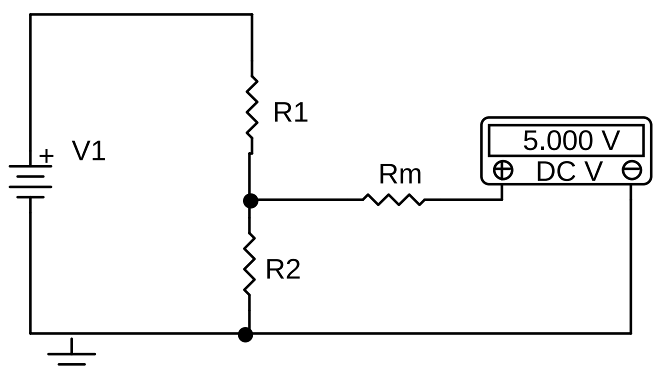

Figure 1. Meter Loading Effects.

The voltage divider formula gives the theoretical value of voltage across R2.

$$V_{R2} = V1\left(\frac{R_2}{R_1 + R_2}\right) \tag{1}$$

The voltage divider formula assumes that a voltmeter with an infinite internal resistance is used to measure the voltage across the resistors in the circuit. Practical voltage measuring instruments have an internal resistance that is in series with the measuring circuits. The resistance can have a value that ranges from 10's of thousands to 10's of mega Ohms. The internal resistance depends on the instrument construction.

When a practical voltmeter is connected to a circuit, its internal resistance is placed in parallel with the component under test. If the instrument measures the voltage across R2, the parallel resistance, R_{eq}, is given by:

$$R_{eq} = \frac{R_m R_2}{R_m + R_2} \tag{2}$$

The formula below finds the voltage across the resistor R2 when the loading effect of the meter is included.

$$V_{R_{eq}} = V1\left(\frac{R_{eq}}{R_1 + R_{eq}}\right) \tag{3}$$

The loading effect of the instrument depends on the relative sizes of the instrument and component resistances. When a large (10xR2) value of meter resistance is paralleled with resistor R2 using equation (2), the result will be nearly equal to R2 alone. Generally the loading effect of the instrument will be negligible when the instrument's internal resistance is large compared to the component under test. As the value of the component under test increases, the circuit loading effect of the meter increases and the value of R_{eq} will change considerably from the value of R2 alone. This will cause the meter reading to differ greatly from the theoretical value given by (1).

Knowledge of the instrument's internal resistance is necessary to avoid loading effect errors. The specification sheets of instruments list the input resistance of voltage measuring instruments. Consult these sheets and compare the value to the range of components that are to be tested. The "10xR2" rule is a good practice to follow when selecting a voltage measuring instrument.

PROCEDURE

The simple voltage divider circuit shown in Figure 2 will be used throughout this activity, but the values of resistance will change.

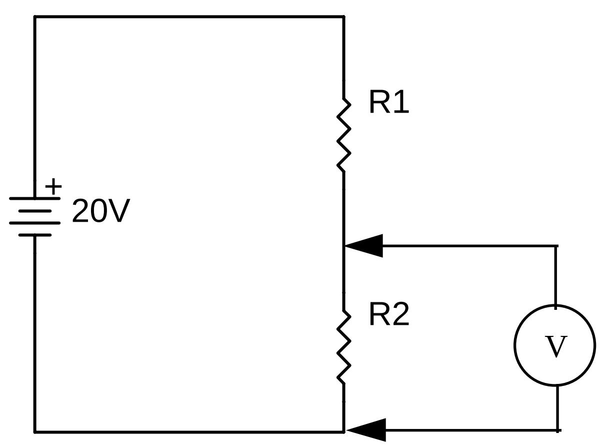

Figure 2. Voltage Divider Test Circuit.

1.) Construct the circuit in Figure 1 using 10kΩ resistors for both R1 and R2.
2.) Measure the voltage across R2 using the DVM, the analog meter, and the oscilloscope. Record these values in Table 1.
3.) Replace the resistors with 220kΩ and repeat step 2
4.) Replace the resistors with 470kΩ and repeat step 2
5.) Replace the resistors with 820kΩ and repeat step 2
6.) Replace the resistors with 1.0MΩ and repeat step 2
7.) Replace the resistors with 2.2MΩ and repeat step 2
8.) Replace the resistors with 3.3MΩ and repeat step 2
9.) Replace the resistors with 4.7MΩ and repeat step 2
10.) Use the voltage divider formula to calculate the theoretical value of the voltage across R2 in each of the circuits constructed. Include these calculations in an appendix in the lab report. Enter these values into Table 2.
11.) Determine the DVM loading resistance by consulting the attached meter specification sheets. Determine the equivalent resistance of R2 and the meter resistance for each value. Use the voltage divider equation to find the theoretical value of measured meter voltage. Enter these values in Table 3.
12.) Find the analog meter loading resistance from the attached meter specification sheets. Repeat the calculations of step 11 to find the theoretical value of measured meter voltage. Enter the values in Table 4.
13.) Find the input resistance of the scope by examining the front panel of the instrument near the channel input connectors. Repeat the calculations of step 11 to find the theoretical value of measured voltage. Enter the values in Table 5.

What to Include in the Report

1.) Include all the data from the tables in the report. Display the data in tables similar to those shown in this hand out.
2.) Include all the calculations in an appendix to the lab report. The calculations should be done on engineering or graph paper.
3.) Construct three graphs that plot the value of R2 on the x-axis vs. two y-axis values a.) the measured voltage value, b.) the theoretical values from tables 3-5. Make a separate plot for each measuring instrument.
4.) Using the tables and graphs explain the loading characteristic of each instrument. Compare the loading characteristics of the instruments.
5.) The report should follow the standard report format.

Table 1- Measured Resistor Voltages

	V_{R2}		
R2	DVM (V)	Analog (V)	Scope (V)
10kΩ			
220kΩ			
470kΩ			
820kΩ			
1.0MΩ			
2.2MΩ			
3.3MΩ			
4.7MΩ			

Table 2 Theoretical Voltage Divider Calculations

R2	V_{R2}(V)
10kΩ	
220kΩ	
470kΩ	
820kΩ	
1.0MΩ	
2.2MΩ	
3.3MΩ	
4.7MΩ	

Table 3 Theoretical Calculations: Voltage Divider With DVM Resistance

R2	R_m	R_{eq}	V_{R2}
10kΩ			
220kΩ			
470kΩ			
820kΩ			
1.0MΩ			
2.2MΩ			
3.3MΩ			
4.7MΩ			

Table 4 Theoretical Calculations: Voltage Divider With Analog Meter Resistance

R2	R_m	R_{eq}	V_{R2}
10kΩ			
220kΩ			
470kΩ			
820kΩ			
1.0MΩ			
2.2MΩ			
3.3MΩ			
4.7MΩ			

Table 5 Theoretical Calculations: Voltage Divider With Scope Resistance

R2	R_m	R_{eq}	V_{R2}
10kΩ			
220kΩ			
470kΩ			
820kΩ			
1.0MΩ			
2.2MΩ			
3.3MΩ			
4.7MΩ			