ESR Meter Assembly & Calibration

Be sure to read this entire instruction set and to develop an understanding of the assembly process *before* beginning the actual assembly. Note that some basic tools and supplies are required for this project, as follows:

- Required…
    - Soldering Iron – ideally, a pencil-type 60-Watt iron with a fine tip is best;
    - Solder Iron Holder and Sponge – holds hot iron and cleans tip;
    - Solder – standard rosin-core solder, maximum 0.060” (1.5mm) diameter;
    - Black PVC friction (electrical) tape, 3/4” (19 mm) wide;
    - Electric drill, drill bits, and 1.5” (38 mm) hole saw;
    - Pliers – Needle Nose, small, and Diagonal Cutting, also small;
    - Screwdrivers - #1 Phillips and small slotted types; and
- Recommended…
    - Solder Wick Braid – for removing solder from PCB;
    - Solder “Sucker” – suction tool for removing solder from PCB;
    - 3M #56 Yellow Poly Tape, 1/4" (6 mm) wide;
    - Component Lead Bending Tool – simplifies forming component leads;
    - “Helping Hands” PCB holding fixture;
    - LED Flashlight – produces white light to enable accurate color-checking of resistors;
    - Hot Glue Gun (with glue sticks) – secure bulky components;
    - Magnifying Glass – for reading small component value markings; and
    - Heat Gun – for shrinking heat shrink tubing – adjustable heat hot air output is best.

The meter requires the items shown on the ESR Meter Parts List, in the quantities shown. Note that the post-assembly meter calibration procedure requires a set of twelve precision resistors that are not a part of the finished unit, but are used solely for calibration of the meter.

It is recommended that these resistors be stored in a safe place so as to keep them available should future re-calibration become necessary. If placed in a small plastic bag, the set of resistors can actually be stored inside the completed meter enclosure.

Enclosure Preparation

As the first pre-assembly step, you must cut or drill all of the required openings in the enclosure. A pair of templates is provided as an appendix to this manual. The templates are full-sized and are drawn to scale. *It is important to note that these templates are prepared for specific paper sizes, and are thus supplied in two formats, i.e., the Letter Size and the A4 size. Those users outside of the USA, who will most likely be printing on A4 sized paper, will have to use only the A4 templates and ignore the Letter Size templates, and vice-versa.* Print the template pages full size (1:1 or 100%) for use in preparing the enclosure. Then, cut out the templates on their outer lines and check their fit to the enclosure. *If the templates are too large or too small, reprint them with a correction to the printer scaling. For example, if a printed template for the enclosure cover measures out to be 4.5" long instead of 4.7" long as it should be, it is only 95.7% of its intended size. In this case, the printer scaling must be reset to 104.5% (95.7 ×1.045 = 100.0065). The scaling factor is derived by dividing 100 by the actual percentage of full size that the printed template ends up. In this case, the solution would be 100.00 ÷ 95.7 which works out to be 1.0449. Unfortunately, this process cannot be used to successfully convert Letter Size to A4 because of the aspect ratio differences of these two paper sizes. A4 paper is narrower (8.27" vs. 8.5") and longer (11.69" vs. 11.0") than Letter Size. However, the same scaling concept applies, only it is done using the metric dimensions when calculating the percentage difference.* Carefully position each template in place on the enclosure, wrapping the housing template around and onto the enclosure end panels along the lines provided, and then securing it there with tape. In a similar fashion, place the enclosure cover template into the enclosure cover and secure it there with tape.

Use a sharp-pointed tool to transfer each of the hole centers to the enclosure face and end panel, and to the enclosure cover, pressing the tool into place through the center markings on the template. Next, drill the required holes in the enclosure and cover, using drill bits of the correct sizes as indicated on the templates.

If a hole saw of the correct size (1.5" or 38 mm) for the large meter body hole is not available, drill a series of 1/8" (3 mm) holes as indicated on the template, offset 1/16" (1.5 mm) to the inside of the large meter hole. When properly drilled, these holes will perforate the enclosure face panel in such a manner that the center of the large hole can be pushed out. Once that is done, carefully clean up the edge of the resulting large hole with a file and/or a utility knife to achieve a finished hole of the required size for the meter.

Printed Circuit Board

The printed circuit board (PCB) is the basic structure onto which most of the functional components of this kit are installed. It is recommended that the board be fabricated as a nominal 0.062" thick fiberglass substrate, two-sided, with 1-ounce (per square foot) copper layers, and screen printed component information on the top side. In this project, all components are installed to the upper surface of the PCB, including all off-board connecting wires. All soldering is done on the lower surface of the PCB. A set of RS-274x format Gerber files for use in ordering the PCB is available.

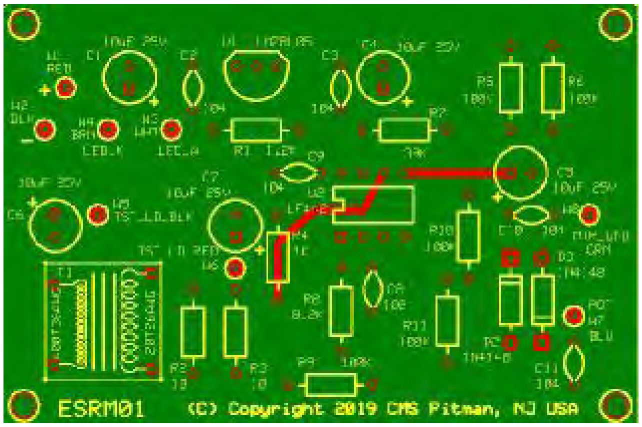


Figure 1 - PCB Component Side

Figure 1 is of the upper or component side of the PCB. Note that every component outline indicates the specific locations of those components, and the wire connect points all indicate the wire connection number, *e.g.,* W1, W2, etc., and the color of the wire to be attached there. The actual PCB is 2.00" x 3.00" (50.8 mm x 76.2 mm) in size, and there are two traces on the upper surface. The Gerber file set provided is in the RS-274x format, which is currently required by most PCB fabrication houses. Your completed PCB should look just like the image here.

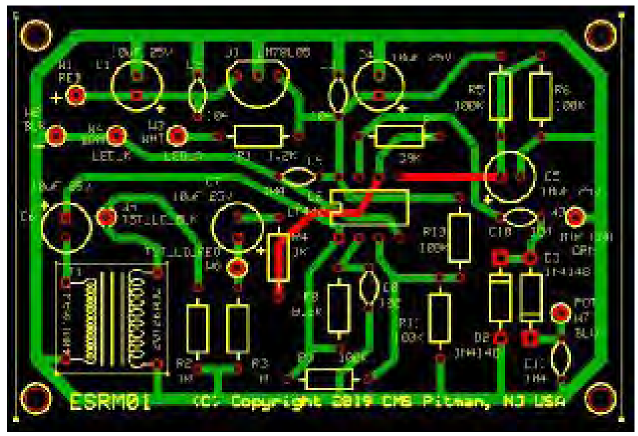


Figure 2 - PCB "Through View"

Figure 2 shows a "through-view" of the printed circuit board (PCB), showing the upper surface screen printed detail while also showing the lower surface foil traces, shown in green. The red areas are PCB through-holes and solder pads on the lower (foil) surface as well as two traces on the upper (component) surface.

Note that the location of each discrete component is identified as well as the values of those components. This diagram can be referenced as necessary when assembling the PCB. Each of the through-hole locations identified with a "W" number is a wire connect point, to which a length of hook-up wire of the indicated color or a test lead will be installed. The wire color to be used at each location is provided in the instructions and is also labeled on the PCB near the attachment point. Each of these wires will be attached at the upper (component) side of the PCB and soldered below. The wire colors and color codes used are as follows:

- RED – Red – (hook-up wire) power switch to PCB – to connection W1;
- BLK – Black – (battery snap wire) battery snap direct to PCB – to connection W2;
- WHT – White – LED anode (A) to PCB – to connection W3;
- BRN – Brown – LED cathode (K) to PCB – to connection W4;
- TST_LD_BLK – black test lead – to connection W5;
- TST_LD_RED – red test lead – to connection W6;
- BLU – Blue – potentiometer to PCB – to connection W7;
- GRN – Green – meter negative to PCB – to connection W8;
- ORN – Orange – potentiometer to meter positive (off-board connection); and
- RED – Red – (battery snap wire) battery snap to power switch (off-board connection).

Figure 3 - Transformer Core and Bobbin

Transformer

Our project uses a small transformer in the test lead portion of the circuit. This transformer is custom-wound as a part of the build process, and its component parts are listed on the ESR Meter Parts List. The transformer consists of a pair of ferrite e-cores that are inserted into a bobbin from either end, meeting in the middle, as in Figure 3. The transformer has two separate wire windings, a primary or input winding, and a secondary or output winding. In our case, the wires used to construct the windings are of two different diameters or gauges, with the primary winding being fashioned from 36AWG enameled magnet wire, and the secondary winding being fashioned from 26AWG enameled magnet wire. Figure 4 is of the two e-cores, while Figure 5 illustrates a bobbin. The transformer windings, which are electrically insulated from each other by the enamel coating on the wire, are wound on the bobbin and are then secured there using tape or clear (fingernail) lacquer.

Figure 4 - "E" Cores

Figure 5 - Bobbin

Figure 6 - Transformer

Our custom-wound transformer uses 400 turns of wire in its primary winding and 20 turns of wire in its secondary winding, for an effective turns ratio of 400:20 or 20:1, an effective voltage step-down. A completed and taped transformer is illustrated in Figure 6.

To prepare your transformer, assuming that you purchased the core and bobbin directly from Amidon, begin by carefully unwinding the yellow poly tape that holds the pieces together. Set this length of tape aside in a safe location, as you will use it later to wrap the completed transformer coil. If you bought your core and bobbin elsewhere, or if the poly tape is otherwise unusable, you will need a length of 3M #56 1/4" (6 mm) yellow poly tape. This tape is widely available from many vendors via the internet.

Separate the three parts of the core, setting the two e-cores aside in a safe place. Locate the 26AWG magnet wire, the heavier of the two wires used for this transformer. Now, holding the plastic bobbin between two fingers of one hand, start wrapping this heavier wire around the bobbin, being sure to leave about one inch (25 mm) of wire extending from the bobbin before starting to wind the coil. Wrap this wire onto the bobbin, working back and forth across the width of the bobbin, and counting up until you reach 20 turns laid down. Once again, leave a one-inch tail of wire before cutting the wire from the spool. Use a short length of masking tape or electrical tape to hold the winding in place while you get the 36AWG wire ready.

Locate the 36AWG magnet wire. This will be the finer of the two magnet wires needed for this transformer. Again, holding the plastic bobbin between two fingers of one hand, remove the temporary tape on the bobbin. Start wrapping the 36AWG magnet wire around the bobbin, laying it down right on top of the 26AWG wire, winding the wire in the same direction as that used for the 26AWG wire, and again working back and forth across the width of the bobbin. When you start winding this coil, leave about one inch (25 mm) of wire loose before the first wrap of wire around the bobbin. Count the wraps (or *turns)* as you go, winding this coil until you have laid down a total of 400 turns. Again, leave about one inch (25 mm) of wire hanging free from the bobbin before cutting the magnet wire off its spool. Holding the bobbin in one hand, with your fingers keeping the wire from unraveling, pull the outer end of the newly-wound wire snug, but not tight enough to crush the wire. Now take the length of poly tape that was originally wrapped around the core pieces and wrap the coils tightly with the tape. When completed, all of the wire and tape should be at or below the top edges of the bobbin form, and there should be a total of four one inch long wire tails extending from the bobbin.

Straighten the four wire tails, aligning them so that the 36AWG wire leads are located together on one side of the bobbin, and the 26AWG wire leads are on the other side. Carefully insert the two e-cores into the bobbin, ensuring that they meet properly at the center. A narrow strip of electrical tape can be used as a wrap around the outside of the assembled cores to keep them tightly together. After assembly, verify that the two leads on each side of the core are of the same size wire. Finally, clip each wire lead so that there is a 3/4-inch (19 mm) length extending below the bottom edge of the core.

