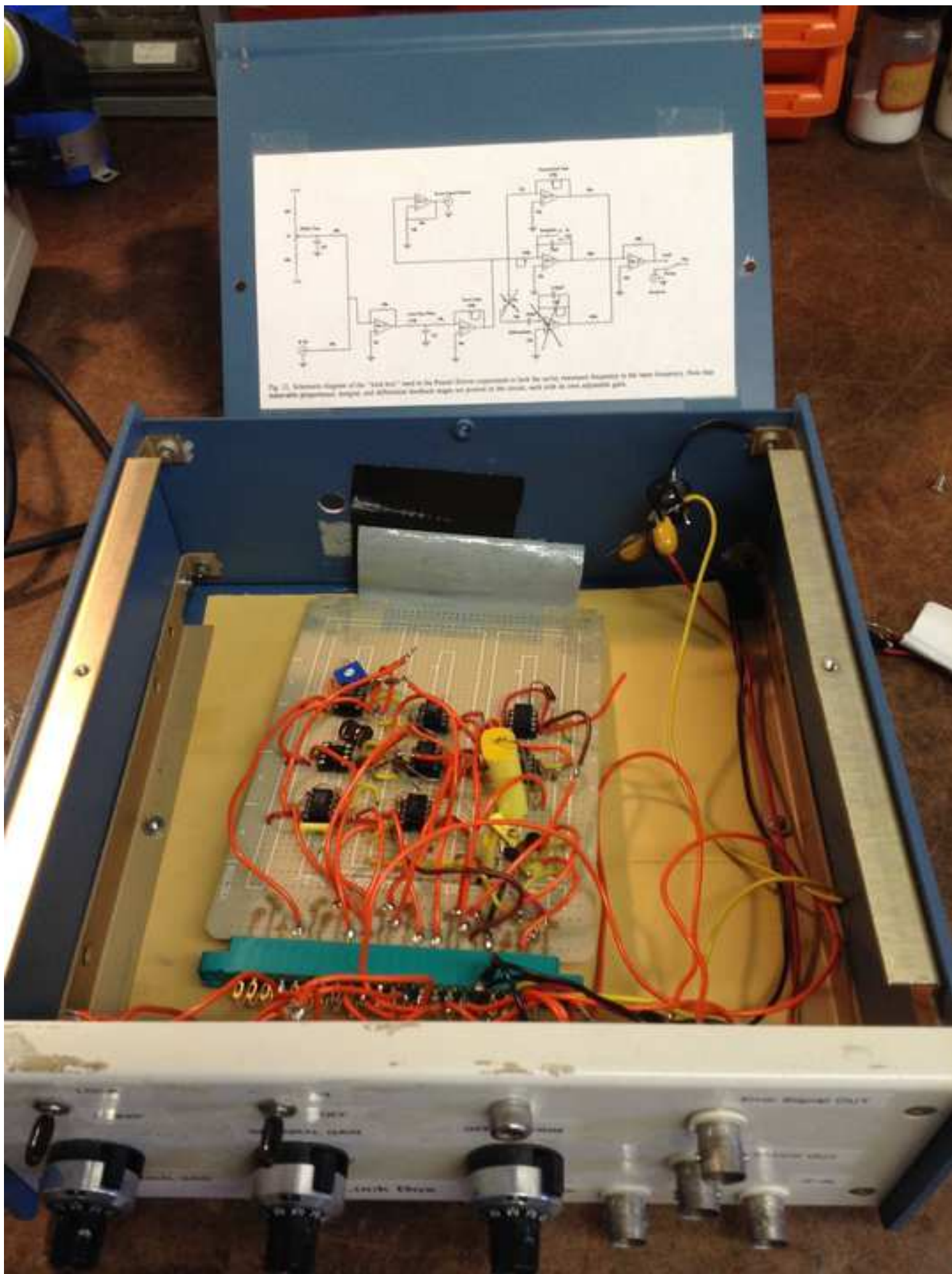


JoVE: Science Education
Soldering for Electronics and Vacuum Applications
--Manuscript Draft--

