Physics 123
Hints and Tips

Solderless Breadboards

All of the analog labs and most of the digital labs will be built on the Proto-Board solderless breadboards. These provide three solderless breadboard strips to insert components and jumpers into for building circuits, power supplies, BNC connectors, DIP (Dual Inline Package) switches, slide switches, debounced pushbutton switches, potentiometers, indicator LEDs, a speaker and a function generator.

The +5, +15 and -15 volt power supplies built into the breadboard are adequate to power most of these labs. The breadboards have been prewired to provide horizontal and vertical power busses as follows:

Remember to turn off the breadboard power when building or making changes to your circuits.
You should not have to adjust the plus and minus 15 volt supplies. If you find a supply voltage low, it is probably because your circuit is drawing excessive current (all three supplies are current limited). Please speak with the course staff before adjusting either power supply potentiometer.

The power supply busses are color coded as follows:

- **Yellow:** +15 Volts
  
  The top horizontal row of contacts is the +15 volt supply. It is indicated by yellow hookup wire. Plus 15 volts is also available on the inner vertical bus on the right side of the breadboard.

- **Red:** +5 Volts
  
  The next horizontal row of contacts is the +5 volt supply. It is indicated by red hookup wire. Plus 5 volts is also available on the inner vertical bus on the left side of the breadboard.

- **Black:** Ground
  
  The second from the bottom horizontal row of contacts is ground. It is indicated by black hookup wire. Ground is also available on the outer vertical bus on the left side of the breadboard.

- **Blue:** -15 Volts
  
  The bottom horizontal row of contacts is the -15 volt supply. It is indicated by blue hookup wire. Minus 15 volts is also available on the outer vertical bus on the right side of the breadboard.

We **strongly urge** you to adopt a color code when wiring your lab projects. It may take a few extra minutes to find the correct color/length hookup wire but it will save you much more time when debugging your circuits (and make life infinitely easier for the course staff).

- **Use the following colors only** for power:
  - Red: +5 volts
  - Black: ground
  - Yellow: +15 volts
  - Blue: -15 volts

- **Consider using separate colors** for inputs, outputs and internal signals, for example:
  - Brown: inputs
  - Purple: outputs
  - Green: internal signal lines
It is also a good idea to add a piece of partially stripped black hookup wire in the ground bus to provide a place to connect test equipment ground clips to:

Note use of stripped jumper wire to provide scope ground connection.
Each of the three solderless breadboard strips consists of columns of five contacts above and below a central horizontal trench:

Normally, you will place ICs (integrated circuits in DIP packages) over the trench so that you can access the IC’s pins via the column of contacts. Remember that all five contacts in each vertical column are connected together when building circuits.
While you may be tempted to insert components and hookup wire by hand, some of the connector strips on may be very tight making insertion difficult. A better method is to use needle-nose pliers:

Also, bend component leads away from the body of the component rather than right at the component, particularly on resistors, diodes and tubular capacitors, to avoid stress that can cause the leads to break.

In addition to color coding your jumpers, avoid daisy chaining multiple short lengths of hookup wire to reach between two components. Each contact introduces a point of failure. If you cannot find a long enough jumper of the correct color, there are spools of wire in the back of the lab you can use to create a new jumper (also note the color change in the photo below that only adds to the confusion):
On complicated circuits (and maybe simple ones) consider building a portion of the circuit and testing it before building the next section. You will find it much easier to debug small portions of a design than one big mess and you will be less likely to disturb a working section while debugging a non-working section.

While building a circuit from a schematic in the notes, use a highlighter pen to mark the components and wires completed. This helps catch missing portions of the circuit and is easier than debugging a non-working circuit only to find you left out a jumper. (See example below.)

When building a circuit from a schematic, write in the pin numbers on the schematic if they are missing. This will make construction and debugging much easier. For example, here is a circuit from Lab 6:

![Schematic of an op amp circuit](image.png)

Before you begin building, add pin numbers for the op amp (operation amplifier – the triangle shaped device) inputs and the output. Also show and number the power supply connections. Note how portions of the schematic have been highlighted to indicate what has been built on the breadboard so far.

![Highlighted schematic](highlighted_image.png)

Label switches and potentiometers on your schematic and on the actual component on the breadboard so you (and the course staff) know what they do. In the circuit above, you should add a label “OFFSET” on or near the 10K pot.