Upon completion of winding and assembling the transformer, the ends of the wire, as stated above, should be left at about 3/4" (19 mm) length. Next, use a small piece of fine (400-grit) sandpaper to remove the lacquer or enamel from the standing ends of the wire. Finally, tin the wire ends with solder to complete the transformer manufacture. The completed transformer should have an appearance similar to that in the illustration at the beginning of this section. Set it aside for later use.

Panel Meter

The data display element of the ESR meter is a 0-50µA panel meter using a jeweled D'Arsonval movement, as shown in Figure 7. The meter itself will be calibrated in Ohms of Equivalent Series Resistance (Ohms ESR or Ω ESR). This will be accomplished by securing a new face plate to the meter unit. This face plate will be paper and will be secured to the back of the existing metal faceplate. Figure 8 illustrates a blank faceplate, while Figure 9 shows a completed (printed) faceplate.

Figure 7 - 0-50µA Meter

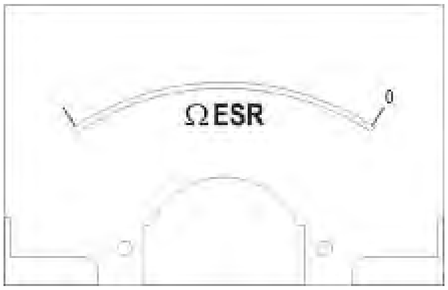


Figure 8 - Blank Faceplate

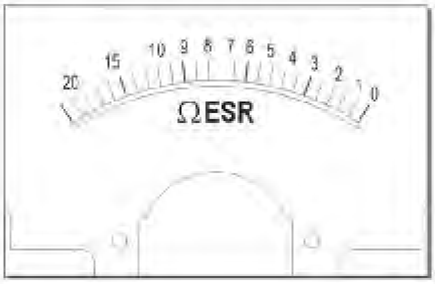


Figure 9 - Completed Faceplate

A pair of blank meter faceplates, in Letter Size and A4 size, drawn full-sized and ready for cutting out and installing on the meter, is provided as an appendix to this manual. The faceplates are arranged two identical faceplates to a printed page. The need for two faceplates will be explained later. Choose the appropriate template for your printer paper size and apply the same size correction methodology explained in the section on Enclosure Preparation. Specific installation instructions for the panel meter and the meter faceplate will be provided when we get to that step of the meter assembly process.

Power Switch

The meter uses a SPST toggle switch. The switch has two terminals; the specific connection positions of the two wires are immaterial.

Step-by-Step Assembly Procedure

In this section, we will provide specific step-by-step instructions for the complete assembly of the ESR Meter. It is very important that you follow the each step of the instruction set EXACTLY as written, doing each step in the EXACT order given. This is intended to get the best possible outcome – a properly working finished ESR Meter.

The PCB assembly process begins with the lowest-profile components and continues by placing those components with increasingly taller profiles, until all components are placed. Then the off-board connecting wires are installed to the PCB. Finally, the IC is inserted into its DIP socket on the PCB, completing the PCB assembly process.

For each of the following assembly steps, solder the component in place immediately after its insertion into the PCB, unless instructed to do otherwise.

1) Mount the PCB in your PCB holding fixture, component side facing upward.

2) Locate the 1N4148 diodes (2 pieces). Bend the component leads perpendicular to the diode body, so that there is a distance of 0.400” (11 mm) between the leads. Insert one each of these diodes into the PCB locations identified as D2 and D3. Solder the diodes in place and clip off the excess lead length. *NOTE: Diodes are polarized devices. Be sure to insert the diode in such a manner as to align the striped end of the diode with the stripe in the diode outline on the PCB.*

3) In this step, we will install a series of 1/4-watt ±5% carbon film resistors, as identified in the list below. You will need to form all of the resistors just as you did the diodes, with a 0.400” (11 mm) distance between the leads. All fixed resistors are to be installed horizontally and flush against the PCB. The resistors can all be soldered at once, or they can be soldered one at a time as they are inserted – it is your choice. Remember to clip off the excess lead lengths after soldering. The list indicates the PCB location identification as well as the value and color code of each of these resistors.
    a. R1 – 1.2KΩ (brown-red-red-gold)
    b. R2 – 10Ω (brown-black-black-gold)
    c. R3 – 10Ω (brown-black-black-gold)
    d. R4 – 1KΩ (brown-black-red-gold)
    e. R5 – 100KΩ (brown-black-yellow-gold)
    f. R6 – 100KΩ (brown-black-yellow-gold)
    g. R7 – 39KΩ (orange-white-orange-gold)
    h. R8 – 8.2KΩ (grey-red-red-gold)
    i. R9 – 100KΩ (brown-black-yellow-gold)
    j. R10 – 100KΩ (brown-black-yellow-gold)
    k. R11 – 100KΩ (brown-black-yellow-gold)

4) Locate the 8-pin DIP socket. Note that the DIP socket has a notch in its frame at one end. This notch is used to indicate the Pin 1 end of the DIP socket and the IC that will eventually be installed therein. Refer to Figure 10, and align the notched end of the DIP socket with the notch in the screen printed outline at PCB location U2. With the DIP socket aligned in this manner, insert it into the PCB, making

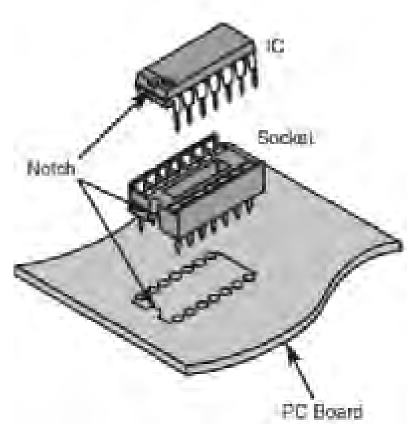


Figure 10 - DIP Socket & IC

sure that all eight pins of the DIP socket go into their respective holes in the PCB. A small length of tape placed over the DIP socket and onto the PCB will hold it in place when the board is inverted for soldering. To properly seat the DIP socket against the PCB, start by soldering the two opposite corner pins while the tape holds the DIP socket. Then, while pressing the DIP socket in place with one finger, reheat the solder at one corner of the DIP socket, and then allow that corner to cool, Repeat that process with the opposite corner that was pre-soldered, again allowing the solder to cool. The DIP socket should now be fully seated against the PCB. Verify that it is before continuing. If the DIP socket is not properly seated, repeat the heating/cooling of each corner as required. Once you are satisfied that the DIP socket is firmly seated in place against the PCB, solder the remaining pins of the DIP socket, being careful not to allow any solder bridges to form between the DIP socket pins. There is no need to clip the DIP socket pins after soldering, as they are already short enough. Remove the tape from the DIP socket. *DO NOT install the LF442 op-amp IC into the DIP socket at this time.*

5) Locate the 0.001µF ceramic disc capacitor. It will be marked either with its actual value as "0.001", or it may be marked with the value code "102". This capacitor is non-polarized, so it can be installed facing either way. Insert this capacitor into the PCB at the location marked C8, and solder it in place about 1/8" (2 mm) above the PCB. Clip off the excess lead length.

6) Locate eight (8) pieces of 0.1µF ceramic disc capacitors. They will be marked either with the actual value of 0.1µF or with the numeric code "104". These capacitors are non-polarized so they can be installed facing either way. Insert these capacitors into the PCB at the locations marked C2, C3, C9, C10, and C11. Solder them in place, each about 1/8" (2 mm) above the PCB, as in previous step. You can solder each one as it is installed, or you can solder them all at once – it is your choice. After soldering, clip off the excess lead lengths.

7) Locate the five 10µF 25V electrolytic capacitors. These will be installed upright and flush against the PCB in the C1, C4, C5, C6, and C7 locations. Remember that these are polarized capacitors, and that the longer positive lead goes into the PCB hole with the square pad, also indicated by a + label. Electrolytic capacitors are also commonly marked with a stripe or arrow indicating the negative side of the capacitor. With focus on the correct polarity, insert each capacitor vertically at its assigned location, and then gently bend the leads apart enough to hold the capacitors in place for soldering. Solder the leads in place, making sure that each capacitor maintains its position against the PCB, and then cut off the excess lead length. You can solder each one as it is installed, or you can solder them all at once – it is your choice. After soldering, clip off the excess lead lengths.

8) Locate the LM78L05 voltage regulator. This voltage regulator is a semiconductor device in a TO-92 plastic package. When inserting this device into the PCB, align the flat face of the package with the longer straight line in the screen printed device outline at location U1 on the PCB. When installed, the bottom of the voltage regulator body should be about 1/4" (6 mm) above the PCB surface. Solder the leads in place and clip off the excess lead lengths.

9) Locate the miniature transformer that you assembled earlier. This transformer will have two very fine wire leads and two somewhat heavier leads. The transformer is to be installed at the T1 location on the PCB. When inserting the wire leads into the PCB, be

sure to insert the finer leads into the two holes that are labeled *400T36AWG* between them, and the two heavier leads into the two holes that are labeled *20T26AWG* between them. A length of tape will hold the transformer in place while the leads are soldered. Be sure to pull gently on each lead prior to soldering it so as to ensure that all excess wire lead length is pulled through the hole. After soldering, clip off the excess lead lengths. A dab of hot glue on each side of the transformer and against the PCB will serve to secure the weight of the transformer in place on the PCB.

10) From the 24AWG hookup wire set of various colors listed in the ESR Meter Parts List, prepare each of the following wire lengths by color. Strip 1/4" (6 mm) of the wire insulation from each end of the wire unless instructed otherwise below. Cut the following wire lengths as closely as possible to the specified lengths:
    a. WHT – cut and prepare a 6-inch (152 mm) length, stripping 1/2-inch (13 mm) of insulation at one end and 1/4-inch (6 mm) at the other end;
    b. BRN - cut and prepare a 6-inch (152 mm) length, stripping 1/2-inch (13 mm) of insulation at one end;
    c. BLU - cut and prepare an 8-inch (203 mm) length;
    d. GRN - cut and prepare an 8-inch (203 mm) length;
    e. ORN - cut and prepare a 6-inch (152 mm) length, stripping 3/4-inch (19 mm) of insulation at one end and 1/4-inch (6 mm) at the other end; and
    f. RED – cut and prepare an 8-inch (203 mm) length.

11) For most of the prepared wire lengths from the step above, the end of the wire with the 1/4-inch (6 mm) insulation stripped off will be inserted into the wire connect points on the PCB, and soldered immediately upon insertion:
    a. RED – insert into connection point W1 (+) and solder into place;
    b. WHT – insert into connection point W3 (LED_A) and solder into place;
    c. BRN - insert into connection point W4 (LED_K) and solder into place;
    d. BLU - insert into connection point W7 (POT) and solder into place; and
    e. GRN - insert into connection point W8 (MTR_GND) and solder into place.

12) Set the remaining prepared 6-inch (152 mm) ORN wire aside for the time being. It will be used in a later assembly step.

13) Locate the battery snap, and insert the tinned end of the black wire into wire connection point W2 (–) and solder it in place. Leave the red wire end loose for now; it will be connected in a later assembly step.

14) Locate and install the 8-pin LF442 op-amp IC, being sure to align all 8 pins with their respective sockets, while also being sure to align the notch or dot on the IC with the notched end of the DIP socket and the notched end of the silkscreen image on the PCB. Refer back to the section on DIP socket installation to refresh your memory if needed. Seat the IC firmly into its DIP socket.

15) Now locate the enclosure body. By now, it should have the following holes drilled and/or cut into it:
    a. A 5/16" (8 mm) hole for the test leads in one end face of the enclosure body;
    b. a large diameter (1.5" or 38.1 mm) hole for the meter body;
    c. four small diameter (3/32" or 2.4 mm) holes around the large hole for the meter securement studs; and

d. an additional three holes, each sized properly for the power switch (1/4” or 6.3 mm), the pilot LED (17/64” or 6.75 mm), and the zero-adjust potentiometer (9/32” or 7 mm).

16) Locate the meter assembly and its mounting hardware (packed with the meter). There will be hardware of two different sizes, and there will also be two solder lugs. Set the larger diameter screws and washers aside, together with the solder lugs. They will be used shortly. Orient the meter so that its top edge is nearest the short end of the enclosure body, and insert the meter into its body and stud holes in the enclosure body, from the outside. Onto each of the four mounting studs, place one of the small flat washers, one of the small lock washers, and one of the small hex nuts. As before, do not tighten any of the nuts fully until all are in place, and then snug them down. Do not over-tighten these nuts.

