Appendix A: Protoboard Setup

Assembly tips:

Before the first lab session, make sure that your protoboard is properly assembled. Figure A.1 shows the STRONGLY SUGGESTED setup for the protoboard. The main concern is that your ground wires should not form a loop. That is why all grounds are connected to a central point, which forms a star connection configuration. This is important because wire loops act as antennas which add noise to your signals, and your ground reference should remain free of such noise. You may use the protoboards available in the lab as a visual guide since they are connected using the suggested setup.

Note that the metal chassis of the protoboard is not a reliable ground connection! You may connect it to ground for safety purposes: if a "live" wire touches a grounded metal chassis, it will cause a short-circuit of which you will immediately be aware. However, DO NOT use the metal chassis to connect the ground of the oscilloscope probes because the connection is not reliable (it is prone to oxidation), and more noise will be added to your signals. Instead, connect a short wire to the ground rail on your protoboard, and connect the ground of the probes to that wire.

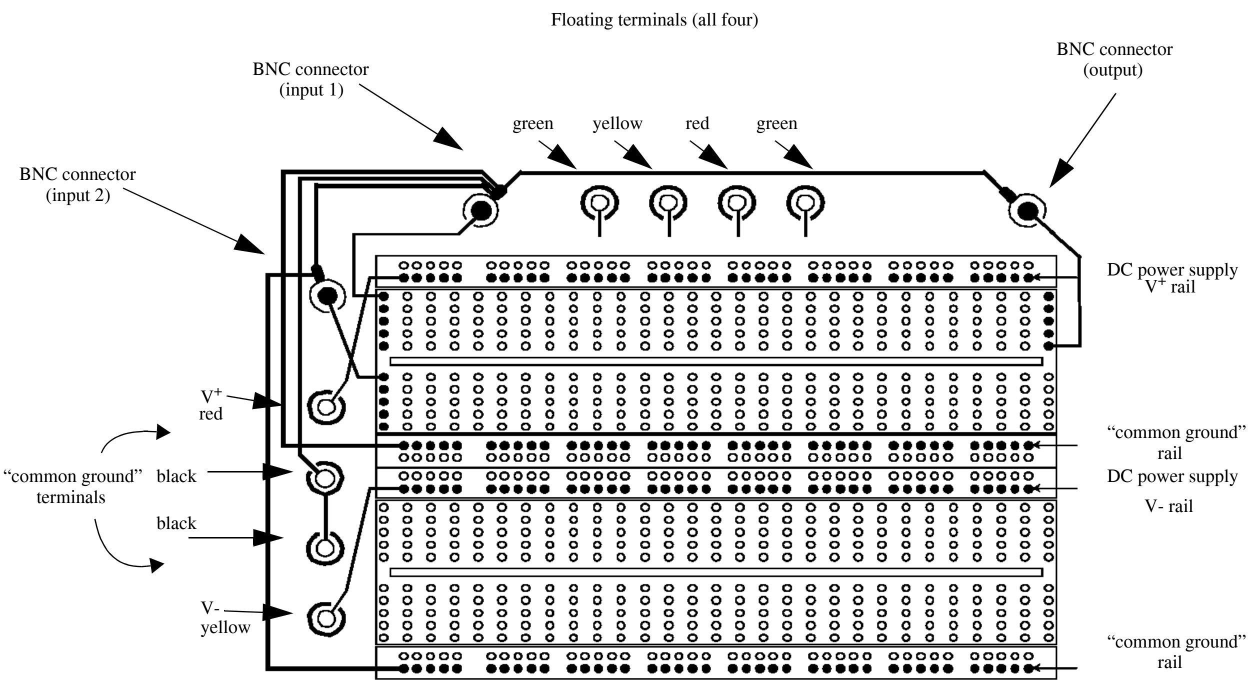


Figure A.1: STRONGLY SUGGESTED protoboard setup.

Power supplies:

The circuits built in this course need single and/or dual voltage power supplies, and they are referenced to the ground line on the protoboard. However, the power supplies available in the lab are floating (they are not referenced to ground). That is, they produce a specified voltage difference between their two output nodes (the positive node is always at a higher voltage than the negative node), but the absolute voltage compared to ground is not fixed.

