

Build a Cool Blue Audio Level Meter for Your Speakers

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I have always thought that those blue meters which McIntosh puts on some of their amplifiers look really cool. Since my main amps are Haflers, I had to build my own meters. This is the story of how I did that, with all the details and art files you need to build a pair for yourself. Please be aware though, that this is a challenging project, best suited to experienced builders.

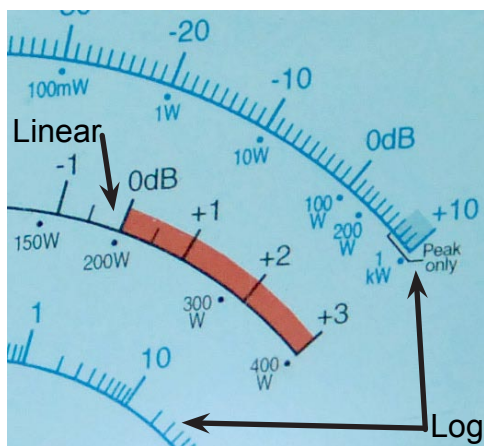
I didn't want just a fancy trinket to decorate the speakers. I wanted to make it show useful information. The requirements for the project included:

- 100dB Logarithmic decibel display so it can show the full audio dynamic range
- Linear display to show music dynamics similar to a VU meter
- Fast peak detect mode to identify when an amp will be clipping.



The completed Audio Level Meter (**ALM**) is shown **above**. I built two, which sit on the two front speakers. The panel meter is from the Heathkit IM-17 VOM, shown in its original form, **at right**. In fact, the front panel and slide switches are from the IM-17, too. These days, IM-17's (and its twin, IM-5217) are both plentiful and cheap, on eBay. Being a vintage collector myself, I don't feel bad about reusing these meters. They are common and have little utility, considering that meters like the HP-3466A are going for as little as \$50, now. I look at this application as giving them a new lease on life.





Meter Scales

The Range switch selects logarithmic (**LOG**) mode or one of three linear ranges, as shown **at left**. When in LOG mode, the two dark blue scales on the meter are used. The upper scale shows decibels (dB) relative to 100W and the one at the bottom indicates the voltage in volts. Decade power levels are also marked, under the dB scale. The AC detection is not true RMS but is calibrated to display the correct RMS power (for sine waves) in average-reading mode. This is typical for AC voltmeters.

With a 100dB display range, the ALM is capable of showing the noise floor of all but the very quietest audio systems. In fact, it is so sensitive that when the amplifiers are off, you can easily see deflections, as the speakers act as microphones to pickup conversation in the room.

When a linear range is selected, the black scale in the middle is used. The scale is marked like a traditional VU meter, with +3dB being the maximum. On the highest linear range, the top of the scale is 400W into 4-ohm speakers. For the two other linear ranges, the top of the scale is 40W and 4W. The 0dB point on the highest linear scale is 200Wrms. A red area above this indicates overload for amps like my Hafler DH-200's which deliver 200W max into 4-ohm speakers. Like the LOG mode, there are power level markings under the decibel scale.

Notice that the top 3dB of the LOG scale is shaded and marked for Peak only. The instrument clips for peak levels higher than 1000W into 4-ohms (63Vpk). That means that RMS power levels higher than 500W are not shown accurately and the top 3db isn't used in averaging mode.

Peak and averaging modes

Sine waves (pure tones), rather than actual music are usually used to test amplifiers for power output. A sine wave which delivers 500W of RMS power will actually be delivering 1000W at its peaks. So an amplifier which is rated for 500W RMS power is capable of delivering 1000W on transient peaks. The ALM has a switch to select either peak or average (RMS) readings. In peak mode, it rapidly captures even the shortest peaks found in music and holds them long enough for the mechanical meter to respond accurately. The setting of the Decay Time control determines how long the reading is held.

The ALM can detect transients in danger of clipping which would be far too short for people to hear the resulting distortion. If you have a 60W amp and you are seeing peak readings above 120W, the amp is probably clipping. Many solid state amps have such prodigious power that clipping is rarely an issue. However, many vacuum tube amps, operating with even moderately efficient speakers by today's standards, can be operated into clipping at reasonable levels. For example, the 35-watt-per-channel Eico ST-70 operated with my 88dB-efficient AR-9's can be made to clip at moderately loud levels. You could use an oscilloscope to monitor clipping but the ALM also provides this function, and is designed for living room decor.



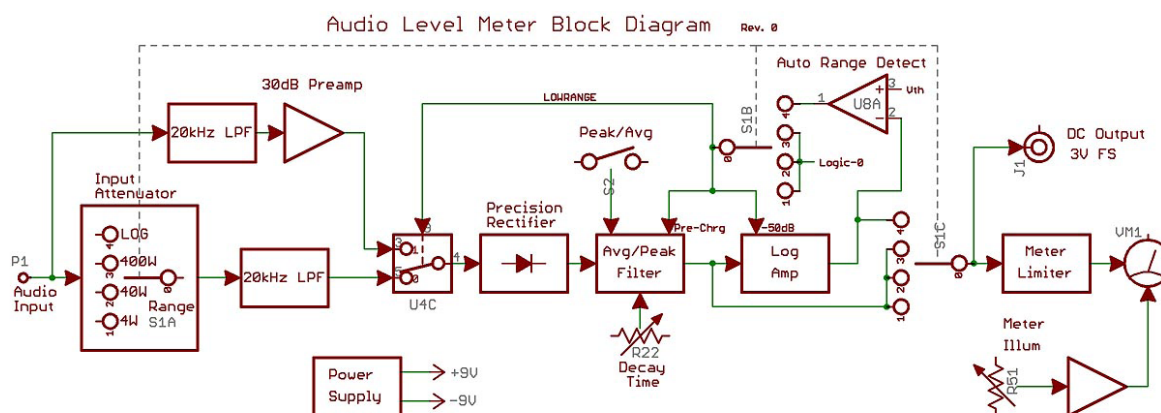
While there is only a 3dB difference between peak and average for a continuous sine wave, actual music shows a much greater difference. I once pegged it as typically 14dB for popular music. Some kinds of music, such as orchestral, might have very large differences. It's surprising to some people that an average level of just one watt can actually sound quite loud with moderately efficient speakers. In fact, I have had engineers look at the readings and refuse to believe that they are accurate, until they were confirmed with lab equipment.

Living room styling

The solid walnut case gives the ALM a homey look, when placed on speakers in the living room. The front ends of the case are beveled to enhance the look and also to tie-in with the beveled meter bezel, as seen **at left**. Variable meter illumination lets you adjust the brightness for various residential lighting situations. (I was concerned that nice illumination with room lights on, might be distracting for TV viewing.) The white LED's bring out the blue background of the scales, while preserving the red of the overload marking.

While speakers are aurally very active, ordinarily, they are visually passive. The presence of the illuminated meter on top gives an indication that they are on and also shows what they are doing. My audio system is switched-on using an X-10 type remote control. I use an extra X-10 module behind the speakers, to switch power to the meters, at the same time.

Theory of Operation



Linear Ranges

The block diagram of the ALM is **shown above**. The Range switch selects LOG mode or one of three linear input level ranges. When a linear range is selected, the audio from the speaker is scaled and then lowpass filtered to remove any RF interference. In linear modes, the Auto Range Detect is not active and the 30dB Preamp is not used. Audio is rendered by the full-wave precision rectifier into a DC signal. A filter circuit smooths the DC. If peak mode is selected, the filter

has very rapid attack time, allowing it to capture very brief transients and hold them for display. The rate at which transients fade is controlled by the Decay Time setting. When average mode is selected, the filter produces the average level of the rectified audio, with a fixed, 33ms time constant.

The output of the filter bypasses the LOG amp on linear ranges, going to the panel meter, via the meter limiter. This precision limiter prevents signals beyond the limits of the panel meter from damaging it or banging the stops.