17) Onto each of the two connection points on the back of the meter body, install a solder lug secured by a machine screw, a lock washer, and a flat washer. Orient the solder lugs toward the “bottom” of the meter body. The assembly order should be screw head, lock washer, flat washer, solder lug. We will be soldering wires to these lugs in later assembly steps.

18) Directly below the meter, there should be a 9/32” (7 mm) hole drilled in the enclosure body. Into this hole, we will install the 100KΩ potentiometer. Locate the potentiometer and look at it carefully. You will see that there is a locating tab next to the threaded mounting bushing. You will need to beak this tab off with small needle-nose pliers before installing the potentiometer. After breaking off the locating tab, remove the securing hardware from the threaded bushing and set it aside for a minute. Insert the potentiometer into the 9/32” (7 mm) hole, orienting it so that the solder lugs on the potentiometer are facing away from the meter. From the securing hardware that was set aside a moment ago, place a flat washer, a toothed lock washer, and a hex nut onto the potentiometer’s threaded bushing. Hold the potentiometer to keep it from rotating, and tighten the hex nut securely. Verify that the potentiometer’s solder lugs are facing directly away from the meter.

19) Locate the T1 LED holder and carefully push it into the 17/64” (6.75 mm) hole in the enclosure body, making sure that all four sections of the LED holder enter into the hole. The LED holder should press in until its upper flange is flush against the enclosure body surface.

20) Locate the T1 blue LED and carefully examine it. There should be a flattened area on the circumferential flange of the LED, generally (but not always) adjacent to the shorter of the two LED leads. Note which lead aligns with the flattened area – this is the cathode (K) lead. It is important to understand which lead is which, as the LED is a polarity-sensitive device, which will not illuminate if connected backwards. We will be attaching wires to the two leads later. For the time being, make a note of which lead is the long lead (usually the anode or “A” lead) and which is the short lead (usually the cathode or “K” lead).

21) Carefully insert the LED into the LED holder, holding the LED holder securely against the enclosure body surface. A small standard screwdriver can be used to push the LED into place until it clicks in, placing the end of the screwdriver blade against the LED back surface between the leads. The LED should lock securely into its holder and remain in place, although it will usually be able to rotate with the LED holder in the drilled hole.

22) Locate the power switch. This switch is a SPST toggle switch with two solder lugs on its back side. Remove the securing hardware from the threaded bushing and set it aside for a minute. Insert the toggle switch into the 1/4” (6.3 mm) hole in the enclosure body, orienting the switch so that its solder lugs are nearer the end of the enclosure body, which should position the machined slot in the switch’s threaded bushing towards the meter. Holding the switch against rotation, place a flat washer, a toothed lock washer, and a hex nut from the hardware set aside a moment ago onto the threaded bushing of the switch. Tighten the hex nut snugly, but do not over-tighten it. Verify that the switch body is oriented along the length of the enclosure body, and that the solder lugs on the switch are oriented towards the “bottom” end of the enclosure body. The importance of this switch orientation is not due to wire connection needs; instead, it is to ensure that when the switch is in its “ON” or closed position, the switch lever will be in its upward position, or towards the meter.

23) Locate the 0.187” (5 mm) ID rubber grommet. This grommet is to be installed into the 5/16” (8 mm) drilled hole in the “bottom” end face of the enclosure body. Work it into the hole carefully, being sure that it seats completely in the hole with both inside and outside face flanges fully in place against the enclosure bottom end face panel. A small screwdriver can be used to work the grommet into place; be careful not to tear the grommet during installation.

24) Locate the pair of test leads. For each of the two (one red and one black) leads, cut the lead wire at a measured 12” (305 mm) distance from the point where the test lead wire emerges from the test probe body. Set the banana plug cut-off leads aside. You can use them later to fabricate a set of test leads by attaching probes, banana jacks, or alligator clips to them, as your needs may dictate.

25) Insert the cut end of one of the test probe leads prepared in the previous step through the rubber grommet from the outside. Now apply a few drops of dishwashing liquid soap to the insulation on the cut end of the other test probe lead, and insert it through the grommet next to the test lead already there. Pull the two test lead wires through the grommet until you have about 2” (51 mm) of each lead wire inside the enclosure body. Strip 1/4" (6 mm) of insulation from each test lead wire. Twist the exposed wire strands of each lead tightly, and then tin the twisted ends. It is important that they wires be tightly twisted before tinning to ensure that they will fit into their respective holes in the PCB.

26) Now locate the assembled PCB that was set aside earlier. Look carefully at the PCB to the right of the installed transformer and you will find two wire connect points (W5 and W6). W5 will be labeled as TST_LD_BLK, and W6 will be labeled TST_LD_RED. Insert and solder each of the test probe leads into its assigned hole in the PCB.

27) Still working with the PCB, examine it carefully to ensure that all is well with the board before we go on to the next assembly step. Using a bright light and a magnifying glass, examine the board carefully in the following areas, correcting any errors that you may encounter as you go through the visual inspection.
    a. On the component side of the PCB, check the orientation of diodes D2 and D3. Make sure that they are properly aligned as to polarity. If you are holding the PCB so that the long edge is towards you with the transformer at the lower left, D2 should be installed with its cathode stripe away from you, while diode D3 should be installed with its cathode stripe towards you.

b. Also on the component side of the PCB, check the orientation of electrolytic capacitors C1, C4, C5, C6, and C7. Make sure that they are properly aligned as to polarity. Post-installation, the easiest way to verify polarity is to visually check that the stripe or arrow on the capacitor body is on the side of the capacitor opposite the positive indicator (+) at each electrolytic capacitor location on the PCB.
c. Still looking at the component side of the PCB, and holding the board as in sub-step (a) above, inspect the LF442 op-amp IC U2 for proper installation. Verify that the notched or dotted end of the IC is to the left, aligned with the notch in the DIP socket and also in the silk-screened information on the PCB surface. Check carefully to make sure that all eight pins of the IC are their socket slots, and are not folded under or bent to the outside.
d. Verify the correct orientation of the transformer. It should be installed with its 36AWG (finer diameter) leads nearest the edge of the PCB, and the 26AWG (thicker diameter) leads towards the center of the PCB.
e. Verify the correct orientation of the LM78L05 voltage regulator IC U1. It should be installed with its flat face towards the board edge and its rounded face towards the center of the board.
f. Verify that all eleven fixed resistors are in their correct locations by value, according to the board markings and assembly instructions. The only way to do this is by matching up the resistor color codes to the proper color band sequence for that resistor's value. For example, resistor R1 is a 1.2KΩ ±5% resistor, and its color band sequence should therefore be (in a four-band version) BRN-RED-RED-GLD.
g. Verify that the ceramic disc capacitors are in their correct locations by value, according to the board markings and assembly instructions. The only way to do this is by reconciling each capacitor's value marking with the assembly instructions and the parts list. This is somewhat simplified by the fact that of the six ceramic disc capacitors used, only capacitor C8 is different from the rest. Capacitor C8 should be marked either "102" or "0.001(µF)". The other five ceramic disc capacitors should each be marked either "104" or "0.1(µF)". Note that the microfarad range of these capacitors is understood, so the "µF" will most likely not be marked on the capacitor bodies.
h. Verify that there are no component locations identified on the PCB that are not populated.
i. Verify that each and every wire connect point on the PCB is populated by a wire of the correct color and/or type in accordance with the board markings and the instructions.
j. Finally, again using the bright light and magnifying glass, carefully examine the solder side of the PCB. Make sure that there are no "cold" solder joints, and that there are no short-circuiting solder bridges between adjacent traces. This board was specifically designed to make solder bridges unlikely, so the most likely area for such a bridge to form is in the soldering of the DIP socket at location U2. These pins are the closest together, being located on 0.100" (2.54 mm) centers.

28) Locate the enclosure cover. There should by now be four drilled holes in this cover, which will align with the four mounting holes in the PCB. Now locate the following hardware items:
a. (4) pieces 4-40 x 3/8" Phillips pan head machine screw;
b. (8) pieces #4 flat washer;
c. (4) pieces #4 toothed lock washer;
d. (4) pieces 4-40 hex nut; and

e. (4) pieces #4 x 1/8" tubular spacer.

29) Assemble the PCB to the enclosure cover, positioning the PCB so that the transformer is nearest the edge of the cover. For each corner of the PCB, place a flat washer on the machine screw, and insert the screw through the enclosure cover from the outside. Next place a tubular spacer onto the machine screw, followed by the PCB. Finish up by placing another flat washer on the machine screw on top of the PCB, then place a toothed lock washer on top of the second flat washer on the machine screw, and finally loosely install a hex nut onto the machine screw. Repeat this operation for the remaining three 3/8" machine screws and their associated hardware. Do not tighten any of the nuts until you have all four machine screws properly installed into the enclosure cover as explained above. Once you have all four machine screws in place, tighten each of the nuts securely.

30) Locate the 6" (152 mm) ORN wire prepared and set aside previously. Refer to Figure 11 and insert the 3/4" (19 mm) stripped end of the wire through the right side and center solder lugs (when viewed with solder lugs pointing towards you – a BLU wire in the photo) of the potentiometer. Crimp the wire in place with needle-nose pliers, and then solder it in place on both solder lugs. Snip off any excess lead length that extends past the solder joint. Make sure that the wire and/or solder do not come into contact with the remaining solder lug.

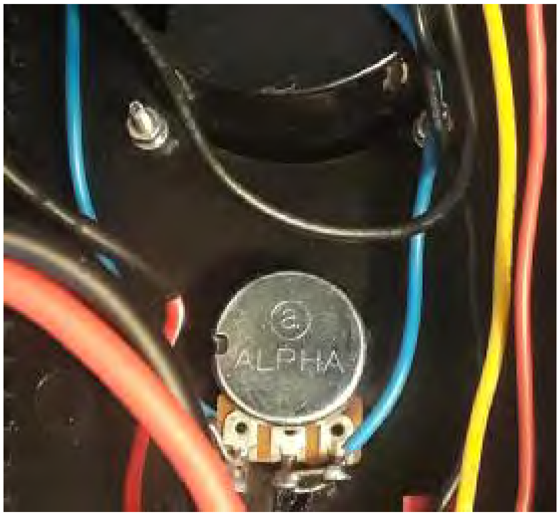


Figure 11 - Zero-adjust Potentiometer Meter Connection

31) Solder the opposite end of the ORN wire to the solder lug on the + terminal of the meter.

32) Locate the 9V battery snap. (It should be attached to the PCB by its BLK wire at wire connect point W2.) Insert the stripped end of the RED wire of the battery clip into either one of the solder lugs on the toggle switch and crimp it there with needle-nose pliers. Solder it in place, making sure that the wire and/or solder do not come into contact with the opposite solder lug. Snip off any excess wire length that extends past the solder joint.

33) In this step, we will connect some of the remaining wires from the PCB to their off-board connection points. Follow the instructions below.

a. Locate the RED wire from the PCB, and insert its stripped end into the remaining solder lug on the toggle switch. Crimp and solder it in place, snipping off any excess wire length that extends past the solder joint. Again, make sure that the wire and/or solder do not come into contact with the opposite solder lug.
b. Locate the BLU wire from the PCB, and insert its stripped end into the remaining solder lug on the potentiometer. Crimp and solder it in place, snipping off any excess wire length that extends past the solder joint. Make sure that the wire and/or solder do not come into contact with the adjacent solder lug.
c. Locate the GRN wire from the PCB, and insert its stripped end into the remaining (–) solder lug on the meter. Solder it in place.

34) Locate the 6” (152 mm) length of heat shrink tube. Using a scissor, cut this length into two 3” (76 mm) lengths. Set them aside for use in the next two steps.

