Dummy Load Assembly Manual

by

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This is the first build of the newly-formed Greater Cincinnati Builders Group. The build is a dummy load (DL) that is used to adjust/monitor the output from a transmitter. The features of this DL include:

- 150 W power handling capabilities
- Digital display of power input to DL; no dangling wires between DL and display
- Self-contained battery powered
- Easily detached display unit
- Small size
- Low Cost

The purpose of this manual is to help the builder complete a successful build. On the other hand, Al and I are not responsible for people who don't read and/or understand these instructions.

The circuit

The electronics of the DL is extremely simple, resulting in low assembly time due to a small parts count. Figure 1 presents the circuit for the DL. The resistor assembly, R3, is built from twenty 3 W 1000 Ω

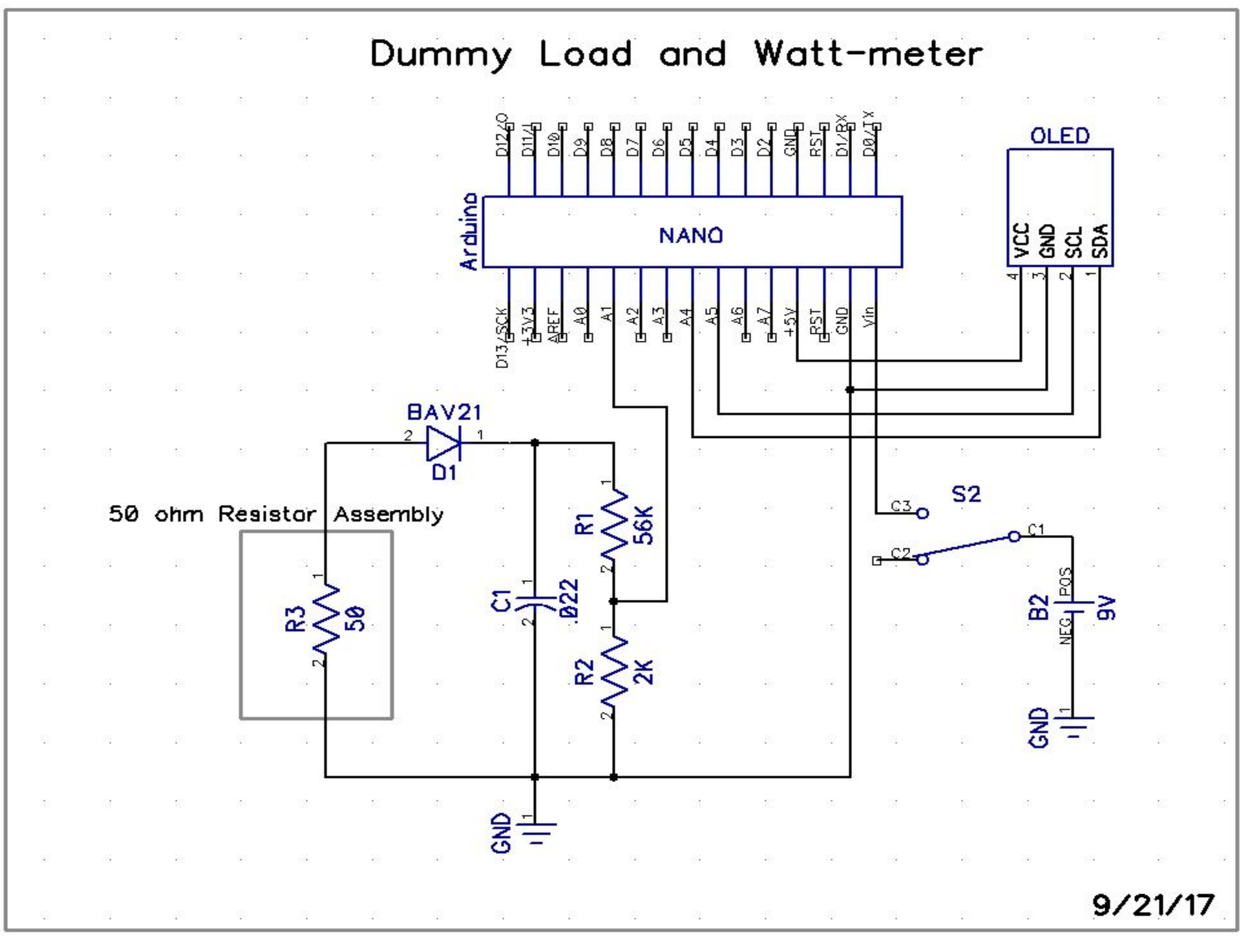

Figure 1. Circuit diagram for DL.

metal film (non-inductive) resistors. By connecting these 20 resistors in parallel, the effective result is a 60 W 50 Ω resistor. By immersing the resistors in a mineral oil bath, the DL is capable of handling considerably more power than if we simply used an air-cooled resistor network. We use mineral oil rather than transformer (or similar oils) because it's non-toxic. Indeed, you could drink the coolant, although you likely will experience the Green Apple Quickstep as a result.

Figure 1 shows that one side of the resistor network is referenced to ground (GND) while the other side is fed through a BAV21 diode to the active circuitry. R1 and R2 create a voltage divider, the output of which we can feed into the Arduino Nano microcontroller. The values selected for these resistors ensure that the voltage being fed into the analog pin A1 on the Nano never exceeds 5 V, which is the maximum voltage a Nano can take on its analog pins. Feeding more that 5 V into a Nano pin almost always makes the Magic White Smoke leave the Nano, leaving you with a small silicon brick. The purpose of C1 is to average the rectified RF to a dc voltage and reduce any other noise present on the input.

The rest of the circuitry is used to feed information to the OLED display using the Serial Peripheral Interface (SPI). This interface simplifies data communications between the Nano and the OLED using the SPI library supplied with your Arduino IDE. Two graphics libraries from Adafruit are also used and their URL's are included in the project source code should you wish to examine them. We will be downloading the compiled code to your Nano at the build in order to calibrate your DL.

The DL Lid

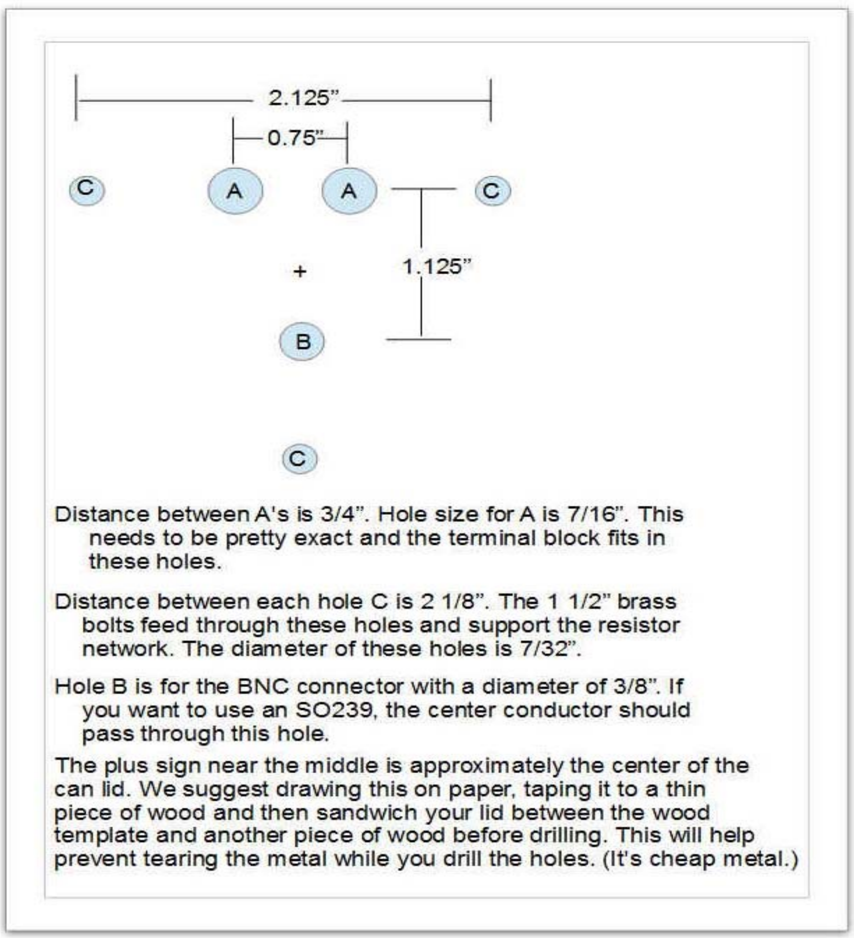

Figure 2. The lid template.