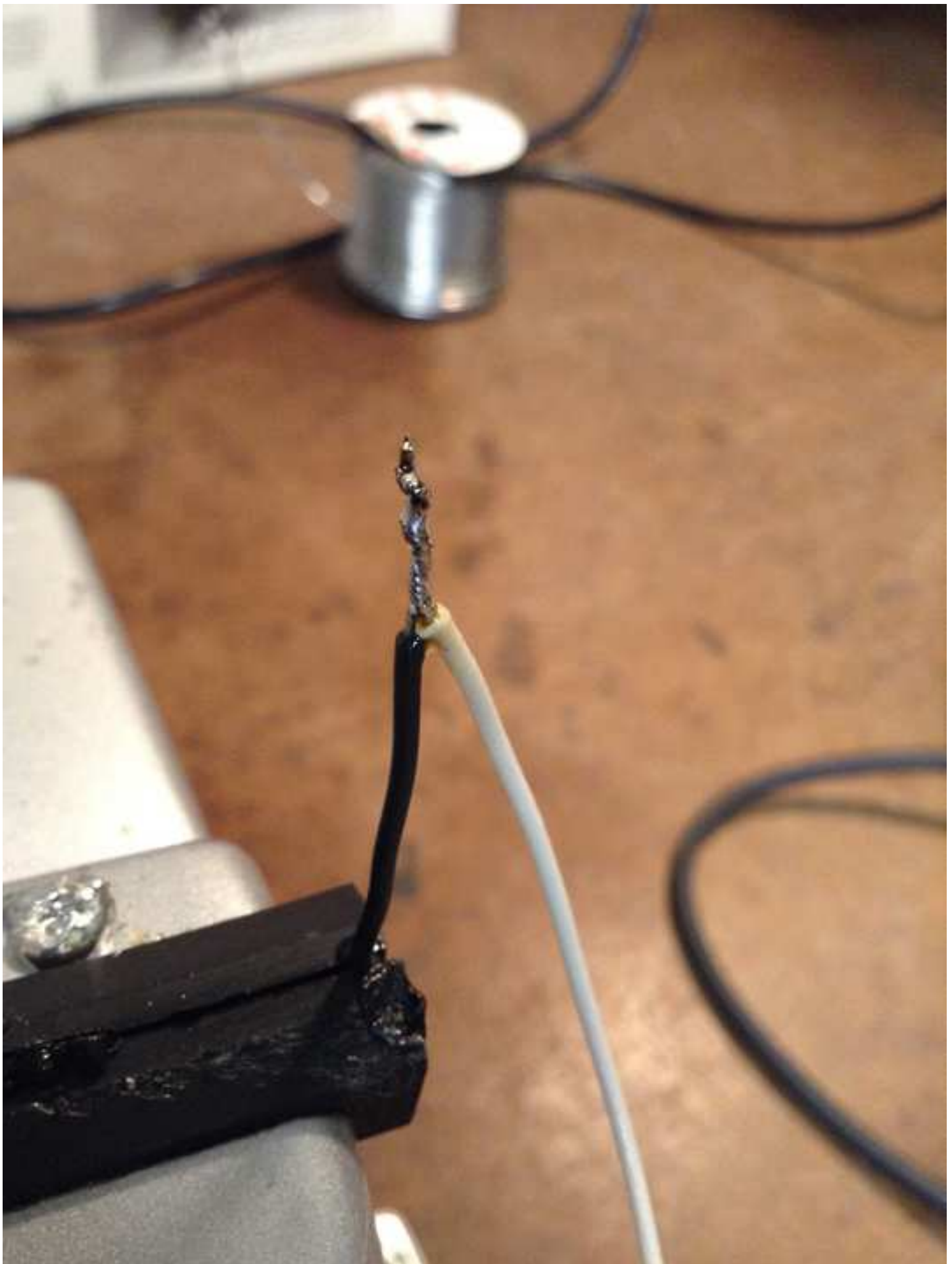
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Overview:
Soldering is an essential skill in a wide variety of experimental contexts. Electronic circuits used as part of an experiment are soldered together to ensure robust and reliable contacts, and many vacuum seals are fabricated using standard plumbing techniques. If a joint is water-tight, it is usually air-tight, as well, and thus, can be used in an experiment that requires vacuum.