35) Locate the anode (A) lead of the panel LED (usually, but not always, the longer lead). You should have made a note as to which LED lead was which when the LED was installed into its panel holder. With the anode lead identified, bend the two LED leads apart slightly. Now locate the WHT wire from the PCB and slide one of the 3” (76 mm) lengths of heat shrink tube onto the WHT wire, pushing it up all the way to the PCB. Next, bend a small hook into the very end of the LED anode lead, and also in the stripped end of the WHT wire. Engage these two hooks into each other and crimp them tightly with needle-nose pliers. Finally, solder them together at the crimped hooks.

36) The remaining LED lead should be the cathode (K) lead of the panel LED. (It is usually, but not always, the shorter lead). You should have made a note as to which LED lead was which when the LED was installed into its panel holder. Now locate the BRN wire from the PCB and slide the other 3” (76 mm) length of heat shrink tube onto the BRN wire, pushing it up all the way to the PCB. Next, bend a small hook into the very end of the LED anode lead, and also in the stripped end of the BRN wire. Engage these two hooks into each other and crimp them tightly with needle-nose pliers. Finally, solder them together at the crimped hooks.

37) Once the solder on the LED leads has fully cooled, slide the heat shrink tubes down the two leads, all the way to the LED body. Using a medium heat source such as an adjustable output hot air heat gun, shrink the heat shrink tubes in place, making sure that they stay put all the way down against the LED body.

38) Locate the black plastic knob. Now rotate the potentiometer fully counter-clockwise. Using a pencil or a very fine-tipped Sharpie marker, mark a line on the end of the potentiometer shaft, oriented in a one-o’clock to seven-o’clock position when the enclosure body is positioned with the meter face upwards and the meter away from you. Rotate to potentiometer shaft to move the line into the twelve-o’clock to six-o’clock position. Using a small standard screwdriver, loosen the set screw in the knob body. Holding the knob with its index line pointing directly towards the meter and aligned with the line you made on the end of the shaft, slide the knob onto the potentiometer shaft, taking care to not turn the shaft as you do so. Carefully slide a piece of card stock like a business calling card under the knob flange to lift the knob slightly of the enclosure body surface. With the knob’s index line pointing directly toward the meter, tighten the set screw in the knob to secure the knob to the potentiometer shaft. This should be just about mid-range of the potentiometer’s rotational range. This positioning of the knob may need some fine tuning. The goal is to have the knob’s index line pointing directly toward the meter with the potentiometer set at its half-range point.

Figure 12 - Rubber Bumper "Feet" Installed

39) Locate the set of four rubber bumpers. These bumpers will be installed to the enclosure cover to serve as feet for the ESR meter once the cover is secured to the enclosure body. Use some rubbing alcohol on a tissue or paper towel to clean the outer surface of the

enclosure cover in preparation for installation of the rubber bumpers. After the cover is dry, one at a time, carefully remove a bumper from its backing paper and position it on the enclosure cover, diagonally inward of the retaining screw countersink in the cover. Install all four of the rubber bumpers in this manner, pressing them all down firmly once they are at their desired locations. Figure 12 shows where to position the rubber bumpers on the cover.

The ESR meter build portion is now complete. Review your work, especially all of the off-board wire connections, and make sure that everything has been done as instructed. When you are satisfied that all is right, we can proceed with the power-up testing of the unit.

Power-up Test of ESR Meter

Since the painstaking steps of the build itself have been completed, it is now time to perform the initial power-up of the ESR meter and some pre-calibration testing. Follow the procedural steps below to accomplish these tasks.

1) Verify that the toggle switch is in its "OFF" position. If the toggle switch was installed in accordance with the instructions, this should have the actuator in its downward direction, or towards the enclosure body short edge and away from the meter. From this point onward, we will use terminology that is indicative of a component's function. Thus, we will henceforth refer to the toggle switch as the *power switch*.

2) Locate the 9V battery and attach it to its connecting snap. Keeping its wire leads from tangling, slide the battery down into the void between the "top" of the meter's round body and the enclosure body "top" end panel, with the battery snap leads to the right. Figure 13 shows the battery stowed in this location. This is the location at which the battery will be stored for meter operation and use. Note that in this photo from the construction of the prototype ESR meter, the wire colors are different than those used in these instructions and in later builds of the ESR meter.

Figure 13 - Battery Placement

3) Rotate the potentiometer to its fully counter-clockwise position. In accordance with the use of terminology that is indicative of a component's function, we will henceforth refer to the potentiometer as the *zero-adjust pot* or sometimes just as the *pot.*

4) Move the power switch actuator to its ON position. The LED should illuminate, and the meter sweep needle should be over to the left, or zero side of the meter scale.

5) Short the two test lead probes together. If desired, you can use a test lead with an alligator clip at each end to accomplish this short, so as to free up both of your hands. Simply clip an alligator clip onto the metal tip of each test probe. With the test lead probes shorted to each other, the meter sweep needle should have swung to somewhere near its center scale position.

6) Rotate the zero-adjust pot slowly to the right. The meter sweep needle should track the zero-adjust pot's rotation, swinging to the right as the pot shaft is rotated. Although the current scale on the meter face is not what we will be using, we want to make sure that the meter can be adjusted to the full-right end of scale position before the zero-adjust pot reaches its fully-clockwise position. Ideally, and with a fresh and fully-charged battery, you should be able to achieve that right-end scale position somewhere near the mid-point of the zero-adjust pot's rotational range.

If the unit reacts as desired and in accordance with these instructions, we can move on to the calibration process. If at any step in the above testing procedure, the ESR meter unit does not behave as expected, refer to the basic troubleshooting appendix to this manual.

Calibration of the ESR Meter

In order to make the assembled ESR Meter into a reasonably accurate and usable piece of test equipment, the meter must be calibrated. Before itemizing the procedural steps to be followed in calibrating the meter, a quick description of the overall process is required.

<u>Overview</u>

We will begin the calibration process by removing the meter lens and faceplate. We will then install one of the two faceplates that were printed, re-installing the original faceplate in the process. Then we will begin the process of calibrating the meter for sweep needle position with twenty different resistance values placed between the probes, marking these sweep needle positions on the installed faceplate. When we have all twenty marks made, we will remove the faceplate again and transfer these marks carefully (for accuracy) and neatly (for appearance) to the remaining blank faceplate. This second faceplate will then be installed, followed by the lens, at which point the job is done and the meter is ready for use.

<u>Calibration Procedure</u>

In order to accomplish the meter calibration, it is of utmost importance that you have a good understanding of the concepts of series connections of discrete components, parallel connections of discrete components, and mixed series and parallel connections of discrete components. We will be connecting certain specific resistors together in various ways to effect this calibration process. Some steps will call for a single resistor, while others will call for two or three resistors connected in series. Additional; steps will call for connecting two resistors in parallel, and yet others will require you to add an additional resistor in series with a parallel pair. If you do not fully understand these concepts, stop now and take some time to review the concepts. You can find information regarding series, parallel, and series-parallel resistive networks in many locations on the Internet. A simple Google search will turn up numerous sources for this information.

1) Start by carefully removing the meter lens. This can be accomplished by gently working the Blade of a small standard screwdriver under the lens edge on one side of the meter face. With the screwdriver blade in place under the meter lens, gently twist the screwdriver. The lens should start to lift on the side by the screwdriver. Continue lifting gently until the lens is completely off the meter.

2) Refer to Figure 14 and note that there are two Phillips head screws – one on each side of the sweep needle pivot – securing the faceplate to the meter frame. Remove these two screws and set them aside for a few minutes. With the screws removed, the faceplate will easily slide out from under the needle. Be sure not to lift the faceplate while sliding it out, as the sweep needle is easily bent but hard to get right again.

Figure 14 - Meter Faceplate Mounting

3) Match the size of the paper faceplate cutout to the metal faceplate from the meter. The cutout one should be almost a perfect fit to the metal one. The specific contours along the bottom edge are irrelevant. What is important is the width of the upper portion of the faceplate is a match. If it is off by no more than 1/16” (1.5 mm), it is acceptable for use. Any variation is size more than that limit will require re-printing of the faceplate, following the scaling instructions presented in the Enclosure Preparation section of this manual.

4) Once you have an acceptably-sized paper faceplate cut out and ready to go, we will attach it to the back side of the metal faceplate. This faceplate is only temporary, so we will attach it to the metal faceplate front side using scotch tape. Tape it down on all four edges, but avoid placing tape in the area of the arc where you will need to make marks. Secure the tape around onto the back of the metal face plate, pulling the paper faceplate tight so that it doesn’t interfere with the sweep needle.

5) Using the screws removed a few minutes ago, carefully push them through the paper faceplate and into the mounting holes in the metal faceplate. The, remove the screws from the holes and carefully slide the faceplate back into place on the meter. Secure it in place with the two screws. The meter is now ready for calibration.

6) Locate the calibration resistor set that you should, by now, have on hand. Any reference to resistors in this section of the manual is referring only to those resistors in this calibration set. This set of resistors includes the following resistor values and quantities:

a. 1Ω ±1% 250mW axial lead metal film resistor – 1 piece;
b. 2Ω ±1% 250mW axial lead metal film resistor – 2 pieces;
c. 10 Ω ±1% 250mW axial lead metal film resistor – 2 pieces;
d. 15 Ω ±1% 250mW axial lead metal film resistor – 1 piece; and
e. 20Ω ±1% 250mW axial lead metal film resistor – 1 piece.

7) Verify that the ESR meter is switched ON, and short the two test probes to each other. Now adjust the zero-adjust pot to align the sweep needle with the “zero” (0) position at the extreme right-hand end of the meter faceplate scale. This zero-adjust procedure must be followed each time a different device is to be measured with the ESR Meter, including at the beginning of each step in this calibration process.

8) Disconnect the test lead probes from each other, and now connect a 1Ω resistor between the probes. Carefully make a mark on the meter faceplate at the sweep needle’s position with this 1Ω resistance in place between the probes. Label this mark as “1”. When finished, remove the resistor from the probes.

9) Perform the zero-adjust of the meter.

10) Connect a 2Ω resistor between the probes. Carefully make a mark on the meter faceplate at the sweep needle's position with this 2Ω resistance in place between the probes. Label this mark as "2". When finished, remove the resistor from the probes.

11) Perform the zero-adjust of the meter.

12) Connect a 2Ω resistor and a 1Ω resistor in series between the probes. Carefully make a mark on the meter faceplate at the sweep needle's position with this 3Ω resistance in place between the probes. Label this mark as "3". When finished, remove the resistors from the probes.

13) Perform the zero-adjust of the meter.

14) Connect two 2Ω resistors in series between the probes. Carefully make a mark on the meter faceplate at the sweep needle's position with this 4Ω resistance in place between the probes. Label this mark as "4". When finished, remove the resistors from the probes.

15) Perform the zero-adjust of the meter.

16) Connect two 10Ω resistors in parallel between the probes. Carefully make a mark on the meter faceplate at the sweep needle's position with this 5Ω resistance in place between the probes. Label this mark as "5". When finished, remove the resistors from the probes.

17) Perform the zero-adjust of the meter.

18) Connect two 10Ω resistors in parallel, and then series-connect a 1Ω resistor to the two 10Ω resistors between the probes. Carefully make a mark on the meter faceplate at the sweep needle's position with this 6Ω resistance in place between the probes. Label this mark as "6". When finished, remove the resistors from the probes.

19) Perform the zero-adjust of the meter.

20) Connect two 10Ω resistors in parallel, and then series-connect a 2Ω resistor to the two 10Ω resistors between the probes. Carefully make a mark on the meter faceplate at the sweep needle's position with this 7Ω resistance in place between the probes. Label this mark as "7". When finished, remove the resistors from the probes.

21) Perform the zero-adjust of the meter.

22) Connect two 10Ω resistors in parallel, and then series-connect a 1Ω resistor to a 2Ω resistor, and series-connect them to the two 10Ω resistors between the probes. Carefully make a mark on the meter faceplate at the sweep needle's position with this 8Ω resistance in place between the probes. Label this mark as "8". When finished, remove the resistors from the probes.

23) Perform the zero-adjust of the meter.

24) Connect two 10Ω resistors in parallel, and then series-connect a 2Ω resistor to another 2Ω resistor, and series-connect them to the two 10Ω resistors between the probes. Carefully make a mark on the meter faceplate at the sweep needle's position with this 9Ω

resistance in place between the probes. Label this mark as “9”. When finished, remove the resistors from the probes.

