Laboratory 2: Voltage and current dividers, Wheatstone bridge, basic circuit analysis

2.1 Introduction

In this lab several circuits and techniques will be used to gain experience and understand of laboratory practices and electric circuit methods. In the previous lab you verified Ohm's Law and Kirchhoff's Laws and saw how to use them to understand parallel and series resistors. Analysis of any arbitrary arrangement of sources and resistors will require techniques other than these fundamental laws. This means that, given a circuit with specified source and resistor values, the method should allow all currents and voltages to be found with as straightforward a procedure as possible.

Voltage and **current dividers** are used to tap a fraction of the input voltage and current respectively, resulting in an output gain of less than 1 for such circuits. In this laboratory we will explore the functioning of voltage and current dividers and also understand the effect of a Light Dependent Resistor (LDR) in divider applications.

The **Wheatstone Bridge** provides a method of measuring resistor values and is easily analyzed with the correct technique.

You are reminded that the passive sign convention (PSC) must be followed in the laboratory as in the theory, and as such always record the voltage and current measurements in accordance to the reference voltage polarities and reference current directions assigned in your record of the experiment and use the PSC correctly in your calculations and analysis that follows.

2.1.1 Objectives:

1) To gain hands on experience with the voltage and current supplies, ammeter and voltmeter function and variable resistors.

2) To study how a voltage divider works and to derive and validate the formula for the output voltage and gain, and the effect of load on the circuit.

3) To study how a current divider works and to derive and validate the formula for the output current and gain.

4) To understand and validate the Wheatstone Bridge's function.

5) To understand the effect of a multimeter's (ammeter and/or voltmeter) internal resistance on its readings.

2.1.2 Components and instruments

Instruments	**Components**

• *Agilent Power Supply Unit (E3631A)*
• *Agilent DT Digital Multimeter (34401A) (DT – Desk Top)*
• *HH Digital Multimeter (M 3860D) (HH – Hand held)*
• *XK 150 Kit*
	• *Resistors*
	  o *various*
	  o *Other resistors from the component kit if required.*
	• *Connecting wires*

2.2 Background Information

2.2.1 Voltage and Current Dividers

This voltage divider produces an output voltage, ***Vout***, that is proportional to the input voltage, ***V1***. The output voltage is measured using a voltmeter. The input voltage is the voltage of the voltage source. The constant of proportionality is called the gain of the voltage divider. The value of the gain of the voltage divider is determined by the resistances, ***R1*** and ***R2***, of the two resistors that comprise the voltage divider as shown in Figure 2-1. Observe how the Agilent Digital Multimeter is connected to the output terminals of the circuit.

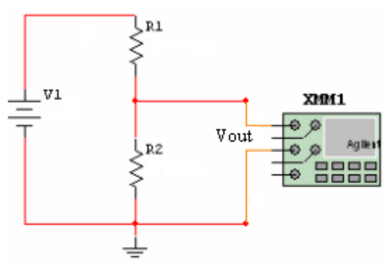

Figure 2-1: Voltage Divider
XMM1 Represents the Agilent 34401A Digital Multimeter

The output voltage of the circuit can be shown to be:

$$Vout = \frac{R2}{R1 + R2} V1 \qquad \text{eq 2-1}$$

The gain 'A' of the circuit could be calculated as the ratio of Vout and V1 as:

$$A = \frac{R2}{R1 + R2} \qquad \text{eq 2-2}$$

A current divider circuit shown in Figure 2-2 divides the current in each of the branch according to the conductance. As you can see there are two Agilent multimeters connected to the circuit to measure the branch current. However, while conducting the experiment students are required to use one Agilent Multimeter to measure the current one reading at a time.