To create a single power supply of +*A* volts, all you need is to set the lab power supply to *A* volts and to connect the negative node to ground (see Figure A.2a). The ground connection ensures that the negative node is at zero volts, which means that the positive node is at +*A* volts, as desired. To create a -A volts supply, you simply connect the positive node to ground, and the negative node will then be at -A volts (see Figure A.2b).

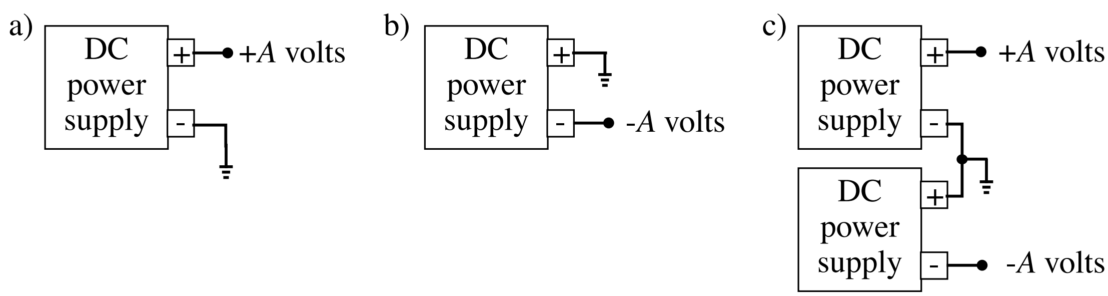


Figure A.2: Connection diagram for (a) a positive single power supply; (b) a negative single power supply; (c) dual power supplies.

Dual power supplies of $\pm A$ volts consists of two single power supplies (one of +*A* volts and another of -*A* volts) both referenced to the same ground, as shown in Figure A.2c. This type of power supply is generally used for op-amps which produce an output that can be positive or negative, and it is often used in this course.

Fortunately, the suggested protoboard setup has connections for dual power supplies, including the common ground connection between the negative node of one supply and the positive node of the other (see Figure A.2c). The four banana plugs on the left side of the protoboard (see Figure A.1) can easily be connected to the lab power supplies using two banana plug wires.

Appendix B General Circuit Building and Debugging Tips ECE231S

Building tips:

• Use all the available space on the protoboard, do not compact your circuit around an integrated circuit. Since performance is not an issue in this lab (except *maybe* for lab 5), build each subcircuit in its own area and interconnect them using longer wires. It is then easier to understand and modify your circuit, and to isolate a subcircuit if it needs to be tested alone.

• Build the circuit in steps and test each subcircuit individually before connecting everything together. This makes it easier to locate problems because your are testing small subcircuits. Also, if each subcircuit works individually but the complete circuit does not, then there is a good chance that the connections are at fault, not the individual components.

• Try to keep your wires as short as possible, recall that wire loops act as antennas. Most important, keep the space above the integrated circuits free of wires and components. This makes it easier to read the information written on the package, and to replace the component if it is faulty. Do not neglect this last element because components WILL FAIL!

• Connect all grounds together on the ground rail of your protoboard. This includes the grounds of power supplies, signal generators and oscilloscope probes.

• A small note on resistor values. Care has been taken to design the circuits using resistor values available in your kits. However, if you do not have the required resistor value (and your friends have none to spare), simply use the closest one available. This substitution may modify the characteristics of a circuit, but will most probably not impact its functionality.

Debugging tips:

• The first rule of debugging is to know your expected waveforms: "With the input that is currently applied to the circuit, what is the expected output?" **If you cannot answer this question, you cannot debug your circuit!**

• To probe nodes in your circuit, attach a small wire to the probes clip and connect the wire at the desired node on the protoboard. DO NOT remove the clip from the probe! There is the risk of losing the clip and the probe's pin will damage your protoboard if it is inserted in a connection hole.

• When a large circuit does not work, break it up into smaller subcircuits. All the circuits studied in this course are composed of small subcircuits. Test each subcircuit individually before connecting them together.

• To test a subcircuit, apply an input similar to the one present when the complete circuit is connected, and verify that the output is as expected. For example, the inverting integrator used in the labs receives a square wave at its input and produces a triangular wave at its output. A square wave is then a good choice for a test signal, and a triangular wave is expected at the output.