25) Perform the zero-adjust of the meter.

26) Connect one 10Ω resistor between the probes. Carefully make a mark on the meter faceplate at the sweep needle’s position with this 10Ω resistance in place between the probes. Label this mark as “10”. When finished, remove the resistor from the probes.

27) Perform the zero-adjust of the meter.

28) Connect a 10Ω resistor and a 1Ω resistor in series between the probes. Carefully make a mark on the meter faceplate at the sweep needle’s position with this 11Ω resistance in place between the probes. Label this mark as “11”. When finished, remove the resistors from the probes.

29) Perform the zero-adjust of the meter.

30) Connect a 10Ω resistor in series with a 2Ω resistor between the probes. Carefully make a mark on the meter faceplate at the sweep needle’s position with this 12Ω resistance in place between the probes. Label this mark as “12”. When finished, remove the resistors from the probes.

31) Perform the zero-adjust of the meter.

32) Connect a 10Ω resistor in series with a 2Ω resistor and a 1Ω resistor between the probes. Carefully make a mark on the meter faceplate at the sweep needle’s position with this 13Ω resistance in place between the probes. Label this mark as “13”. When finished, remove the resistors from the probes.

33) Perform the zero-adjust of the meter.

34) Connect a 10Ω resistor in series with two series-connected 2Ω resistors between the probes. Carefully make a mark on the meter faceplate at the sweep needle’s position with this 14Ω resistance in place between the probes. Label this mark as “14”. When finished, remove the resistors from the probes.

35) Perform the zero-adjust of the meter.

36) Connect one 15Ω resistor between the probes. Carefully make a mark on the meter faceplate at the sweep needle’s position with this 15Ω resistance in place between the probes. Label this mark as “15”. When finished, remove the resistor from the probes.

37) Perform the zero-adjust of the meter.

38) Connect a 15Ω resistor and a 1Ω resistor in series between the probes. Carefully make a mark on the meter faceplate at the sweep needle’s position with this 16Ω resistance in place between the probes. Label this mark as “16”. When finished, remove the resistors from the probes.

39) Perform the zero-adjust of the meter.

40) Connect a 15Ω resistor in series with a 2Ω resistor between the probes. Carefully make a mark on the meter faceplate at the sweep needle's position with this 17Ω resistance in place between the probes. Label this mark as "17". When finished, remove the resistors from the probes.

41) Perform the zero-adjust of the meter.

42) Connect a 15Ω resistor in series with a 2Ω resistor and a 1Ω resistor between the probes. Carefully make a mark on the meter faceplate at the sweep needle's position with this 18Ω resistance in place between the probes. Label this mark as "18". When finished, remove the resistors from the probes.

43) Perform the zero-adjust of the meter.

44) Connect a 15Ω resistor in series with two series-connected 2Ω resistors between the probes. Carefully make a mark on the meter faceplate at the sweep needle's position with this 19Ω resistance in place between the probes. Label this mark as "19". When finished, remove the resistors from the probes.

45) Perform the zero-adjust of the meter.

46) Connect one 20Ω resistor between the probes. Carefully make a mark on the meter faceplate at the sweep needle's position with this 20Ω resistance in place between the probes. Label this mark as "20". When finished, remove the resistor from the probes. Switch the meter OFF.

47) This completes the calibration process. It is recommended that the set of seven calibration resistors be placed in a small sealable plastic bag and stored within the meter enclosure.

48) Locate the four enclosure cover retaining screws. Place the bag of calibration resistors inside the enclosure body, and then place the enclosure cover in place on the enclosure body. Install the four cover retaining screws to complete the enclosure assembly, the testing, and the calibration of the ESR Meter. The meter is now almost ready for use.

Going through the above calibration process, you may well notice that some of the marks, especially those over ten ohms, are so close together as to be almost on top of each other. This would make for a very cluttered meter face scale if left that way. Follow the steps below to complete the meter and make it ready for use.

1) Remove the two faceplate retaining screws, and carefully slide the faceplate out from beneath the meter sweep needle.

2) Without damaging it, carefully remove the taped-on paper faceplate from the metal faceplate.

3) As accurately as possible, transcribe the resistance scale marks from the original paper faceplate to the second blank paper one. Make the marks as neatly and as accurately as is possible. It is suggested that only the "5", "10", "15", & "20" ohm marks be labeled to aid in meter face clarity. It is also suggested that the marks for each of the values listed above be made longer and heaver to make them stand out.

4) Once you have transcribed the marks and you are happy with their appearance, mount the cut-out paper faceplate to the back side of the metal faceplate, using rubber cement or a children's construction activity glue stick. Position it carefully, then place a sheet of wax paper or parchment paper beneath and another over the glued faceplate. Then place a weight of some sort, like a heavy book, on top of the upper cover sheet until the glue has set.

5) After the glue has set, remove the faceplate from is cover sheets and then use the screws as before to open the two screw holes in the faceplate.

6) Carefully slide the faceplate into place and secure it with the two screws.

7) Power on the meter and short the test probes together. Use the aero-adjust pot to cause the needle to travel its full range, checking to see that it does not come into contact with the faceplate at any point. Power off the meter when this step is completed.

8) Locate the meter lens, and carefully examine the underside of it. You will see that there is a rotatable post that is attached to a slotted plug in the lens face. This post and screw are used to set the downscale (left) side "zero" position of the meter. While this adjustment is of no import for our completed meter, we none the less want to assemble the lens back to the meter face properly. Look carefully at the meter below the sweep needle pivot and you will see a loop of metal. It is into that loop that the post is meant to engage the needle mechanism. Visually adjust the post by turning its screw plug until the post is oriented in such a position that it will slip into the adjustment loop when the lens is re-seated on the meter.

9) Carefully align the lens with the meter face and press it down into place. Rotate the meter's zero-adjust screw plug to verify its proper engagement in the adjusting loop. As the screw is turned, the sweep needle should first move in one direction, and then should move back the other way as the screw is turned fully around. Adjust the sweep needle to its left-most position.

10) Once again, power on the meter and observe the sweep needle's full scale movement by shorting the test probes and rotating the zero-adjust pot. Once satisfied that all is well, power the meter off. It is now complete and ready for use.

Appendix 1 – Parts List

ESR Meter Parts List

Supplier	Part #	Location	Qty	Description	Notes
Jameco	198791	BT1	1	PC1604 Battery, 9V 600mAH	
Jameco	1946367	C1, C4, C5, C6, C7	5	10µF 25V ±20% 85°C Radial Aluminum Electrolytic Capacitor	
Jameco	15270	C2, C3, C9, C10, C11	5	0.1µF (104) 50V ±20% Ceramic Disc Capacitor	
Jameco	15190	C8	1	0.001µF (102) 50V ±20% Ceramic Disc Capacitor	
Jameco	137411	D1	1	LED, Blue Diffused ø3mm λ430nm 3.5V_F 10mcd 50°VA T-1	
Jameco	36038	D2, D3	2	1N4148 100V 150mA Fast-Switching Small Signal Silicon Diode DO-35	
Jameco	315301	PM1	1	Precision Panel Meter, 0-50µA Velleman AIM60005	
Jameco	691180	R1	1	1.2KΩ 5% 250mW Carbon Film Resistor	can use 1% resistor
Jameco	690380	R2, R3	2	10Ω 5% 250mW Carbon Film Resistor	can use 1% resistors
Jameco	690865	R4	1	1KΩ 5% 250mW Carbon Film Resistor	can use 1% resistor
Jameco	691340	R5, R6, R9, R10, R11	5	100KΩ 5% 250mW Carbon Film Resistor	can use 1% resistors
Jameco	691243	R7	1	39KΩ 5% 250mW Carbon Film Resistor	can use 1% resistor
Jameco	691083	R8	1	8.2KΩ 5% 250mW Carbon Film Resistor	can use 1% resistor
Jameco	286302	VR1	1	100kΩ 20% 125mW ø 16mm Linear Taper Potentiometer, ø 1/4" Shaft	
Jameco	76523	SW1	1	SPST Miniature Toggle Switch, 5A/120VAC ON-OFF Solder Lug	
Jameco	51182	U1	1	LM78L05 Low-Power 5V 100mA Voltage Regulator TO-92	
Jameco	106681	U2	1	LF442CN Low-Power JFET-Input Dual OpAmp, DIP-8	
Jameco	104176	for VR1	1	Knob,ø 0.75" Skirted, Shaft ø 0.25" with Set Screw, Black with White Line & Dot	
Jameco	112206	for U1	1	DIP Socket, 8-pin, 0.1" x 0.3"	
Jameco	101470	for BT1	1	Battery Snap, PC1604 with 10" wire leads	
Jameco	95513	for D1	1	LED Panel Holder, T-1 (ø 3mm)	
Jameco	18914	Meter Assembly Enclosure	1	Enclosure, Black ABS Plastic 4.9" x 2.5" x 1.5"	includes cover screws
Jameco	77746	TL1, TL2	1	Test Lead Set, 42" Long with Probes and Banana Plugs, Red & Black (1 each)	
Jameco	2207751	Component Hook-Up	1	Set 24AWG Hook-Up Wire, 105°C 60V Solid, 10 Colors 60m Total Length	10m RED & BLK; 5m Others
Jameco	2207751 (INC)	Component Hook-Up	12"	Hook-up Wire, BRN, 105°C 60V, 24AWG Solid	From 2207751 Wire Set
Jameco	2207751 (INC)	Component Hook-Up	12"	Hook-up Wire, RED, 105°C 60V, 24AWG Solid	From 2207751 Wire Set
Jameco	2207751 (INC)	Component Hook-Up	12"	Hook-up Wire, ORN, 105°C 60V, 24AWG Solid	From 2207751 Wire Set
Jameco	2207751 (INC)	Component Hook-Up	12"	Hook-up Wire, GRN, 105°C 60V, 24AWG Solid	From 2207751 Wire Set
Jameco	2207751 (INC)	Component Hook-Up	12"	Hook-up Wire, BLU, 105°C 60V, 24AWG Solid	From 2207751 Wire Set
Jameco	2207751 (INC)	Component Hook-Up	12"	Hook-up Wire, WHT, 105°C 60V, 24AWG Solid	From 2207751 Wire Set
Jameco	419127	Component Hook-Up	6"	Heat Shrink Tube, 1/16" x 4' Black Polyolefin (sold as 4' length)	
Amidon	EA-77-188	for T1	1	Ferrite E-Core with Plastic Bobbin	Amidon
Amidon	AWG#26SP	for T1	1	Magnet Wire, Lacquered/Enameled, 26 AWG (sold as 1/4 lb Spool)	Amidon
Amidon	AWG#36SP	for T1	1	Magnet Wire, Lacquered/Enameled, 36 AWG (sold as 1/4 lb Spool)	Amidon
Keystone	736	for TL1 & TL2	1	Grommet, Black Rubber, 0.187" ID, 0.312" Panel Bore, 0.062" Panel Thickness	Digikey p/n 36-736-ND
Bivar	9908-125	PCB Mounting	4	#4 x 1/4" Tubular Spacer	Digikey p/n 492-1072-ND
Jameco	2034997	PCB Mounting	4	4-40 x 3/8" Phillips Pan Head Machine Screw	
Jameco	40943	PCB Mounting	4	4-40 Hex Nut	
Jameco	106826	PCB Mounting	8	#4 Flat Washer	
Jameco	106850	PCB Mounting	4	#4 Toothed Lock Washer	
Jameco	2119718	Enclosure Bottom	1	Bumper Pad Set, Self-Adhesive 0.375" x 0.125" Cylindrical, Set of 4 Black	sold as 100 pcs, or 25 sets
	ESRM01FP	for PM1	1	Blank Faceplate to fit Jameco 315301 panel meter (white min 24#, max 110#)	In Reference Document
	ESRM01PCB	Meter Circuit Base	1	Printed Circuit Board, Custom, 3" x 2" x 0.062"	PCB Fabricator via Gerber file
	ESRM01INST	Reference Document	1	Assembly and Calibration Instructions	
Stackpole	RNF14FTD1R00	Calibration Use	1	1Ω 1% 250mW Metal Film Resistor NOTE: Must be 1%, but 125mW is OK	Digikey p/n RNF14FTD1R00CT-ND
Stackpole	RNF14FTD2R00	Calibration Use	2	2Ω 1% 250mW Metal Film Resistor NOTE: Must be 1%, but 125mW is OK	Digikey p/n RNF14FTD2R00CT-ND
Stackpole	RNF14FTD10R0	Calibration Use	2	10Ω 1% 250mW Metal Film Resistor NOTE: Must be 1%, but 125mW is OK	Digikey p/n RNF14FTD10R0CT-ND
Stackpole	RNF14FTD15R0	Calibration Use	1	15Ω 1% 250mW Metal Film Resistor NOTE: Must be 1%, but 125mW is OK	Digikey p/n RNF14FTD15R0CT-ND
Stackpole	RNF14FTD20R0	Calibration Use	1	20Ω 1% 250mW Metal Film Resistor NOTE: Must be 1%, but 125mW is OK	Digikey p/n RNF14FTD20R0CT-ND

Appendix 2 – Oscilloscope Traces

ESR Meter Oscilloscope Traces

For those who have a 'scope and may be interested, the images below are some traces obtained at various key points in the ESR meter circuit. In those images with dual traces, Channel 1 is in yellow, and Channel 2 is in violet. Note that there is no trace for IC Pin 4 as that pin is at ground potential. Traces were obtained with power on and zero-adjust potentiometer fully counter-clockwise. Input voltage from 9V battery is slightly under 8 volts.

