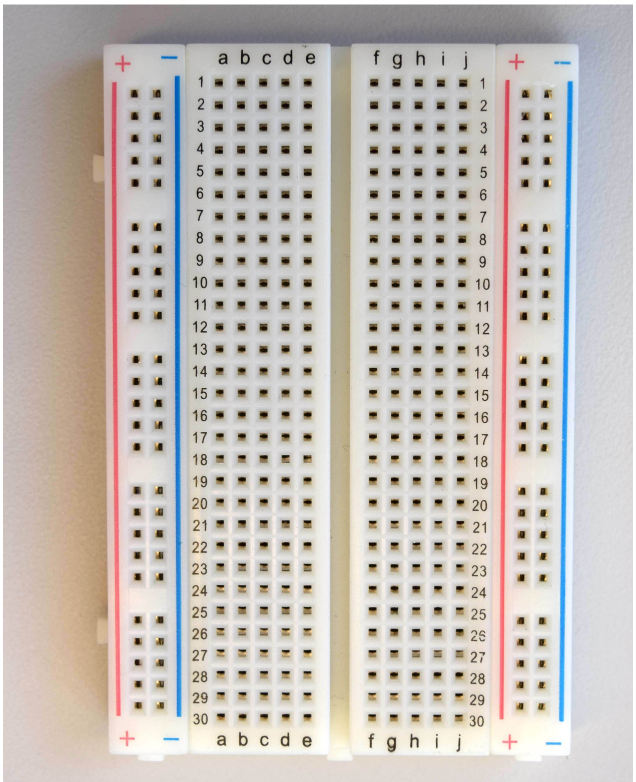
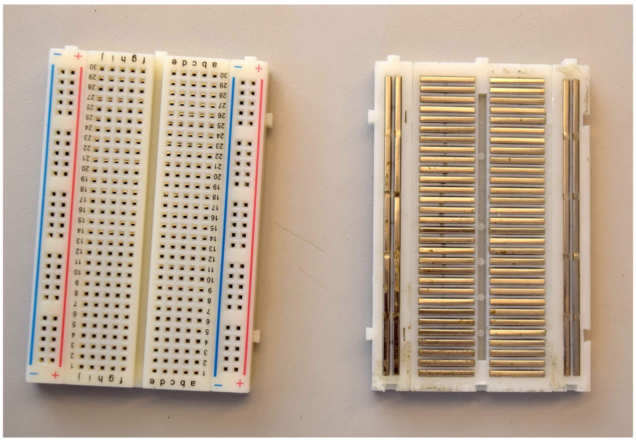
Parts

The propeller-arm assembly will consist of the following electrical parts:.

Breadboard



The above prototyping breadboard is a convenient way to connect electrical components together to make a circuit, while also holding the components securely in place. When wires or metal leads on components are inserted in to the holes, they are "grabbed" by metal clips that are electrically connected in groups. The clips are connected together either in rows of five, or in four long columns spanning the entire length of the breadboard. When multiple wires or leads are inserted in to holes in the same row, or the same long column, they become electrically connected. In this way, we can conveniently connect (and hold together) parts.



The coupling of clips in rows, or in long columns, can best be seen by stripping off all of the breadboard backing (do not do this, it will ruin the breadboard!!!!), as we show in the above figure. Note the metal rows and long metal columns.

The breadboard has an easily-removed thin paper backing, and underneath that backing is a sticky coating that can be used to attach the breadboard to a firmer surface (such as the floor of the plastic project box). We strongly recommend you attach your breadboard to the floor of the box or to another hard surface. Otherwise, thicker wires or component leads can push the metal clips through the soft backing instead of being "grabbed". No electrical contact will be made, and the circuit will fail.

Jumper Wires

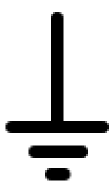
Wires are used to make electrical connections between components that can not be placed in the same row or long column. We use three types of wires in the copter-levitated arm circuitry: prestripped wires for connecting breadboard rows together, male-to-male jumpers wires for making longer distance connections between the breadboard and the microcontroller or the copter, and female-to-male jumper wires for making connections between the breadboard and the angle-sensing potentiometer. The kit of prestripper wires is shown below (we will use the short orange, yellow and blue wires from the kit).

