

Circuit Loading and the Analog Computer

Purpose

Examine circuit loading at an interface and one way an op amp can be used in an interface circuit.

Equipment Required

2 - Digital Multimeters
 1 - Triple power supply
 1 - Protoboard
 1 - $1\text{M}\Omega$ Resistor
 1 - 741 op amp
 Various resistors for design problem

Prelab

1. Reading

Read Chapter 16 of Faissler, Digital Multimeters.

2. Circuit Loading

In the lab one day, you set out to confirm that V_{out} in Figure 1 is really 5V. It certainly should be, you reason, since there is an open circuit at the interface and therefore no current flows through (nor voltage drops across) the $1\text{M}\Omega$ resistor. You carefully wire up the circuit and, with a digital multimeter (DMM) configured to measure voltage, you measure a somewhat lower voltage! What happened? The problem is one of "loading." This happens to some degree in all measurements—adding test equipment to the circuit necessarily changes the circuit under test. In previous lab exercises this has probably gone unnoticed because the effect is usually small. This lab examines why this occurs and how an op amp can be used to minimize the problem.

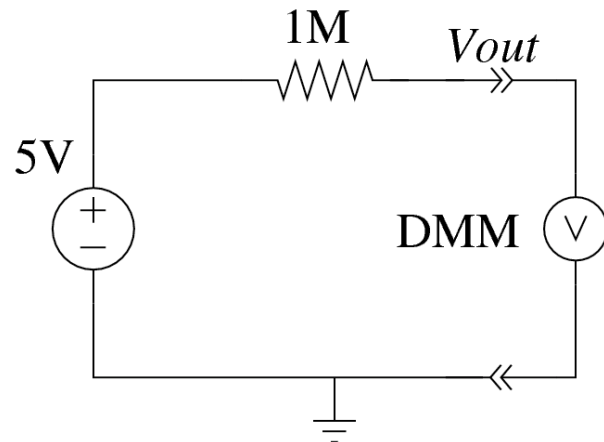


Figure 1

- a. An ideal voltmeter (symbolized by the circled "V" in figure 2a) would have zero current regardless of the voltage applied across the terminals. The DMM (figure

2b) can be modeled as an ideal voltmeter in parallel with a resistor, R_m . If $R_m = 5\text{M}\Omega$, what would the DMM report for the output voltage of the circuit in Figure 1?

- b. In this exercise you will build an interface circuit using an op amp follower (or buffer amp), which substantially reduces loading on the circuit under test. In your lab journal, explain for an ideal op amp why the voltage read by the buffered voltmeter in Figure 3 will be 5V, regardless of the value of R_m . Also explain how this result would change if the input resistance of the op amp is taken into account (the VCVS or Dependent Source model of the op amp).

Procedure

1. Prepare the test equipment

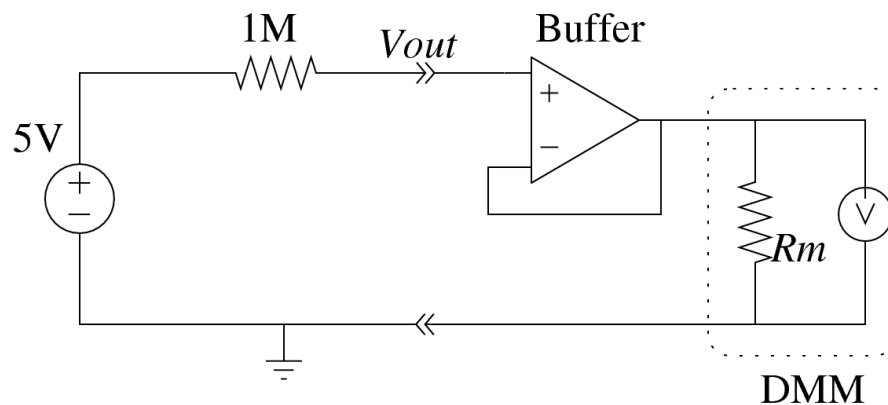
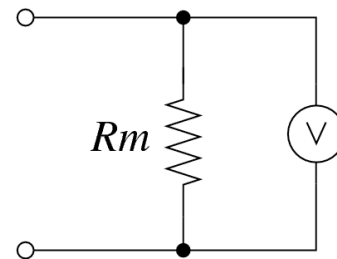


Figure 3

- Use the benchtop DMM to perform voltage measurements. From now on, we will refer to this as the *voltmeter*. Record the brand name and model in your lab journal.
- Use the other DMM to measure the resistance, R_m , of the voltmeter. Please note that the results may change if the voltmeter changes its range. Therefore, select a voltage range that is appropriate for 0-15V, and leave it set that way.
- Accurately measure the output of the 5V supply with the voltmeter and the actual resistance of the $1\text{M}\Omega$ resistor with the handheld DMM. Record these data in your lab journal.