• If the connections are correct but the output is still wrong, try replacing some of the components (especially integrated circuits) to see if they may be faulty. However, before doing so, make sure that EVERYTHING ELSE is correct, because it might be that a wrong connection in your circuit is destroying some components (and will also destroy all other replacement components).

• When modifying your circuit, make sure that the power supplies and signal generators are OFF. This prevents accidental short-circuits from destroying components. Also, try not to apply signals to unpowered integrated circuits (turn OFF power supplies last, and turn them on first) because some types of ICs may burn.

• When testing closed-loop feedback circuits, break the loop! For these circuits, the signal path of a closed-loop circuit forms a loop: the output comes back as an input. If the output is wrong, then an input will be wrong and most probably all internal signal will also be wrong. To test the open-loop version of the circuit, apply the expected output at its corresponding input, and check if the output produced by the circuit is what you expect. For example, the circuit of Figure B.1a shows a closed-loop system with the expected waveforms at each node. If we break the loop between O_1 and I_3, as shown in Figure B.1b, then we have to apply a triangular wave at input I_3 and check that we obtain a similar triangular wave at output O_1. However, we can also choose to break the loop between O_2 and I_2 (see Figure B.1c), in which case we have to apply a square wave at input I_2 and check for a similar square wave at output O_2. It is preferable to break the loop at the node with the waveform that is easiest to generate.

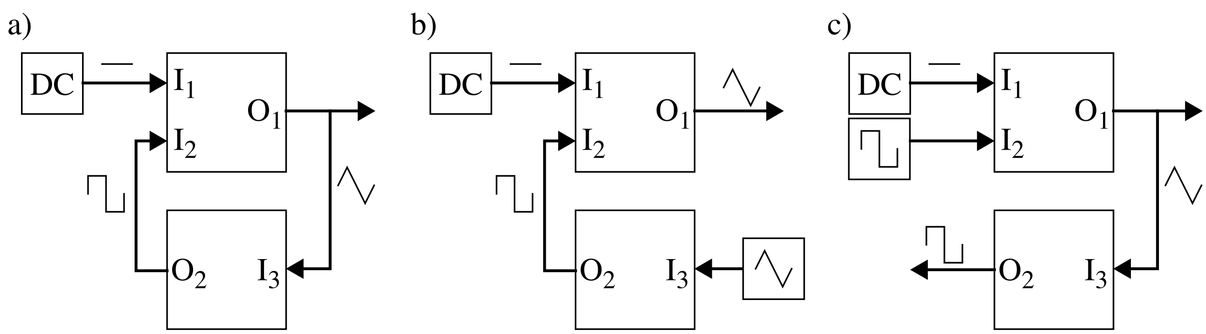


Figure B.1: (a) Closed-loop circuit; (b) and (c) methods of breaking the loop.

• When comparing your expected and obtained (generally from the oscilloscope) outputs, make sure that you are correctly measuring the obtained waveform. Knowing the expected waveform, it is possible to adjust the oscilloscope BY HAND, without using the “auto set” button. That “handy” function may (and will) cause you some problems because it does not know the expected waveform. For example, if the node you are measuring happens to be a 0V DC voltage, using “auto set” will show you a small signal (about 20mV) in the MHz frequencies, which is far from what you expect. Indeed, the oscilloscope just zoomed in to the inherent noise of the system, and hid the important information (the 0V DC signal).

Appendix C Tips on using the Digital Oscilloscope ECE231S

Channel menu: (buttons are located in the'Vertical'section)

- Coupling: DC or AC (or Ground)

With DC coupling, the oscilloscope gives the voltage measured by the probe: DC and AC components. With AC coupling, the DC offset is hidden and only the voltage variations are shown. This last mode is quite useful when you want to measure a small AC signal that has a large DC offset. It is then possible to easily zoom in to the AC signal. However, unless you specifically want only the AC signal, always use DC coupling because then you have all the information. The Ground "coupling" is mostly a relic from analog oscilloscopes and was used to set the ground on the display. The digital oscilloscope in the lab constantly shows the ground level with an arrow located at the left of the display.