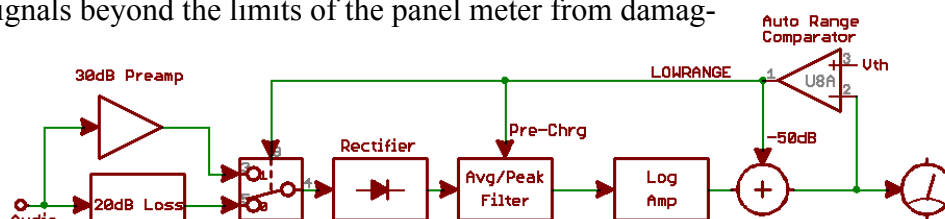
LOG Range

In LOG mode, there is only one range, because the meter covers the full range of dynamic levels on one scale. After lowpass filtering to remove any RF, the audio is rendered by the full-wave precision rectifier into a DC signal. A filter circuit smooths the DC. If peak mode is selected, the filter has very rapid attack time, allowing it to capture very brief transients and hold them for display. The rate at which transients fade is controlled by the Decay Time setting. When average mode is selected, the filter produces the average level of the rectified audio as a DC signal.

Next, the DC signal level is processed by the LOG amp, which performs a logarithmic function on the voltage. The output of the LOG amp goes to the panel meter, via the meter limiter. The precision limiter prevents signals beyond the limits of the panel meter from damaging it or banging the stops.

Auto Range Switching

The 100dB span puts challenging demands on the circuitry, so it is necessary to provide auto-ranging. The auto-ranging is seamless and completely invisible to the user. It addresses the issues of DC offset in the rectifier and limited 60dB range in the LOG amp, while maintaining a continuous, glitch-free display of level on the panel meter. A simplified block diagram of the auto-ranging is **shown above**.

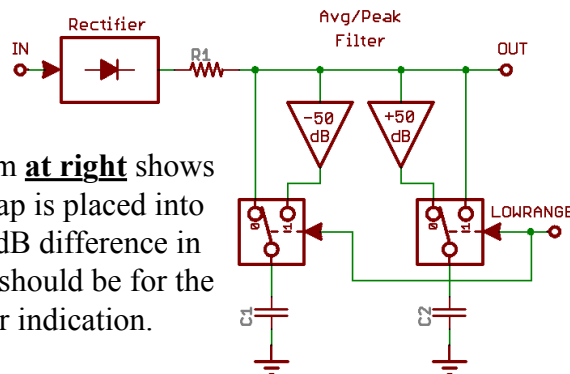


The Auto Range Comparator switches for levels under 50dB below max, asserting the LOW-RANGE logic signal. The overview of this is that input gain is increased 50dB, while a DC offset equivalent to 50dB is summed into the output of the LOG amp. As a result, the output of the LOG amp/sum does not change at the transition point. However, for signals under 50dB below max, the levels seen by the rectifier and LOG amp are boosted 50dB. So these circuits process the 100dB range of the instrument within a 50dB range, internally. Note that there is hysteresis in the Auto Range Detector, so the unit will not chatter near the transition point.

In LOWRANGE mode, the analog switch selects the 30dB Preamp which boosts audio from the input. For signal levels within 50dB of max, input is taken from the input attenuator, which inserts 20dB loss at the LOG setting. This accommodates the maximum 63V input peak signal level. So the input gain changes a net 50dB between the automatic internal ranges. As input signals are decreased from max, switching occurs at the -50dB level and internal levels return to the max level, at that point.

To make the transition point seamless, though, requires that something be done to handle the charge which is on the capacitor in the Avg/Peak filter. At the moment that the range is switched from the low range to the high range, the audio level at the input of the rectifier drops 50dB. The DC level at the output of the Avg/Peak filter needs to drop 50dB and this will be canceled by the 50dB offset inserted into the LOG amp output. Ordinarily, the filter would take time to respond to the new audio level. While the output is dropping 50dB, the output of the LOG amp would have a spike and the meter would show a glitch.

The solution is to maintain a second filter cap in the Avg/Peak filter which is charged to a level 50dB away from the current filter cap. The simplified block diagram **at right** shows the concept. When the range is switched, the standby cap is placed into service and the other is pre-charged in standby. The 50dB difference in charge puts the new cap's initial voltage level where it should be for the new audio signal level, so there is no glitch in the meter indication.



DC Output Function

A calibrated DC voltage is derived from the level developed for the panel meter. This voltage is available on a connector on the back of the ALM. A full-scale meter indication corresponds to 3VDC at this output. The voltage can be used, for example, to drive charting equipment to display level versus frequency. This makes the logarithmic function useful to other instruments.

Construction Notes

Equipment Required

- Oscilloscope
- Audio generator (one with accurate 10dB step attenuator preferred)
- AC voltmeter capable of reading 0.6mVrms accurately
- Table saw (for the wooden box)
- (desirable) Pair of lab power supplies

Fabricating the PCB (Printed Circuit Board)

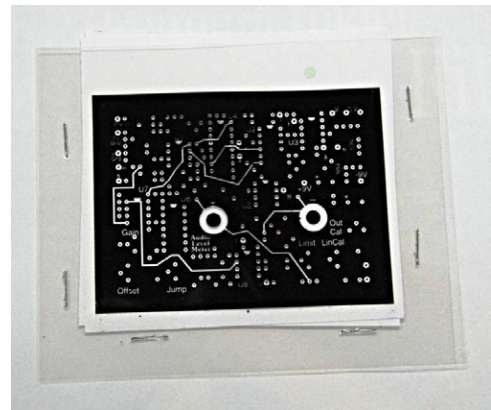
Though I use Eagle software these days to layout PCB's, when this project was built seven years ago, I had no good PCB layout tool. So I simply used a general-purpose vector drawing program, CorelDraw, to create the layout. That, of course, included cobbling-up all of the patterns needed for the various components. Anyway, the result is that I do not have a standard Gerber file which a commercial PCB house might need to make the board. However, if you plan to make your own PCB, as I did then, that should not be a problem. With this article, you will find graphic files, from which you can print negatives from which to make PCB's. I have provided the original CorelDraw files, as well as standard graphic files, in case you do not have CorelDraw. You can print files with bmp and png extensions using a free viewer such as Irfanview:

- ALM pcb.cdr - If you have CorelDraw-12 or later, this has all the PCB art.
- ALM pcb top.bmp - Top side metal.
- ALM pcb bottom.bmp- Bottom side metal.
- ALM pcb silk.png - "Silkscreen" and info layer.

The PCB is two-sided 4.0" x 3.0". The mask rectangle is actually 4.1x3.1." Outside that will be metal, so you can trim that off, plus a little and get the nominal PCB size. The actual layout area is 3.6x2.7," leaving 0.1" margin to the North edge and 0.2" margin to the other edges. Most tracks are on the bottom of the board, minimizing the places where you have to solder on the top.

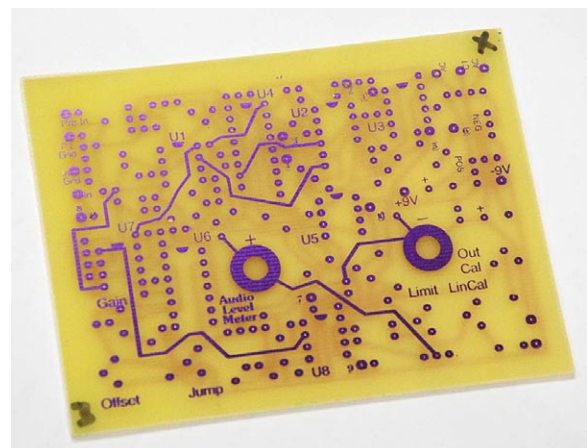
Printing the Negatives

- If you are printing from the BMP files, open the first file in a graphics application, such as PhotoShop. Applications such as Irfanview should also be able to print the files. You do not need to be concerned about print formatting; just print at the size in the document.
- If you are printing from the CDR files, open the file in CorelDraw-12 or later. To print the top-side negative:
 - » In the Object Manager window, set these layers for viewing and printing: Top, Holes and Background. Silk and Bottom layers should be off for viewing and printing.
 - » Select File|Print and in the Prepress tab, check Mirror and Invert. Print.
- To print the bottom-side negative from the CDR file:
 - » In the Object Manager window, set these layers for viewing and printing: Bottom, Holes and Background. Silk and Top layers should be off for viewing and printing.
 - » Select File|Print and in the Prepress tab, uncheck Mirror and check Invert. Print.
- Use clear, ink jet transparency film. I used HP Premium Inkjet Transparency Film on an HP Deskjet 952C printer. Make sure that the printer setting is for the Transparency Film. Use the "Best" quality setting. After printing, make sure the black area is accurate: 4.1" x 3.1".
- The top metal is mirrored while the bottom metal is not mirrored. That allows the ink-side of both negatives to be next to the PCB when exposing (see below).
- After the prints are fully dry, clear-coat the ink side with gloss clear-coat. I used three coats of clear gloss lacquer, 2-minutes apart. Dry thoroughly.