The sets of female-to-male and male-to-male jumpers wires are shown below (female-to-male on the left, and male-to-male on the right). The sets of jumpers are easily pulled apart, in to single jumpers, or in to sets of several jumpers. If you strip the insulation off these jumper wires, you will see that the metal wire is stranded. Jumpers made with stranded wire are more flexible than solid wire jumpers (solid wire is used for the jumpers in the kit above), and can tolerate repeated bending, such as when the arm moves up and down.

Breadboard and Jumper Wire Schematic Symbols

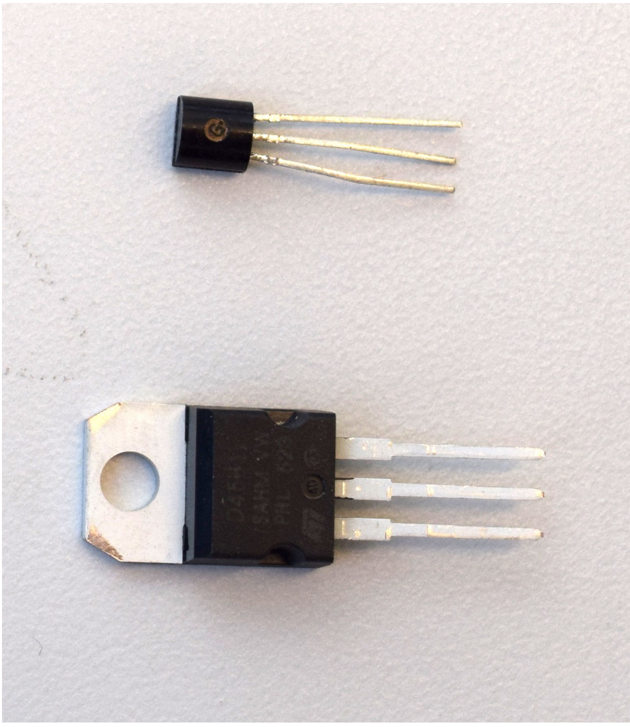
Schematically, breadboard and jumper wire connections are represented by lines:

Like any physical potential, voltages in a circuit must be specified with respect to a reference, and that reference is referred to as "ground". By definition, ground has a voltage of zero, and in most circuits, many components are connected directly to ground. For this reason, we assign one of the long collumns of connection points on the breadboard to be ground, and in a schematic, connections to ground are indicated with a special symbol:

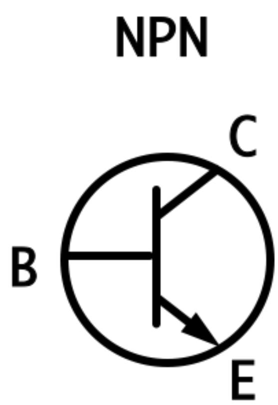


Transistors

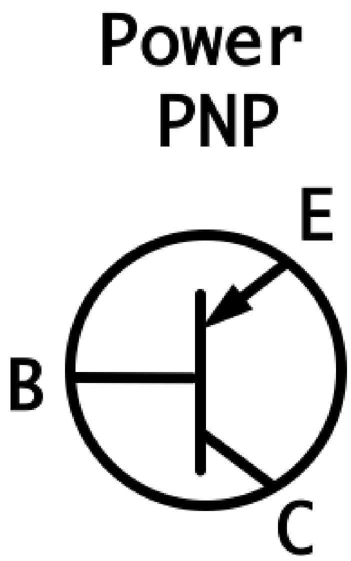
We use two different types of transistors in our circuit. We use a general purpose NPN transistor capable of switching one hundred milliamps of current, the 2N3904 (a classic), to drive a power PNP transistor capable of switching several amps of current, the D45H11. The poower transistor is much larger and has a metal tab with a hole in it. The metal tab helps dissipate heat, and the hole in the tab can be used to connect the tab to a larger metal heat sink. The two transistors are shown below, with the NPN on top and the power PNP on the bottom. IN the picture, the NPN's flat side is facing away, as is the PNP's tab side.



