Supplementary Notes for Electronics
(Spring 2007, Department of Physics)

by

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These notes are intended to supplement and clarify the material in the “Student Manual for the Art of Electronics” (henceforth referred to as “the manual”), which is the basis for the laboratory portion of this course. Included are background material on the instrumentation used, changes to the labs, lab design exercises and helpful hints in conducting the experiments. There are questions to be answered in conducting and reflecting on the laboratories. As with the question posed in the manual with each laboratory, these are to be answered in you lab reports.

Before you set out to complete the first laboratory familiarize yourself with some of the instrumentation by following the description (lab 0) below.

Lab 0:
INTRODUCTION TO THE BREADBOARD (GLOBAL SPECIALTIES PB503)

First become acquainted with the breadboard on which the circuits you will be working with will be wired up—the Global Specialties PB503 Breadboard frame. Take a few moments to look over the breadboard with the diagram (on page 4) and description of the components given below. Then start on the following exercises:

0-1 Voltage Supplies

There are three DC powers supplies on the board. These are located at the top of the board. They consist of +5 to +15 V, –5 to –15 V, and +5 V voltages sources with a common ground. These supplies are indicated on the board. They can be accessed via the two breadboard strips at the top of the board (by plugging small wires) or via the four plugs at the right top of the board (using larger “banana” plugs). The output voltages for the +15 and –15 V sources can be adjusted using potentiometers on the top of the board. The red switch on the top left of the board turns on the power. Turn it on and complete the following exercise:

Ex. Use the digital multimeter (DMM) to measure the output from the three DC power supplies. Change the potentiometers to adjust the output voltages. Set the output voltages as closely as possible to +15V, –15V and –5V.
0-2 Function generator

There is a function generator located in the upper left hand side of the board. This is used to output sine, square and triangle waves. The amplitude can be varied from 0 to 21 Volts, and the frequency adjusted from 0.1 Hz up to 100 kHz. The six holes on the small eight-pin breadboard are connected to one terminal of the generator. This signal is relative to the common ground of the breadboard, so the other lead or common must be connected to use the generator. The two contacts on the left-hand side of the breadboard give a TTL (transistor-transistor logic) signal. This is a fancy way of saying a square wave of amplitude of 5 V, suitable for generating the high and low states for a type of digital logic. As with the dc power supplies the main power must be on to use this generator.

Ex. Connect an oscilloscope (description on page 29 of the manual) to the output of the function generator. Vary the frequency, amplitude and function type (sine, square and triangle) and note the output on the scope.

0-3 Transformer

On the top close to the center of the breadboard is a transformer output. There are three contacts. Between the left and right plugs is 12.6 V rms (root-mean-square) and between the central and end contacts is 6.3 V rms.

Ex. Contact the output of the transformer to the oscilloscope. What is the output amplitude and frequency? Is this what you expect?

0-4 Debounced pushbuttons

Below the function generator there are two pushbutton switches. These are not standard switches that are either open or closed. They output a voltage signal that is either logic high or low, +5 V or +1 V, respectively. You will use these in the later part of the course when we get to digital electronics. For more information refer to page 311 of the manual.

Ex. Use the DMM to understand the output and function of these debounced pushbuttons. Measure the voltage of the Normally Open (NO) and Normally Close (NC) leads.

0-5 BNC connectors

There are two BNC connectors on the bottom left and right of the breadboard. These BNCs are used to connect signals from your circuits to measuring instruments such as a DMM or oscilloscope. The outside conductor is a shield at ground potential. The central connector is tied to the small breadboard. To use this BNC, connect the signals to be measured to the small breadboard and a BNC cable to your measurement device.
0-6 DIP switch

The 8-position DIP switch (bottom left hand side) is fed from a +5V/0V slide switch (marked DIP switch S1). This can provide logic high, low or neither (output floating) depending on the position of the slide switch. Refer to page 311 in the manual for additional information about this switch.

0-7 Potentiometers

To the right of the 8-position DIP switch are 1 kΩ and 10 kΩ potentiometers (pots, for the electronically hip). Three leads, left, right and sliding contact are accessed from the small 8-pin breadboard above as indicated in the associated diagram. The knobs are used to adjust the position of the sliding contact and hence the resistance between the sliding and fixed contacts.

