# EE 105: Microelectronic Devices & Circuits

# General Lab Instruction Manual

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## 1.0 EE105 Laboratory Introduction

### 1.1. Introduction

The EE 105 laboratory is an integral and important component of the course. The laboratory has three basic objectives:

   (1)   Reinforce concepts from the lecture.

   (2)   Strengthen your ability to actually build and make measurements on real circuits.

   (3)   Provide experience in actual circuit design (in addition to analysis).

The first several labs will consist of structured experiments, including constrained design problems. Towards the end of the term, the labs will entail unconstrained *designs*. In particular, Lab 5 will involve both design and physical implementation of an analog transistor amplifier. Lab 6 entails the design of a mixed analog/digital circuit with a complexity on par with that seen in actual industry practice.

This handout provides you with general information on lab protocol and on the components and equipment common to most electronic labs. The equipment instruction manuals available in the lab or your lab TA should be consulted for more detailed information.

### 1.2. Lab Protocol

Each of the labs (except for the design Labs 5 and 6) consists of the following sections:

   (1)   *Preliminary Exercises*: This section introduces the lab and provides some of the needed background. It contains exercises that you must complete *before* entering the lab. Without the advanced preparation obtained by completing this pre-lab section, the actual lab will be very difficult to complete in the time allotted.

   (2)   *Results Sheet for Preliminary Exercises*: A sheet on which to record answers to the preliminary exercises. Note that not all of the required work will be entered on this sheet; some of the work, such as simulation plots or derivations, must be attached on separate sheets.

   (3)   *Laboratory Exercises*: This section gives the step-by-step procedure required to obtain data needed to answer various questions embedded within this section. Obtain all data during your lab section, and answer all questions to turn them in in at the beginning of the next lab section.

   (4)   *Results Sheet for Laboratory Exercises*: A sheet on which to record answers to the laboratory exercises. Note that not all of the required work goes on this sheet; some of the work, such as measured plots or derivations, should attach on separate sheets.

As you can probably deduce from the above, each lab requires that you follow a set procedure. The procedure is as follows:

   (1)   Come to the lab with (i) a completed *Results Sheet for Preliminary Exercises* and any additional required information for the lab to be done; and (ii) a completed *Results Sheet for Laboratory Exercises* and any additional required information for the previous lab. The *Preliminary Exercises Results Sheet* will be graded on the spot. If you anticipate that you will require information from your *Preliminary Exercises Results Sheet*, make a copy of the needed results (by either photocopying or writing the results down next to the specific

Pre-Lab questions in this lab manual).

(2) Complete the experimental section of the lab during the allotted time period, following the written procedure and taking data as needed.

(3) Outside of the lab, answer all questions in the Laboratory Exercises section of the lab, putting required answers on the *Laboratory Exercises Results Sheet*. (Note that your work and other required information, such as graphs and plots, must accompany the results sheet on separate sheets.) Have the results sheet and accompanying information ready to turn in for the next lab.

### *1.3. Laboratory Reports*

There is no specific format required for laboratory reports. They should contain the following information:

- Demonstration of all work.
- Derivations for all work.
- Properly labelled graphs.
  - Give every graph a title and number, and refer to these numbers in the report.
  - Label every axis, and specify (on the axis label) the relevant units (volts, Amperes, µsec/div, etc. ...)
  - For Bode plots, always plot frequency in Hz (not radians/sec) on a log (base 10) axis.
- Neatness counts; if it cannot be read, it will not be graded. The TA has to grade at least 30 labs each time and does not have time to decipher a messy report.

Laboratory reports must be turned in by the specified due date. No credit goes to late assignments.

If you are unable to complete your lab work during your scheduled session, you may work in the lab outside of other scheduled laboratory sessions. Use of the lab during a scheduled laboratory session is at the discretion of the TA.

In your lab reports, you will often need to compare two quantities. If so, give the value of each and give the percent difference between the two. If there are several values to compare (e.g., if you must compare values at several different bias voltages), then use a table. (Title and number your Tables.)