Making the PCB

- To expose the PCB, staple the two negatives together into a three-sided envelope, with the ink sides turned inward, as shown **at upper right**. (Paper is inserted in place of the board, in the photo.) Align them very carefully. This is important because there are several places where traces pass between IC pins and clearance is down to 16-mils or so. Misregistration could cause a problem.
- The PCB is shown **at right**, before stripping the resist and doing the tin plating. Notice that the resist makes the copper look purple.



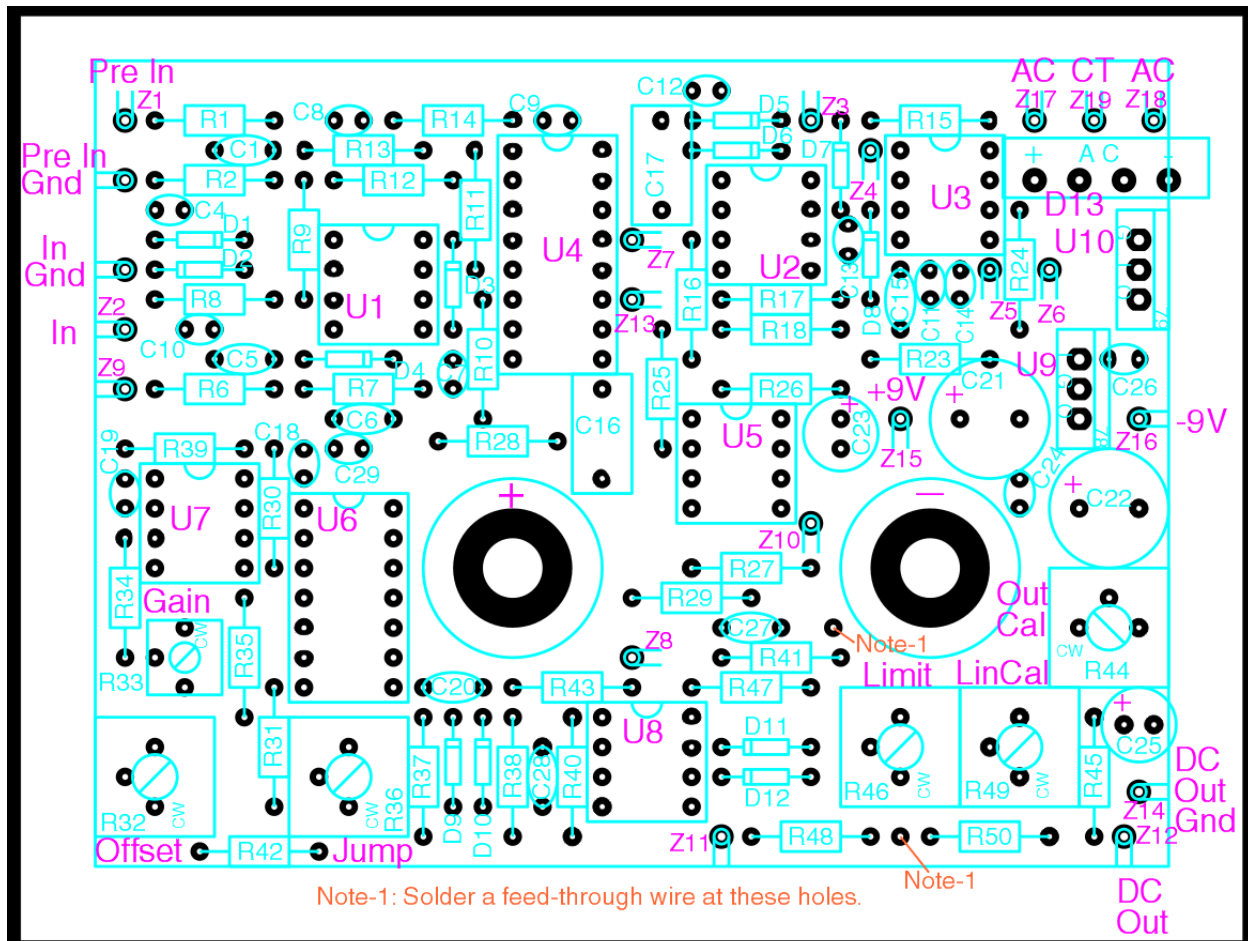
- A detailed tutorial on PCB making is beyond the scope of this article (just Google “PCB making”), but the general steps would be:
 - » In the darkroom: Insert a cut-to-size piece of double-sided, UV-sensitive PCB material into the negative pocket. Expose both sides to UV light for the appropriate interval.
 - » Develop the photoresist in a tray of resist developer. Lights-on when done.
 - » Etch the PCB (usually with ferric chloride), being careful not to scratch the photoresist on the bottom side.
 - » Strip the photoresist from the copper area, if you are going to plate with tin.
 - » Tin plate the copper with a product such as Tinnit electroless tin plating solution.

Drilling the PCB

It's important to drill the right size holes for the component leads. Very small drill bits are either specified by a drill bit size number which gets larger as the bit gets smaller (go figure) or simply by size in mils (thousandths of an inch). The sizes I used were:

- #72 bit, 25-mil - For most holes, including 1/4W resistors.
- 33-mil - For the bridge rectifier.
- 1/16" - For the flea clips used as terminals for external connections.

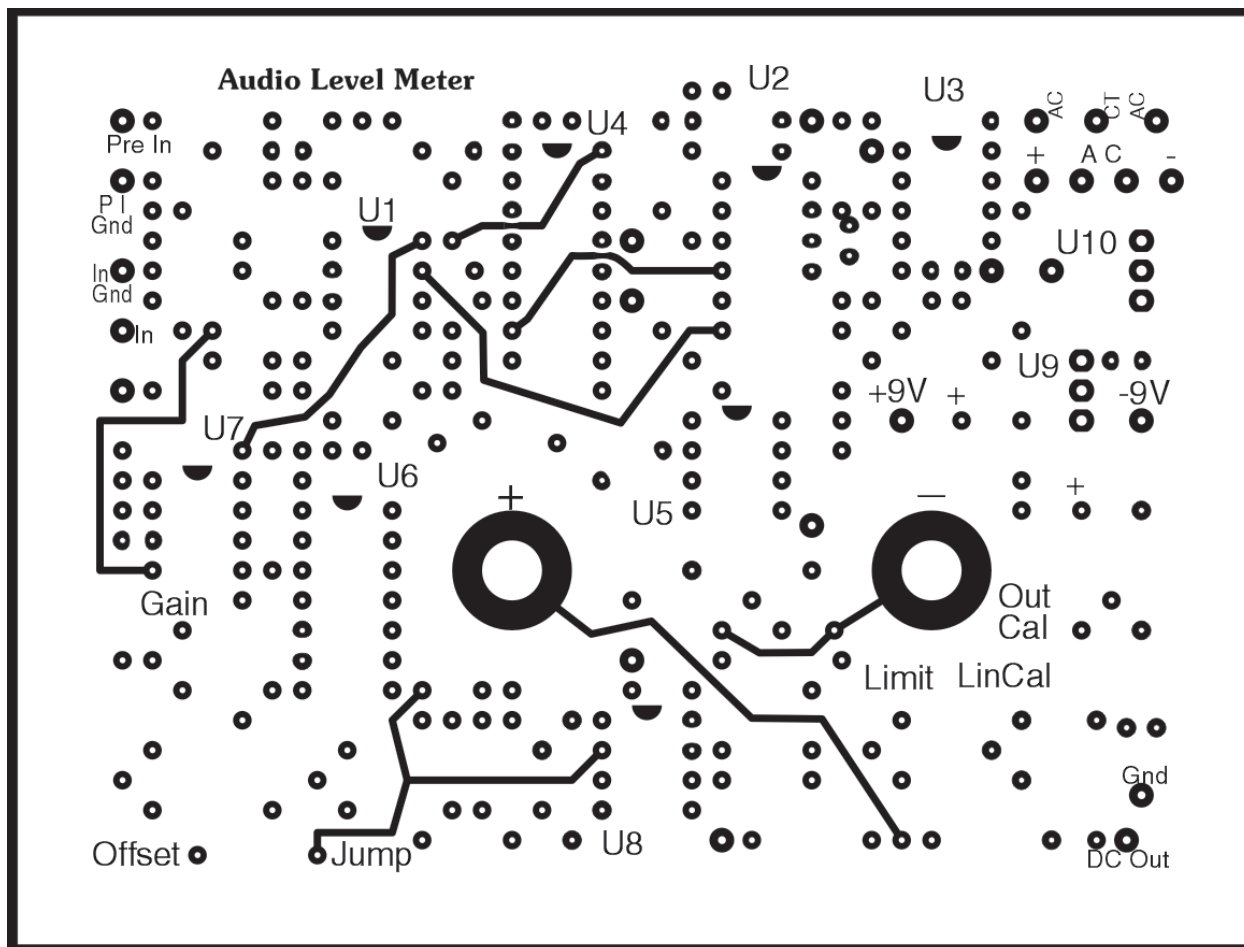
I used a Dremel rotary tool and accessory drill press stand to do the drilling. Since some tolerances are tight, it is important to drill accurately. Fortunately the center of the donut pads helps guide the bit. There are a surprising number of holes, but the drilling goes pretty quickly, once you get started. The PCB is mounted on the panel meter screws, which require a 3/16" hole.