- BW limit: OFF 60MHz or ON 20MHz

The digital oscilloscope in the lab can measure signals up to 60MHz, when the bandwidth limiting filter is OFF. However, this might not always be useful in a noisy environment because a lot of noise will be added to the measured signal. If this happens to you (the waveform on the oscilloscope display is a thick line), do not hesitate to turn this filter ON to limit the bandwidth to 20MHz. This will not affect your measurements because the signals used in this course are at much lower frequencies, but it will visually "clean up" the waveform and ease measurements.

- Probe: 10x (DO NOT change this)

The inputs of an oscilloscope are not ideal, they have a certain capacitance which limits the bandwidth. In other words, high frequency signals are modified by the presence of the oscilloscope. The probes that connect your circuit to the oscilloscope are specially made to compensate this, and to increase the bandwidth as much as possible. However in doing so, they decrease the amplitude of the signal by a certain factor (usually 10). This digital oscilloscope internally multiplies the measured voltages by a certain factor (10) so that the voltage on the display is the same as the one in the circuit. That is why in the channel menu of the digital oscilloscope, the "probe" submenu should be set to "10x".

Trigger menu:

On an oscilloscope, triggering synchronizes the waveforms on the display so that they remain stable. For example, when measuring a sine wave of constant frequency, all the points where the signal crosses ground (0V) with a positive slope are displayed one on top of the other. Notice that a triggering point consists of a threshold level (ground in the last example) and a slope. The threshold level is marked with a small arrow located at the right of the display.

- Edge or Video: always use in Edge mode
- Slope: Rising or Falling

The oscilloscope triggers when the input crosses the threshold with the given slope. Use rising or falling as you wish, but rising seems more natural (think positive!).

- Source: Channel 1, Channel 2, External, External/5, AC line

There can only be one trigger source to which all displayed waveforms are synchronized. You will use either channel 1 or 2, but it is also possible to synchronize using a third signal (useful when the measured waveforms are complex). It is also possible to synchronize with the 60Hz AC line voltage, but you will not need this option.

- Mode: Normal, Single, Automatic

Leave the oscilloscope in Automatic mode. The Single mode makes the oscilloscope trigger once and then freeze the display.

Display formats:

An oscilloscope can display the waveforms of both channels as voltages in time, or as channel 2 voltage versus channel 1 voltage. The latter is useful to measure the transfer characteristic of a circuit (output voltage versus input voltage). To accomplish this, the input must be on channel 1 and the output on channel 2. You then press on the "Display" button to show the display menu, and you select the XY format (the YT format is the normal "voltage in time" format).

Before doing so, make sure that both signals (channels 1 and 2) are centered on the display (the ground reference level should be centered vertically on the screen) and that they take up as much space as possible, without being clipped by the edge of the display. In other words, they must overlap, because the XY mode uses these settings to display channel 2 versus channel 1.

Persist feature: The persist option introduces a 'memory' in the display so that the viewed image is a composite of the last few seconds seen on the screen. You can select a hold time of 1, 2, or 5 seconds, or an indefinite hold time.

Automatic measurements:

A great feature of digital oscilloscopes is that they automatically accomplish several measurements: mean value, peak to peak voltage, RMS voltage, frequency and period. This saves a lot of time, but you must ensure that the measurements are valid.

These measurements use the waveform displayed on the screen, and are dependant on its quality. For example, if the waveform is not synchronized properly, frequency measurements will not be valid. Also, amplitude measurement will not be correct if the edge of the display clips the waveform. In conclusion, before writing down a value given by the oscilloscope, make sure the waveform is stable and that it is not clipped. It is also preferable that the signal uses as much vertical space as possible on the display to increase the precision of amplitude measurements. Likewise, to increase the precision of frequency measurements, display as few cycles as possible, but there must be at least one COMPLETE cycle. If the oscilloscope has trouble measuring a value, a question mark will appear beside it on the screen.

Automatic adjustment:

The digital oscilloscope has a “feature” called the “auto set” button which automatically adjusts the display settings to display a waveform. While this may be quick and easy, it does not necessarily save time because the result is not always what you need. Also, it does not always adjust to the correct waveform. Remember to this feature with care and to make sure the display shows you what you expect to see. This function cannot think for you!

Appendix D Component Information ECE231S

Resistors:

The color bands on a resistor indicate its value, according to the following table.