Our NPN transistor (the small one) is represented using the schematic below. With the transistor flat side facing you (so that you can read the text on the transisor), the leads are, from left-to-right, the emitter (E), the base (B) and the collector (C). These pins are shown in the schematic representation:



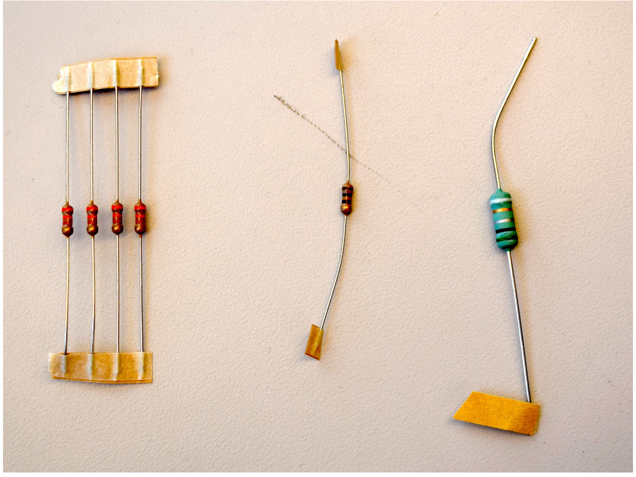
For the power PNP transistor (larger), when looking down on the non-tab side of the transistor, the PNP pins base(B), collector(C), and emitter(E). NOTE that the PNP transistor leads are NOT in the same order as the NPN transistor. The schematic symbol for the PNP is also a little bit different from the NPN schematic, in that the arrow points in instead of out:



NOTE that the transistors must be connected EXACTLY as specified in the assembly document.

Resistors

Three different values of resistors are used for both 6.302.0x and 6.302.1x, and a fourth value of resistor is used only for 6.302.1x (to scale voltages for the different microcontroller). There are four 3300 ohm, or 3.3K ohm, resistors (labeled with orange-orange-red color bands), two of which are used in two low-pass resistor-capacitor filters, one is used to limit the current in to the base of the NPN transistor, one is used to limit the copter indicator LED. The one 100 ohm resistor (labeled with brown-black-brown color bands) is used to limit the current in to the base of the power PNP transistor. There is also a large power resistor (green in color), a 0.5 Ohm 2W resistor. This resistor is used to both limit the current in to the copter motor and to provide a voltage measurement of the motor current. For 6.302.1x, there are two additional 6800, or 6.8k, ohm resistors (labeled with blue-grey-red color bands) used to scale voltages for the Teensy microcontroller. **The resistor values are not interchangeable! If you use the wrong resistor value, the circuit will almost certainly not work as intended, and could even DAMAGE your parts. Check the values carefully!!**



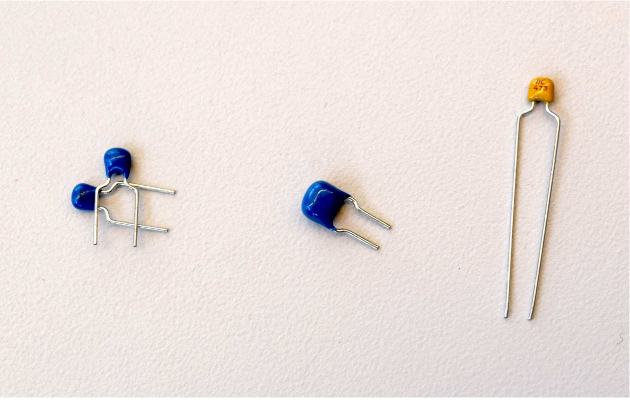
The schematic symbol for a resistor is a zig-zag shape, and is usually accompanied by a label or a value. Resistors are non-polar devices, meaning that their two leads are interchangable. The resistors used for the 6.302.0x are shown below, and are, from left to right, four 3.3k ohm resistors, one 100 ohm resistor, and one 0.5 ohm 2 watt resistor:

Capacitors

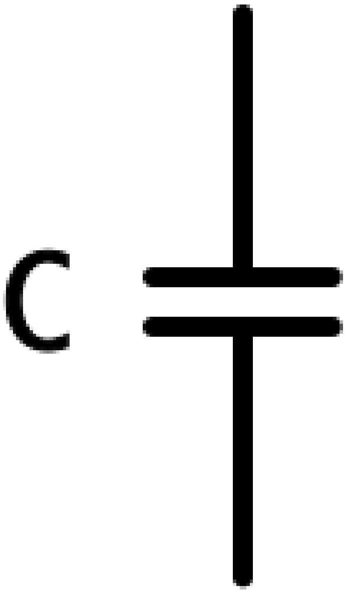
We use three values of capacitors in the circuit:

- 47μF (Farad) (labeled with "476")
- 2.2μF (labeled with "225")
- 0.047μF (labeled with "473")

The interpretation of the three digit labels are: 47×10^6 picoFarads or 47 microFarads, 22×10^5 picoFarads or 2.2 microFarads, and 47×10^3 picoFarads or 0.047 microFarads. The capacitors are shown below, and are, from left to right, two 2.2uF capacitors (to filter motor signals), one 47uF capacitor (to filter the external power supply), and one 0.047 uF capacitor (to limit the PWM switching speed of the motor current).



The schematic symbol for a capacitor is a pair of parallel lines, as shown below, and is a reminder that originally, capacitors were made using parallel metal plates. Our capacitors are non-polar, meaning the leads are interchangable, but this is not always true for capacitors. Electrolytic capacitors are polarized, and can actually pop if connected backwards, so we did not use themn in the this project.



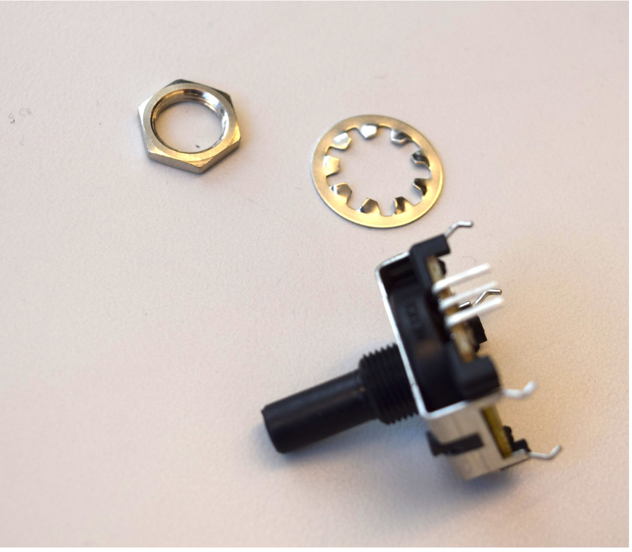
Power Supply and Barrel-Jack

The current for the copter motor can exceed two amps, and is provided by an external five-volt three-amp power supply that plugs in to an outlet (sometimes such power supplies are referred to as "wall worts" because they stick out from the wall when plugged in). Most of the copter driver circuit uses the external five-volt supply, but the angle sensor potentiometer is supplied seperately with power from either the Arduino or the Teensy microcontroller. The reason for seperating the copter power supply from the sensor power supply is that the copter generates an enormous amount of power supply noise, and we wish to isolate the angle sensor from that noise. The power supply is shown below:

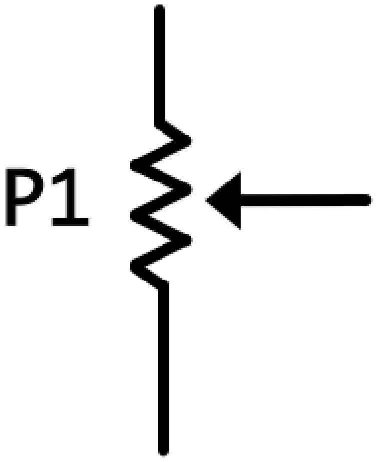
The external power is connected to the breadboard using a 5.0 mm barrel jack with breadboad pins, as shown below. The two pins nearest the opening of the jack are connected to ground, the pin at the opposite end of the opening is the five-volt pin.