You were sent the dimensions of the holes that need to be drilled into the can lid that holds the oil. This is repeated in Figure 2. We ask that you do this before coming to the build to free up that time for the rest of the build. Be sure to sandwich the lid between two pieces of wood before drilling as the metal used to make the lid is very thin and will tear. Note that if you use an SO239 connector for the coax, hole B can be a little smaller, but you must also drill 4 additional holes for mounting that type of connector. Also note that the C holes form an isosceles triangle with each leg measuring 2 1/8" apart.

Mounting the Electronic Components

Figure 3 shows the components for the DL.

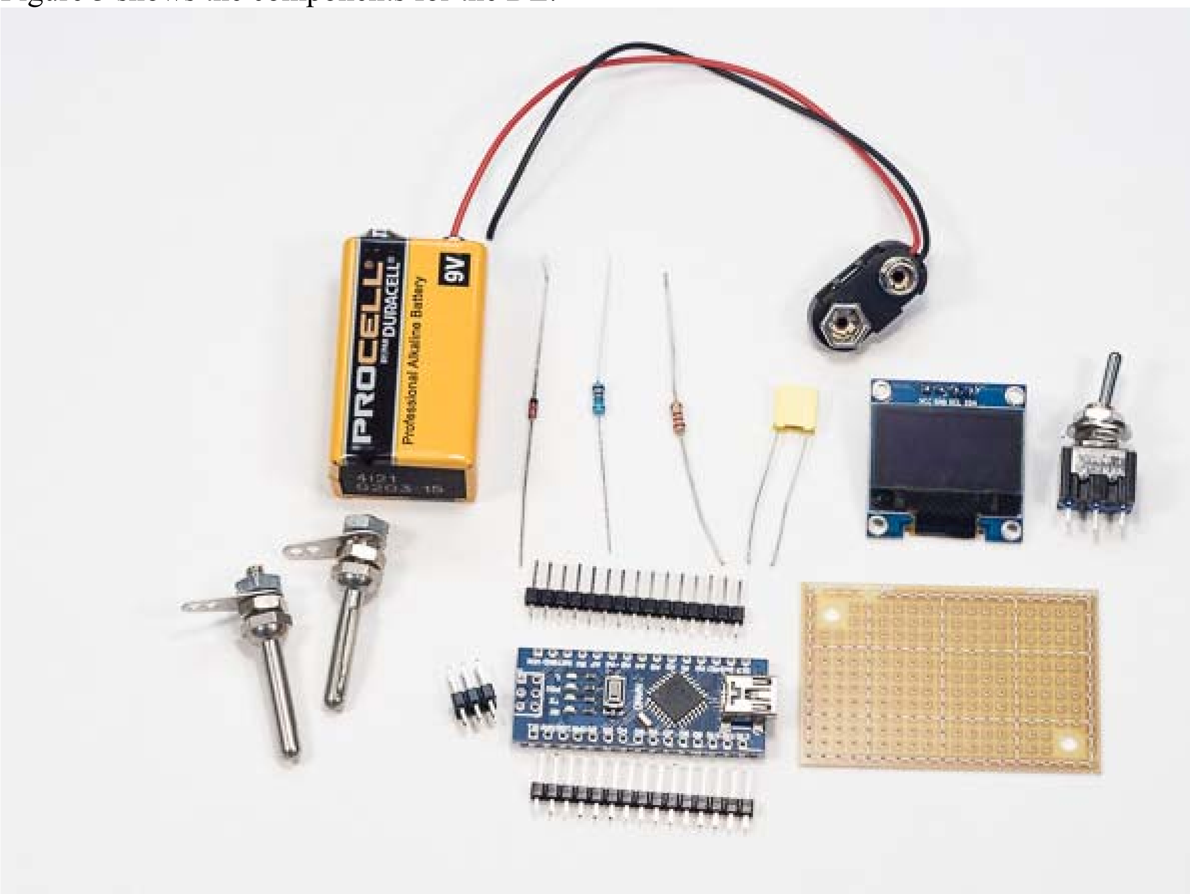

Figure 3. DL components.

Not shown in Figure 3 is the resistor network that you will construct at the build or the 4 pin header socket. Al has fabricated two jigs to make assembling the resistor network faster and easier. Figure 4 shows the resistor network on one of Al's jigs. The second jig allows you to bend the resistors for a

Figure 4. The resistor network jig with loops and resistors in place.

perfect fit on the two copper wire loops. When all of the resistors are soldered in place, loosen a threaded nut that is on one of the jig's end pieces, which lets you easily take the resistor assembly off the jig. Thanks Al!!

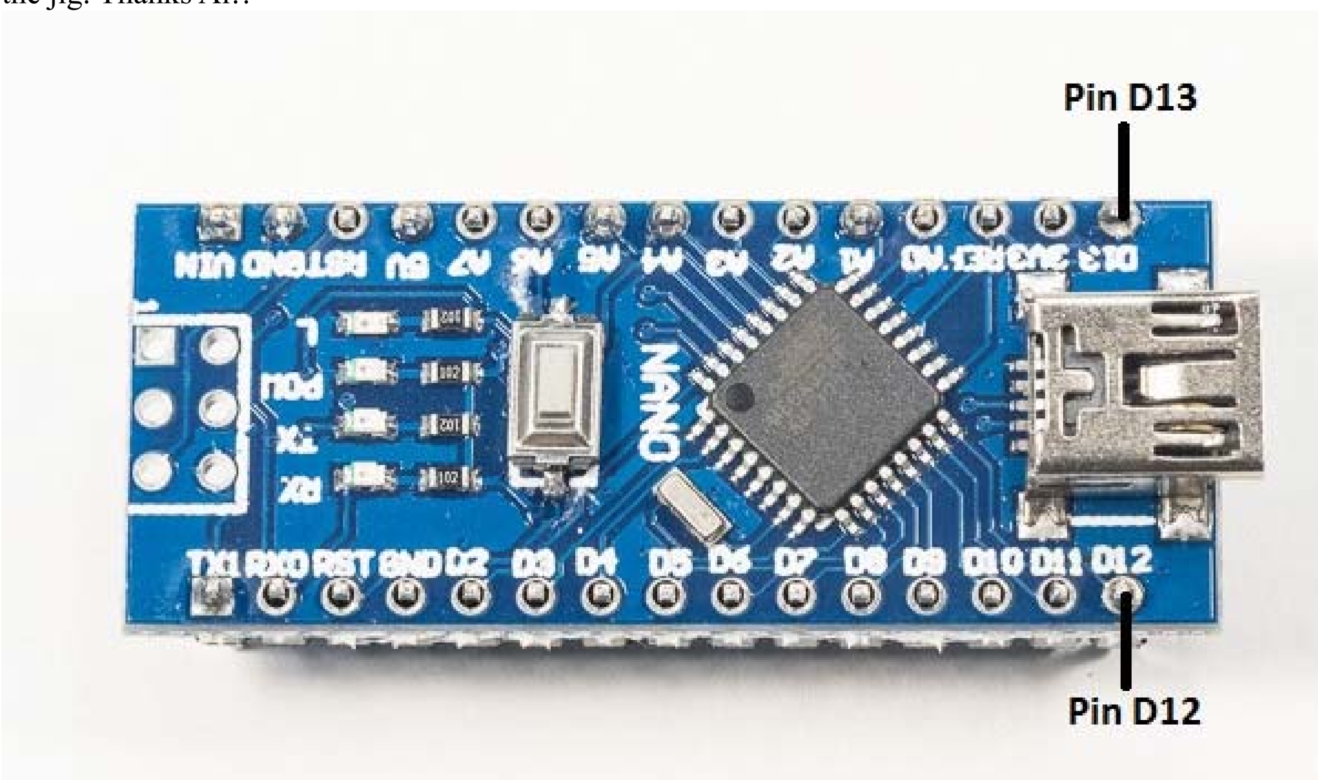

Figure 5. Soldering header pins for the Nano to the circuit board

Soldering Header Pins to the Nano Board

Figure 5 shows how the header pins are soldered to the Nano. First, inspect the Nano header pins shown in Figure 2. You will note that the plastic collar is not symmetric; there is a "long pin" and "short pin" side for each pin. You can probably tell in Figure 5 that it is the short side pins that are protruding through the Nano pin holes. The plastic collar and the long side of the header pins are on the other side in Figure 5. Place the 2 rows of header pins on either side of the Nano with the short side protruding through the Nano. You can use the circuit board to steady the pins. The weight of the Nano allows you to hold the pins in place. Now solder pin D12 and pin D13. Do not solder the rest of the pins at this time. With those two pins soldered in place, flip the Nano over and make sure the plastic collar is fitting snugly to the Nano board. It is important that the plastic collar fits snugly to the board as the long pins eventually will be threaded through the small circuit board and become tie points for other components. When you are sure the plastic collar is seated properly, you can solder the rest of the pins to the Nano board.