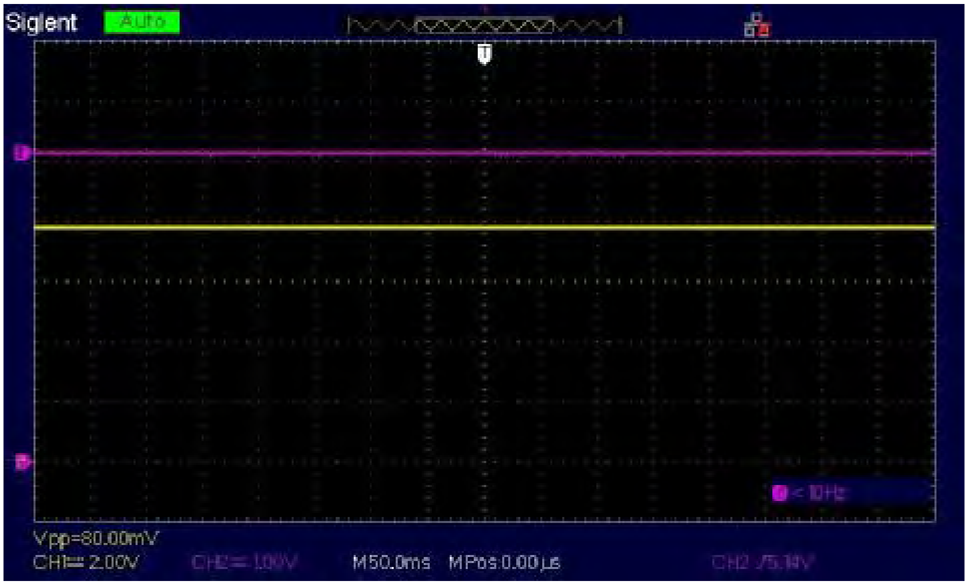


Figure 1 - Voltage Regulator In (CH1) & Out (CH2) - Common "zero" but different scales