For circuits that you plan to leave constructed for several lessons, consider keeping leads and jumper wires short and close to the surface of the wireless breadboard. This will reduce the chance of components or jumpers being pulled out of a working circuit and make debugging new additions much easier. (Of course you can do this for every circuit if you wish.)
Here is an example of a neatly-built circuit:

Note how the power supply jumpers are color coded (Red: +5, Black: ground), the switches are labeled by function and the jumpers are placed close to the surface of the breadboard and neatly routed to avoid snagging. The resistors are also placed low to the breadboard and are bent away from the body of the component.

When you disassemble a circuit, remove integrated circuits carefully using a chip puller or a thin screwdriver to avoid bending any of the leads. See the video on the Hints and Tips page of the course web site. Please do not remove ICs by hand, you will bend the leads!

If you find an IC in your parts bin that has bent leads (because the last class did not follow my advice):

Do not try to force it into the breadboard. Rather, use your needle-nose pliers to carefully straighten the pins out before inserting the IC into the breadboard. You can align the pins by holding the IC on its
side against a hard surface and bending all the leads simultaneously to a right angle to the body of the device. *If you have not done this before please ask for help.* It is very easy to break the pin off entirely, rendering the IC useless.

Be careful with TO-220 packages. The metal tab is usually connected to the collector of a bipolar transistor. Make sure this does not short out against any other component or wire.

![TO-220 Package (used for transistors and voltage regulators)](image)

You will have the following tools available when you build circuits:

![Useful tools for breadboarding. Use screwdriver ("green tweaker") to remove ICs and adjust trimpots. Needle nose pliers are used to insert components and jumpers and to straighten bent IC pins. Wire strippers allow you to create new jumper wire lengths. The BNC T connector lets you connect the external function generator to the breadboard and the oscilloscope simultaneously to monitor the circuit input.](image)
The thin screwdriver (“green tweekeer”) can be used to adjust trimpots and remove ICs.

The “T” shaped BNC connector is useful to connect an external signal source to the breadboard and an oscilloscope (“scope”) at the same time:

Please keep the component drawers in the same order all the time. This will make it easier to find components when you need them and make life much easier for lab staff. (Bigger image on web site.)
Be very careful of polarity when inserting components such as diodes and electrolytic capacitors. Here is what’s left of an electrolytic capacitor that was inserted backwards during the spring 2013 Physics 123 course. It exploded with a bang that sounded like a firecracker going off. A student was stung by flying shrapnel but luckily not permanently injured. Even if you do not get an explosion, a reversed or incorrectly inserted component can lead to odd circuit behavior that is difficult to diagnose. It is better to take your time building a circuit than to waste time debugging it.

Make notes on the lab handouts or in a lab notebook of what you are doing and any measurements you make. This will make it easier for you to complete the problem sets and study for the midterm and final.

Finally -- David’s Axiom: If you do not understand why changing something appears to fix your problem you probably have not fixed the problem.
Configuring and Using the Analog Oscilloscopes

We use an analog Tektronix oscilloscope (either the model 2213A or the 2215) in the first half of the course. These scopes use a CRT (Cathode Ray Tube) with an electron beam which lights up a coated phosphor screen. Please keep the intensity control adjusted so that the beam does not “bloom.”

Excessive beam intensity may damage the oscilloscope phosphor screen. Note that when you decrease the sweep (sec/div) rate, you will need to reduce the intensity to avoid blooming.

If you are only using one channel of the scope, use Channel 1 (CH 1).

When using both channels, use Channel 1 for a source that you can trigger on. If the input signal is large enough that you can trigger on it, use Channel 1 for your input and triggering source and use Channel 2 for output and intermediate signals.

Make sure you know if you should be using the “1X” or “10X” scale on the input channel “VOLTS/DIV” dial. If you are using a straight BNC-to-BNC cable, read sensitivity under the 1X scale. If your scope probe is a 10X probe (most are), use the 10X scale:
Before you use the scope, you may want to set the controls to the following default positions:

This will make it easier to find the beam and trigger the scope.

Make sure you know where the zero volt level is for each channel by setting the input selector to the “GND” position and adjusting the channel position. For bipolar signals (signals that are both positive and negative) or when the channel input selector is set to AC, you will find that using the vertical center of the screen as zero is convenient. For positive-going signals, you may want to set the zero point at the vertical center of the screen for Channel 1 (as shown above) and at the bottom or one major division up from the bottom for Channel 2.

Make sure the three red “CAL” knobs are turned all the way to the calibrated position (i.e., to the right) to ensure your measurements are valid.