Soldering the 4-Pin Header Socket

Figures 6 shows the top view of the circuit board while Figure 7 shows the bottom side of the circuit board. Place the 4-pin header socket on the board so that it is positioned as shown in Figures 6 and 7. Figure 7 should be used to check that you have the proper placement of the 4-pin header socket. The placement of the 4-pin header socket is important because it must align with the OLED that will be mounted to the project case. With the 4-pin header socket in place on the circuit board (and the Nano not yet on the board), flip the board over so you can check its placement compared to Figure 7. Solder

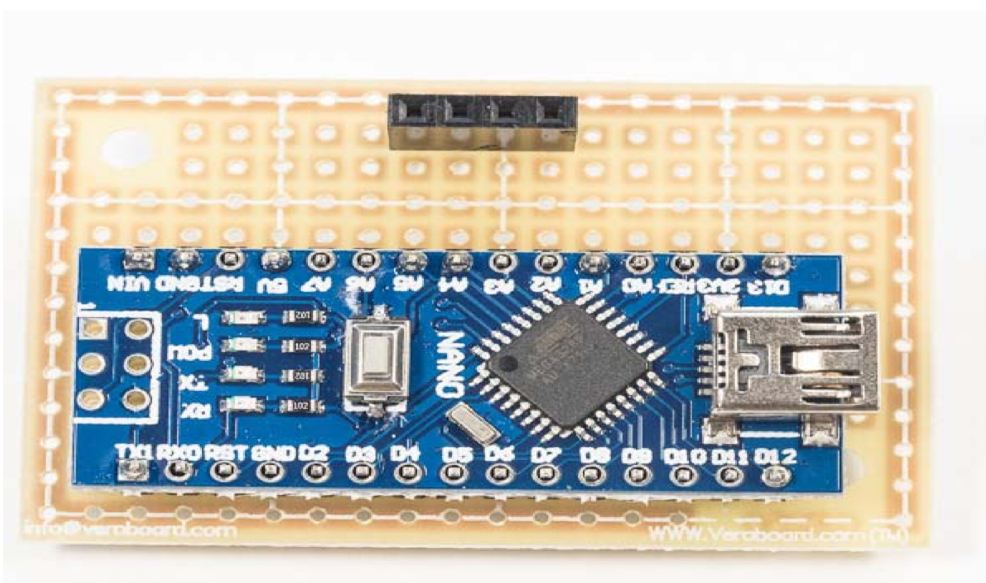

Figure 6. Top view of circuit board.

one of the end pins of the 4-pin header socket in place. Flip the board over and make sure the socket fits snugly to the small circuit board. Once you are certain it is in the proper position on the board, flip it back over and lightly solder the remaining 3 pins. The purpose of the solder is to simply hold the header socket in place on the circuit board. You don't want to gob-up the solder on the pins as those pins eventually plug into the OLED display.

If you look closely at Figure 7, you will note that Al only completely soldered the end pins of the Nano. Again, you should do this to make sure the Nano is sitting snugly on the circuit board as we want the maximum length of the long pins sticking through the circuit board. Some of these long pins are used as mounting points for other components.

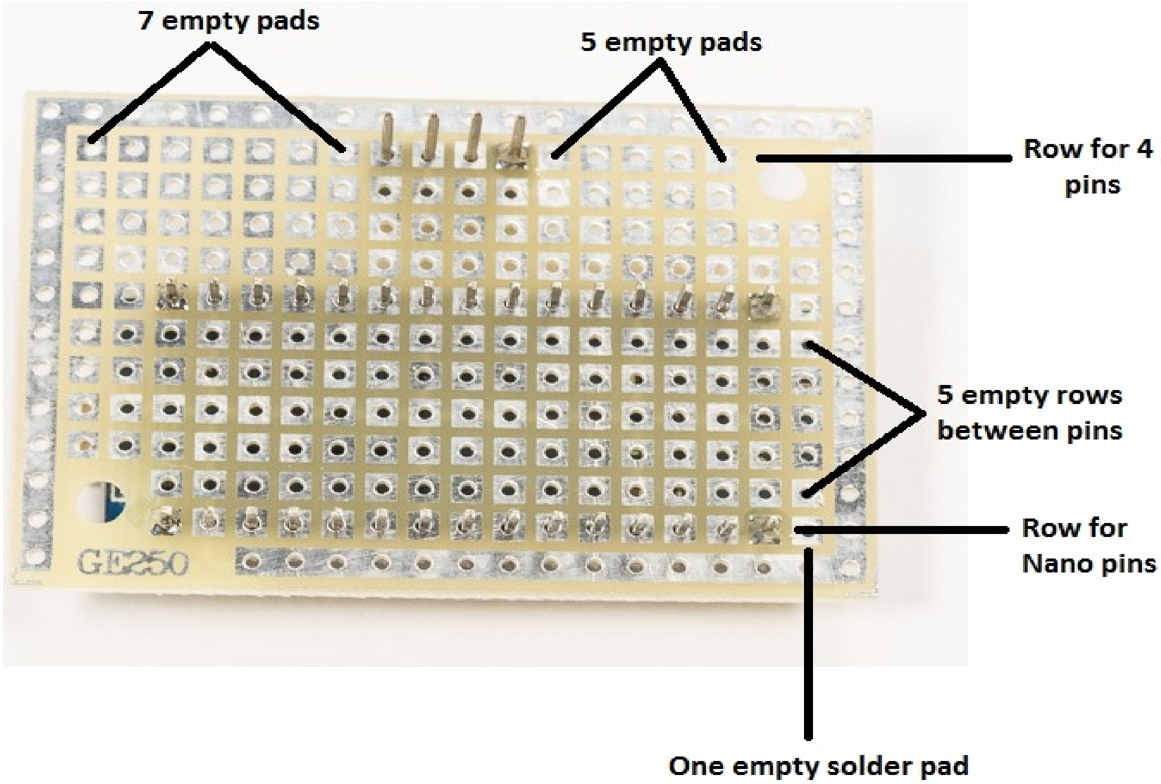

Figure 7. Underside view of circuit board.

You are now ready to solder the Nano header pins to the circuit board. Again, use Figure 6 and 7 to position the Nano properly on the circuit board. When positioned correctly, the top view of the board should look like Figure 6. Figure 7 allows you to double-check you've got it right. Lightly solder each of the Nano pins using small amounts of solder like Al used. Note again: Al and I are not responsible for people who rush through and don't understand these instructions.

Wiring the Circuit Board

If you look near the upper-left corner of the Nano in Figure 6 and count inward towards the center, you see that the 4^{th} pin is marked "5 V". The Nano can be fed an input voltage between 7 V and 15 V and the onboard voltage regulator drops it to 5 V for use by the Nano. We power this circuit, for example, using a 9 V battery and the regulator converts it to 5 V. It is also possible to share this 5 V provided you're not trying to run a refrigerator on it. Fortunately, the current draw by the OLED is sufficiently small that we can share that 5 V to power our OLED display.

Wiring the OLED

The solder connection you must make for the 5 V connection is shown in Figure 8. It is a common convention to use red wire for making positive voltage connections (e.g., 5 V in our case).