When asked a question like, "Why was the measured value different from the prediction?" explain why it could or might have been different, *even if you did not see a difference*. This is to help you think of possible sources of problems, even if you do not have a problem yourself.

Explain how all values were generated, i.e., were they assumed? measured? calculated? For calculations, include all equations used and explain how you obtained the values that go into the calculations (not necessary for fundamental constants). Also, explain your specific measurement technique if there is more than one way to do it, unless it is blatantly obvious.

Be sure to draw and label all circuits used in the lab. Label components (i.e., resistors, transistors, etc.) as well as any voltages, currents, etc., to which you refer in your report.

### 1.4. Lab Etiquette.

Cleanliness in the lab is important. Before leaving the lab, return all components (except non-functioning ones) to the storage bins. Also, clean the lab stations, making sure that they are free of wire cuttings, cut leads, etc., so that the next group can start with a clean station.

If you have any questions about anything—equipment, measurement procedures, etc.—ask the TA.

## 2.0 Laboratory Equipment

### 2.1. Proto-boards

A proto-board provides a fast way of hooking up circuits with no soldering. The proto-board consists of an array of interconnected holes. One makes connections by pushing leads into the holes. When using a proto-board, insert only straight wires of small diameter (a resistor lead or smaller) into the holes. In general, when building a proto-board circuit, a good rule is "the fewer the wires, the better." A circuit that looks like a rat's nest is likely to perform poorly and be a pain to debug.

Some of the labs (the design labs in particular) may require more than one testing session to complete. For these labs, it is advantageous to be able to keep your circuits constructed between testing sessions. For this purpose, you will receive a proto-board from your lab GSI during your first lab session. Note that you must return this proto-board prior to the final. If not returned before the final, you will receive a grade of "incomplete" for the course.

### 2.2. Oscilloscopes

*General.*

An oscilloscope is often the most useful piece of test equipment in the laboratory. It graphically displays time-varying voltage signals, most often to display voltages as a function of time.

Each of the stations in the EE 105 laboratory is equipped with an Agilent Technologies DSO5014A Digital Oscilloscope. These instruments provide on-screen markers to simplify the extraction of quantitative measurement data. While it can take a little time to get used to the digitizing instrument, you will likely find them easy to use after very little time.

You should already be familiar with the use of oscilloscopes from previous required courses (e.g., EE 16A/16B). To best familiarize yourself with the HP 54645A Digitizing Oscilloscope used in the EE 105 laboratory, browse through the "Getting Started Guide" usage booklet located near the oscilloscope.

*Some Helpful Pointers.*

The following usage pointers are helpful in insuring the most accurate circuit measurements in the EE 105 laboratory:

  i.   Use an oscilloscope probe whenever possible.

  ii.  Make sure to ground each probe.

  iii. Compensate the oscilloscope probe frequently.

iv.   Always know where the ground reference is located on the display.

v.    Use an external trigger whenever possible.

### 2.3. Digital Multimeters (DMM's)

*Voltage Measurements.*

A DMM measures both AC and DC voltages. The measurement procedure involves setting the DMM to the appropriate scale, selecting AC or DC volts, and connecting the probe between the two measurement points. If set to the wrong scale, the display will usually flash or give some other error indication.

Some points to keep in mind:

i.    The EE 105 DMM's will usually not load the circuit excessively, because they have an input impedance of 1 M$\Omega$ ± 20 k$\Omega$.

ii.   Make voltage measurements in parallel.

iii.  When reading AC volts, most meters will read true RMS only if the AC voltage is a sine wave. Some DMM's, usually marked "True RMS", will read the RMS voltage of arbitrary waveforms.

iv.   When reading AC volts, the DMM has a fairly low upper frequency limit, usually around300kHz or less. Consult the instruction manual for further details.