Table D.1: Resistor color code

Color	**First band (tens digit)**	**Second band (units digit)**	**Third band (multiplier)**	**Fourth band (tolerance)**
Black	-	0	$\times 10^{0}$	
Brown	1	1	$\times 10^{1}$	1%
Red	2	2	$\times 10^{2}$	
Orange	3	3	$\times 10^{3}$	
Yellow	4	4	$\times 10^{4}$	
Green	5	5	$\times 10^{5}$	
Blue	6	6	$\times 10^{6}$	
Violet	7	7	$\times 10^{7}$	
Grey	8	8	$\times 10^{8}$	
White	9	9	$\times 10^{9}$	
Gold			$\times 10^{-1}$	5%
Silver			$\times 10^{-2}$	10%

Mnemonic: *Remember "Bad Beer Rots Our Young Guts But Vodka Goes Well!"*

To find the value of the resistor, first build the two-digit number given by the first two color bands (just put the tens digit and the units digit side by side). Second, multiply that two-digit number by the multiplier given by the third color band. Third, determine the precision of the resistor value (the maximum difference between the indicated value and the true resistance value) with the help of the fourth color band. Note that if there is no fourth band, then the tolerance is 20%. For the resistances in your kit, the fourth band is most probably gold.

As an example, an 18kΩ resistor with a tolerance of 5% will have the following color bands: brown, grey, orange and gold.

Note that the resistances in your kit are most probably 1/4W resistances (0.25W). Thus in your designs, make sure they do not dissipate more than that power.

If you are not sure about the resistance (sometimes the colors are hard to see), do not hesitate to measure them using an ohmmeter or an impedance bridge (available in the lab).

<u>Capacitors:</u>

There are different types of capacitors, with each its own way of indicating the capacitance value. Some of them are pretty easy to read (1uF, 2.2 uF, 10 uF, where u stands for micro) but others only have numbers like 101, 102, 221, etc. Reading a capacitor's value is much like reading a resistor's value. If the quantity printed has no decimal point and no letters (it looks something like 102 or 223) then apply the following rule: The unit of measure is pF and the three digits are interpreted as illustrated in Figures D.1 and D.2.

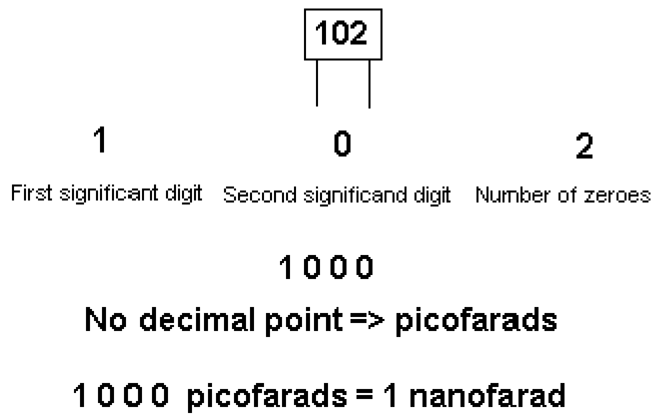


Figure D.1

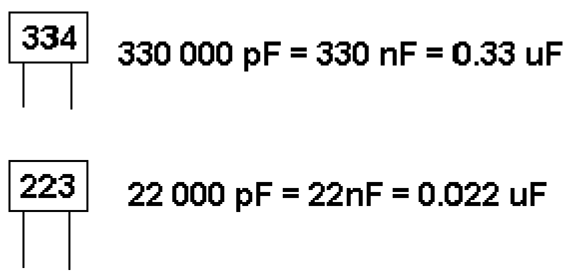


Figure D.2 Examples.

If the quantity includes a decimal point then the value is in microfarads and the value shown is the capacitor's actual value in microfarads.

Examples:

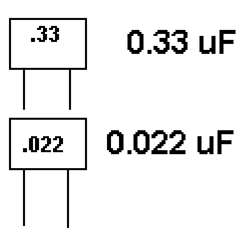


Figure D.3 Microfarad examples.

Sometimes you will find a letter between two digits (1n5, 2p2, 4u7), in order to find the capacitor's value use the following rules.