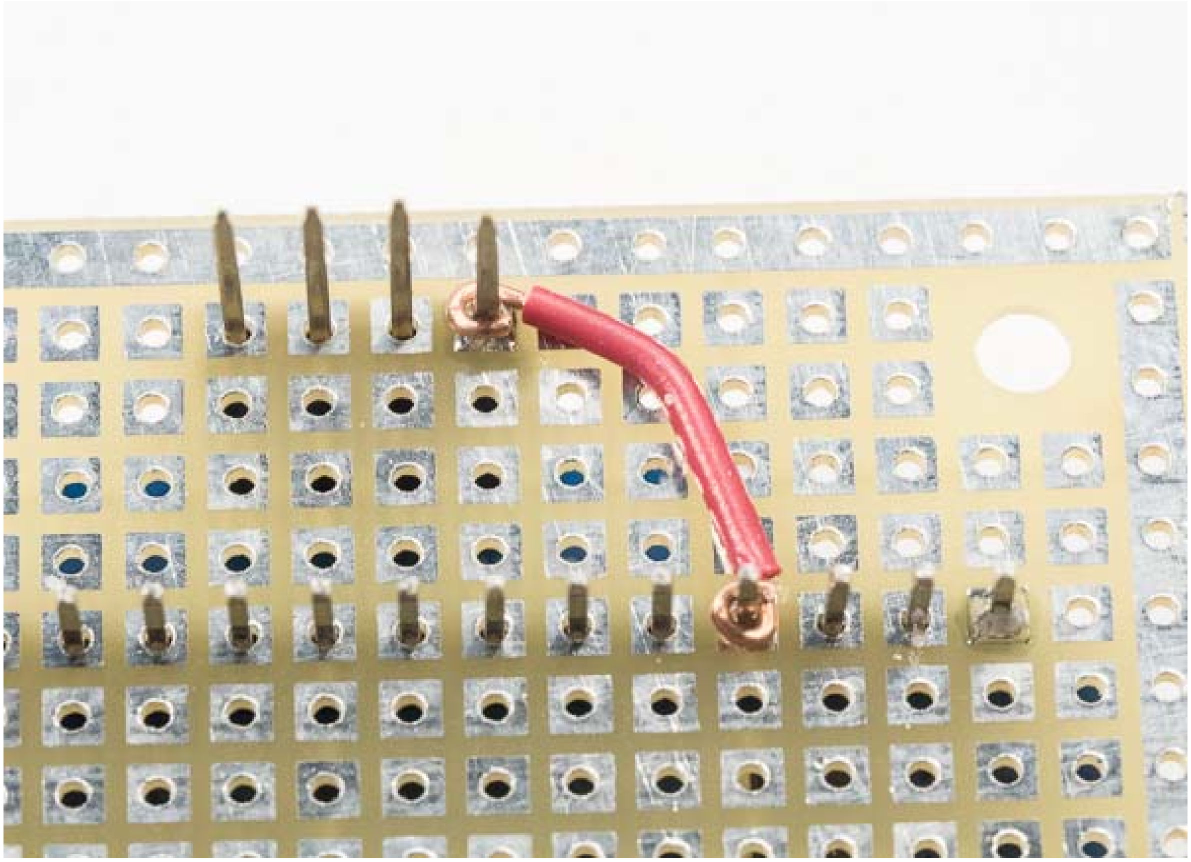

Figure 8. Wiring the 5 V source from the Nano to the OLED.

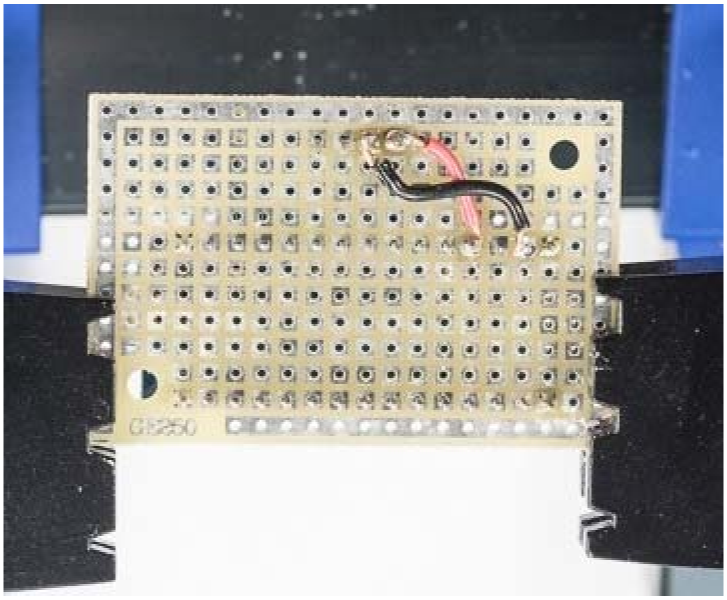

Figure 9. Wiring the ground path for the OLED.

Because every circuit needs a return path to work properly, the next task is to solder a ground connection to the OLED display. This can be seen in Figure 9. The common wiring convention is to use black wire when making a ground (GND) connection. Solder both ends of the red (5 V) wire, but only solder the end of the black wire that connects to the 4-pin header socket. The unsoldered end on the GND pin of the Nano will be soldered later.

There are two more connections on the OLED; the clock (SCL) and the data (SDA) lines. The OLED display uses what's called the SPI interface protocol. Simply stated, the protocol allows multiple devices to communicate with the Nano using a simple two-wire buss plus power and ground. For the Nano, the SCL and SDA lines are wired to pins A4 and A5. (See circuit diagram in Figure 1.) Figure 10 shows these connections on our circuit board. There is no established wire color for the SPI protocol that we are aware of, so use whatever is handy. Make sure you have the wires connected to the proper pins on both the Nano and the OLED. (Note that there are two unused pins between the 5 V Nano source pin (5 V) and pin A4 connecting to SCL on the OLED. The next pin on the Nano, A5, connects to the SDA pin on the OLED.)

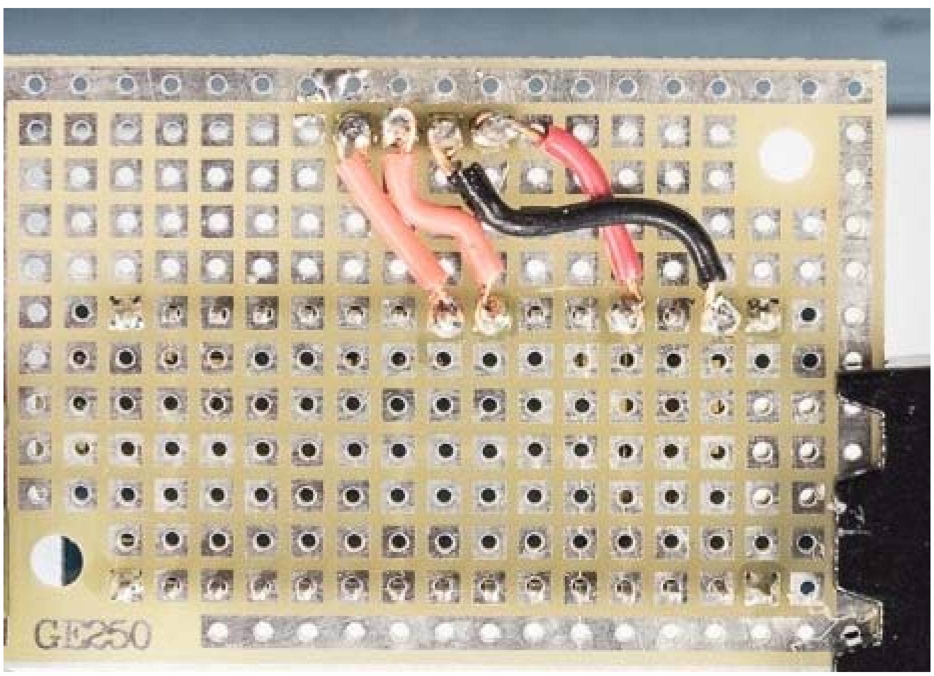

Figure 10. Wiring the I2C protocol SCL and SDA lines to the Nano.

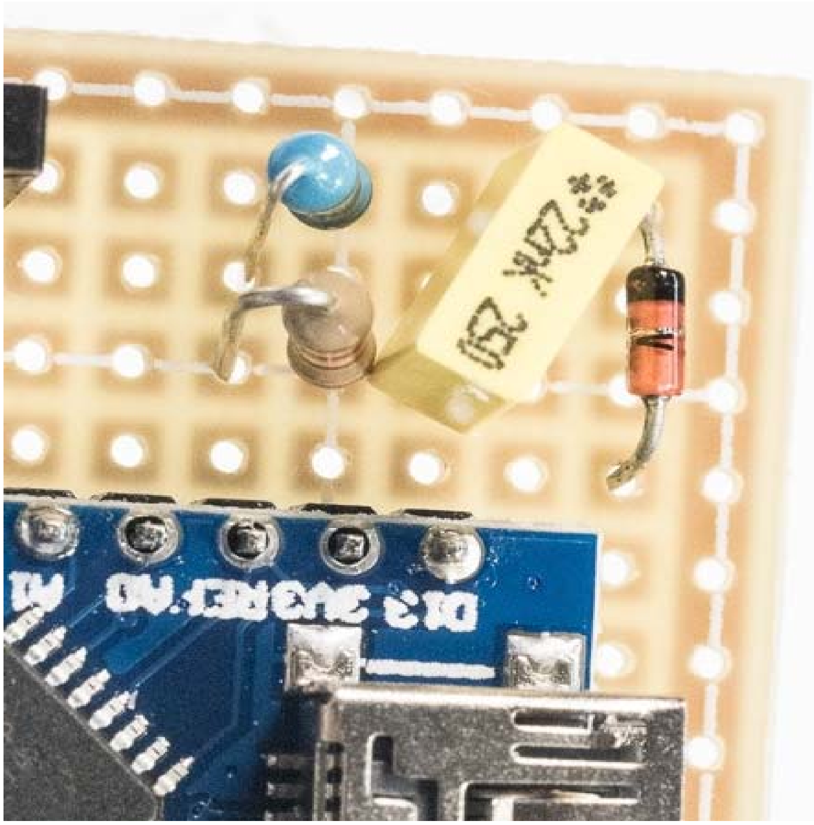

Figure 11. Placement of Power Sensor Components

Wiring the Power Sensor Components

As you can see in the schematic in Figure 1, there are two resistors, a diode, and a capacitor that need to be added to our circuit. The components are shown in Figure 11. Notice that these parts are located in the upper-right corner to the circuit board, above the Nano and to the right of the 4-pin socket. The diode is the glass component on the right edge of the circuit. Note that the “banded end” must be oriented towards the top of the board as diode polarity is important. You can put the diode in the circuit the other way, it's just that the DL won't work then. Your choice...