*Resistance Measurements.*

To measure resistance, set the DMM to ohms and select the appropriate scale. Connect the probes across the resistance to be measured. Some fine points:

i.    When taking data using the high resistance scale, make sure not to handle probe tips. Handling will add your skin resistance in parallel with the resistance to be measured, which will make the DMM read a value lower than the actual resistance.

ii.   Only certain scales will supply enough current to forward bias a diode. These are marked with a diode symbol.

iii.  Make resistance measurements *outside* of the circuit whenever possible. In-circuit measurements are often suspect.

*Current Measurements.*

When measuring current, it is necessary to set the DMM to mA and to select the appropriate scale. Note that the probes connect to a different set of jacks for current measurements. One must always remember to make current measurements in **SERIES, not parallel**. Connecting the meter across a voltage is likely to blow a fuse in the meter. The DMM can measure both AC and DC current. The same limitations as those on AC voltage measurements apply here.

## 2.4. Function Generators

Function generators produce various voltage waveforms. The most common are square, sine, and triangle. The HP 33120A Function Generators in the EE 105 lab have various triggering and gating functions. For our purposes, it will be sufficient to set the function generator to free run and use it as the trigger source for other instruments in the setup. To adjust the peak-to-peak voltage of the output signal, use the **AMPLITUDE** controls. The DC level of the signal is also adjustable via the **OFFSET** control. There are two adjustments to control the frequency: a large prominent knob, which controls the **FREQUENCY**, and a set of left and right arrow keys, which control the **RANGE**.

Of particular interest is utilizing the signal generator output as an external triggering source. Whenever possible, this signal directly connects to the external triggering input of the oscilloscope. On the Agilent scope, the "external triggering" signal can be connected to the port on the back of the oscilloscope labeled **EXT TRIG IN**, with the trigger source set to **EXT** in the **EDGE** menu within the **TRIGGER** options..

## 2.5. Capacitance Meters

In EE 105, we will only be concerned with simple capacitance meters. To use a capacitance meter:

  i.  Press the **C** button in the **FUNCTION** section to put the meter in capacitance measurement mode.

  ii. Set the measurement range to adjust automatically by pressing the **AUTO** button in the **LCR RANGE** section.

  iii. Press the **1kHZ** button to set the **TEST SIGNAL** frequency.

  iv. Using banana cables, connect one of the two leads of the capacitor to the **L POT** terminal and the other lead to the **H POT** terminal.

  v.  Observe and record the measured capacitance value from the display.

## 2.6. Electronic Components

*Resistors.*

The resistors used in the EE 105 lab are all 5%, 1/4 Watt carbon film resistors. "5%" refers to the resistance tolerance at room temperature (i.e., how far off from the stated value it may be), "1/4 Watt" refers to the maximum safe power dissipation, and "carbon film" refers to the resistor construction.

Color-coded bands indicate the value of a given resistor. Learning to read the color code will save you both grief and time in the lab (since you need not use the DMM to measure every time you need to know an approximate resistor value). The colors represent digits as indicated in Table I.

The actual value of the bands depends on their relative position. The right most band indicates tolerance. To read the color code, hold the resistor so the gold or silver tolerance band is on the right. (20% resistors do not have a gold or silver tolerance color band, although they do have a

space where the band would be). Now, reading from left to right, the first two color bands read directly as numerals. The third band (sometimes called the multiplier band) indicates the number of zeros to concatenate on the first two digits.

For example, if you read BROWN-GREEN-ORANGE-GOLD, the resistor would be of 5% tolerance and would have the value 15000, or 15 kΩ. In other words, "1", "5", and 3 zeros (for orange) following. BROWN-BLACK-YELLOW-SILVER would be a 10% 100000, or 100 kΩ resistor. In other words, "1", "0", and 4 zeros (for yellow) following.