Potentiometer

We will use a low-friction potentiometer manufacturered by Honeywell (or Bournes) as an angle sensor. The potentiometer is comprised of a ring of resistive material and wiper contact that rotates with the potentiometer shaft. When the two ends of the resistive ring are connected to ground and a reference voltage (five volts on the Arduino, 3.3 volts on the Teensy), the voltage on the wiper will track the rotation angle of the potentiometer. So when the potentiometer shaft is attached to the copter arm, the wiper voltage can be used to sense the arm angle. The potentiometer is shown below, note that the wiper is the center of the three connection leads.



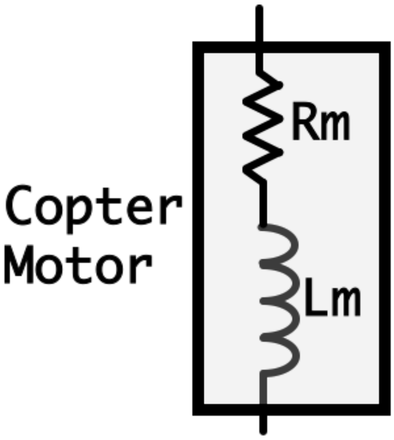
The schematic symbol for a potentiometer is shown below, with the arrow indicating the wiper.

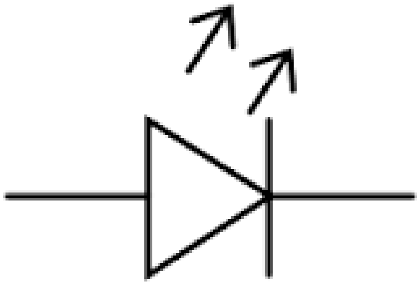


Copter Assembly with motor, propellor and LED

The copter assembly shown below has a power-indicator LED, a power-hungry motor, and a plastic propeller. There are two two-pin connectors terminating two pairs of wires on the copter assembly, the thicker pair of wires is attached to the motor and the thinner pair is attached to the LED. one connected to a pair of very thin wires, and one connected to a pair of thicker wires.

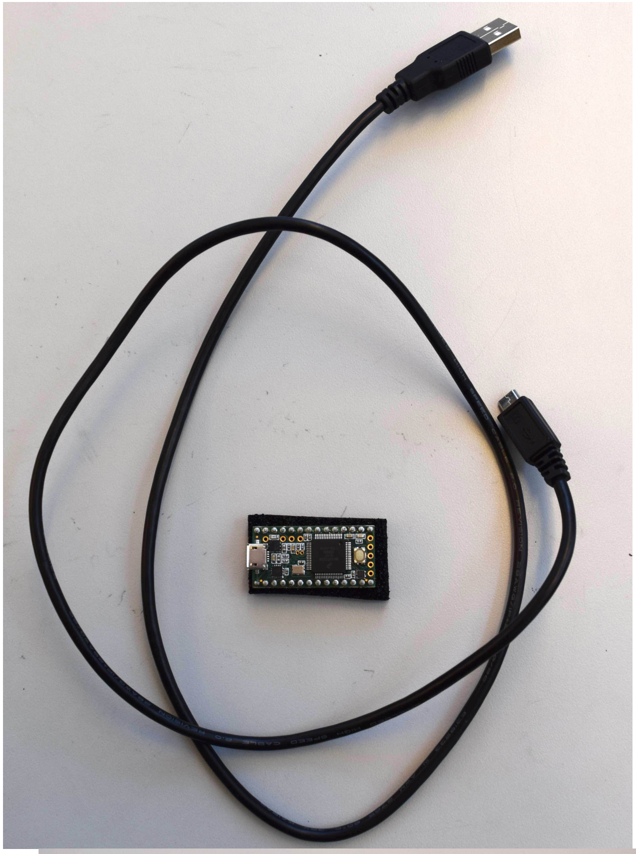
The schematic we used for the motor is indicative of how we model the motor, it is a box with a resistor in series with an inductor, shown on the left in the figure below. On the right, we show the schematic for an LED.