Figure 12 shows the component leads shown in Figure 11, but from the opposite side of the circuit board. If you look closely in Figure 1, you'll notice that each “side” of a component has been labeled with a 1 or a 2. Those pin positions on the schematic are used in Figure 12 to make the component placement more clear.

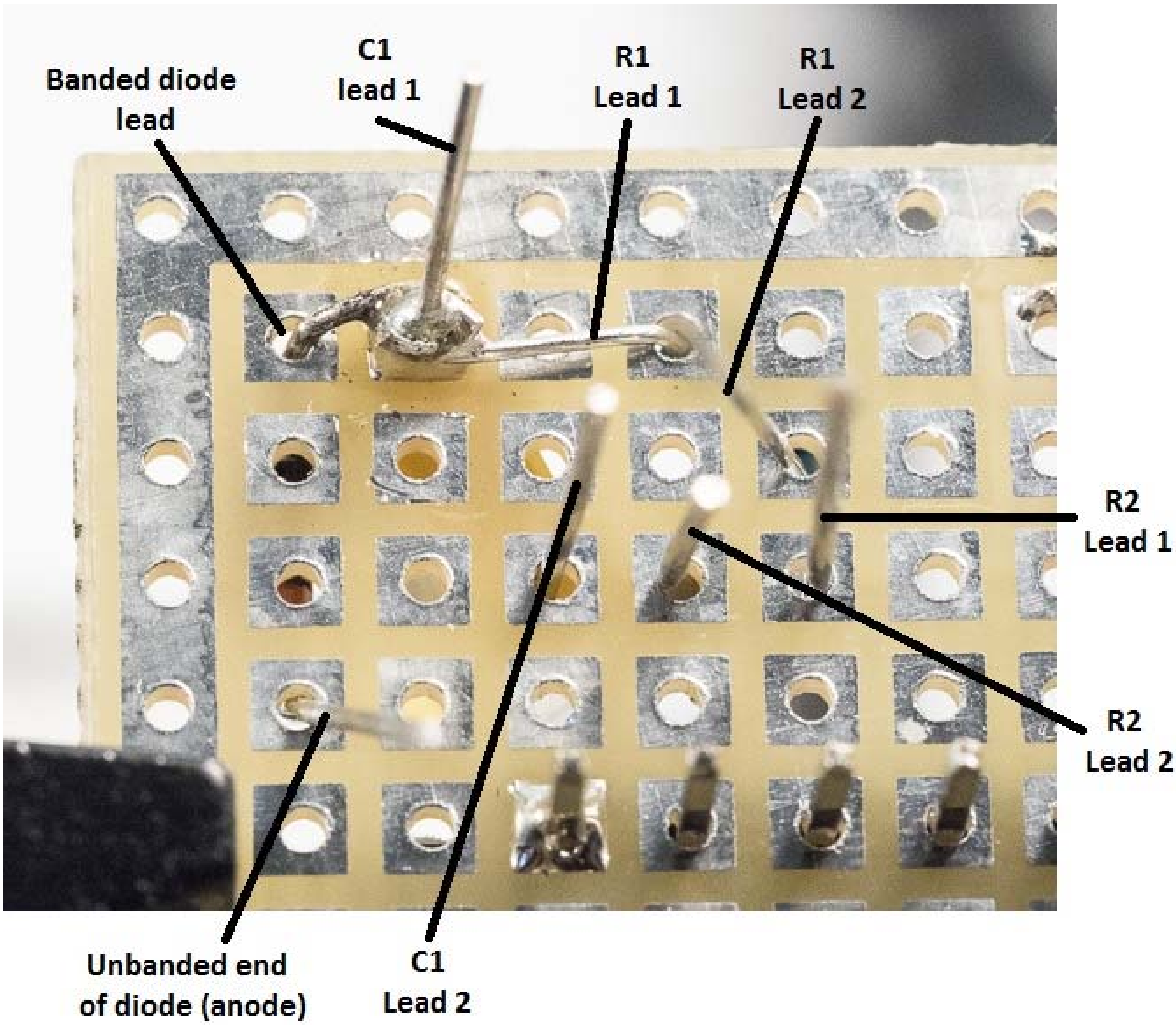

Figure 12. Power sensor leads, underside view of circuit board

Figure 13, along with Figure 12, will help make the following instructions more clear. The banded end of the diode (cathode, or Lead 1 in the schematic) is wrapped around Lead 1 of capacitor C1. Lead 1 of resistor R1 is also wrapped around Lead 1 of capacitor C1. You can see this three-wire junction in Figure 1. Note: diodes are not happy with a lot of heat, so quickly solder the three-wire junction you just formed. (Figure 12 shows these leads in their soldered state.)

The unbanded end (anode, lead 2 in the schematic) of the diode has a 6" red wire soldered to it. Strip 1/8" of the insulation off both ends and wrap one end of the wire around lead 2 of the diode, D1. Eventually, this red wire is soldered to a chassis mount banana plug. That plug ultimately plugs into the red binding post on the banana terminal block on the can. For the moment, however, simply solder the wire to the diode. Remember: Diode get cranky with a lot of heat.

Wrap lead 2 of R2 around lead 2 of C1. Push the wire down as close to the circuit board as you can. Next, cut a 6" piece of black wire, trim off 1/8" from both ends, and wrap one end around lead 2 of C1. Now cut a 2" piece of black wire, trim off 1/8" from both ends, and also wrap one end around lead 2 of C1. There should now be 3 wires wrapped around lead 2 of C1:

1) lead 2 of R2,
2) a 6" black wire
3) a 2" black wire

You can see the three connections on the right side of the board in Figure 13. Loosely twist the 6" red and 6" black wires together. (Al did not strip the other ends prior to the photograph.) Now solder all three wires to lead 2 of C1.

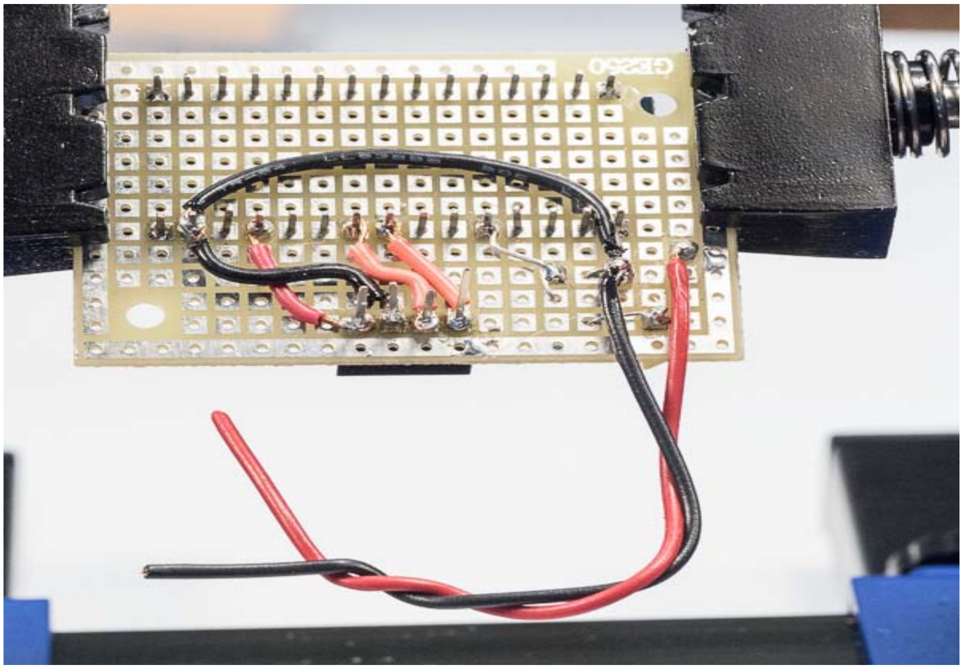

Figure 13. Connecting the sensor leads

Now route the short 2" black wire as shown in Figure 13 to the GND pin on the Nano. The Nano GND pin should now have two black wires attached to it. Solder the two black wires to the GND pin of the Nano. Your board should look like Figure 13 at this point.

Mounting/Wiring the Switch

Locate the SPDT toggle switch and mount it in the same size hole in the case faceplate. (If you have a different case, mount the switch in the hole you drilled in your case front.) Al's custom faceplate has a hole for the switch. Mount the switch as seen in Figure 14.