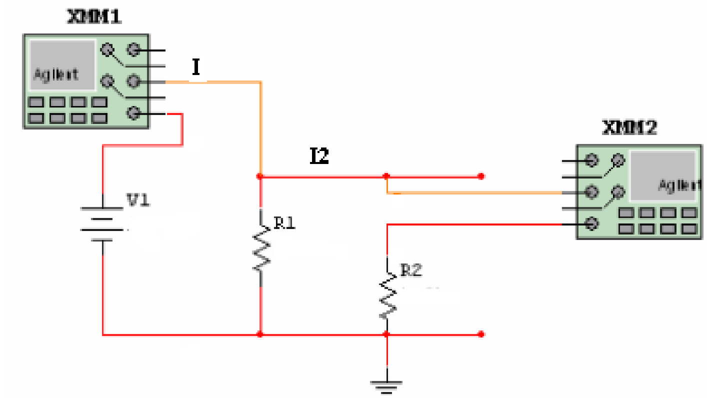

Figure 2-2: Current divider

The output current I2 flowing through the divider of the circuit can be shown to be:

$$I2 = \frac{R1}{R1 + R2} I \qquad \text{eq 2-3}$$

The gain 'A' of the circuit could be calculated as the ratio of I2 and I as:

$$A = \frac{R1}{R1 + R2} \qquad \text{eq 2 4}$$

2.2.2 Wheatstone Bridge

The Wheatstone Bridge combines both voltage and current divider circuits and allows for the accurate measurement of resistance. It does this using a circuit, as in Figure 2-3, of the unknown resistor and three known resistor values (including one variable resistor), and an ammeter to measure the current between the terminals A and B.

As seen in Figure 2-3, the two series branches each act as a voltage divider, while the two branches together make a current divider.

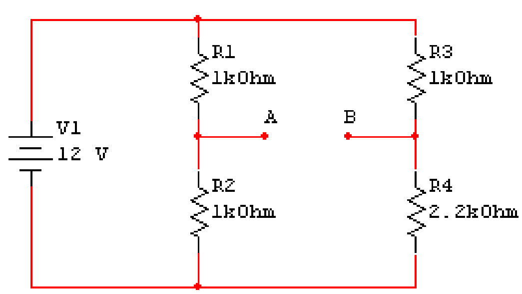

Figure 2-3: Wheatstone bridge

The goal is to adjust the variable resistor such that the current through the ammeter connecting is zero at which point a simple calculation will provide the resistance value of the unknown resistor.

Please refer to your class notes and the text, section 3.6 of the text for additional details, and be aware that such circuits are not always presented in precisely the same configuration.

2.2.3 Links and Readings

http://academics.vmi.edu/ee_js/Teaching/ee222/materials/voltage_divider.html --> Interactive demos

Read sections 3.1 – 3.4, 3.6 in the textbook

See Lecture Slides (available on WebCT) and your notes from Chapters 2 and 3.

2.3 Pre-lab Tasks:

Warning: This pre-lab requires a good deal of time and calculations

Please print off and complete your answers on these pages, attach additional sheets if necessary and/or indicate if you are using the backs of pages.

Complete the following tasks before coming to the laboratory:

1. For the circuit in Figure 2-1 with an input voltage V1 of 10V, a fixed R1 resistor of 10 kΩ and for each value load resistor R2 of 1 kΩ, 2 kΩ, 3.3 kΩ, 4.7 kΩ, 5.6 kΩ, and 10 kΩ:

   1.1. Compute the voltage gain of the voltage divider and the output voltage as discussed above for each value of R2. Record these calculated values in the appropriate rows of Table 2-1.

   1.2. Simulate the voltage divider circuit in OrCad/PSpice (or NI MultiSim) and measure the output voltage for each value of R2. Compute the voltage gain and record these simulated values in the appropriate rows of Table 2-1. Also, calculate if there is an error.

   1.3. What will the output voltage be if R2 is replaced by a:

      a. Short circuit? Vout = ____________ V

      b. Open circuit? Vout = ____________ V

Table 2-1: Calculated and simulated values in a voltage divider circuit

	R2 Values					
	1 kΩ	2 kΩ	3.3 kΩ	4.7 kΩ	5.6 kΩ	10 kΩ
Calculated output voltage (V)						
Simulated output voltage (V)						
% Error in output voltage						
Calculated voltage gain						
Simulated voltage gain						
% Error in output voltage						

2. Using the same circuit in Figure 2-1, add a load resistor RL in parallel to R2 and use the values V1 of 10 V, R1 and R2 both of 2 kΩ and RL of 1 kΩ, 2 kΩ, 3.3 kΩ, 4.7 kΩ, 5.6 kΩ, and 10 kΩ:

   2.1. Simulate this loaded voltage divider circuit in OrCad/PSpice and measure the output voltage for each value of RL. Compute the voltage gain and record these simulated values in Table 2-2. Also, calculate if there is an error.