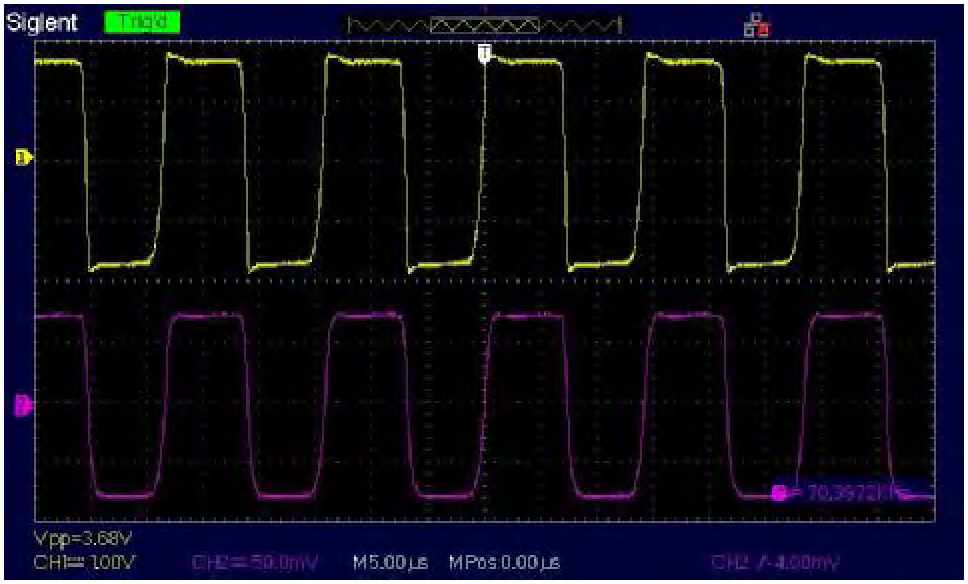


Figure 2 - Transformer Pin 1 (CH1) & Pin 4 (CH2) - Note different scales

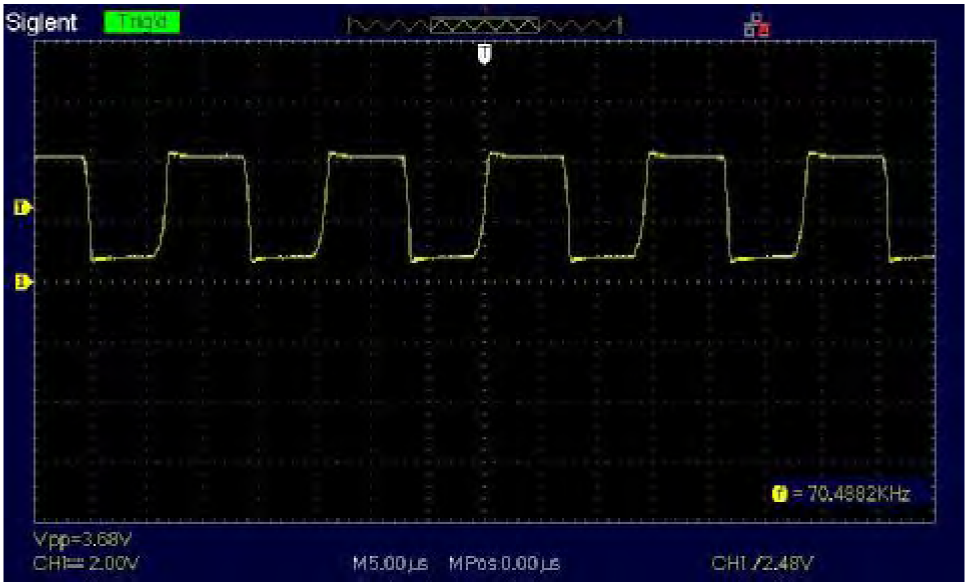


Figure 3 - IC Pin 1

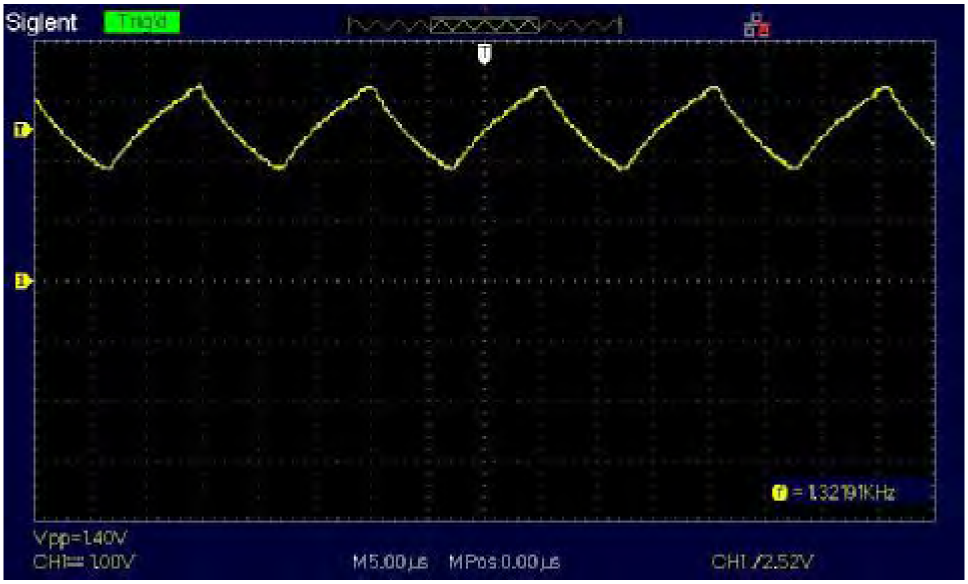


Figure 4 - IC Pin 2

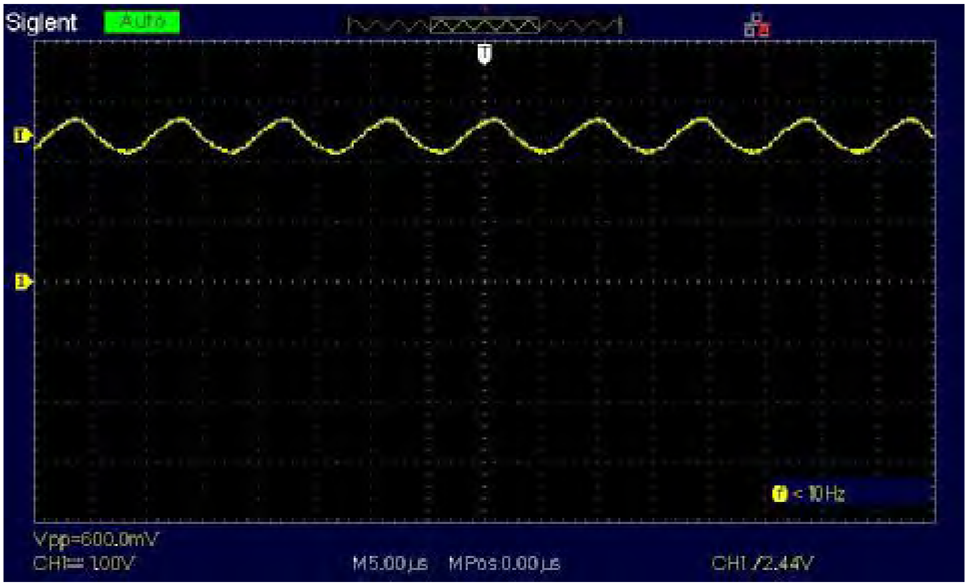


Figure 5 - IC Pin 3

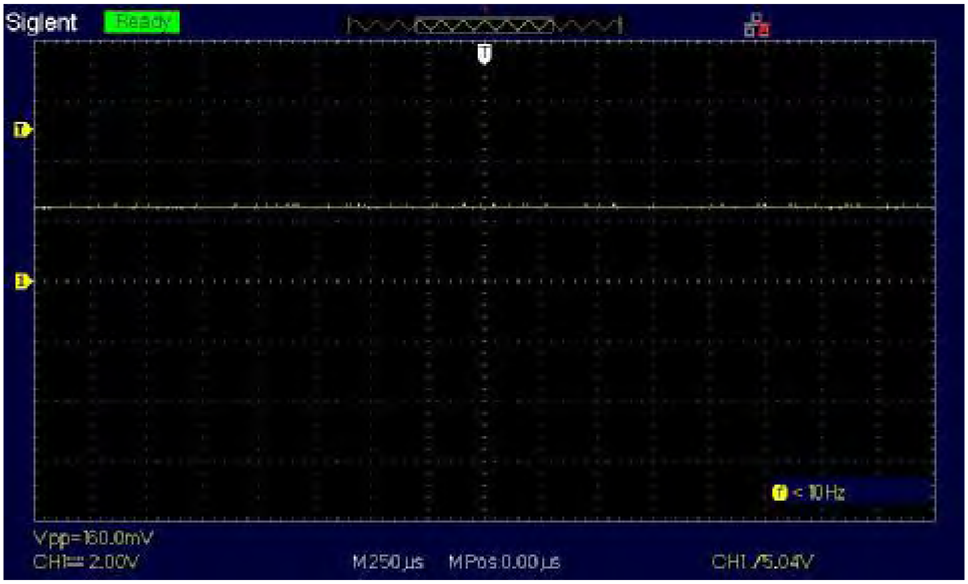


Figure 6 - IC Pin 5

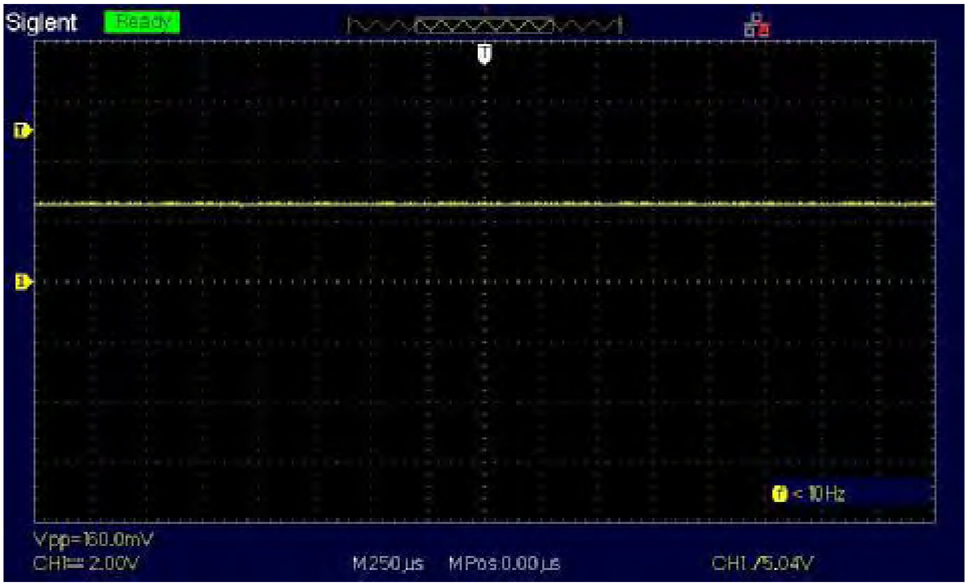


Figure 7 - IC Pin 6

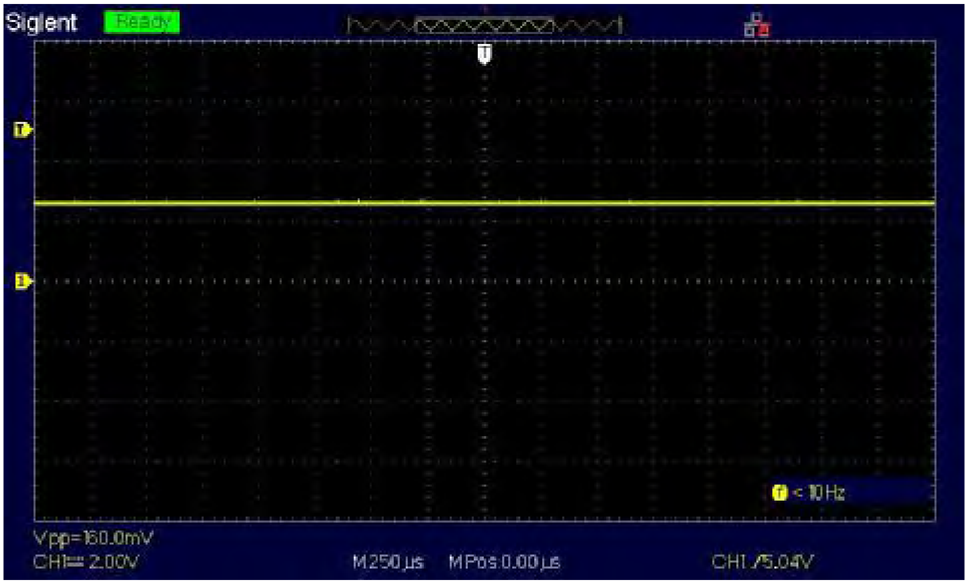


Figure 8 - IC Pin 7

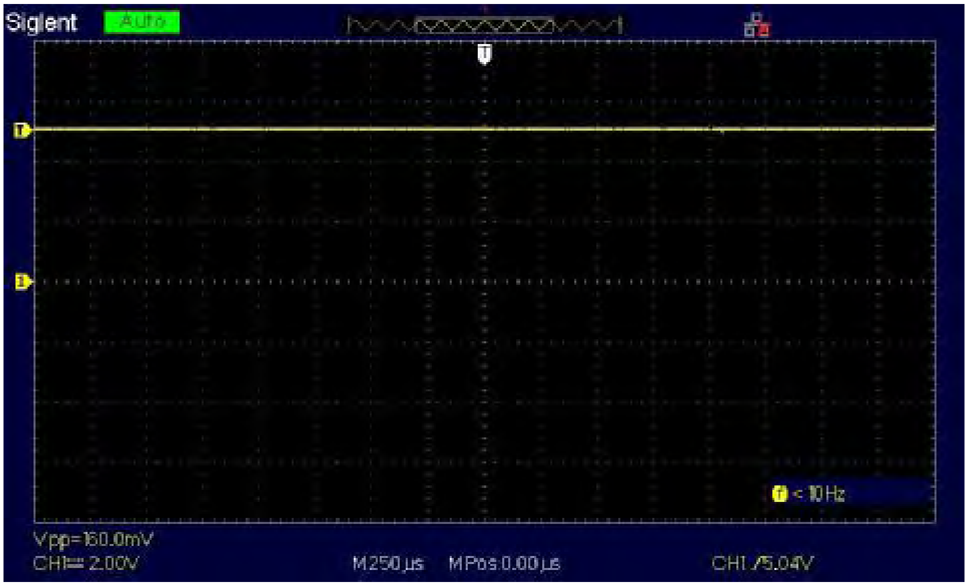
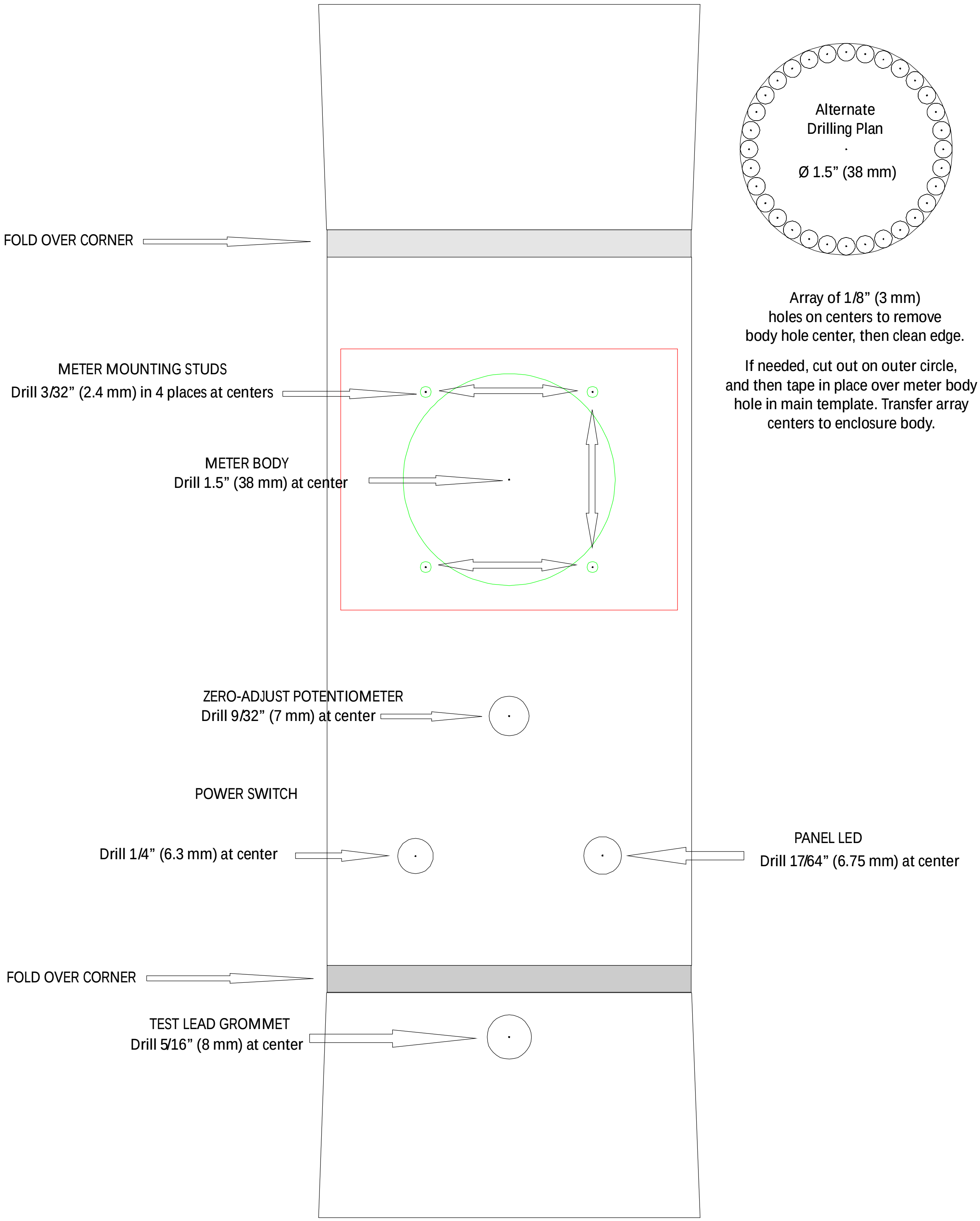