Principles:
Soldering is the process of joining two metals by the use of a third that [sticks](#) [adheres](#) to both surfaces and has a low melting point, making it easy to work with. Soldering is very similar to gluing; however, unlike most glues, solder is electrically conducting. This makes it ideal for joining circuit elements, such as wires, resistors, capacitors, and integrated circuit chips, where current must flow relatively unimpeded between components.

Soldering is different from welding in that the surfaces to be soldered are not themselves melted.

To solder two pieces of metal together, first clean both and apply a fluxing agent. Flux helps the solder to wet and stick to the metal surface by dissolving oxides that form on metal surfaces upon exposure to the air (**Figure 1**). Second, press the two surfaces together and heat them, ideally by applying heat to the larger of the two and allowing it to heat the smaller one by conduction. Once the surfaces are hot enough to melt the solder, apply solder to the joint, allowing it to fill in all the necessary gaps. Remove the heat source, allow the joint to cool, and then inspect the solder joint. If all is well, the solder should solidify with a meniscus, having wet both surfaces evenly.

Many commercial solder wires contain a core of flux that melts, flows, and prepares the surface as soon as the solder is melted and applied, and this is often sufficient in place of a separate fluxing operation.

Traditionally, solder is a mixture of ~~6~~40% tin and ~~4~~60% lead, by weight. An ideal ratio of 63/37 forms an eutectic alloy with a distinct melting point at 361 °F (**Figure 2**). Concern over lead, however, has ~~lea~~d many to substitute other alloys, most of which are primarily >95% tin. (Both the state of California and the European Union have laws mandating the use of lead-free solder.) These lead-free alloys typically have a somewhat higher melting point, but other than that, the same techniques for tin/lead solder apply.

Procedure:
1. Safety.

Commented [A1]: Are these values reversed?
References online used 60% tin, 40% lead.

1.1 Always wear safety goggles. It is easy to flip a small drop of molten solder into an eye.

1.2 Clear the workspace of clutter, especially flammable objects, such as paper or cardboard.

1.3 Do not eat or drink while soldering.

1.4 Always solder in a well-ventilated area, especially when using lead-free solder, fluxes of which can be toxic.

1.5 Always wash hands after soldering and before eating or drinking. While the risk of forming lead oxide while using tin/lead solders is small, flux is not good for a person and is present even when using lead-free solders.

2. Basic Soldering.

2.1 Turn on the soldering iron.

2.2 Set its temperature to about 550°F (750°F for lead-free solders) (**Figure 3**).

2.3 Use wire strippers to remove the about 1 cm one-centimeter of insulation from approximately half of two sections of 22 AWG wire.

Commented [A2]: What is the length of exposed wire needed?

2.4 Clean the ends of the wire with a Kimwipe and isopropanol.

2.5 Twist the two ends together in a pigtail configuration.

2.6 Dip the pigtail into a tin of flux.

2.7 Anchor the wires in a bench vise.

2.9 Check that the soldering iron is hot enough by touching the solder to the tip. It should melt immediately upon contact with the iron.

2.10 Clean the tip by wiping it on the damp sponge stored with the iron's control unit.

2.11 Apply the tip of the iron to the pigtail, and wait a few seconds for it to heat up. The flux should melt and begin to smoke but not ignite.

2.12 While holding the tip against the pigtail with one hand (the left, for right-handed experimenters), gently feed solder in with the other, observing the melting and wetting of the solder into the pigtail (**Figure 4**).

2.13 When the joint is sufficiently covered with solder, remove the solder wire and the iron.

2.14 Allow the solder joint to cool. Blow on the joint to cool it.

Commented [A3]: Is this best practices?