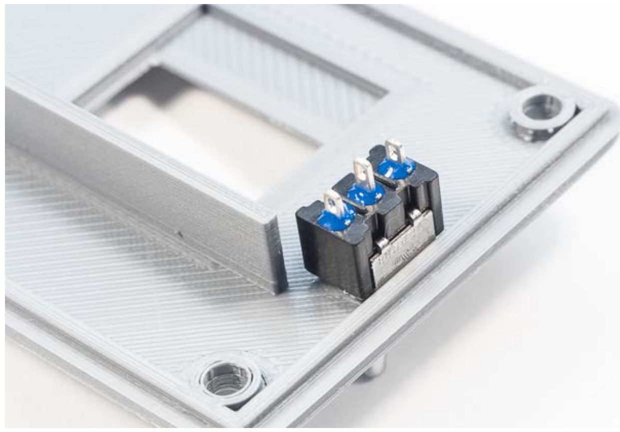

Figure 14. Mounting the SPDT switch

Take a 4" piece of red wire and trim 1/4" of insulation from both ends.

If you look back to Figure 6 of the Nano, in the upper-left corner the last pin is labeled VIN. This stands for the "voltage input" that will power the Nano. For our project, that power comes from a 9V battery. That 9V is fed into the Nano's internal voltage regulator which, in turn, generates the 5V that we routed to the OLED via the Vcc pin on the OLED.

Because we are working on the opposite side of the Nano as seen in Figure 6, the red wire from the switch is attached to the right-most pin (Vin) of the row of pins near the center of the circuit board. (See Figure 15.) Solder one end of the 4" red wire to the VIN pin of the Nano. Solder the other end of the 4" red wire to the center post of the switch shown in Figure 14.

Wiring the Battery Clip

Take the battery clip and strip off 1/4" from both the red and black leads. Because these wires are stranded, take your soldering iron and heat the bare wire for a few seconds and then lightly touch the solder to the wire. A small amount of solder will flow through the stands, holding them together. This process of "tinning" the leads makes it easier to thread the lead through a switch post or wrap around a Nano pin.

The (now-tinned) red battery wire should be attached to one of the remaining empty posts on the outer edge of the switch. Solder the wire to the switch post. Take the black (also tinned) battery wire and add it to the ground pin (GND) of the Nano. The Nano GND pin is the same pin that has the black wire leading to the OLED display and a second black wire that goes to lead 2 of C1. Solder the three wires to the GND pin of the Nano.

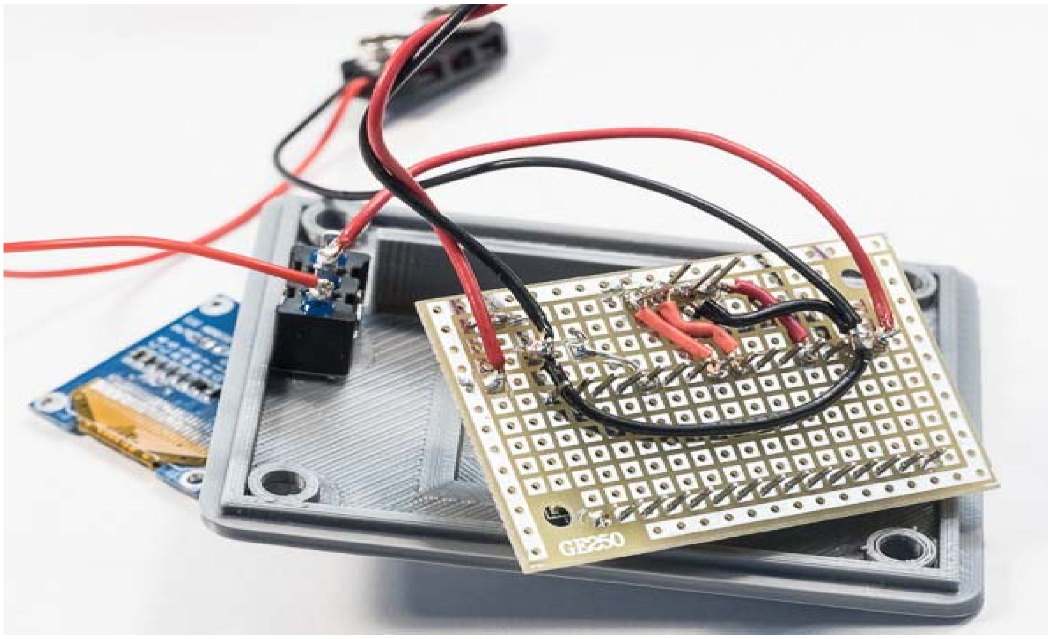

Figure 15. Switch and battery clip wiring

Mounting the OLED Display

Take the OLED display and orient it in the OLED cutout in the faceplate. Al molded a "shelf" that is immediately above the OLED and the OLED should fit snugly against the shelf and in the faceplate cutout. You may want to test the fit of the OLED and the small circuit board since the 4 pins you see on the OLED must mate properly with the 4-pin header socket you mounted on the small circuit board. Using a hot glue gun (we will have one at the build), put a small dab of hot glue on each corner as shown in Figure 16. Take a short break and go buy Jack and Al a Krispy-Kreme doughnut while the glue cures. The glue should set completely before continuing.

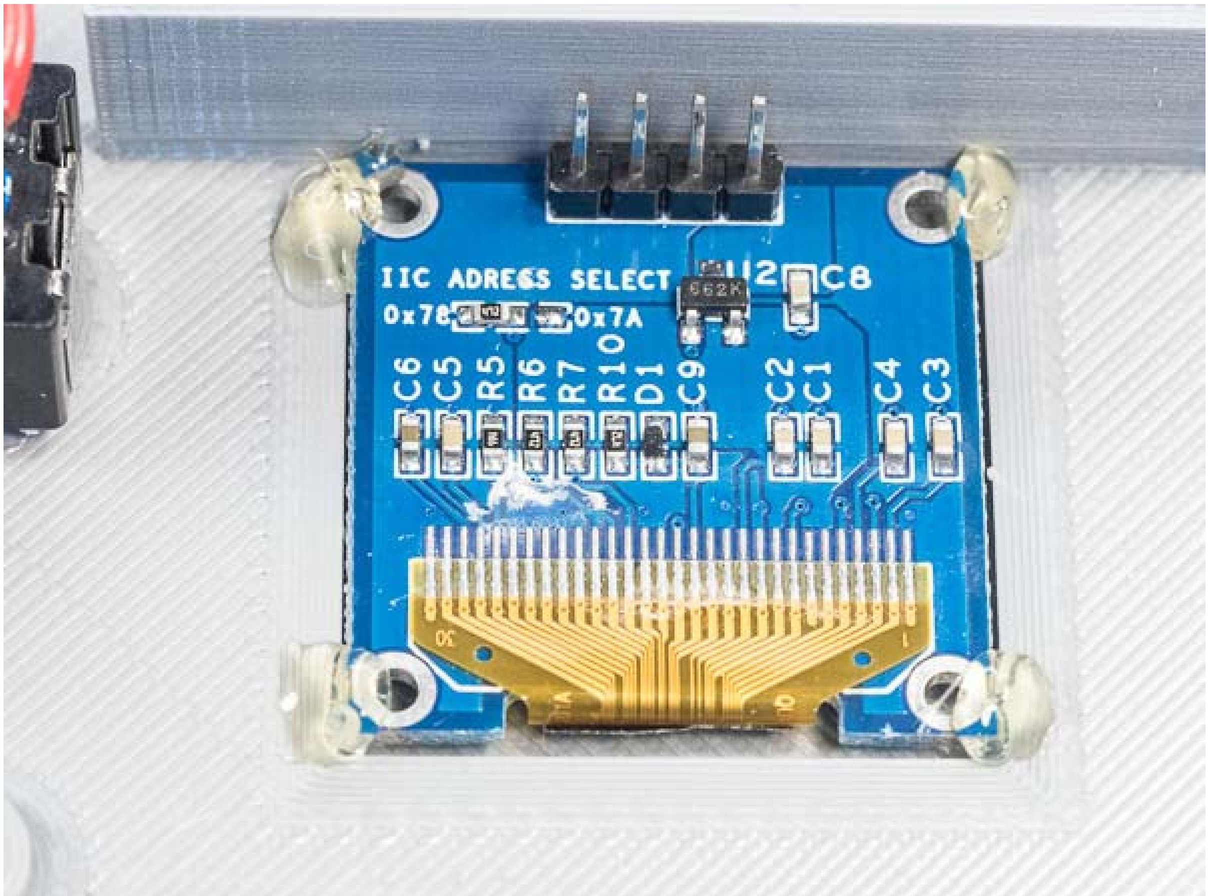

Figure 16. Gluing the OLED in place

Mounting and Wiring the Banana Posts

Plug the four pins on the OLED display into the 4-pin header on the circuit board. Figure 17 shows how the 6" red and black wires from the circuit board are connected to the chassis mounted banana posts. it does not matter which post gets which wire, since the signal at this point is AC. With this arrangement, the display unit can be plugged in either way.