Assembling the PCB

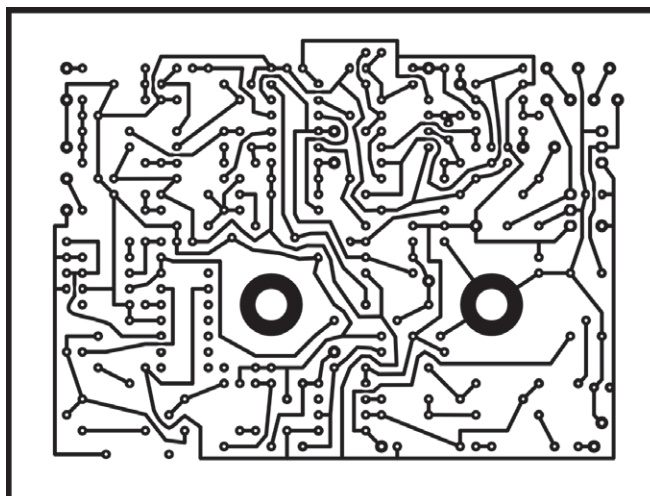
Introducing the PCB Layout

Since our PCB is homemade, it probably won't actually have a silkscreen but the silkscreen art **shown on the previous page**, is provided to help in stuffing the parts and making external connections. You can see the pattern for the two large holes where the panel meter screws go through the board. These provide the connections to the meter and also support the board. External con-



nections, IC's and cap polarities are labeled in **magenta**. Notice that all IC's are oriented in the same direction. External connection points are illustrated with flea clips, which we used as terminal pins. Orient diodes with their cathode bands as shown.

The top-side metal pattern is **shown above**. Since the home-brew PCB process probably doesn't provide plated-through-holes, you will need to solder the top-side pad (as well as the bottom-side pad) at every point where a top-side trace is connected to a pad.



Since there isn't a real silkscreen on the board, some key info is written in the topside metal, including labels for IC's, adjustments, supply voltages and a few external connections. The half-moon shapes indicate the pin-1 end of the IC's. Bottom-side metal is **shown at the bottom of the previous page**.

Note that the resolution of the PCB illustrations used in this document is not good for actually fabricating the board. Please use the art files which are supplied separately for that.

Installing PCB Components

By referring to the silkscreen drawing and the schematic, you can identify the parts to solder into the PCB. I recommend using sockets for the IC's as this protects them from the heat. Use high-quality machined sockets instead of the cheap ones with stamped-metal contacts. Be careful to install diodes and electrolytic caps in the proper direction.

Since top-side traces have to be soldered on both sides of the board, you should stuff the parts which connect to those traces first. That way, you will be able to solder the top before it gets too crowded. Pay particular attention to IC's which have top-side traces which approach the pad from underneath the IC. You can note those as you insert the IC socket; then solder the top-side pad right away. If necessary, you can also use the top-side metal drawing (shown on the previous page) to identify which top-side pads need solder.

The flea clips used as external connection terminals at the points labeled Z1, Z2, etc., can be installed with a special tool, but I just use a sturdy pair of needle nose pliers to push them in. Don't worry about crushing the top part sides together. You can spread those later. See the parts list for details on the flea clips.

When installing the bridge rectifier (D13), you might find that it has to be bent a little towards the East side of the board, to fit it in. Do not push D13 flush with the board. Rather, leave about 3/16" of lead so that you can clip onto the outer two leads with hook test leads.

Don't forget to solder wires through the board as mentioned by Note-1 on the silkscreen art. That provides feedthroughs in two places, in lieu of plated-through-holes.

PCB Testing

Power Supply for Testing

With the PCB assembled, you are now ready to test and adjust it on the bench. For details on how the circuit works, please refer to the Schematic Discussion section near the end of this article. For testing, we need to connect power to the board. I recommend using current-limited lab supplies, but if those aren't available, you could construct the project's power supply or use a couple of 12VDC, AC-adapters.

Voltage isn't critical but at least $\pm 12V$ would be about right. Current consumption will be up to about 60mA per supply, so setting limits of about 90mA would be reasonable. With them turned off, connect the supplies to the outer two leads of bridge rectifier, D13. The negative side is toward the outside (East) end of the board. Connect the power supply common to Z19 (ground).

External Connections for Testing

We need to attach some external resistors and connections to take the place of those which will be wired on the front panel in the final unit.

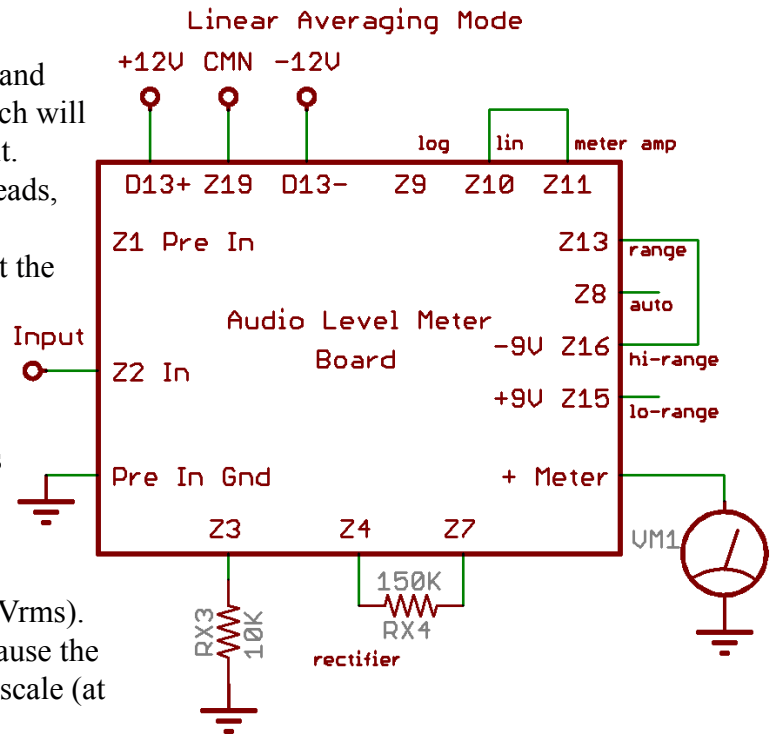
Wire these as shown **at right**, using clip leads, except leave out the panel meter, for now.

Initially, connect Z13 to Z16. This will put the board in linear averaging mode. Preset all pots to center rotation.