(a) Ideal voltmeter



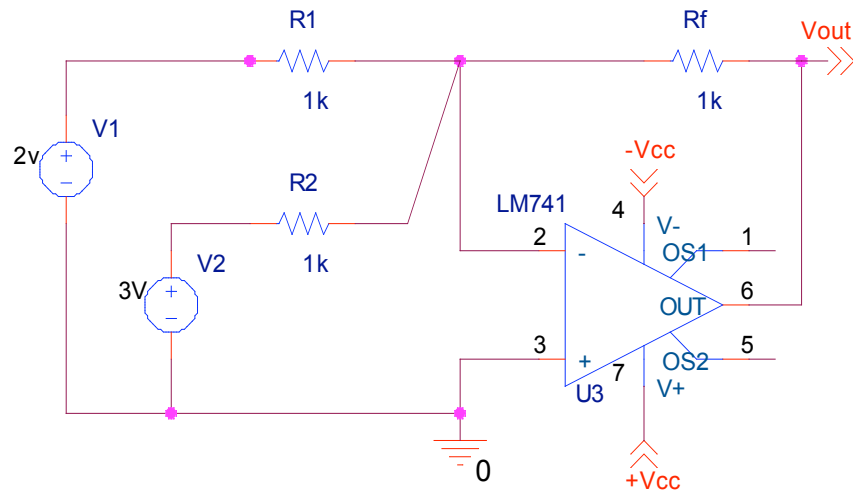
(b) Real voltmeter

Figure 2

2. Loading caused by Test Instruments

- a. Use the results of c & d to predict the voltage that you will measure by hooking the voltmeter directly to the test circuit, as in Figure 1. Now make the measurement and record your result.
- b. Construct the buffered voltmeter circuit in Figure 3. Configure the power supplies to provide $\pm V_{CC}$ of $\pm 15V$ to power the LM741 op amp. Refer to Fig. 1 in Lab 7 as a guide. Ensure that the 5V supply shares a common ground with the $\pm 15V$ supply.
- c. Measure the voltage using the buffered voltmeter, and record the result.

3. In part 2 an op amp circuit was built that provides a gain of 1. . . not a very interesting function, but a function nevertheless. In this part, we'll use the op amp summer circuit to build an analog computer that implements the function $y=mx+b$.



The output of an op amp summing junction is given by the equation:

$$v_{out} = K_1 v_1 + K_2 v_2$$

The proportionality constants are:

$$K_1 = \frac{-R_f}{R_1} = -1 \quad K_2 = \frac{-R_f}{R_2} = -1$$

For the circuit above the voltage transfer function T_V is:

$$K_1 v_1 + K_2 v_2 = -2V - 3V = -5V$$

Build an analog computer that performs the function.

$$v_{out} = -2v_1 - 3v_2$$

Collect data sufficient to demonstrate that your computer is linear to 3 significant figures for a range of values for v_1 and v_2 that places v_{out} in all four quadrants. [*Hint*: You may find it helpful to construct voltage dividers between the $\pm V_{cc}$ rails to create the input voltages for testing. Remember that the actual input voltages when hooked to the summer may differ from the open circuit voltages of your voltage dividers.] Ask your instructor for accolades and a signature.

Conclusion

You began by measuring the input resistance (also called input impedance) of the benchtop DMM. This parameter can be used to compute the loading error introduced when measuring any high resistance circuit. It is so important, in fact, that DMM manufacturers usually give the input resistance in the manual or on the device itself. Look up this parameter in the manual for the DMM you used in this exercise and discuss whether your data agrees with this value.

Explain the results of measuring the 5V supply through the $1M\Omega$ resistor. Did the buffer improve the voltage measurement? Does the LM741 behave as an ideal op amp? Based on your measurements, calculate R_I , the input resistance of the op amp.