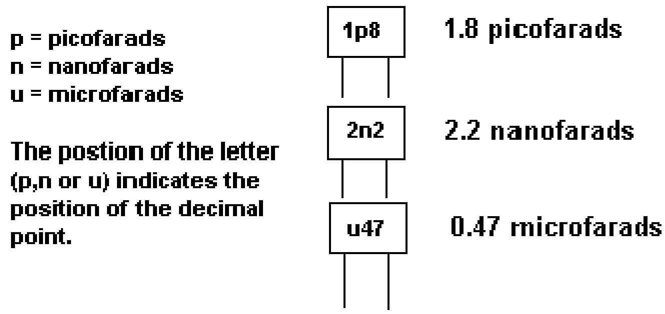


Figure D.4 Capacitors with letter codes.

In very unusual cases, especially for small capacitors (picofarad range), there will be nothing but one number. The number will indicate the capacitor's value and none of the rules described above will apply.

WARNING: a capacitor showing 100 on its surface, like the one depicted below, is likely to have a value of 100 pF and not 10 pF! WHEN IN DOUBT USE A METER.

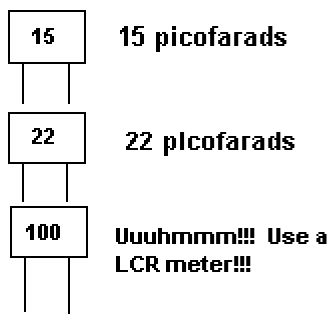


Figure D.5 Special capacitor markings

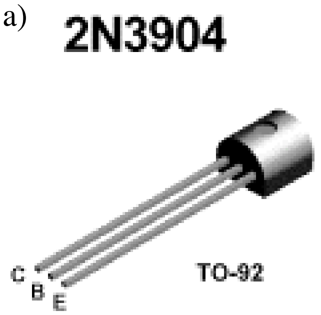
Warning: Electrolytic capacitors

Electrolytic capacitors are small cylinders with both leads usually sticking out of the same end. Do not forget that these capacitors have a polarity and must be connected the right way, or else they may explode! The negative lead is marked with arrows or with minus signs. Also, if the leads have not been cut, it is the shortest of the two. Their capacitance value is clearly marked on the package, generally in µF.

Transistors:

In this course, you will use two types of discrete transistors, and their pin assignment is given in Figure D.6. For more information on their characteristics, consult the websites listed at of National Semiconductor or Fairchild Semiconductor.

a)



b)

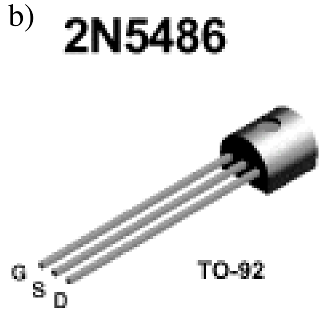


Figure D.6: Pin assignment for (a) 2N3904 NPN-BJT transistor and (b) 2N5486 N-channel JFET transistor.

Microphone (WM-034C):

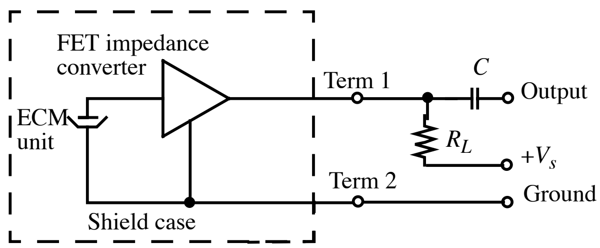


Figure D.2: Typical schematic circuit for microphone.

The standard operating conditions for Model No. WM-034C are: V_s = 4.5V; R_L = 2.2kΩ and C = 33pF.

Quad Voltage Comparators (LM139 or LM339):

The LM339 consists of four independent voltage comparators designed to operate from a single power supply in the range of 3V to 16V. Note that the comparator outputs ***require a pull-up resistor*** because it has an open collector (it can pull the output voltage down but leaves the output as an open circuit rather than pulling the voltage output high).

The pin connection diagram is shown below.

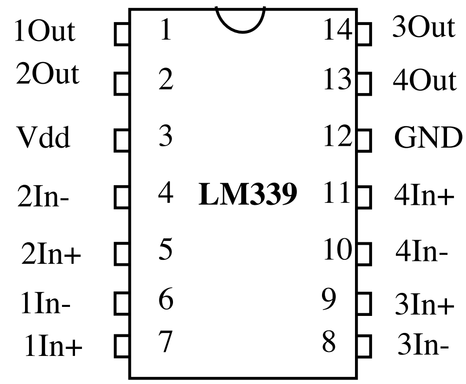


Figure D.7: Pin connection diagram for the LM139 or the LM339.