Expected Levels

Here is some basic info on the ideal levels in the circuits, when the unit is properly adjusted.: In *linear averaging mode*, at max sensitivity (4W scale):

- Max input level at Z2 is 5.66Vpk (4Vrms). (The preamp isn't used.) This will cause the meter to read at the top of the black scale (at "+3dB") in averaging mode.
- At max input level, the output of the rectifier/filter (Z10) will be 3.33VDC, which is full scale on the meter.



In log mode:

- Max input level to the ALM is 63.3Vpk (44.7Vrms, 500Wrms into 4ohms). The level at Z2 is one-tenth of that. This will cause the meter to read at the top of the blue dB scale (at "+10dB") in peak mode and 3dB lower in averaging mode.
- At max input level in averaging mode, the input of the log amp (Z10) will be 3.72VDC. The output of the log amp (Z9) will be 3.23VDC, which goes to the meter. Log amp output varies 33.3mV/dB.
You might ask why max voltage to the meter is 3.23VDC here and 3.33VDC above in linear averaging mode. Since, it's the same meter, why wouldn't max voltage be the same? The answer is that for max level in log averaging mode, the meter is supposed to read 3dB below full scale. Hence the highest meter voltage for log averaging mode is $3 \times 33.3\text{mV} = 100\text{mV}$ less than full scale. For max level in log *peak* mode, the output of the log amp will be 3.33VDC, driving the meter to full scale.
- The auto range switching has 6dB of hysteresis. It switches from low range to high range above 1.76VDC out of the log amp and from high range to low range below 1.56VDC out of the log amp. These two thresholds are centered on half the full scale voltage here, which corresponds to 50dB below full scale.

Initial Checkout

Detailed test and debug procedures are beyond the scope of this article, so we will just cover them in a general way. If you have problems or questions, email me and I will try to help. First, we want to get an idea of whether the circuits are basically working, **using the circuit above**.

- Apply 4.47Vrms, 1kHz to Z2. This is max input level (after the attenuator) in log mode.
- Verify with a scope that the waveform on Z3 is a clean, fullwave-rectified signal.
- The output of the rectifier/filter (Z10) should be about 3.72VDC.

- The output of the log amp (Z9) should be in the ballpark of 3.23VDC.
- Drop the input level 3dB to 3.16Vrms.
- The output of the log amp should drop roughly 100mV, to about 3.13VDC.

Of course, if things aren't working, you will need to debug before proceeding.

Next, we can verify that the 30dB preamp is working:

- Move the generator to Z1 and apply about 141.4mVrms (30dB less than 4.47Vrms).
- Instead of the connection from Z13 to Z16, make it Z13 to Z15. Selects the preamp.
- Verify with a scope that the waveform on Z3 is a clean, fullwave rectified signal.
- The output of the rectifier/filter (Z10) should again be about 3.72VDC.

Replacing the Panel Meter Scale

Before we can do the calibration adjustments, we need to install the new panel meter scale. The original scale for the Heathkit IM-17 panel meter was excellent for its multimeter function, but for this application, we created a new, custom scale. The art for the scale is supplied both in a standard graphics file format and in the CorelDraw file format, in which it was created:

- ALM mtr4.png - standard graphics file format
- ALM mtr4.cdr - CorelDraw-12 format

Preparing the Scale Platen

Warning: Many parts of the meter movement are extremely delicate, so be careful to avoid touching them. We need to remove the aluminum scale platen from the panel meter, so we can affix the new printed scale to it. To remove it, first carefully pry-off the plastic front cover of the meter. It snaps off of the meter assembly. Start at the top back, working your way around. Be as gentle as possible to avoid cracking the plastic. The aluminum scale platen is affixed to the meter assembly by two screws, down near the pivot, where the indicator needle rotates. Remove the screws and slide the scale platen out, being very careful not to touch the delicate pointer.

We will paste the new scale onto the scale platen. Before printing the scale, we need to know the exact size of the platen so the new scale can be precisely aligned. Measure the platen's overall width and height using a caliper. Mine measured 4.484 x 3.797 inches.

To avoid any bleed-through, you should turn the platen over and use the back side. First lightly sand the platen with 150-220 grit sandpaper and then spray-paint it with white primer. That will provide a reflective backing for the new scale paper and hide any metal blemishes that may be there. When sanding, be very gentle with the thin platen. Keep it on a hard, flat surface to avoid bending. After sanding, brush away the dust. Then clean with Windex before applying the primer. While the primer is drying, you can print the scale on an inkjet printer, as discussed below.

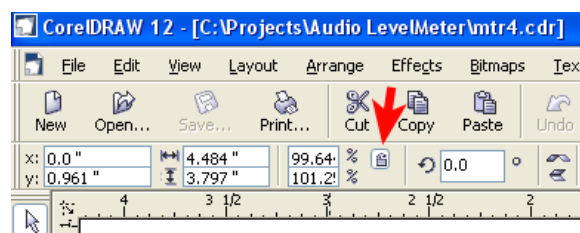
Customizing and Printing the Scale

One reason the CorelDraw scale file is supplied is so that you can customize it. To get the best alignment results with the meter platen, you may need to resize the outline rectangle which defines the edges of the platen. Yours might be slightly different from mine and you will need to cut the scale to exact size. The outline rectangle is shown selected in CorelDraw in the **figure on the next page**. You will see its current size of 4.484 x 3.797 in the property bar. The rectangle and the pivot alignment line are drawn in a color very close to the blue background, so they are



barely visible on the screen and on paper. That is done to minimize any visible artifacts from the alignment marks. If you have any trouble seeing it on-screen, choose View|Wireframe. To set the rectangle to the exact size you measured above for your platen, select it. Then *make sure that the non-proportional scaling mode is selected* as indicated by the **red arrow below**. Now you can enter the new width and height of the outline rectangle.

for 8-ohm speakers, just change the text of the power values (e.g. “100W,” “200W,” etc.), dividing each number by two. Remember to change the note near the meter pivot, from “Power into 4-ohms,” to “Power into 8-ohms.” Also, the power range markings on the front panel art will need to be changed. That CorelDraw file is also supplied. More on that later.



Another change you could make is to modify the red overload region bar. If your amplifier delivers less than 200W into 4-ohms, you could extend it downward. However, mostly the red bar was put there to make it look more like a VU meter :) Finally, it is possible for you to change the linear scale ranges by altering the circuit. In that case, you could modify the power markings on the scale and front panel, appropriately.

If you are using the scale as-is, you can use either the PNG graphics file or the CorelDraw CDR file to print the scale on an inkjet printer. Doubleclick either file to open it in the appropriate application and print from there. I printed from CorelDraw to an HP-952C printer, using Hammermill Laserprint paper. (This high-brightness, neutral-color, 24-lb paper has been my favorite for many years.) In the printer setup, select: Print Quality: Best, Paper Type: Other inkjet papers. If you need to adjust the outline size of the PNG file, use scaling in the print dialog. Otherwise, print the document at original size. Ignore any warning about fitting in printable area.

Make sure that the printed output is of good quality and that the alignment rectangle and pivot alignment line are (barely) visible. If not visible, you can increase the amount of black (K-value) in the color of the outlines of those objects in CorelDraw. If you are printing from the PNG file, you will probably have to work with it as-is. Check the size of the rectangle with the caliper. If it is off more than say, 0.04-inches in either direction, use printer dialog scaling to compensate.

Affixing the Scale to the Platen

The next step is cutting the scale to exact platen size. Use an X-Acto knife with a new blade and a metal straight-edge to cut precisely along the alignment rectangle. Make sure that it matches the platen accurately. Now you are ready to attach the scale. We will use 3M Super-77 spray adhesive to do the bonding. Cover a table with a newspaper sheet to catch sticky overspray. Be aware that this stuff gets around. Clean up with Goo-Gone, if necessary.

If you are not familiar with Super-77, I highly recommend that you try some experiments with a rectangle of paper representing the scale and cardboard representing the platen, before attempting to do the meter. It bonds very quickly and doesn't allow much repositioning.

