Circuit Loading and the OP AMP

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Purpose:

Examine circuit loading at an interface and one way an OP AMP can be used in an interface circuit.

Equipment Required:

- 1 - Agilent 33401A Digital Multimeter
- 1 - Analog Multimeter
- 1 - Agilent E3631A power supply
- 1 - Protoboard
- 2 - 180-kΩ Resistors
- 1 - 741 OP AMP

Prelab:

Read Section 4-7, Interface Design with OP AMPs in the text*.

Loading

1. Loading
   a. Consider the circuit of Fig. 1. Suppose you wish to measure the output, V_x. From voltage division, you expect to read 2.5 V. You carefully wire up the circuit and, with an analog voltmeter, measure a much lower voltage! What happened? The problem is one of "loading." This happens to some degree in ALL measurements. Adding test equipment to the circuit changes the circuit-under-test. In previous lab exercises this has gone unnoticed because the effect is very small with a digital meter. Loading is much more pronounced with an analog meter. This lab examines why this occurs and how an OP AMP can be used to correct the problem.

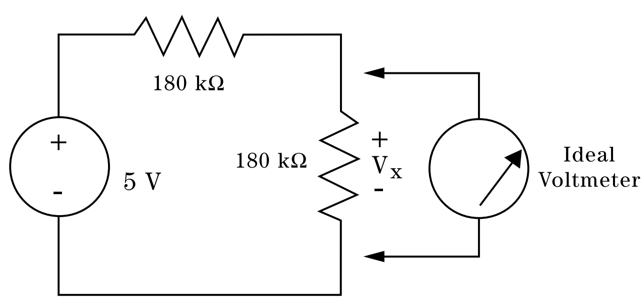

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Figure 1

   b. Use the voltage divider equation to show that for the circuit of Fig. 1 the anticipated value of V_x is indeed 2.5 V. Figure 2 shows a model of the analog voltmeter (AMM). The meter movement is actually an ammeter, with a resistance very near zero. It is made to act like a voltmeter by inserting a carefully chosen series resistor. For the circuit of Fig. 1 compute the anticipated value of V_x, if measured using the non-ideal voltmeter. Assume the meter resistance plus the scale resistor equals 50 kΩ .

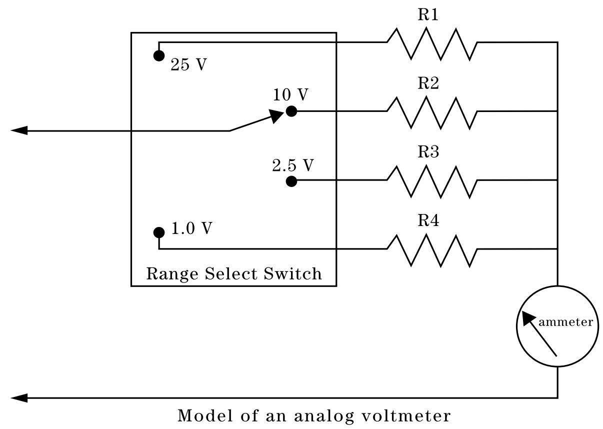

Figure 2

c. In this exercise you will build an interface circuit using an OP AMP follower (or buffer amp), which substantially improves voltage measurements using the AMM (analog multimeter). In your lab journal, explain why the voltage read by the buffered analog voltmeter in Fig. 3 will be 2.5 V.

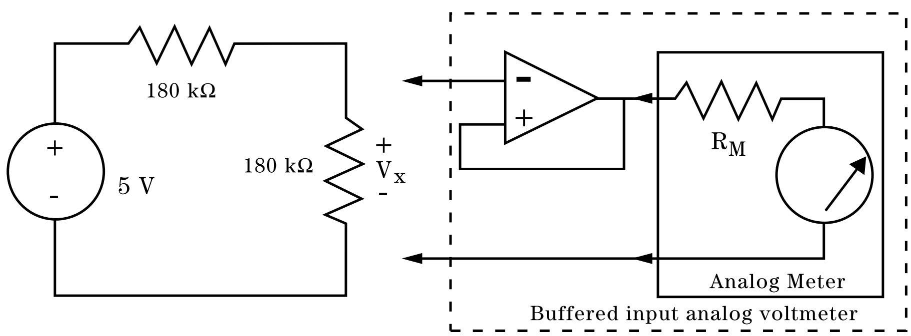

Figure 3

Procedure:

1. Prepare the power supplies

   a. Configure the power supplies to provide $\pm V_{CC}$. Refer to Fig. 1 in Lab VI as a guide. Adjust the output of the supplies so that $\pm V_{CC}$ is ±15 V.

   b. Set the out put of the third variable supply to 5V. Use the DMM to measure the actual resistance of the two 180–kΩ resistors. Record these data in your lab journal.

   c. With the power supply output turned off, connect a wire from each supply and the common ground to your protoboard. To reduce the risk of connecting the wrong voltage level to your OP AMP, label each point on the protoboard with its appropriate voltage: V_{5V}, $+V_{CC}$, $-V_{CC}$, GND. Turn the output on and verify that the voltage at each of these points match your labels. Measure and record the actual voltages in your lab journal. Turn the output off.