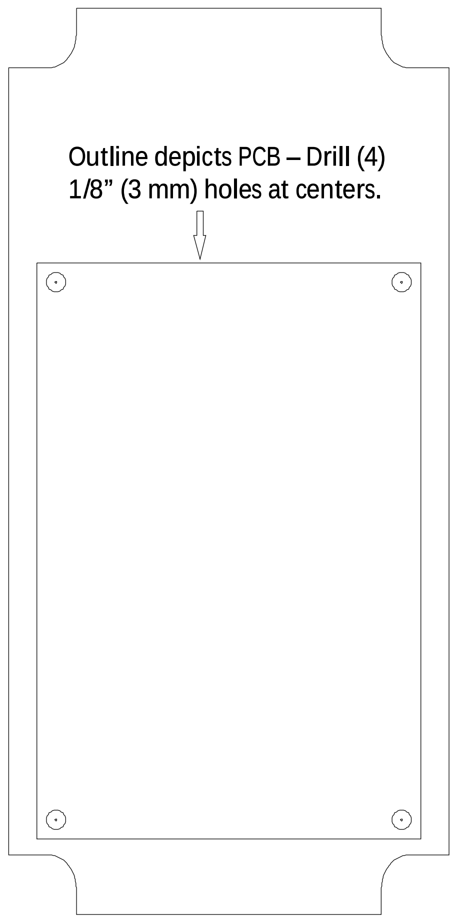
Figure 9 - IC Pin 8

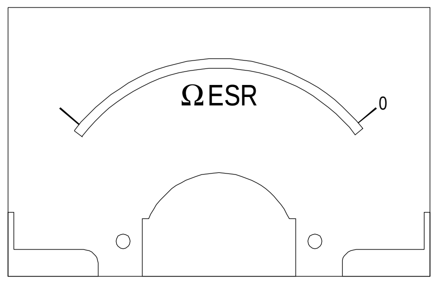
Appendix 3 – Templates

TEMPLATE LETTER_1
ENCLOSURE BODY

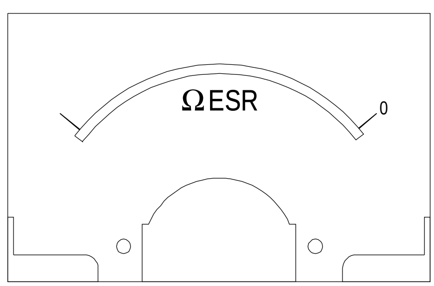


TEMPLATE LETTER_2
ENCLOSURE COVER

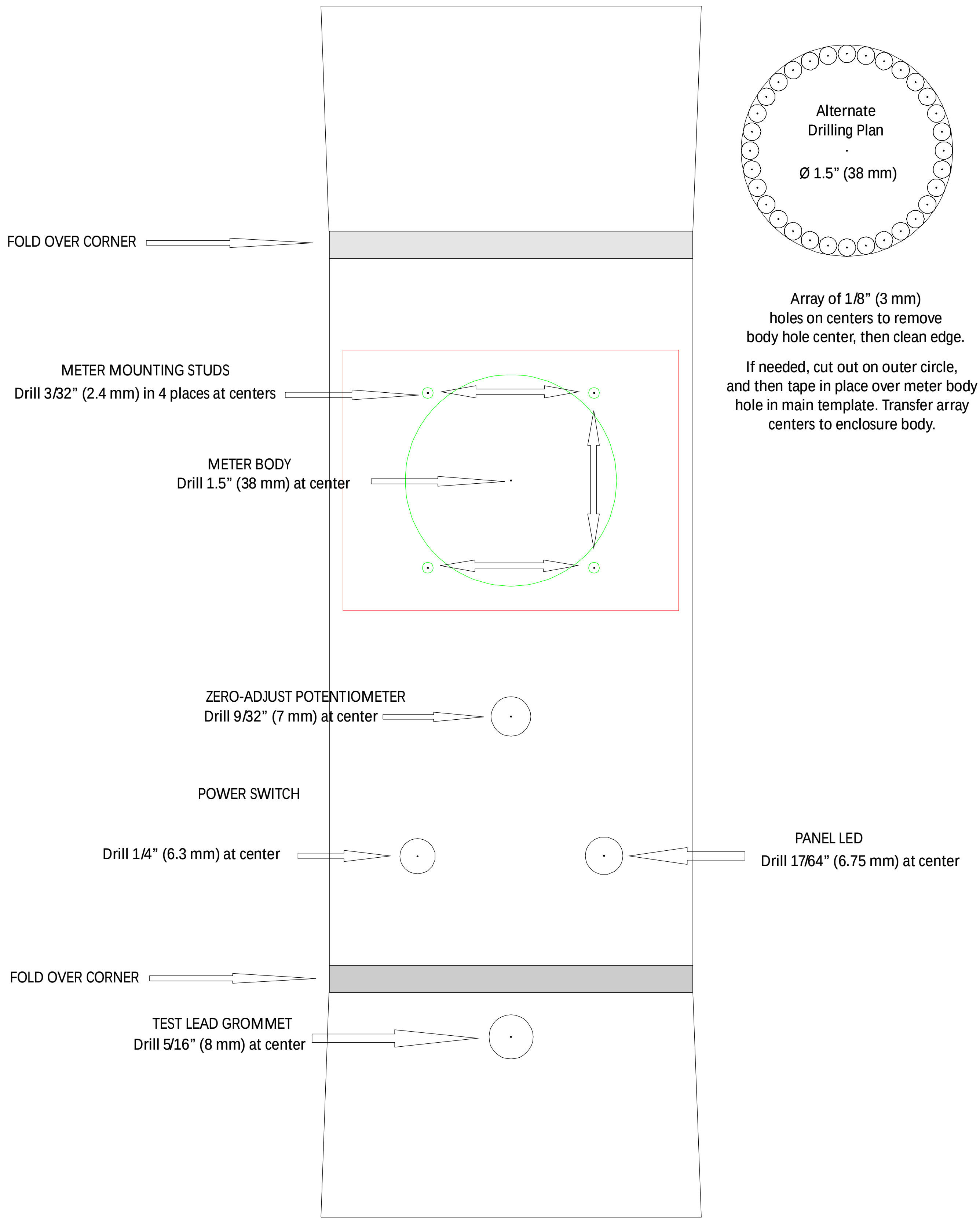




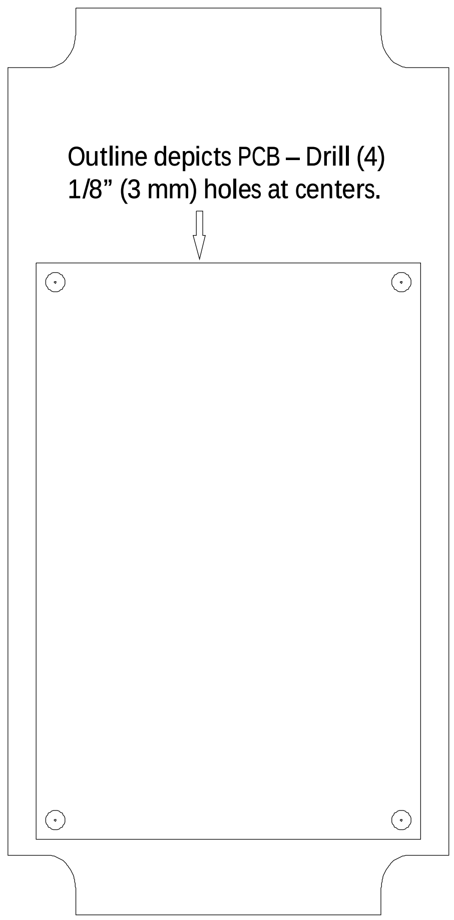
TEMPLATE LETTER_3 - FACEPLATES

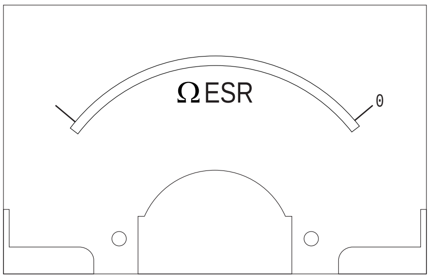


TEMPLATE A4_1
ENCLOSURE BODY

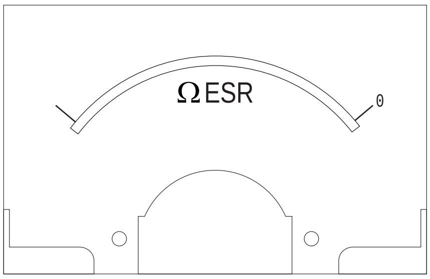


TEMPLATE A4_2
ENCLOSURE COVER

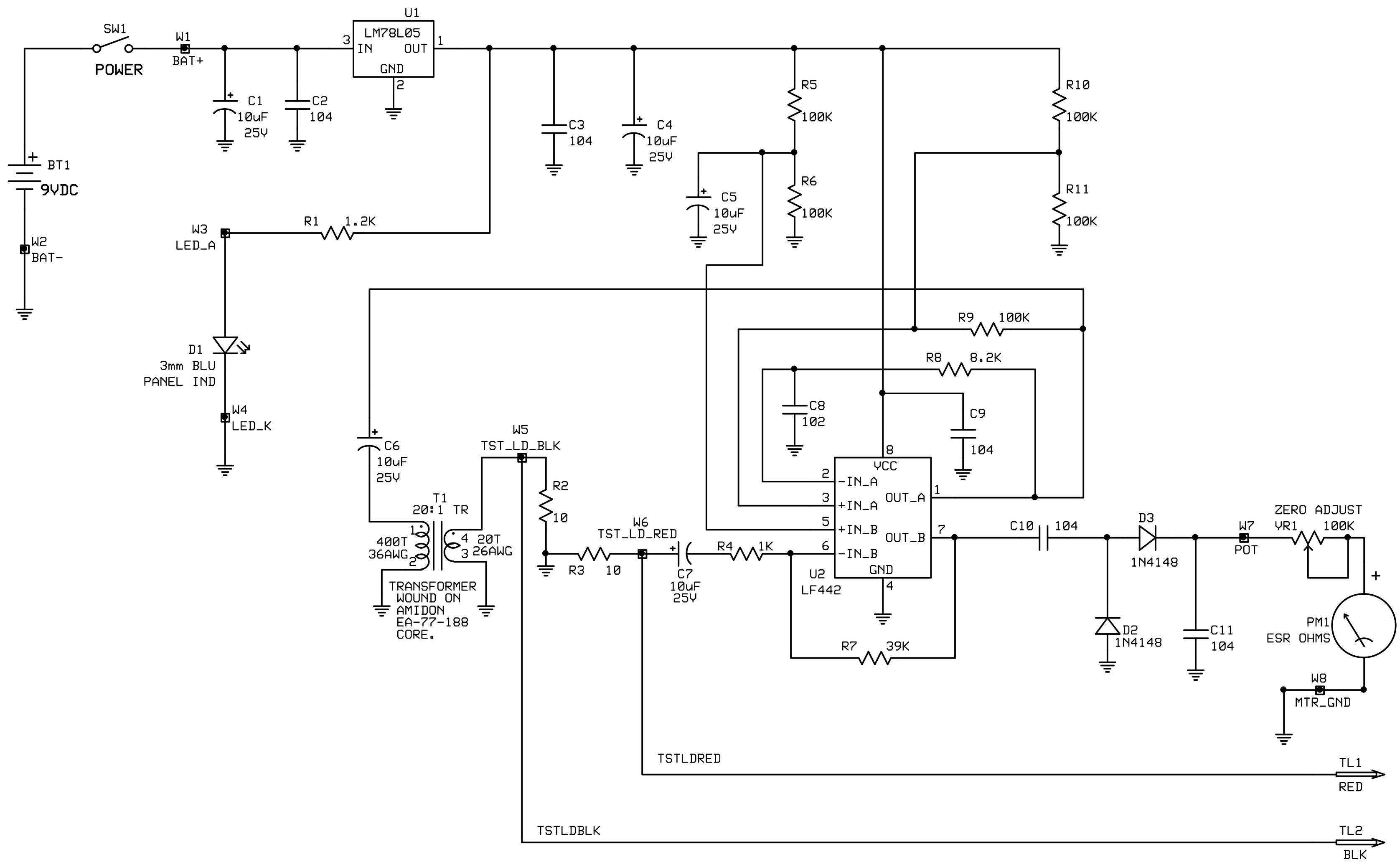




TEMPLATE A4_3 - FACEPLATES



Appendix 4 - Schematic



NOTES:

1. Value of resistor R1 (1.2K) was chosen to limit (mute) luminosity of panel LED D1.
2. IC U2 (LF442) is drawn as a single monolithic structure for PCB design purposes.
3. Panel meter PM1 is a 0-50uA meter with replacement faceplate calibrated in ohms ESR.
4. In order to have the zero adjust control track properly, the + terminal of the meter is connected to the center and right terminals of the pot as viewed from behind.
5. Transformer T1 is custom-wound using an Amidon EA-77-188 E-core and bobbin, with 400 turns of 36AWG magnet wire (Primary) and 20 turns of 26AWG magnet wire (Secondary).
6. Test leads and probes are fabricated from a standard test lead set with the banana plugs removed.
7. Working length of each test probe lead is approximately 10 inches; leads are soldered to the PCB.
8. Pre-installed length of test lead wire is 12 inches from end of probe body.
9. IC U1 is socketed to PCB.
10. Unless otherwise noted, all fixed resistors are 1/4-Watt 5% carbon film types.
11. Wire connect points are locations of off-board connections to PCB.

Contract Maintenance Service		
CMS ESRM01 Luden ESR Meter		
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Appendix 5 - Troubleshooting

Basic Troubleshooting

Common problems such as cold solder joints are solder bridges are not addressed here, as the PCB should have already been carefully inspected for such conditions. The problems discussed in this section are more related to inadvertent construction errors other than those related directly to soldering techniques.

Problem	Possible Causes
panel LED does not illuminate	battery, LED polarity, voltage regulator polarity, V_{CC} open or shorted
sweep needle tracks opposite of pot	potentiometer not connected as per instructions – connected backwards
LED lights, but meter does not respond	IC U2 inserted into DIP socket incorrectly; DIP socket installed to PCB incorrectly, IC U2 defective
transformer Pin 1 trace identical to IC U2 Pin 1	C6 shorted or bypassed
signal at IC U2 Pin 1 but no signal at transformer Pin 1	C6 open
no signal at transformer Pin 4	transformer or transformer circuit open