EE 105: Microelectronic Devices & Circuits

General Lab Instruction Manual

Prof. Nguyen

Dept. of Electrical Engineering and Computer Sciences
University of California at Berkeley
Berkeley, CA 94720

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:

i. Reinforce concepts from the lecture.

ii. Strengthen your ability to build and make measurements on real circuits.

iii. 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 utilizing a constrained circuit topology. Lab 6 will then ask you to design an analog transistor amplifier where you choose both the topology and design.

This handout provides you with general information on lab protocol and on the tools we will use to recreate the components and equipment common to most electronic labs. However, there will be cases where you should consult the specific equipment instruction manuals and datasheets available on the course website for more detailed information.

1.2 Lab Protocol

Each of the labs (except for the design labs) consists of the following sections:

i. *Preliminary Exercises*: This section introduces the lab and provides some of the needed background. It contains exercises that you must complete *before* undertaking the lab. Formally, it will be due at the start of your scheduled section for the corresponding 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.

ii. *Results Sheet for Preliminary Exercises*: A sheet on which to record answers to the preliminary exercises. Note that not all 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. If you do not have access to a device with digital drawing capabilities or a printer, please follow the format of the Results Sheet as closely as possible in your write-up.

iii. *Laboratory Exercises*: This section gives the step-by-step procedure required to obtain data needed to answer various questions also embedded within this section. You should do your best to obtain all data during your scheduled lab section, where your lab TA will be best prepared to assist you. Each lab write-up, including answers to all questions and attached measurement data, will be due at the beginning of the next lab section.

iv. *Results Sheet for Laboratory Exercises*: A sheet on which to record answers to the laboratory exercises. Note that not all the required work goes on this sheet; some of the work, such as measured plots or derivations, should be attached separately.

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

i. Show up for the lab with *both*: (1) a completed *Results Sheet for Preliminary Exercises* and any additional required information for the current lab; and (2) a completed *Results Sheet for*

Laboratory Exercises and any additional required information for the previous lab.

ii. Do your best to complete—or at least attempt—all parts of the experimental section of the lab during your scheduled lab section, following the written procedure and taking data as needed.

iii. Outside of your scheduled section, gather any missing data, answer all questions in the Laboratory Exercises section of the lab, putting required answers on the *Laboratory Exercises Results Sheet*. (Note that any supplementary work and other required information—such as calculations, graphs and plots—must accompany the results sheet on separate sheets.) Be sure to have the completed *Results Sheet* and accompanying information ready to turn in at the start of the next lab.

1.3 Results Sheets & Laboratory Reports

Aside from the structured exercises indicated in the *Laboratory Exercises Results Sheet,* there is no specific format required for supplementary work. Once we begin the design labs, you will be provided with detailed guidelines for your laboratory reports. All submitted work not captured by the *Results Sheet* should adhere to the following guidelines:

- Demonstration of all work
- Derivations for all work including any calculations specific to your design (you may reference derivations performed in lecture to avoid re-writing them)
- 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.
  - For any data extracted from a plot, you must annotate the plot to demonstrate how the data was extracted
- Neatness counts; if it cannot be read, it will not be graded. The TA must grade many labs each time and does not have time to decipher a messy report or hunt for your answers.

Results Sheets and Laboratory reports must be turned in by the specified due date, which will be at the start of your lab section for the next lab. Any lab *Results Sheets* or reports turned in past the due date will receive a 10% penalty per day.

If you are unable to complete your experimental lab work during your scheduled session, you may work finish the lab on your own time. However, note that the TAs' ability to help debug your circuits will be limited outside of your scheduled lab section.

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 in the same manner as graphs.)

When asked a question like, “Why was the measured value different from the prediction?” explain why it might have been different, *even if you did not see a significant 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 or specified in the .

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 Neatness & Debugging

When building prototype circuits, although you may be tempted to rush into building your designs given the flexibility offered by a solderless breadboard, it is paramount that you take care to keep your circuits neat. This means that you color code your wires wherever possible and keep them as planar as possible. In other words, you should try and keep your wires as close to your breadboard as you can, confining them to two-dimensions and only passing wires over each other when absolutely necessary. Any circuits presented with messy loops of unclear wiring quickly became very difficult to debug remotely, and you will be asked to rebuild your circuit before the TA is able to help you debug. You may also consider labelling your test leads (e.g. by attaching tape with the signal name written on it) in order to ease debugging.

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

2.0 Laboratory Equipment

2.1 Proto-boards

A proto-board, a.k.a., breadboard, 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 Analog Discovery 2 USB Oscilloscope w/ BNC Adapter Board

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 you will be sent a Digilent Inc. Analog Discovery 2 USB Oscilloscope. This instrument connect to a computer via USB to provide time-domain signals and on-screen markers to simplify the extraction of quantitative measurement data. While it can take a little time to get used to the this instrument, you will likely find many similarities between it and the full-sized bench-top oscilloscopes found in the physical lab.

You should already be familiar with the basic features of oscilloscopes from previous required courses (e.g., EE 16A/16B). To best familiarize yourself with the specifics of the AD2 USB Oscilloscope used in this laboratory, refer to the documentation found on the course website.