Table 2-2: Calculated and simulated values in a loaded voltage divider circuit

	RL Values					
	1 kΩ	2 kΩ	3.3 kΩ	4.7 kΩ	5.6 kΩ	10 kΩ
Calculated output voltage (V)						
Simulated output voltage (V)						
% Error in output voltage						
Calculated voltage gain						
Simulated voltage gain						
% Error in output voltage						

3. For the current divider circuit in Figure 2-2 and with an input current I1 of 50mA, a fixed R1 resistor of 4.7 kΩ and a load resistor R2 of 1 kΩ, 2 kΩ, 3.3 kΩ, 4.7 kΩ, 5.6 kΩ, and 10 kΩ:

   3.1. Compute the current gain of the current divider with two resistors and the output current I2 for each of the values of R2 and enter the results in the appropriate rows of Table 2-3.

   3.2. Simulate the current divider circuit in OrCad/PSpice and measure the output current I2 for each of the values of R2 and enter the results in the appropriate rows of Table 2-3.

   3.3. What will the output current be if R2 is replaced by a:

   a. Short circuit? I2 = ____________ mA

   b. Open circuit? I2 = ____________ mA

Table 2-3: Calculated and simulated values comparison in a current divider circuit

	R2 Values					
	1 kΩ	2 kΩ	3.3 kΩ	4.7 kΩ	5.6 kΩ	10 kΩ
Calculated output current (mA)						
Simulated output current (mA)						
% Error in output current						
Calculated current gain						
Simulated current gain						
& error in current gain						

4. Derive the formula to find the voltage across the terminals AB of a Wheatstone Bridge as shown in Figure 2-3 and enter this in the space below. Then calculate the voltages and currents in each component and enter them in Table 2-4.

5. If there is a short circuit placed between AB of the Wheatstone Bridge shown in Figure 2-3, derive the formula to find the current across the terminals AB and enter this in the space below. Then calculate the voltages and currents in each component and enter them in Table 2-4.

6. Use OrCAD/PSpice (or NI MultiSim) to simulate the circuit in Figure 2-3 in the conditions of 4 and 5 (open circuit voltage and short circuit current) and to determine the various currents and voltages as indicated in the Table 2-4. Enter these in Table 2-4 under the 'simulated' columns. Attach your OrCAD (or MultiSim) circuit diagrams including the bias point information from PSpice (or NI MultiSim).

Table 2-4: Wheatstone bridge open and short circuit data – calculated and simulated values

Variable	Calculated Open Circuit condition	Calculated Short Circuit condition	Simulated Open Circuit condition	Simulated Short Circuit condition
I_{V1}				
I_{R1}				
I_{R2}				
I_{R3}				
I_{R4}				
I_{AB}				
V_{R1}				
V_{R2}				
V_{R3}				
V_{R4}				
V_{R5}				
V_{AB}				

2.4 Lab Tasks

2.4.1 Voltage Divider:

1. Connect the circuit as shown in Figure 2-1. Using the +25V power supply from the Agilent power supply unit to provide V1 = 10V and measure the voltages across each resistor with R1 of 10 kΩ. Use R2 of 1 kΩ, 2 kΩ, 3.3 kΩ, 4.7 kΩ, 5.6 kΩ, and 10 kΩ. Measure the output voltages for each step. Record your readings in table similar to Table 2-5 and also enter your calculated values from the Prelab.

Table 2-5: (SAMPLE) Calculated and measured values in a voltage divider

	R2 Values					
	1 kΩ	2 kΩ	3.3 kΩ	4.7 kΩ	5.6 kΩ	10 kΩ
Calculated output voltage (V)						
Measured output voltage (V)						
% Error						

2. Using the same circuit in Figure 2-1, add a load resistor RL in parallel to R2 and use the values V1 of 10 V, R1 and R2 both of 2 kΩ and RL of 1 kΩ, 2 kΩ, 3.3 kΩ, 4.7 kΩ, 5.6 kΩ, and 10 kΩ. Measure the output voltages for each step. Record your readings in a table similar to Table 2-6 and also enter your calculated values from the Prelab.