If you find it difficult to accurately align paper and cardboard before the adhesive grabs, you can try this trick: After spraying the cardboard, cover the lower part of it with wax paper. Leave only a small horizontal strip at the top. Begin attaching the paper at one corner there. Align the paper down the left side of the cardboard platen, sighting through the wax paper. Press down more of the paper on the exposed strip of adhesive. Slide some or all of the wax paper out to bond the rest of the piece, gradually.

The standard instructions are: Lightly spray the platen-only with Super-77. Align the top edge of the scale with the top edge of the platen, but with the scale held vertical. Still in that position, slide the scale along the edge of the platen to align the sides. Now bring the scale down over the platen, maintaining alignment. Touch just the upper left corner lightly together to bond some. Align the left side and touch the side together lightly to bond. Lay down the rest of the scale lightly, checking alignment. If all is well, begin pressing down lightly, radiating out from the upper left corner. Smooth out any undulations. Ideally, with the platen backed by a hard surface and paper over the scale to protect it, roll over the scale with a rubber roller to set the bond.

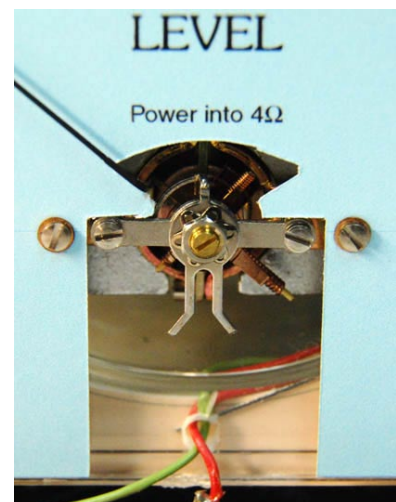
If you didn't get it right the first time, don't get discouraged. Just pull the scale from the platen quickly, before the bond sets. I don't advise trying to reposition at this point. You will need to clean the adhesive off of the platen thoroughly. Goo-Gone should take it off fairly easily. Just print another scale and try again. You'll get better with each try. When you have it right, congratulations! You just completed one of the toughest parts of the project!

If necessary, trim any overhang off the edges of the platen. You will also need to trim away paper in the cutout for the meter movement, as shown below. The straight edges go pretty easily. You just slide the X-Acto along the edge, using the aluminum platen to guide it. The curves though, are harder. As you can see at right, my effort was a bit rough. Punch out the holes for the screws using a sharp point. Do that from the front, shining a light from the back to show where to poke.

Reassembling the Meter

I have left the task of adding illumination to the meter for later in this article but if pulling off the front cover was a hassle, you might want to do that part now. To reassemble the meter, slide the scale platen back in place, again being very careful not to touch the pointer. Reinstall the two screws that hold the scale.

Before tightening the screws, carefully align the top of the scale platen to the back of the meter housing. Make sure that the scale does not overhang on the top, left or right. Also make sure that the scale is centered between the left and right edges of the back. Slip the front cover over the bottom part of the housing and gently press on the top until it snaps. Make sure the zero adjust screw (located over the pivot) is working. Ta-dah! You have your new panel meter with its cool blue scale.



PCB Calibration

Linear Calibration

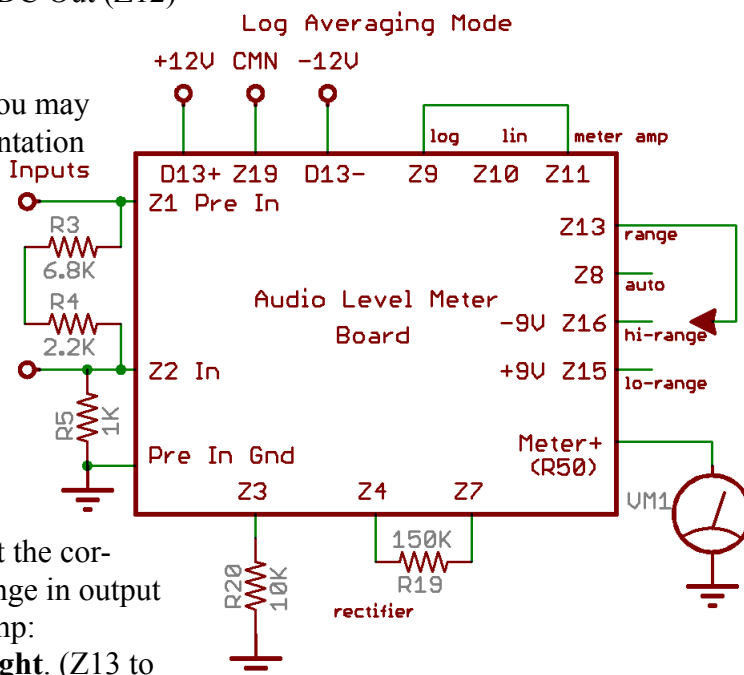
- The ALM board should be connected **as shown on page-10**. Orient the panel meter, facing horizontal, making sure that it is level. Adjust the meter zero on its front panel. Connect the positive panel meter terminal (on left, from rear) to the left side of R50, by the Limit pot.
- Move the Z13 lead from Z15 back to Z16.
- Apply 4Vrms 1kHz to Z2.
- Rotate Limit (R46) max clockwise. Initially set Lin Cal (R49) to pin the meter past max.
- Adjust Limit (R46) to bring the meter back to about the distance of 2dB past the max end of the top blue scale.
- Adjust Lin Cal (R49) for a full scale reading on the black scale.
- Adjust Out Cal (R44) for 3.0VDC at DC Out (Z12)

Log Amp Adjustments

Now, we are ready to adjust the log amp. You may find it a bit tricky but with a little experimentation and the procedure below, you should be able to get it adjusted properly. The odd thing about it is that the range switching is a feedback mechanism. If it is too far out of adjustment it may oscillate. You can refer to the Schematic Discussion for help on how the log amp works.

The general idea is that we will adjust the Gain pot to make a 40dB change swing the proper distance and use the Offset pot to set the correct max level. The Jump pot zeros the change in output due to range switching. To adjust the log amp:

- Connect the board as shown **above right**. (Z13 to Z16). The resistors should be the actual ones to be used later in the front panel subsystem.
- Apply 4.47Vrms 1kHz to Z2.
- Adjust Offset (R32) for -3dB reading on the blue decibel scale.
- Drop the level 40dB to 44.7mVrms and adjust Gain (R33) for a -43dB reading.
- Repeat until these two adjustments are stable.
- Move the Z13 lead from Z16 to Z8. Connect a multimeter to show the DC voltage on Z8.
- Now move the generator to Z1 and apply 447mVrms, 1kHz. The panel meter should read about -43dB. The multimeter should show about -5.3V (indicating high range).
- Decrease the generator level smoothly until the multimeter voltage switches to +5.3V, indicating the low range condition. That should happen around -56dB on the panel meter.
- Ideally, the reading on the panel meter should not jump, when the range switches. If it does jump, adjust “Jump” control R36 to correct half of the amount.
- Increase the generator level until the multimeter switches back to -5.3V. That should happen about 6dB up. If there is a jump, again correct half of it with R36.
- Repeat until there is the least amount of jump in both directions. It should be less than 1dB.



Checking Log Tracking

To test log operation, apply the following voltages at 1kHz to Z1, starting with the highest one you can manage. Note the deviation in meter reading on the top blue scale, from ideal:

Log Accuracy Test Ideals (Avg Mode)

<u>Vrms at Z1</u>	<u>Meter Reading</u>	<u>Z9 Voltage</u>
44.7	+ 7dB	3.23VDC
20.0	0	3.00
6.32	-10	2.67
2.0	-20	2.33
0.632	-30	2.00
0.200	-40	1.67
63.2mV	-50	1.33
20.0mV	-60	1.00
6.32mV	-70	0.667
2.00mV	-80	0.333
0.632mV	-90	0.000

Note: Zero Z9 voltage at -90dB does not indicate that the log amp has bottomed-out. It will continue into the negative range at lower levels.

Tracking should generally be within 1-2dB, through at low levels, you will need a pretty good test setup to check that accurately. If tracking is off more than that and you are confident that your test equipment is accurate and that hum is not affecting readings, it could be that your panel meter nonlinearities are somewhat different than the meters I tested. The scale markings are skewed slightly to compensate for the errors I found in those. The result was accuracy generally within 1dB over the entire range. To check the results of your adjustment of the log amp (and the inherent circuit error), you can compare the voltage at Z9 against the ideal values given above. You should scale for any disagreement in the top value. We are only concerned with the relative tracking below that.