In its default configuration, the AD2 USB Oscilloscope utilizes single conductor probes in order to measure time-varying voltage signals. However, as you may have seen in other courses, many bench-top oscilloscopes utilize specialized attenuated oscilloscope probes with BNC coaxial terminations to connect the probes to the oscilloscope inputs. To replicate this system, the AD2 requires a separate component, the BNC adapter board. Each of you will receive one BNC adapter board along with two BNC-terminated oscilloscope probes. By connecting this BNC adapter board to your AD2 USB Oscilloscope Lab you will be able to measure time-varying voltages more accurately. Lab 1 will teach you more about the benefits of these specialized probes.

Some Helpful Pointers.

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

i. Use a compensated oscilloscope probe whenever possible.

ii. Compensate the oscilloscope probe frequently. See Lab 1 for compensation instructions.

iii. Make sure to always ground each probe. Note that the BNC adapter board has the outer conductor of all four outputs connected the AD2 USB Oscilloscope ground. Attaching the BNC probe ground clips to any other AD2 power supply voltage will short the supply to ground, at which point the AD2 will shut itself off as a safety precaution.

iv. Always know where the ground reference is located on the oscilloscope plot. Similarly, always keep track of whether your oscilloscope inputs are configured for AC or DC coupling on the BNC adapter board.

2.3 Arbitrary Waveform Generator

Arbitrary waveform generators (AWGs) are capable of producing various voltage waveforms of a custom nature in addition to standard waveform types, the most common being square, sine, and triangle. The Analog Discovery 2 USB Oscilloscope includes two AWGs whose outputs are also accessed through the BNC adapter board. We will primarily use these AWGs to create sinusoidal signals for testing analog amplifiers and square waves for step response measurements and triggering the oscilloscope. Each of the two AWG outputs has a BNC connector on the BNC adapter board and a jumper to select either 0 or 50 Ω termination impedance. When using an AWG, be sure to use either of the two BNC cables in your lab kit that are not oscilloscope probes. You should also be able to tell which termination impedance is selected and the meaning of this selection.

2.4 Digital Multimeter (DMM)

Voltage Measurements.

A DMM measures both AC and DC voltages in addition to various other quantities such as current (AC and DC), resistance, capacitance and even temperature. The measurement procedure for voltage involves setting the DMM knob to select either AC or DC volts, connecting the probes to the correct ports on the multimeter (usually COM and INPUT, though some measurements like current require use of the other ports) and touching the two measurement points with the probe tips. The multimeter you will receive is auto-scaling, which means that the display should automatically adjust to the optimum scale depending on the order of magnitude of the measured voltage.

Some points to keep in mind:

i. The DMMs we use usually will not load the circuit excessively, as they have an input impedance of approximately 10 MΩ.

ii. Always make voltage measurements in parallel.

iii. When reading AC voltage, many multimeters will read RMS voltage accurately only if the AC voltage is a sine wave. However, some DMMs—including ours—are designated with "True RMS" measurement capability and will accurately read the RMS voltage of arbitrary waveforms.

iv. When reading AC voltage, the DMM has a fairly low upper frequency limit, usually around 400 Hz or less. Consult the user manual for further details.

Resistance Measurements.

To measure resistance, turn the DMM knob to the ohm symbol, connect the probes to the INPUT and COM ports, and touch the probe tips across the resistance to be measured. Some fine points:

i. The ohm setting on the DMM also allows you to easily check for electrical connectivity. After turning the knob to the ohm setting, press the SELECT button once until you see the volume icon. Touching the two probes to the same conductor should result in an audible beep, allowing you to easily check whether two points are shorted together.

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

Current Measurements

The DMM can measure both AC and DC current. When measuring current, it is necessary to connect one probe to the COM port and the other to the current port corresponding to the range you wish to measure (either A or μA/mA). Note that the DMM has a separate setting for each range. 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 same limitations as those on AC voltage measurements apply here, and as before, please refer to the user manual for more information.

2.5 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.

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.

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%

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 usually marked on the outside of the capacitor along with a longer lead to denote the positive anode. 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.

Transistors

The transistors used in the EE 105 lab do not have standard markings or pinouts. You will receive specific datasheets to help you identify the terminals and proper connections for the transistors in the corresponding labs. Ask your TA for help in identifying transistor pinouts.

Integrated Circuits.

The only integrated circuit used in the EE 105 lab is the LMC6482 dual op amp. The LMC6482 contains two op amps in an 8-pin DIP (Dual In-line Package). Its pinout can be found by referring to the datasheet. 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. Make sure you consult the data sheet whenever you are unsure of the pinout for a specific device.

3.0 Software and Simulation Tools

In order to use the Analog Discovery 2 USB Oscilloscope, you must download the corresponding software, Waveforms. This software can be found at https://store.digilentinc.com/waveforms-download-only/. Please refer to the WaveForms Reference Manual for more information on running the software.

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 lack of GUI is less friendly as it requires spice netlist (i.e., text file) 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 exercises 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).