TABLE I. Resistor Color Coding

| COLOR | Value |
|--------|-------|
| Black | 0 |
| Brown | 1 |
| Red | 2 |
| Orange | 3 |
| Yellow | 4 |
| Green | 5 |
| Blue | 6 |
| Violet | 7 |
| Gray | 8 |
| White | 9 |
| | Tolerance |
| Silver | 10% |
| Gold | 5% |

*Capacitors.*

The marking for capacitors is not nearly as standardized as that for resistors. The most common method is to mark the capacitor in picoFarads (pF = $10^{-12}$ Farads) using the same format as resistors, but with numerals instead of colors. For example, 101 indicates 100 pF ("1", "0", and 1 zero following), 100 would be 10 pF. Ask your TA for help in identifying capacitors.

We will use two basic types of capacitors in the EE 105 lab: ceramic and electrolytic. Ceramic caps are relatively temperature stable and have the advantage of being non-polarized; that is, they can charge to either polarity. Electrolytic capacitors, on the other hand, can only take on a specific DC voltage polarity. The polarity is marked on the outside of the capacitor. DO NOT hook up an electrolytic capacitor backwards, as this will almost certainly damage the capacitor. (It could possibly explode.) Electrolytic capacitors have the advantage of possessing a high capacitance per unit volume; i.e., the largest valued capacitors will often be electrolytic.
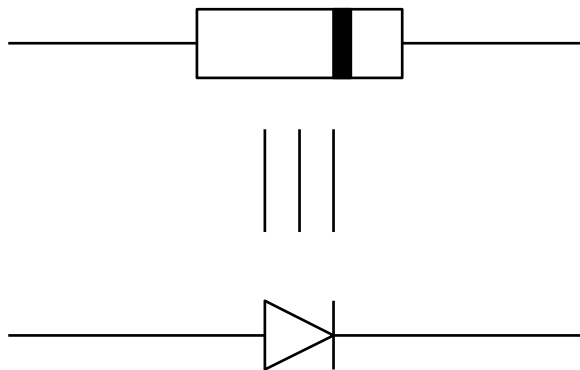
*Diodes/Transistors.*

Figure 1:   Correspondence between component markings and diode polarity.

The diodes used in the EE 105 lab are general-purpose signal diodes and are marked as shown in Fig. 1. Transistors do not have standard markings or pinouts. Ask your TA for help in identifying transistor pinouts.

*Integrated Circuits.*

The only integrated circuit used in the EE 105 lab is the 741 op amp. Different manufacturers make 741's with different prefixes. To name a few, uA741 indicates manufacture by Fairchild Semiconductor, NE741 indicates Signetics, and LM741 indicates National Semiconductor. Despite different manufacturers, all of these chips are functionally identical.

The 741 comes in an 8- or 14-pin DIP (Dual In-line Package). Fig. 2 presents its pinout. The pin numbers in any DIP package can be determined by first looking down on the IC such that the notch or dot is facing left. Pin 1 is now in the lower left hand corner. The pin numbers increase as you count counterclockwise around the IC starting at pin 1. Fig. 2 illustrates this in the example sketches of the 741.

More information on the actual 741 op amps to in the lab, as well as all of the other electronic components used, are in the data sheets presented in Appendix. Make sure you consult the data sheet whenever you are unsure of the pinout for a particular device.

### 3.0 Simulation Tools

As mentioned in lecture, EE 105 will utilize HSpice and LTSpice to simulate circuit performance at different periods of the course. HSpice is perhaps the more capable circuit simulator, but its GUI is less friendly as it requires spice netlist input. This means you will need to type out the netlist for a given circuit and insert device models and commands manually. While sometime perceived as more tedious than drawing a circuit schematic, you might be surprised how much faster you can work with a circuit this way once you familiarize yourself with spice netlist syntax. The first few exercise in this course will purposely use HSpice to make sure you experience spice netlist generation firsthand.