Make sure the “HORIZONTAL MODE” is set to “NO DLY.” The scope has a delayed mode that allows you to expand a portion of the total trace but it can be very confusing if you don’t know it is enabled.

Similarly, make sure the trigger “VAR HOLDOFF” mode is set to “NORM” and the trigger source is “INT” and set to “CH 1” unless you explicitly want to use another triggering mode. You may occasionally want to use the “LINE” triggering mode to see signals that are synchronous with the 60 Hz AC power line or the
“EXT” mode when you want to trigger on an external source. However, these are exceptions to the general rule that you want to trigger on the Channel 1 input.

When viewing two channels simultaneously, you can choose “CHOP” or “ALT” mode. Typically you will use “ALT” mode for faster sweep times and “CHOP” for slower sweeps. If you can see the beam alternating between the two channels, switch to “CHOP” mode. If you can see both traces alternately chopped between signal and ground, switch to “ALT” mode. The “ADD” position adds the two channels to show a single trace. This is useful in conjunction with the “CH2 INVERT” button to see if two signals are identical. If they are, Channel 1 added to an inverted Channel 2 should be close to a flat line. (Otherwise make sure the “CH2 INVERT” button is not depressed.)

Do not use scope probes for anything other than oscilloscope inputs! One term, a student could not understand why nothing was coming out of the function generator connected with a scope probe. This will not work (we will discuss why when we talk about RC circuits):

![Image of oscilloscope with an X mark on one of the probes](image-url)
Configuring and Using a Function Generator

We use a Krohn-Hite function generator (a model 1400, 1400A or 1600A) in the course to generate sine, square and triangle signals, usually as inputs to our analog circuits.

Typically we use a continuous output and you should make sure that the “CONT” mode button is pressed. We will use the sweep mode, which outputs a signal that changes frequency over time, in a few labs. Make sure to reselect “CONT” mode when you are done using any other mode.

When the “DC OFFSET” button is not selected, the output signal from the “MAIN OUT” is centered around zero volts (i.e., there is no D.C. component in the output). Selecting the “DC OFFSET” button allows you to add a D.C. offset to the output with the vernier knob below the button. A common use of a DC offset is to set up a zero-based square wave output.

The “AMPLITUDE” vernier works in conjunction with the “ATTENUATOR” switch to set the output signal amplitude. Each position to the left of the “0” attenuator selection, reduces the amplitude of the output signal by a factor of 10. The “AMPLITUDE” vernier allows you to adjust the signal amplitude within that range. If you need a smaller amplitude signal, consider choosing a larger dB attenuator setting rather than turning down the AMPLITUDE adjustment all the way. This may result in a less distorted signal.

The function generator is designed to drive a 50 ohm load. For higher frequency signals (which includes almost any square wave) you will get less distortion by making sure the load impedance is around 50 ohms.

If all you need is a logic signal (i.e. square wave with amplitude from +0.3 to about +3.0 volts) use the TTL output.
Using the Multimeters

We use a variety of multimeter makes and models in class. They are all very similar. A few are auto-ranging but most require you to guess what the amplitude range of your signal will be. It is better to start on a higher range and decrease it than to subject the input to a much higher signal than it is expecting. (The multimeter is designed to withstand excess voltage or current but you may blow a fuse that temporarily renders the multimeter unusable.)

All the multimeters use separate inputs from current and voltage. Be very careful not to apply voltage to a current input to avoid blowing the internal fuse. (We are short on replacements.)

All of our multimeters can read resistance and most of them can read capacitance and/or inductance. This is very useful for double checking that a component is the value you think it is, particularly on hard-to-read metal film resistors and secret-handshake encoded capacitors. Some multimeters can check semiconductor components such as diodes and transistors as well.
User Manuals

- Tektronix 2213 (analog oscilloscope)

- Tektronix 2215A (analog oscilloscope)
  - [http://w140.com/kurt/tektronix_2215a.pdf](http://w140.com/kurt/tektronix_2215a.pdf)

- Tektronix TDS3014B/TDS3014 (digital oscilloscope)
  - [http://www.tequipment.net/pdf/tektronix/TDS3000B_datasheet.pdf](http://www.tequipment.net/pdf/tektronix/TDS3000B_datasheet.pdf)

- Tektronix MSO2014 (digital oscilloscope)

- Krohn Hite 1200A (function generator – similar to 1400 model)

For the multimeters (and the logic probes we will use later in the course), google\(^1\) the manufacturer and part number to find a manual.

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\(^1\) A generic term for “the Internet search engine of your choice.”