Lab 2: Basic Instrumentation

Analog Integrated Circuit Design Laboratory

December 18, 2000

The objectives of this lab are as follows:

- To familiarize yourself with the use of your data acquisition system and its MATLAB based command language.
- To supplement your data acquisition system with several instruments not available on your bench: a voltage buffer, a current-to-voltage converter, and a voltage-to-current converter. The latter two allow you to measure and source currents using the voltage-mode A/D and D/A of the acquisition system.
- To understand the capabilities and limitations of your data acquisition system.
- Learn how to read device data sheets and determine which device parameters might impose limits on the operation of your circuit.
- Compare the experimentally obtained results with those from SPICE simulations

1 Prelab

Reminder: Prelab questions are due at the time scheduled for the laboratory in your section, and need to be prepared individually. It is recommended that your solutions are no more than one sheet long, plus printouts of computer generated output and supporting files in case it is so requested.

All questions refer to ideal meters, sources, and devices unless otherwise stated.

- Make the correct choices in the following statements:
  1. A voltmeter has (zero/infinite) impedance and should be connected in (series/parallel) with the circuit being tested.
  2. An ammeter has (zero/infinite) impedance and should be connected in (series/parallel) with the circuit being tested.
- Using the symbols in Figure 1, draw the test setups you would use to measure:
  1. the current I through a diode as a function of voltage V;

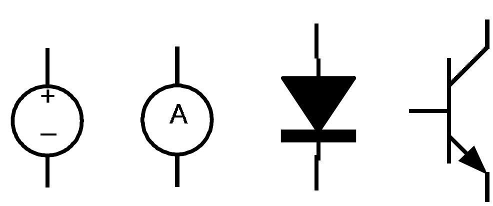

Figure 1: Circuit Elements: Voltage Source, Current Meter (Ammeter), Diode, and npn Bipolar Transistor.

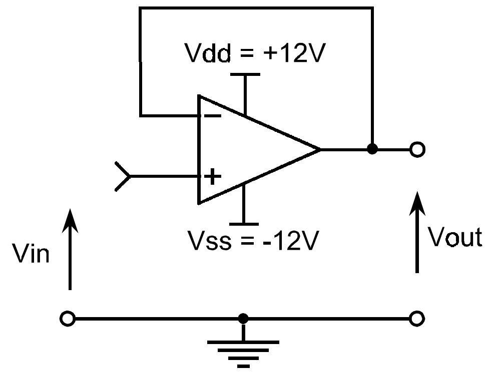

Figure 2: Voltage Buffer.

2. the current I_c at the collector of a npn bipolar transistor as a function of collector-emittor voltage V_{ce}, for constant base-emittor voltage V_{be}.

Don't forget to ground your circuit!

- Given the circuit figures you have drawn, qualitatively sketch:

1. The current through a diode as a function of voltage.
2. The current I_c through the npn bipolar transistor as a function of V_{ce}.

2 Experiments

All questions in this and subsequent sections should be answered in your group's laboratory report.

2.1 Voltage Buffer

For some of your measurements you will need to add a high input impedance voltage buffer to measure the voltage on some node in your circuit. This is how you will be able to isolate a high impedance node in your circuits from the relative low impedance nodes of the oscilloscope or your data acquisition system and thus make sure that the measuring instrumentation does not affect the experiment. A simple buffer which you might use is illustrated in Figure 2.

- What problem does this buffer alleviate for DC measurements?
- What problem does it remedy for AC measurements?

Illustrate your answer to those questions by considering the values if the input impedance R_{in} and input capacitance C_{in} of the oscilloscope probes.

2.2 Current to Voltage Converter (Transresistance Amplifier)

For most of our experiments, we will need to measure both voltages and currents. Since our data acquisition system measures only voltages, we must build a circuit whose input current can be easily calculated by measuring an output voltage. We will use the following op-amp circuit in Figure 3 (*Transresistance Amplifier*, or *Transimpedance Amplifier*) to accomplish this.

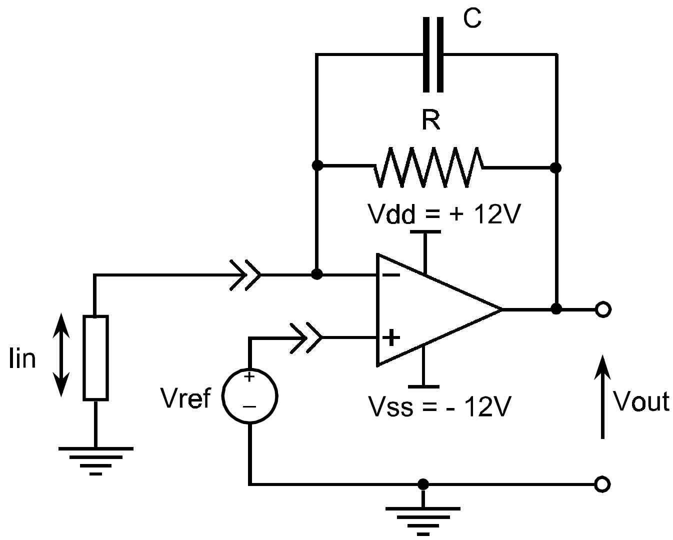

Figure 3: Current to Voltage Converter (to Implement an Ammeter).