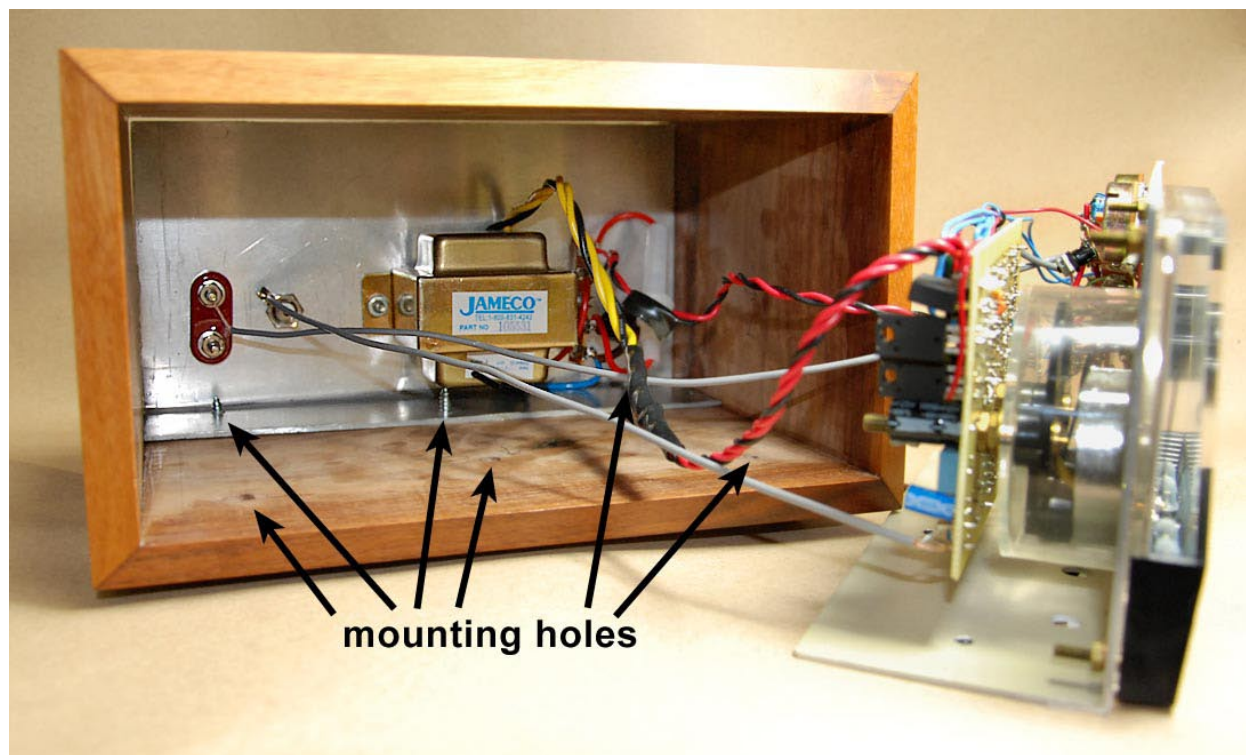
Whether or not the log amp output accounts for a mistracking problem, you will want to make fine adjustments in Offset and Gain to minimize it. That might involve compromising a bit at higher levels to reduce deviation at lower levels or vice versa. Try to do the fine tweaks solely on the upper side the range switching. Then correct Jump at the transition point. Finally, verify that the lower range is okay.

That completes the adjustments to the ALM board.

Overview of the Packaging

Of course, you may wish to package your ALM differently from the way I did. The packaging info I present here can be a specific guide if you wish to build it the same way or it can be a general guide if you want to do something different.

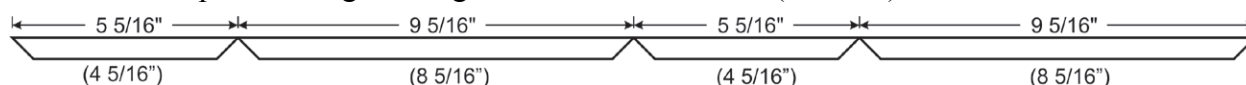
You can see the overall construction in the photo below:



It consists of two L-shaped pieces of aluminum (**front panel and rear panel**), mounted in a walnut box. Each metal piece is mounted with three sheet metal screws, arranged in a triangle. The front panel is from the Heathkit IM-17 and is used pretty much as-is. It is not necessary to drill any additional holes in the front side. The bottom side needs the addition of three holes for the mounting screws. The front panel is finished with a covering of printed art. Concerned about providing shielding on all sides, I added a shield over the circuit board. (Not shown above.) The rear panel is fabricated from a sheet of 0.065-inch aluminum. I shaped it using a bending brake. It is finished with satin black paint on one side.

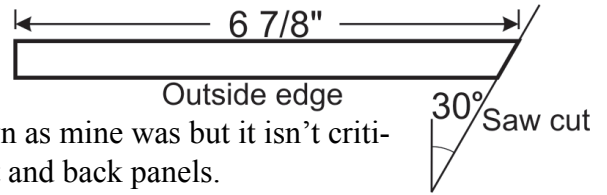
Making the Walnut Box

- We begin with the box, so you can adjust the size of the panels to fit, if necessary.
- You will need an accurately aligned table saw to do this well.
- Each box requires about 30" of walnut board, 0.5" thick. I let the width of the walnut board set the depth of the box at 6.875." This leaves some extra space.
- The Front Panel is 4.25 x 8.25" and the rear panel was cut to match, so the inside dimension of the box is close to this. On my first box, I targeted leaving 1/32" extra height and width for clearance. It actually came out 1/64" under for width and 1/32" under for height, due to clamping pressure. (Note that you can sand the metal pieces to fit, if there is a small shortfall.) As a result, I needed to target having 1/16" extra height and width for the second box. The bottom line on cutting follows:
- Cut four pieces along the length of the board like this (in-order):



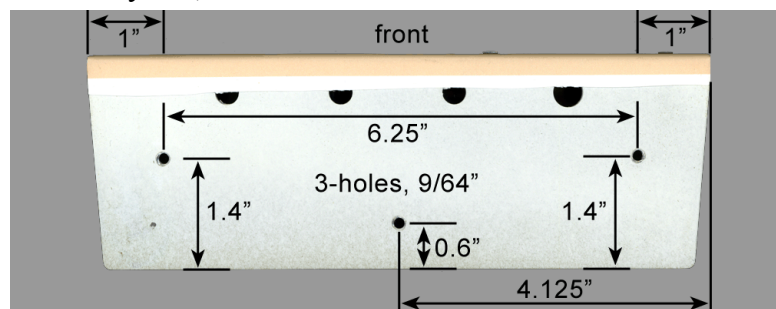
That will make the grain pattern run continuously around the box, a very nice effect. Notice that the ends at the crosscuts are mitered 45deg. The outer side of the box must come from one side of the board.