Operational Amplifier (741):

The pin connection is as shown below:

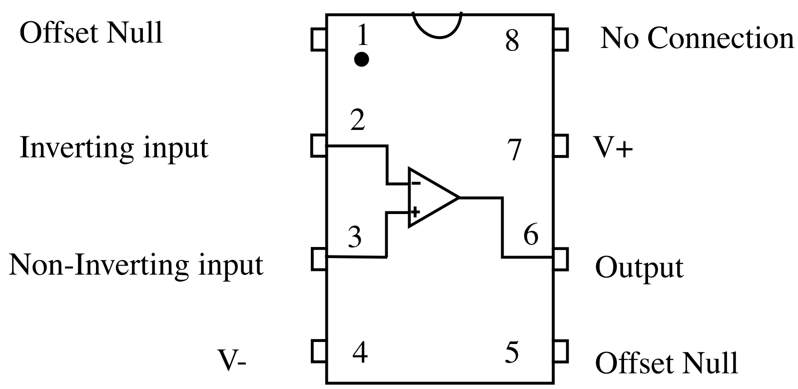


Figure D.8: Pin connection diagram for the 741.

Operational Amplifier (TL084):

This chip contains 4 op-amps. The pin connection is as shown below:

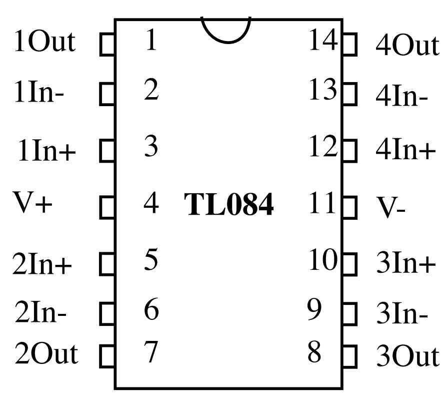
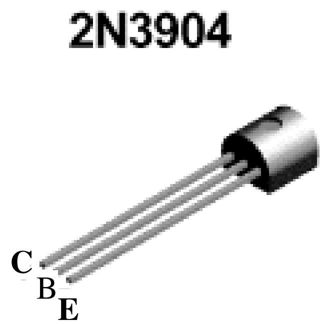


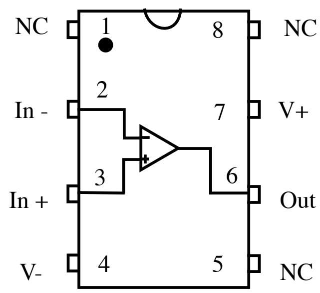
Figure D.9: Pin connection diagram for the TL084.

Appendix E Component & IC Pinout Diagrams ECE231S

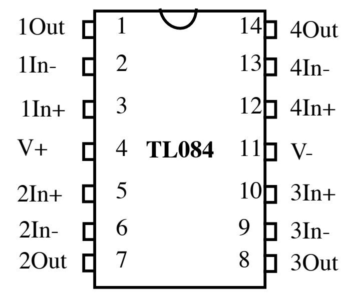
NPN-BJT Transistor



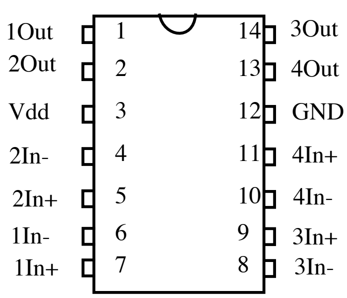
741 Op-Amp



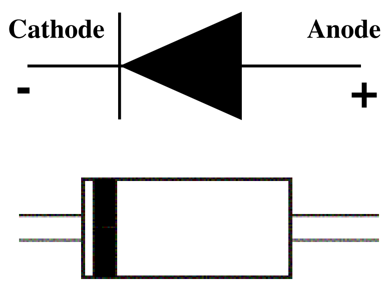
TL084 Quad Op-amp



LM139 or LM339 Quad Comparator



Diode(1N4148)



LED