2. Loading caused by test instruments

a. Connect the circuit shown in Fig. 1. Measure the output, V_x, with the analog voltmeter. Does it indicate the predicted voltage? It will not because the analog meter draws current to deflect the needle, thus "loading" the voltage divider circuit.

b. Figure 4 represents an equivalent circuit that occurs when an attempt is made to measure V_x with an AMM. In Fig. 4, R_M is the input resistance of the AMM. This equivalent circuit will be used to develop a method of characterizing the input resistance of the analog meter on each of the available ranges.

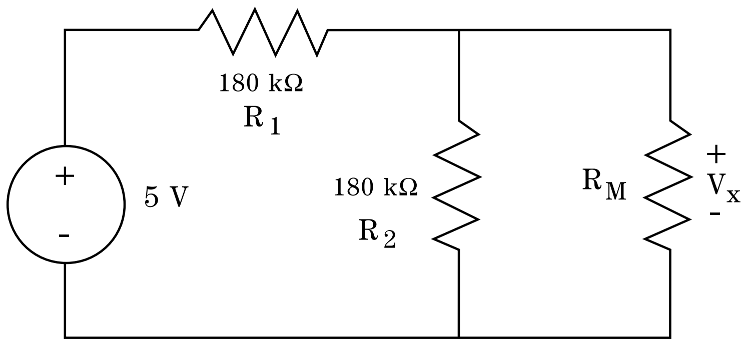

Figure 4

Make a table in your lab journal for recording data. The table should have eight columns, labeled Range, AMM Voltage, DMM Voltage, Apparent Resistance R_A, Meter Input Resistance R_M, Buffered AMM Voltage, Buffered DMM Voltage and Error. Connect a DMM to the same points to which the AMM is connected. The DMM will provide a reliable value of the actual voltage at the interface, regardless of the range used on the AMM. Select the most sensitive voltage range available on the AMM. In your table, record the range selected on the AMM, the voltage indicated by the DMM, and your best estimate of the voltage displayed by the analog meter. Make this measurement for each of the voltage ranges available on the AMM.

c. With the AMM attached to the circuit the voltage V_x is lower than expected. Using the voltage divider equation on these results leads to an "apparent" value of R_2 which is much lower than the expected 180 kΩ . This apparent resistance R_A is the parallel combination of R_2 and R_M. For each range on the AMM, use the voltage indicated by the DMM and the voltage divider equation to compute the apparent resistance R_A. Record this value in the column labeled "apparent resistance".

d. Compute the input resistance R_M of the AMM on each range. The procedure is to use the computed value R_A, and the measured value of R_2, to calculate what value of R_M is required to produce the apparent resistance.

$$\frac{1}{R_A} = \frac{1}{R_2} + \frac{1}{R_M}$$

3. A buffered analog voltmeter

a) Insert the OP AMP follower as an interface circuit between the source circuit and the AMM as shown in Fig. 3.

b) Set the AMM to the highest range available, then turn on the power supplies. Collect data to fill in the last column of your table. *Caution; do not "peg" the analog meter. If you select a range on the AMM that is so sensitive the needle goes past* *the top end of the scale, it could damage the meter*. Except for ranges more sensitive than 2.5 V_{DC} full scale, repeat the measurement at each of the different ranges available. For voltage ranges more sensitive than 2.5 V_{DC} full scale, write "pegged" in that cell of your table.

c) Compute the error between the unbuffered and buffered voltage as measured with the DMM for each range of the AMM.

Conclusion:

A measure of the quality of an analog voltmeter is the amount of current required to produce full-scale deflection of the needle. Use your data to compute the current required to produce full-scale deflection on this particular meter movement. In effect, most AMMs specify this value on the face of the meter. Expressed in Ω /V, this specification provides a way to calculate meter input resistance on any given range. For example, if the meter has the specification 10,000 Ω /V, then the meter input resistance on the 10 V range is 100 kΩ . If the Ω /V specification is present on the AMM you used for this exercise, calculate the meter input resistance on each VDC range. For each voltage range compute the percent error between the specified input resistance and the meter input resistance R_M computed in Procedure 2d.

Assume you needed to measure the output of a voltage divider consisting of two equal-value resistors. The input to the voltage divider network is known to be 10 V_{DC}. You are told that a measurement error of 10% is acceptable. How large could the resistances in the voltage divider be to still make an "acceptable" measurement of the output using this particular AMM?

Your data should indicate that the performance of the analog voltmeter is improved by "buffering" the input. Provide some reasons why AMM manufacturers do not buffer their AMMs.

Does your data make it possible to estimate the input resistance of the OP AMP? Suggest a method that could be used to determine the input resistance of an OP AMP.

* Roland E. Thomas and Albert J. Rosa, The Analysis and Design of Linear Circuits, Prentice Hall, (New Jersey, 1994)