Lay the back of the case on your work surface and attach the two banana posts to the mounting holes. Don't forget to place solder lugs on each post. Now take the gently-twisted red and black wires (See Figure 13) and connect the red wire to the left banana terminal post's solder lug. Solder the connection. Take the black wire and connect and solder it to the remaining solder lug. Make sure the mounting nuts are tight. Once tightened, a drop of hot glue on the threads of each post will help insure that the banana posts remain secure.

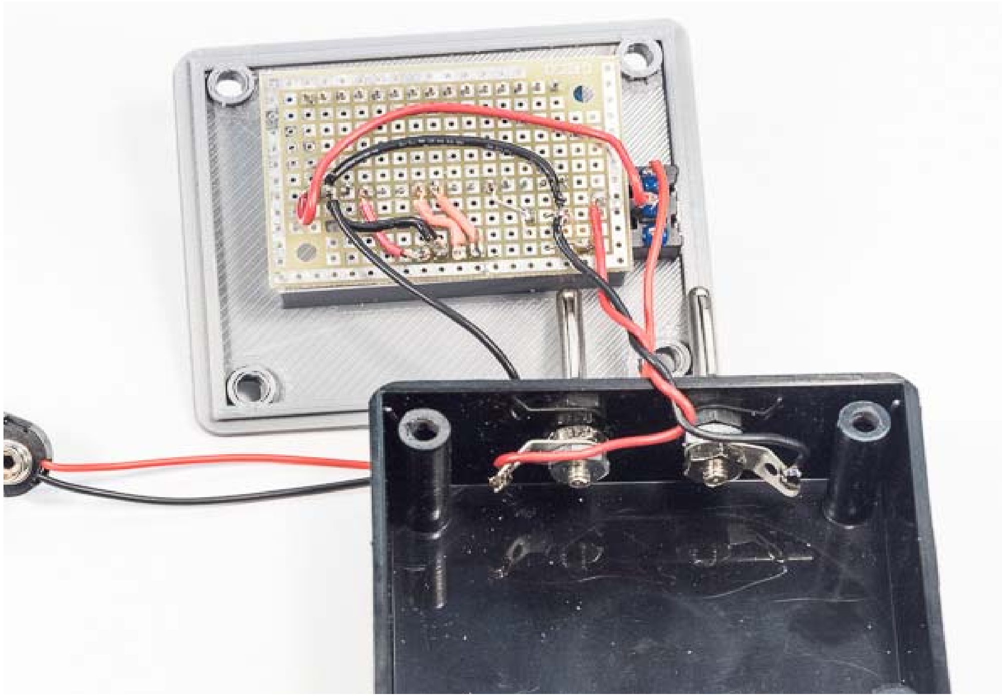

Figure 17. Mounting/Wiring the banana posts

Figure 18. Positioning the Battery

Now connect the 9V battery to the battery clip using the polarity that is enforced by the clip. The battery sits on the shelf that is molded into the case. See Figure 18. Flip the toggle switch to make sure it activates/deactivates the OLED display. If so, tuck the wires into the case and secure the faceplate with four screws.

Mounting the Resistor Network

Figure 19 shows how the resistor network is secured to the can lid. Brass washers are required since

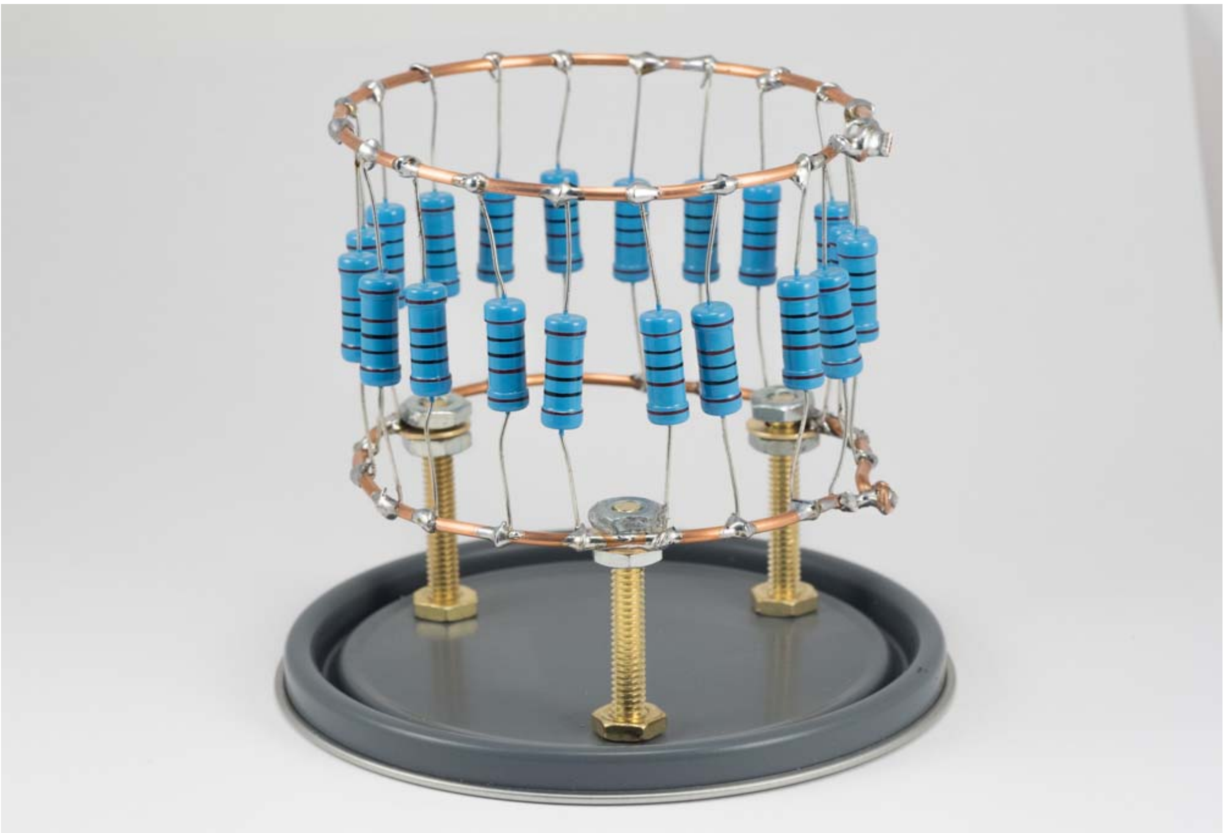

Figure 19. Securing the resistor network to the DL can lid

stainless steel does not solder well. Although not shown in the figure, you should also have already mounted a coax connector on the lid and made cutouts for the two-post banana terminal block. This is not shown in Figure 19 because the connector depends on which connector you chose to use (e.g., BNC, SO239). Scrape away any paint on the can lid that is under a mounting nut for your coax connector to insure a good ground connection.

Position the banana post terminal block so the outside of the block looks like the cover photo. Secure it in place with the nuts and bolts supplied with the terminal block. Figure 20 shows the internal wiring of the resistor network and how it is attached to the lid of the can. Use the heavy gauge black wire and connect the wire from the ground lug on your coax connector, to the black banana terminal post, and then to the copper wire of the resistor network that is closest to the lid. Connect the heavy gauge red wire from the center conductor of your coax connector to the red banana terminal post and then to the copper wire that will be closest to the bottom of the can. Solder the connections to the coax fittings and to the copper wires. The connections to the terminal posts are secured with the bolts that come with the terminal block.