Later in the course, you will have a choice of using HSpice or LTSpice. LTSpice allows you to draw a circuit graphically, for which it then generates the spice netlist automatically. Some will find this faster and more convenient. Either spice version will be fine for the project labs (5 and 6).
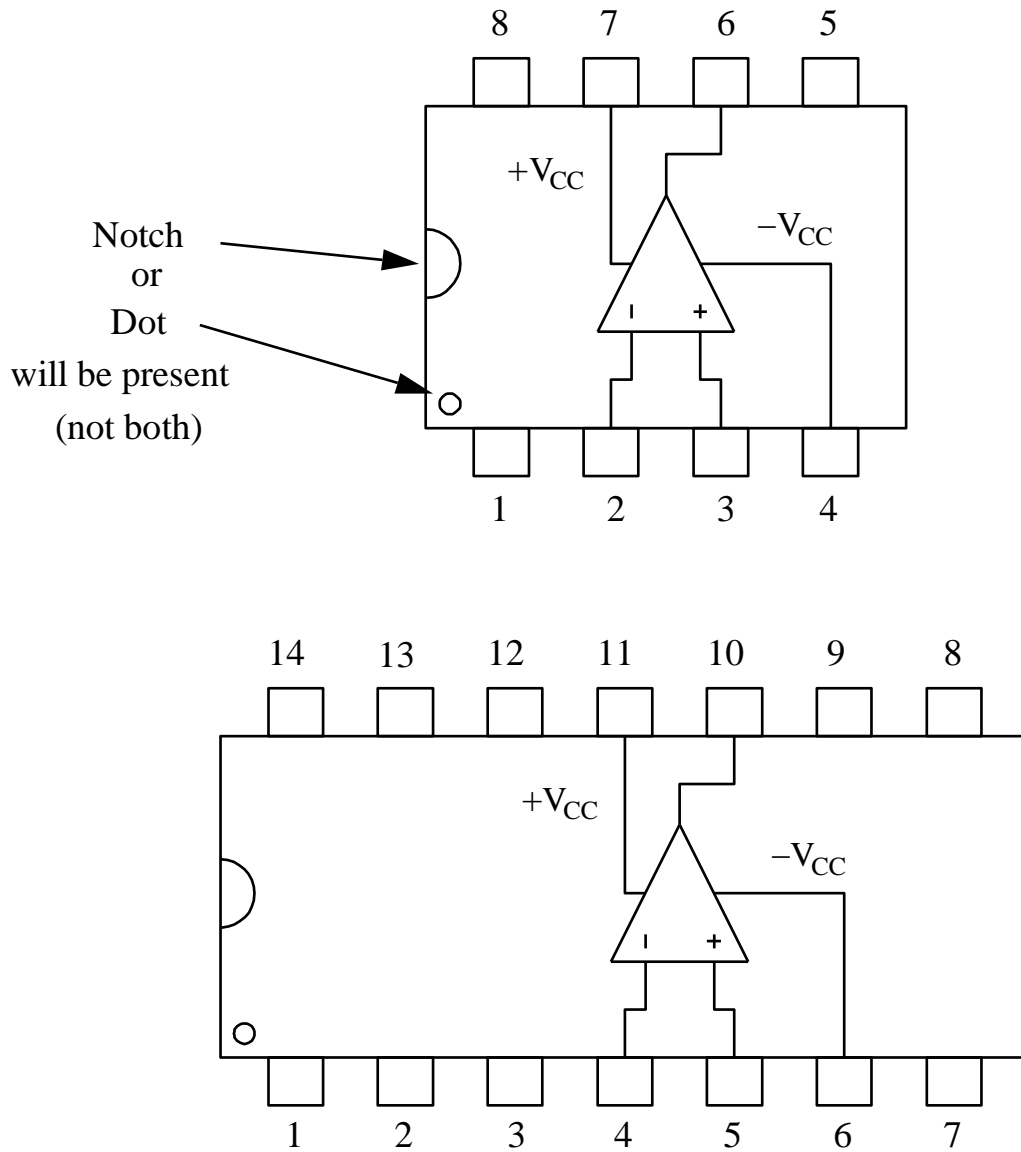
Figure 2:    Pinouts for 8- and 14-pin DIP 741 op amps.