You are provided with a quad operational amplifier, resistors of different values, variable potentiometers and a capacitor. In addition you have diodes and bipolar transistors, which you don't need for this particular circuit. The data sheet for the quad opamp, and some other devices, will be available in the laboratory.

The capacitor is intended to reduce the gain of your transresistance amplifier at high frequencies. This will make data acquisition of the D.C. signals easier (reduce noise and the possibility of oscillation).

Answer the following questions:

- What is the relationship between the output voltage and the input current, in terms of V_{out}, V_{ref}, I_{in}, and R ?
- What is the voltage range of V_{out} ?
- What is the voltage range which the A/D can measure?
- What is the voltage range for the power supplies of the opamp?
- Assuming you could have resistors of any size, what op-amp specifications (refer to data sheet) limit the maximum and minimum currents you can measure?
- Given five resistors (10KΩ, 100KΩ, 1MΩ, 10MΩ, 100MΩ), what is the current range which you can measure?
- Given a capacitor of size $C = 1nF$, What is the time constant of your converter? Will this affect your measurements? (See, e.g., Horowitz and Hill, pp.22-25).

2.3 Diode Characterization and Simulation

Build the transresistance amplifier and use it to measure the I-V characteristics of a diode. Apply a voltage across the diode (1N4148) and measure the current flowing through it. Use the D/A as your voltage source and the A/D to measure V_{out}. Make sure you don't apply a voltage higher than what it should be. Make two sets of measurements. One in the micro-ampere ($1\mu A = 10^{-6}A$) current range and one in the nano-ampere ($1nA = 10^{-9}$A) range. Convert the voltage measurements into estimates of current using the different values of R.

- Sketch the diagram of the circuit you used for the measurements, including the circuit of the transresistance amplifier.

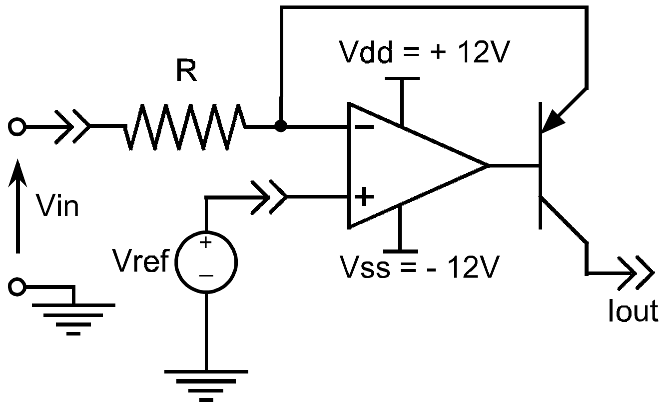

Figure 4: Voltage to Current Converter (to Source a Current).

- Using Matlab, plot current vs. voltage. On the plot, indicate the values of R used for different parts of the plot.
- Print the Matlab code you wrote to take, convert, and plot the measurements.
- Save all your data on your floppy disk. Record, for future reference, the name of the files, what the D/A and A/D columns of data represent, which values of R were used, etc.

Create a TSpice file to simulate current vs. voltage across a diode. Run the DC analysis on it and plot the voltage vs. current. Using the spice model for the 1N4148 diode, do your theoretical and experimental curves match? If not, why?

- Print the TSpice input netlist file.
- Save all your data on your floppy disk.
- Plot voltage vs. current from the TSpice simulated output. (Use W-Edit, Matlab, or whichever graphing program you are comfortable with.)

2.4 Voltage to Current Converter (Transconductance Amplifier)

We will also need to apply (or “source")) currents for certain experiments where an input current is needed. Since our data acquisition system applies only voltages, we must build a circuit that receives an input voltage, and converts that voltage into an output current. We will use the following op-amp circuit in Figure 4 (a *Transconductance Amplifier*) to accomplish this. We will assume that the pnp bipolar transistor in the feedback loop has a negligible base current ($\beta = \infty$, and $I_e = I_c$).

Answer the following questions:

- What is the relationship between the input voltage and the output current, in terms of V_{in}, V_{ref}, I_{out}, and R?
- Given an opamp with infinite voltage gain, what is the input impedance R_{in} of your circuit? What is the output impedance R_{out}?
- What is the allowable voltage range for V_{in}?
- What is the allowable range for the output voltage V_{out} on the collector at which I_{out} is received?
- Given five resistors (10KΩ, 100KΩ, 1MΩ, 10MΩ, 100MΩ), what is the current range which you can apply?

Bonus questions (for extra credit, 10% per question):

- Extend the circuit to allow for output currents of either polarity (positive as well as negative).
- Come up with a circuit that implements the transconductance amplifier without using a transistor, but using resistors instead. Hint: you may use two opamps.

3 Next Week

Laboratory 3: Above threshold MOS model parameter extraction.