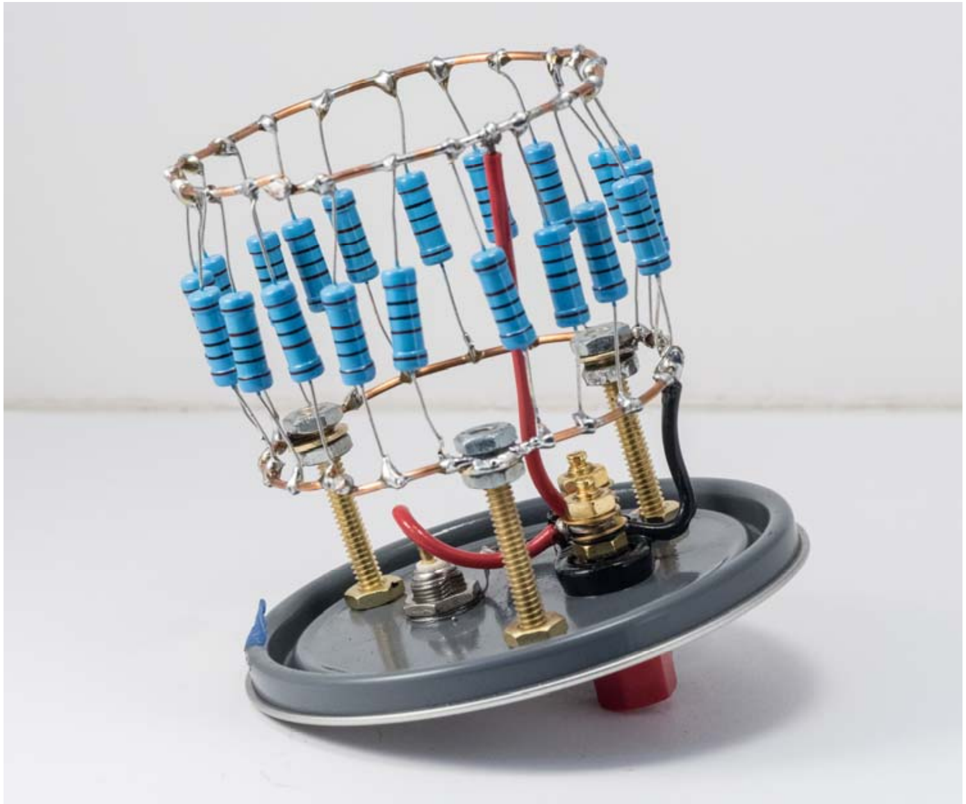

Figure 20. Wiring of resistor network

Liberally apply silicon caulk to all of the areas on the lid that have been drilled to prevent leakage. That's it! Fill the can with a quart of mineral oil and you're done.

Calibration

You will need to borrow a watt meter with known accuracy to calibrate the watt meter section of the DL. If you don't have one, check with your local ham club, or college/university physics department. Most would be happy to help you. We would suggest checking at low wattage (e.g., < 5W) and again at higher output (e.g., 100W) and see how the DL compares without calibration. Even without calibration, the meter should be accurate within 10% worst case.

The DL Software

The DL software is named DLProjectCode.ino and is a standard Arduino IDE source code file. The source file begins with several *#include* preprocessor directives which make certain code libraries available for compilation:

```
#include <SPI.h>
#include <Wire.h>
#include <Adafruit_GFX.h>       // https://github.com/adafruit/Adafruit-GFX-Library
#include <Adafruit_SSD1306.h>   // https://github.com/adafruit/Adafruit_SSD1306
```

As with all of my code, any (non-standard) library file that is not provided as part of the default installation of the IDE has its URL provided so you can download and install the library. Because of the graphics routines used by the OLED, two Adafruit libraries are used in the program. These are free downloads.

It would be an unnecessary denuding of the nation's forests to yet again repeat how to compile and upload a program using the Arduino IDE. If you are unfamiliar with the process, simply Google "Compiling and uploading an Arduino program". Surely one of the almost 400,000 hits will show you the proper steps. Fortunately, the Nano comes with a USB connector which makes compiling/uploading a program extremely easy. If you want to learn more about programming for the Arduino, we think *Beginning C for Arduino* is a very good book, although we might be a bit biased.

The Source Code

In the source code, the yellow highlighted statements will depend upon your specific DL. The first symbolic constant (`MYDUMMYLOADOHMS`) is the actual resistance of you resistor network. We would expect it to be less that 1 ohm from the desired 50Ω load. The second constant (`CALIBRATIONOFFSET`) is the value that, when multiply it by your measure wattage you show the same wattage as the calibrate wattage.

```
/*
    Release 1.0   Oct.13, 2017, Jack Purdum, W8TEE, Al Peter, AC8GY. You may use/modify
       this code, but keep this comment intact in the file and place any changes in from of
       this entry.
*/
//#include <SPI.h>
#include <Wire.h>
#include <Adafruit_GFX.h>       // https://github.com/adafruit/Adafruit-GFX-Library
#include <Adafruit_SSD1306.h>   // https://github.com/adafruit/Adafruit_SSD1306

//#define DEBUG                       // Uncomment to calibrate and debug

#define OLED_RESET                 4
#define SENSORPIN                 A1               // pin that the sensor is attached to
#define ITERATIONS                30

#define MYDUMMYLOADOHMS           50.1             // This needs to be changed for yours
#define CALIBRATIONOFFSET         0.008704         // This, too.
#define DIODEVOLTAGEDROP          0.7              // Voltage drop from diode

Adafruit_SSD1306 display(OLED_RESET);

int sensorValue = 0;         // the sensor value
int sensorMin = 1023;        // minimum sensor value
int sensorMax = 0;           // maximum sensor value


void setup()   {
#ifdef DEBUG
  Serial.begin(9600);
#endif

  display.begin(SSD1306_SWITCHCAPVCC, 0x3C);  // initialize with the I2C addr 0x3C (for the
128x32)

  display.clearDisplay();     // Clear the graphics display buffer.
  display.setTextSize(1);
  display.setTextColor(WHITE);
  display.setCursor(0, 0);
```

```
  display.println(" GCBG DUMMY LOAD");
  display.println("       by");
  display.println(" Al Peter, AC8GY");
  display.println("Jack Purdum, W8TEE");
  display.display();
#ifdef DEBUG                              // Probably only need to call once to tweak things
  Calibrate();
#endif
  delay(4000);
}


void loop() {
  char buff[10];
  char pad[] = "       ";    // 7 spaces
  int where;
  int i;
  float sum;
  float watts;

  sum = 0.0;
  i = 0;
  while (i < ITERATIONS) {
    sensorValue = analogRead(SENSORPIN);    // Input from voltage divider
    delay(10);                              // Let pin settle
    watts = CalculateWatts(sensorValue);
    sum += watts;
    i++;
  }
  sum /= ITERATIONS;
  dtostrf(sum, 4, 2, buff);

  where = strlen(buff);
  strcpy(&pad[6 - where], buff);
  display.clearDisplay();
  display.setTextSize(1);
  display.setTextColor(WHITE);
  display.setCursor(0, 0);
  display.println("      WATTS IN");
  display.setTextSize(3);
  where = (6 - where) * 10;
  display.setCursor(where, 10);
  display.println(buff);
  display.display();
  delay(1000);

}

/*****
  Purpose: To convert the value read from the DL and convert it to watts

  Parameter list:
    int sensorValue       the value read on the analog input pin

  Return value:
    float               the calculated watts
*****/
float CalculateWatts(int sensorValue)
{
  float temp;

  temp = sensorValue + DIODEVOLTAGEDROP;  // add back diode voltage drop
  temp *= temp;                           // Square for power
  temp /= MYDUMMYLOADOHMS;                // Replace with your measured resistance
```

```
  return temp * CALIBRATIONOFFSET;
}

/*****
  Purpose: To figure out calibration constant, See book for details.

  Parameter list:
    void

  Return value:
    void
*****/

void Calibrate()
{
  int i = ITERATIONS;                       // We're going to get a series of readings

  while (i--) {
    sensorValue = analogRead(SENSORPIN);
    delay(100);                           // Settle between readings...
    if (sensorValue > sensorMax) {        // record the maximum sensor value
      sensorMax = sensorValue;
    }
    if (sensorValue < sensorMin) {        // record the minimum sensor value
      sensorMin = sensorValue;
    }
  }
 #ifdef DEBUG                             // Only show if DEBUG mode set
    Serial.print("sensorValue = ");
    Serial.print(sensorValue);
    Serial.print("   sensorMin = ");
    Serial.println(sensorMin);
#endif
}
```

The source code can be downloaded from the **www.arrl.org/qst-in-depth** web page too. Once the program is installed in the Nano, connect the DL to your transmitter, turn the unit on, and start using your new DL!

Appendix A
Parts List

The appendix table presented here lists the parts necessary to build the DL, along with some suggested vendors. When an eBay number is given, type that number into the eBay search box which will bring up the vendor we used. Even though they may not have the item currently listed, most can reorder and sell to you or suggest another vendor. Note: Some are for multiple parts, since we did the build for 28 club members.

Part	Description	Potential Vendor
R3	Resistor network, 20 3 W, 1000 Ω metal film resistors	eBay #272456185792 *
	Banana jack terminal block	eBay #400575504329
	Prototype perf board	eBay #201553019480
	Arduino Nano	eBay #253104293783
	Battery connector	eBay #111844319226
D1	BAV21 diode	eBay #231568890166
	128x64 0.96" OLED display	ebay #272675577262
C1	0.022 µF capacitor, 250 V (or more)	www.debcoelectronics.com
R1	56 kΩ 1/4W resistor	www.taydaelectronics.com
R2	2 kΩ 1/4W resistor	www.taydaelectronics.com
S2	SPDT switch. ON-OFF-ON	www.taydaelectronics.com
	Enclosure, 2 15/16" x 2 15/16" x 1 1/4"	www.surplussales.com
	panel mount, uninsulated banana plug	www.surplussales.com

* You need to write and ask for the 1000 Ω resistors. He will sell 20 at a time.