Ex. Use the digital multimeter (DMM) to understand the function of these potentiometers. Between which terminals does the resistance vary as the pot knobs are turned? Are the resistances what you expect?

0-8 Switches

The two slide switches next to these pots are standard switches--either they’re open or closed. To use these switches the small breadboard next to the switches must be wired as indicated on the schematic.

0-9 Speaker

On the right hand side of the board is a small 8 Ω speaker. Both leads of the speaker are connected to four pins on the eight-pin breadboard.

Ex. Connect the function generator to the speaker. Remember that one lead of the generator is the ground, so you should connector one end of the speaker to the ground. Vary the amplitude and frequency of the function generator to hear different sounds from the speaker.

0-10 LED Logic Indicators

The LED indicators respond (turn on) with the input is a logic high, namely, five volts with respect to the ground, more a voltage greater than about 2.5 V. Refer to p 310 in the manual.

Ex. Use the slide switches (see above section 0-8) to control the LEDs. Can you do this with the debounced pushbuttons? Give it a try.
0-11 Main Breadboards

The guts of this instrument are the three large breadboard sections smack in the middle of the board on which you will wire up your circuits. Refer to the figure below for the connections of the pins. Typically the 4 outer strips (which run vertically), 2 on each side, are used for voltage supplies and common (such as 15V, -15V, 5 V and ground) while electrical components are positioned in the central portion of the board.

**Breadboard technique** It’s very important to get in the habit of wiring things up clearly and carefully on the breadboard. You’ll find that a good deal of time in this laboratory is finding out why circuits *do not* work as expected (note: this is true of electronics in general). So a little extra time taken in initially laying out your circuits is in greatly rewarded in less time spent debugging them. This becomes even more important as the labs get more involved.
Lab #1 DC Circuits

1-1 to 1-3 Ohm’s Law and I-V Curves

Follow the description in the manual to measure the I-V response of the various components.

(The typical characteristics of the diode 1N914 are: reverse breakdown voltage of 75V, forward voltage drop of 1 V, reverse current 5 mA)

There is another method you can use to measure I-V characteristics which makes use of the oscilloscope. The following is an optional portion of the laboratory. (It requires some experience with the oscilloscope.)

Use the method described in Lab 5-1 and 5-2 of the manual to show an I-V curve on the oscilloscope.

a) First, have a look at figure L5.1 of the manual (p 118). How does this circuit work?
b) Wire up the circuit shown in figure L5.1
b) Turn the “sweep” switch on the scope to “0.5V” (only the “50mV” and “0.5V” are for external sweeping, but 50mV is too small for the experiment. Why?)
c) Before the AC power is on, adjust the bright point on the screen to the origin of the screen, or to the point where you want to chose as origin of the I-V curve.
d) Turn on the AC power, watch the I-V curve on the screen. Compare it with the theory. With the diode, can you observe the breakdown voltage? Why?
e) Substitute the diode with other kinds of components (#47 lamp, resistor, etc.) and measure their I-V curves.

Question: Can one do this experiment using the signal from the on-board function generator instead of the AC transformer? Why or why not?

1.7 Thevenin Equivalent of Mystery Supplies

a) Find the mystery boxes that we have setup for you, each of which contains a battery and resistors. Using your DMM to determine the Thevenin equivalent circuit. Of the boxes you have tested which would be the best supply to use with a low resistance load?

b) Now open the box and determine the circuit diagram. Analyze this to find the Thevenin equivalent circuit. Do your calculations agree with what you found in part a?

Lab #2 Capacitors

2-1 to 2-7

The oscilloscope enables us to show the input and output signal on the same screen. When comparing the amplitude of the input and output signals, be aware of the vertical scales you are using for different channels.

The measured 3 dB frequencies in these labs should be consistent with the theory, although there are always a difference. Are these within the experimental error or tolerances of the components?

2.7a Design Exercise (!) High Pass Filter

Design a high-pass filter that will keep most of the “signal” (that is, the signal
from the function generator) and get rid of most of the 60 Hz “noise.” (the signal on the transformer). Assume that the frequency of the “signals” may range between about 2 kHz and 20 kHz.