Table 2-6: (SAMPLE) Calculated and measured values in a loaded voltage divider circuit

	RL Values					
	1 kΩ	2 kΩ	3.3 kΩ	4.7 kΩ	5.6 kΩ	10 kΩ
Calculated output voltage (V)						
Simulated output voltage (V)						
% Error in output voltage						
Calculated voltage gain						
Simulated voltage gain						
% Error in output voltage						

3. Obtain two 10 MΩ resistors from the components kit. Designate one of the resistors as R1 and the other as R2.

   3.1. Measure the resistor values using the DMM as an ohmmeter. Be sure to keep track of which resistor corresponds to which value measured.

      a. R1= _____MΩ,

      b. R2= _____MΩ.

   3.2. Build the voltage divider circuit in Figure 2-1 using the 10 MΩ resistors as R1 and R2 and set the power supply to 10V.

   3.3. Using the DMM, measure the voltage across resistor R1, and then across resistor R2. Record these values in a table similar to Table 2-7.

Table 2-7: (SAMPLE) Calculated and simulated values comparison in a voltage divider

Resistor	Nominal value	Measured value	% Error	Remarks
R1				
R2				
VR1				
VR2				

3.4. Comment on the accuracy of the voltage measurements made (consider the internal resistance of the voltmeter). Consider whether your theoretical values for the voltages across R1 and R2 should include the effect of shunt resistance Rm (see Figure 2-1).

2.4.2 Current Divider
(please read very carefully and refer to the Agilent Power Supply User Manual):

4. Connect the circuit as shown in Figure 2-2 and measure currents in the source, branch R1 and branch R2. Use R1 of 4.7 kΩ and R2 of 1 kΩ, 2 kΩ, 3.3 kΩ, 4.7 kΩ, 5.6 kΩ and 10 kΩ. Please note the following steps:

4.1. Use the +25V connection on the Agilent power supply to provide I1 of 5 mA.

4.2. To do this set the unit to provide Constant Current (CC) as described in the User Manual (pages 38 and 39), which is available on the course WebCT site. Specifically:

4.3. set the Current Limit to 0.005 A and

4.4. set the Voltage Limit to 12 V.

NOTE: When using the power supply in Constant Current mode be very careful to set the Current Limit correctly, and to always disable the Power Supply Output when connecting and disconnecting the elements of the circuit including the ammeter.

5. Measure all currents for each value of R2. Record these in a table similar to Table 2-8:

Table 2-8: (SAMPLE) Calculated and simulated values comparison in a current divider

	R2 Values					
	1 kΩ	2 kΩ	3.3 kΩ	4.7 kΩ	5.6 kΩ	10 kΩ
Measured source current (A)						
Measured output current (A)						
Calculated output current (A)						
% Error						

6. Comment on and explain any unexpected readings.

2.4.3 Wheatstone Bridge

7. Build the circuit in Figure 2-3 using a supply voltage of V1 = 10 V, and resistor values of R1 = 1 kΩ, R3 = 2 kΩ, R4 = 3.3 kΩ and for R2 use the 1 kΩ variable resistor on the XK 150. As you add the resistors, measure and record the actual resistor values used with DMM.

    7.1. Before powering up the circuit, measure and record the value of resistor R1, R3 and R4 with the DMM Ohmmeter.

    7.2. Connect the DMM as an ammeter between A and B in Figure 2-3.

    7.3. Power up the circuit and adjust R2 to get zero current between A and B.

    7.4. Depower the circuit and without changing it, measure and record the resistance of R2 as it was set for zero current.

    7.5. Replace R3 with a 4.7 kΩ resistor.

    7.6. Repeat steps 7.1 – 7.4

8. Are you able to get zero current between A and B? If not, determine a better value for R3 and replace it with that resistor. Repeat steps 7.1 – 7.4.

2.4.4 Basic Circuit Analysis Techniques

9. Replace resistors to get the same circuit as shown in Figure 2-3. As you build it, measure and record the actual resistor values used with DMM.

    Note: As part of your Lab Report, you will need to recalculate the current and voltage values (using Matlab) and the error calculations for the actual resistor values and enter these values in a table similar to Table 2-9 under the column 'Calculated'.