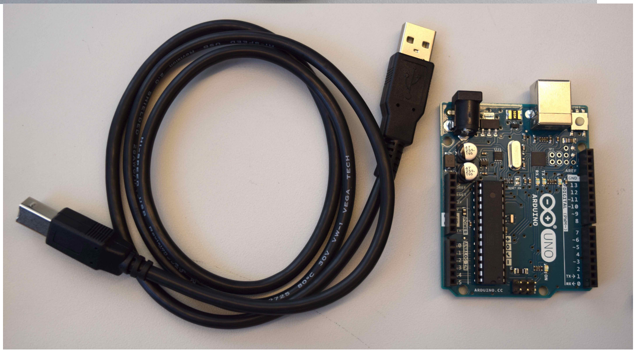




Microcontroller

The bulk of our controls and changes and experiments will be implemented in code which we run on our microcontroller. We've designed this course to work with the open-source Arduino/Genuino Uno shown below (right) because it is supported on all major operating systems, is open source, and is very widely available. We will also provide code compatible with the Teensy 3.2 (shown below left) which is a more powerful, more recently developed microcontroller. We are using the Teensy 3.2 in our 6.302.1x course where we investigate state space methods.



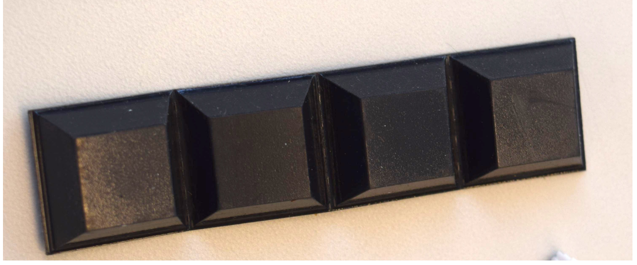


Project Box

We'll construct our system within the project box shown below.

Rubber Feet

The plastic project box slides easily on almost any surface, so when the propeller arm is waving up and down, the box is very likely to slide right off any table or lab bench. We know this from a great deal of experience. Attaching rubber feet to the bottom of the box makes a tremendous difference, it almost completely eliminates box sliding.

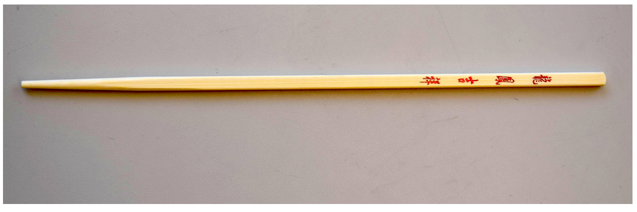


The Copter Assembly (again)

The copter assembly is attached to the shaft of the box-mounted angle-sensing potentiometer using a bamboo chopstick (bamboo chopsticks are squarer than regular round wooden chopsticks), electrical tape, and rubber bands.

Chopstick

The propeller arm is lengthened using a square bamboo chopstick.



Electrical Tape

We'll use electrical tape to connect the propeller to the chopstick.

Screwdriver

A small phillips screwdriver is needed to tighten the screw that holds the propeller blade to the shaft motor gear. If you forget this screw, the propeller with fly off the motor, and that is unsafe.

Scissors

Scissors with a sharp point is useful for cutting holes in the plastic box.

Braces/Rubber Band

Rubber bands, and particularly orthodontic rubber bands, can be used to attach the chopstick to the shaft of the angle-sensing potentiometer. You can try gluing the chopstick to the shaft, but we do not recommend it. We've found that when your system goes out of control (which will and should happen), one hard collision of the arm with a table or wall will break a glue joint. Rubber bands are quicker to apply and reapply as needed.