As you design, consider—
- what is an appropriate $f_{3dB}$?
- what $Z_n$ is appropriate for your filter?

Run the composite waveform (“signal” plus “noise”) through your high-pass filter. How well does it work?

2-8 Blocking Capacitor
To see how this circuit works, use the WAVETEK function generator and change the DC offset of the output. The offset knob is on the back panel of the generator. In order to apply a DC offset, you must be using the 50Ω output.

How does the output from the blocking capacitor change when the DC component of the input signal changes?

What’s the $3\,\text{dB}$ frequency of the circuit (figure L2.10A)?

Lab #3 Diode Circuits

3-4b Design Exercise: Choose C for acceptable ripple
Suppose you want to let your power supply provide a current of up to 20 mA with ripple of about 1V.

Your design task is to do the following:
- choose R so as to draw about 20mA (peak)
- choose C so as to allow ripple of about 1V

Draw your design. Then try your circuit. Is the ripple about right? (Explain, to your own satisfaction, any deviation from what you expected.)

This circuit is now a respectable voltage source, for loads of low current. To make a “power supply” of higher current capability, you’d use heftier diodes (e.g., 1N4002) and a larger capacitor. (In practice you would always follow the power supply with an active regulator, a circuit described in Lab 12 on the manual.)

3-5 Signal Diodes
Without the 2.2 kΩ resistor, try to measure the RC time constant of the circuit with the oscilloscope.

What is the result? Why?
Why does this give a different answer?

3-6 Diode Clamp
Remember the definition of the dynamic resistance— at a given point on the I-V characteristics it is the slope $dV/dI$.

3-7 Diode Limiter
Design and wire a circuit to limit an input signal between approximately, +5V and -5V.
3-8 Impedance measurements
   1) Measure the impedance of the VOM. Is it consistent with the mark of “20kΩ/V” (see page 10 of the main text)?
   2) Measure the impedance of the scope. The input channels are marked “1MΩ/47pF”. Are your results consistent with this?
   3) Measure the output impedance of the on-board function generator. For what size loads (impedance) will this output impedance start to become problematic?

Lab #5 Op Amps I

8-1 Open-loop Test
   Estimate a lower limit for the open loop gain of the 411 Op Amp.

8-2 Inverting Amplifier
   Op Amps are “real” amplifiers. They amplify DC signal as well as AC signal. No bias or blocking capacitor is needed unless you want to get rid of the DC component of a signal. But notice the output power limit (refer to Figure L8.4 on page 178 and the description there).

8-3 Non–inverting Amplifier
   Now since the input impedance of this amplifier is very high (it could be in the GΩ range), you should be aware of the impedance of the measurement tool (i.e. the scope). The inputs to the scope have an impedance of 1 MΩ, as you measured in Lab #3. To avoid perturbing the measurement (because of the low input impedance) measure the output voltage instead of the input, and then divide by the gain to determine the input voltage.

8-4 Follower
   How does this follower compare with the transistor follower?

8-5 Current Source
   Use first a 10kΩ pot as load then a 1kΩ pot. What’s the range of loads for which the current remains constant? How does this compare with the transistor current source?

8-6 Current to Voltage Converter
   a) Photodiode
      Is there output signal when you cover the transistor with your hands (or turn off all the lights in the room)? If there is, what is the “dark current” that goes through the BE junction of the phototransistor?

   b) Phototransistor
      The output signal may not change with the intensity of the light on the transistor. You may try to look at the AC response by using a blocking capacitor between the output of the phototransistor and the input of the Op Amp.

   c) Explain the phenomenon observed.

8-7 Summing Amplifier
   Our function generator on the board does not have a DC offset. Try to make one for it using the summing amplifier. You may use the on-board DC source for the offset.
Lab #6 Op Amps II

9-2 Integrator
Measure the RC constant of the circuit using a square wave as input. Is the result consistent with the theory?

9-3 Differentiator
You can do the same thing as in the integrator part measuring the RC constant of the circuit. What input wave form should you use this time? At high frequency, the differentiator acts as an integrator. What is the RC constant of this “integrator”?