2.15 Remove the wires, and examine them. There should be a meniscus where the solder meets the wire on both sides.

2.16 Set a digital multimeter to “continuity test.”

2.17 Apply the leads of the multimeter to the outside ends of the wire segments, and verify that the solder joint conducts electricity.

2.18 Switch from “continuity” to “resistance,” and measure the resistance of the solder joint. It should be near the minimum the multimeter is capable of registering, some small fraction of an ohm.

3. Surface mount.

3.1 Set the circuit board on the lab bench, and rest the component on its pads to verify that its footprint matches that of the solder pads it fits.

Commented [A4]: Wording is ambiguous.

3.2 Clean the pads on the circuit board and the feet of the chip with a Kimwipe soaked in isopropanol.

3.3 Apply a small amount of flux to each pad on the board and to each foot on the chip, or verify that the solder wire has a flux core.

Commented [A5]: Discuss this in the Principles section. When would you use separate flux and solder vs. solder with a flux core?

3.4 Heat each pad individually, and apply a very small amount of solder to each one. This process is called “tinning” and helps the solder adhere to both sides of the joint. to “tin” it.

Commented [A6]: What does this phrase mean?

3.5 Set the chip back on the board in its final configuration.

3.6 Hold the chip down with a pair of forceps with one hand, and with the other, apply the tip of the soldering iron to the top of each foot until it seats onto its respective pad.

3.7 Inspect all of the solder joints. A microscope is usually needed to observe the meniscus here, which is usually more trouble than it’s worth for a quick prototype. but each foot being flat on its pad is usually a good indication of a meniscus.

Commented [A7]: Do you ever check the meniscus with a scope? If so, we’d like to show the process.

3.8 Check to make sure no solder has slopped over from one pad to the next. Each pad should be distinct and electrically isolated from its neighbors. This is a special concern with lead-free solders, which tend to form “tin whiskers” that can short

adjacent pads.

3.9 Check each connection with a multimeter.

Representative Results:

Figure 4 (placeholder- we can show the item soldered at the shoot in the actual video).

Applications:

In the past (up to about the 1980s), physicists often designed and built most of their own electronics themselves (**Figure 5**). Today, most electronics are commercially manufactured and bought with funding from research grants. The small amount that is built by physicists, however, is crucial to the success of their experiments. It is essential for any competent experimentalist to know how to design and construct electronic devices, and that means soldering their components together. A single poor solder joint with intermittent electrical contact can bring down the most ambitious research project. Care at this level is the difference between success and failure of an experiment.

In engineering, one would not dream of starting production without first building a prototype and testing it. This "one-off" construction should utilize the same printed circuit boards and surface-mount components as the final product, but it ~~should be~~ usually assembled by hand (**Figure 6**). The finished product should be essentially indistinguishable from a conventionally-manufactured unit, but making a single prototype does not require the facilities or techniques used in mass production. Soldering "by hand" becomes a very useful skill to have in your repertoire in this context.

Commented [A8]: Could you provide footage of the same circuit that has been both assembled by hand, and also manufactured professionally?

Legend:

Figure 1: Flux container. The flux inside is about the consistency of thick grease.

Figure 2: Two kinds of solder wire in spools. Optimum eutectic alloy of 63% tin, 37% lead on the left, more common 60/40 Sn/Pb on the right.

Figure 3: A typical soldering station in an electronics prototyping area. Note the soldering iron set to 550 °F, small vise, safety goggles, two kinds of solder wire, flux, and wire strippers.

Figure 4: Soldered "pigtail" connection between two wires. **Placeholder- actual final result will be shot day of filming.**

Figure 5: The simplest example of an experimenter-built electronic device. A passive lead for stabilizing a feedback servo, composed of two resistors and one capacitor soldered in a particular configuration between two connectors. It doesn't have to be pretty to get the job done, but its solder joints do have to work.

Figure 6: A more complicated prototype for laboratory use. This is a PID box with adjustable offset for laser-frequency stabilization. Note the schematic taped to the underside of the box cover for future reference.