    9.1. Connect the negative voltmeter lead of the Agilent DMM to the negative V1 terminal and measure the voltages at each node of the circuit the circuit (i.e. the V1 + terminal, A and B). Enter these readings in under the column 'measured'. For error calculations, you need to measure the actual resistor values and will recalculate the current and voltage values using Matlab and enter these values in a table similar to Table 2-9 under the column 'Calculated'.

Table 2-9: (SAMPLE) Calculated and measured voltages in open circuit condition

Variable	Measured	Calculated	% Error
V_{1+}	[redacted]	[redacted]	[redacted]
V_A	[redacted]	[redacted]	[redacted]
V_B	[redacted]	[redacted]	[redacted]

    9.2. Replace the open circuit between A and B with the Agilent DMM Ammeter to measure the short circuit current. Record this current along with the voltages as in the previous step in a table similar to Table 2-10. You will repeat the calculation of the expect values and error.

NOTE: this method of measuring the open circuit voltage and short circuit current is analogous to , to Example 2.5 of the text, and to the Thévenin and Norton theorems which we will learn later in the course.

Table 2-10: (SAMPLE) Calculated and measured voltages in short circuit condition

Variable	Measured	Calculated	% Error
V_{V1+}	[redacted]	[redacted]	[redacted]
V_A	[redacted]	[redacted]	[redacted]
V_B	[redacted]	[redacted]	[redacted]
I_{AB}	[redacted]	[redacted]	[redacted]

9.3. Add a 1 kΩ resistor in series with the Ammeter in the central branch. Repeat the voltage and current measurements of the previous step and record them in another table similar to Table 2-10. You will repeat the calculation of the expect values and error.

NOTE: this method of using a reference (usually ground) voltage to compare other voltages is analogous to the “Node-voltage” method of solving circuits.

9.4. Compare the values for the open and short circuit tests to those of the Prelab. You will recompute the calculated values for your Lab Report, but if these are very different from those of the Prelab you should check your results and work.

9.5. **Bonus Step *(to be completed only after completion of other tasks and clean-up of the lab bench)***: Using the hand held DMM, determine how to measure the resistance of the Agilent DMM as an ammeter and as a voltmeter. Do so, then reverse them and measure the hand held DMM using the Agilent DMM. ***Note this should not require any additional components except for the meters and probes/cables.***

2.4.5 What should be in the report?

(Follow the sample report format as given in the Introduction section of this manual. Include the following in appropriate topics)

1. For each step in the Lab Task, present the any and all relevant Prelab derivations, calculations and simulations as well as the measured results, and compare and comment on the results.

2. In your comments and analysis of the lab tasks, be sure to:

   2.1. Discuss the effect of loading the circuit and the practical implications this would have in your design of a voltage divider.

   2.2. Explain the results of using the 1 MΩ resistors in the voltage divider.

   2.3. Compare measurements made with the current divider. Include your comments and tables to support your remarks on the accuracy of the measurements in relation to the component tolerances.

   2.4. For the Wheatstone Bridge, determine and comment on the accuracy of the method.

   2.5. For the Basic Circuit Analysis Techniques section, create tables similar to Table 2-9 and Table 2-10 (or combine them into one table) and re-compute and re-simulate the results using the measured resistance values in place of those computed and simulated in the prelab. Present these with the measured results for the voltages and currents. Comment on the results.

   2.6. Using your results of steps 9.1 and 9.2 in Basic Circuit Analysis Techniques section, construct a model of the circuit as done in Example 2.9 of the text book, showing the graphical representation of the data and the circuit model. Show whether or not the data from 9.3 fits this model.

   2.7. Using your results from 9.3 in Basic Circuit Analysis Techniques section, determine the currents in each branch of the circuit using the measured voltages and Ohm's Law.

      a. Does your calculation for the current in the central branch (the 1 kΩ resistor in series with the ammeter) agree with the calculated value of current?

      b. Check all your currents determined from the measured voltages by writing Kirchoff's Current Law equations for each node and determine the error in these results. Comment on the accuracy.

   2.8. If you completed the bonus step in 9.5, compare the measured resistances of the DMM to the effects and errors you observed in the voltage divider and current divider circuits.

3. Conclusion.