9-4 Microphone Amplifier
You need to connect the output of the circuit on page 204 to the on-board speaker, but it must go through a capacitance of a few hundred µF (we recommend 100 µF).
Try to get eliminate of the 60 Hz noise. You can “look at” your sound on the oscilloscope.

Lab #10 Counters
In this section, we use a different kind of counters from those recommended in the manual. They are simpler. They only count up and have are 4-bits. However, we can build the electric piano, stop watch and capacitor meter with this kind of counters just as well as with those in the manual.

Description of SN74LS163 4-bit synchronous binary counter

1. Pin-out
   Refer to the attached pages for pin arrangements of the counter.

\[ V_{cc}(pin 16): \text{connect to } +5\text{V as usual;} \]
\[ Carry \text{ out (pin 15): usually low. This is the carry bit, it is high once the outputs overflows.} \]
\[ Outputs (pin 11\text{~}14): \text{output of the counter. Change (increase) by one every time the clock pulse comes. MIN=0000, MAX=1111} \]
\[ Enable T (pin 10) \text{ and Enable P (pin 7): these two pins must be both high in order to perform counting. They have the same function as the “carry in” pin of the 74LS469.} \]
\[ Load (pin 9): \text{Once low, it loads the input data to output} \]
\[ Inputs (pin 3\text{~}6): \text{data inputs. Usually used to set initial values of the counter.} \]
\[ Clock (pin 2): \text{clock input} \]
\[ Clear (pin 1): \text{when low, it clears the outputs, i.e. set outputs to 0000.} \]

2. Application
   One 74163 can be used as a 4-bit auto-load counter. It can automatically load inputs (initial value) to outputs once the outputs reach 1111. Two 74163 chips can be used to make an 8-bit counter. Three chips a 12-bit counter, and so on.
   Labs (15-2 and on) involve building and using 16-bit counters, so four chips are required. There is lots of wiring, of course, including the wiring to the array display. Please do this carefully and neatly so you will spend less time checking the circuit if it doesn’t work properly the first time!
   There are circuits designs for 4-bit and 8-bit counters on the attached pages. Understand these and then design and build your own 16-bit counter.
Components for Labs

**Lab #1**
Resistors: 1kΩ, 10kΩ(*2), 20kΩ;
Diode: 1N914; Lamp: #47.

**Lab #2**
Resistors: 100Ω, 1kΩ, 10kΩ, 4.7kΩ, 15kΩ, 150kΩ;
Caps: 100pF, 0.01µF, 4.7µF.

**Lab #3**
Resistors: 1kΩ(*2), 2kΩ, 2.2kΩ, 100kΩ;
Caps: 560pF, 0.01µF, 15µF, 470µF;
Inductor: 10mH;
Diodes: 1N914(*4).

**Lab #4, 5, 6**
ICs: 411, 311, 358;
Resistors: 470Ω, 560Ω, 1kΩ(*2), 1.2kΩ, 2.2kΩ, 2.7kΩ, 4.7kΩ, 10kΩ, 12kΩ, 15kΩ,
100kΩ(*2), 1MΩ(*2), 3.3MΩ, 10MΩ;
Caps: 100pF, 0.01µF(*2), 0.1µF(*2), 4.7µF(use the one in Lab #4), 100µF;
Transistor: 2N3906 (use the one in Lab #4);
Phototransistor: FPT100;
Lamp: #344;
Microphone.

**Lab #7**
ICs: 74LS00, 74HC00, 74HC74, 74HC112, 74HC175;
Logic Probe.

**Lab #8, 9**
ICs: 74LS163(*4), 74HC14, 7408, 555;
Resistors: 1kΩ, 100kΩ, 1MΩ;
Cap; 0.1µF;
Display*;
Keypad*.

**Lab #10**
74HC541 8-bit Octal 3-state buffer
HM6264-LP-12 (or equivalent p 395) 8kx8 SRAM, 120 ns
74LS469 8-bit up/down counter (Nat’l only?)

**Lab #11**
AD558JN D / A converter single supply with register
74LS502 (SAR) 8 bit successive approx. register (Nat?)
TLC372P comparator, single supply
74HC4040 ripple ctr.
74HC4046 phase detector and VCO