- After cutting the sides, run the pieces back through the saw to bevel the front ends at 30deg, as shown **at right**. The width of the board is shown as mine was but it isn't critical, as long as there is plenty of room for the front and back panels.
- Use a router to cut a groove on the inside of the top panel to accept the top edge of the front panel. It should be set back from the front by 0.2-inches and is 1/8" wide by 3/16" deep.
- To be honest, I can't remember exactly how I glued the box. I think I did all four pieces at once. First, I suggest that you use masking tape to protect visible surfaces near seams. Without that, any glue seepage, even if wiped-off, might cause blemishes. Gluing the box:
 - » Arrange the sides on a flat surface, with the front of the box facing up.
 - » You can use two band clamps: one near the upper end and one near the lower end.
 - » Prepare the clamps loosely around the box, ready to be tightened. Have a square handy.
 - » Apply the wood glue to the four joints and assemble them quickly. (Wood glue sets-up surprisingly quickly.) Get the first clamp snug and briefly square the box. Get the second clamp snug, trying to keep the box square.
 - » Tighten both clamps, wipe off any excess glue and make sure the box is square.
 - » Allow to dry overnight.
- I finished my ALM's with tung oil. It makes a very nice finish and works well with walnut. There is no need to stain the wood, since oiled walnut is dark anyway. I found it to be an easy finish to apply and I am hardly much of a wood craftsman. You do need at least four coats, though. To apply tung oil:
 - » Assuming the wood is reasonably smooth to begin with, sand with 220-grit.
 - » Wipe off all dust with a dry rag, with the grain. Then clean the board with another rag lightly moistened with turpentine. Let the turpentine dry about 20-min.
 - » I used Behr #600 Natural Clear Tung Oil Finish. Apply with a rag, *with the grain of the wood*, wetting it thoroughly. This is regular, pre-thinned, (not pure) tung oil. Allow it to soak-in for 15-min. Don't forget to cover the inside of the box, to about a half-inch from the front and back ends. That is needed because the front and back panels are inset by 1/4." (See the pic on page-1.)
 - » With a rag, wipe off excess oil and buff, with the grain. Allow to dry at least 60-min.
 - » Repeat for a total of four coats, except on the last coat, use #0000 steel wool to apply the tung oil, rubbing the wood, in the direction of the grain. After the soak, wipe with a rag and buff with the grain, to a nice satin lustre. Allow to dry at least an hour. The tung oil has been an excellent finish for seven years, now. It still looks like new.



Fabricating the Front Panel

Starting with the panel from the Heathkit IM-17 helps a lot, because most of the cutting and drilling has been done for us (particularly the hole for the meter). The steps we need to do to turn it into the ALM front panel are covered next.



Preparing the Panel and Art

- Drill three holes in the bottom side of the IM-17 panel for mounting in the box, as shown **above**. (You can see the edge of the front panel paper, bending around from the front.)
- Next, lightly sand the front and bottom. Then paint the front (continuing well-over the bottom corner) with white primer. Dry thoroughly.
- As mentioned on page-11, if you changed the meter scales on that CorelDraw art, you will want to change the scale indications on the front panel art to match. As before, the CorelDraw file is provided for this purpose, as well as a standard format graphics file for those who do not want to make any changes.

Be aware that the background color of the front panel seen in CorelDraw (or in the PNG file), does not match the color reproduced on my HP-952C printer. I had to skew it towards blue to get the result I wanted. The print should be a tan color, something like Pantone-155 and the photo on page-1. (On my monitor, the color on page-1 is paler and bluer, though.) In any case, you may want to adjust the background color to your taste, if you have CorelDraw or can shift the color of the PNG image with another application. The general idea is that the front panel color should contrast with the panel meter background color.

The art files are:

- » ALM FrontPanel.cdr - Front panel art in CorelDraw format
- » ALM FrontPanel.png - Front panel art in standard graphics file format
- Print the front panel art file. This is done much like the meter scale on pp.11-12. Important: If you are printing from CorelDraw, make sure that only the Drawing and Bleed layers are selected for printing. If you are printing the PNG file, center the art on the page.

Affixing the Art to the Panel

The next step is to affix the print to the front panel. The hardest part about this is get the alignment correct. I do not recall how I originally did it but this is what I would do today:

- Make sure your hands are clean.
- At the top and bottom of the art, initially trim at about 1" past the color area. At the left and right sides, trim at about 1/2" past the color area.
- Attach two, 1" pieces of masking tape to the bottom of the art, hanging off, 1/2". The pieces should be about 1" inside the left and right sides of the color area. This insures that the tape is within the width of the metal panel.
- With a light behind the panel, lay the art on it and line it up with the holes in the panel. While we want the meter holes to be in the ballpark, put priority on the right-hand side, where the controls are.
- When it is aligned, bend it at the bottom, tightly around the corner of the front and bottom sides. While making sure that the paper doesn't move, secure the masking tape to the bottom panel. Verify that the art still aligns with the front, when stretched around the corner.
- Put the panel on a box in the middle of a newspaper or similar. Allow the front panel art to lay face-down, drooping down the side of the box and onto the newspaper. Cover the art with paper, to protect it from overspray. Spray a light coating of 3M Super-77 adhesive onto the panel. Pick up the panel and roll the art around from the bottom, tightly over the front panel. Keep a piece of protective paper between your hands and the art.
- Rub over the protective paper to press the art onto the adhesive, working your way from the bottom to the top. Try to prevent bubbles or wrinkles. Note: Don't get discouraged if you mess this up on the first try. It took me another try too. If it's bad, pull the paper off of

the panel as soon as possible. Copious amounts of Goo-Gone and paper towels will clean-up the mess on the panel. Make sure it is clean before you print another copy and try again.

- At the top, form the art around the top edge of the panel and around to the back. Try to crease it tightly around there. Bend it back up and coat the back of the art lightly with rubber cement.
- Still keeping protective paper between your fingers and the visible art, tightly roll the art over the top edge and down the back. On the back, press the art onto the panel.
- Use a straight-edge and X-acto knife to trim the art on the backside of the panel about 1/2" down from the top. Peel off the waste part.
- At the bottom of the panel, remove the masking tape. Bend the flap of art up and coat the back of the art lightly with rubber cement.
- Again protecting the art with paper, press it down tightly around the corner and onto the bottom panel. Trim away all but 1/2" on the bottom.

Trimming the Sides of the Front Panel

- Using the edge of the aluminum panel to guide the blade, trim the sides of the art to the width of the panel. Keep the blade angled so that the edge of the art covers the edge of the panel. That is, don't cut at such an angle that the art falls a bit short of the edge of the panel. Be very careful near the top corners of the panel, as the rear flap is there too. Try for a clean corner.
- At the bottom be careful trimming the side as it goes around the corner.
- Cut out the holes for the meter, eight screws and three controls. The edges of these holes don't show.
- Handling the rectangular cutouts for the two slide switches is a bit tricky, as these *do* show. We don't want to leave cut edges of the paper that close to the moving part, fingers, etc. With a light behind the panel, carefully make four cuts from the center of the rectangle to the corners. This will leave four, triangular flaps. Apply a bit of rubber cement to each flap and fold it through the hole, around the back and secure it to the back of the panel. This avoids having exposed paper edges and covers the edges of the rectangular cutout.

Clear Coating the Front Panel

We need to protect the paper from accidents, so it is necessary to apply multiple coatings of clear coat. I don't recall the exact product I used for that. The concerns are:

- Needs to be compatible with the printing.
- Should not have a glossy finish. Satin is probably right. Matte may have loose grit.
- Needs to be as tough and water resistant as possible.
- Should not loosen the adhesive.

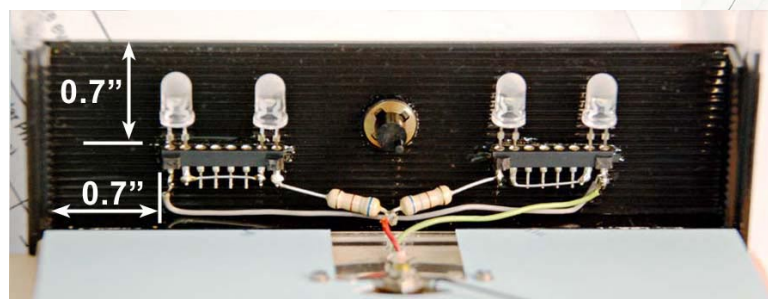
For the first two issues, you should print extra copies of the art and test the clear coat to make sure the art is okay and the finish is what you want. As for water resistance, I'm not optimistic. In the past, even three coats (oddly enough) didn't seem to protect. I can only urge you to use many light coats and try a test page.

The problem with loosening the adhesive is very real, due to the solvents in paint. Perhaps a clear latex or a low-VOC formulation would help. I would use very light coats at first and let them dry for 15-min or so between. The idea is to build-up a coating without harming the adhesive, which will protect the adhesive from subsequent heavier coatings.

Adding Illumination to the Panel Meter

The McIntosh meters, which I mentioned on p.1, had rear illumination which seemed to make them glow. That isn't easily done with the IM-17 meter but we can have the next best thing by installing white LED's to illuminate the front of the meter. White was chosen, rather than blue, because I wanted the red bar to show up well. Using ink to color the background blue gets the same effect.

The overview of the LED installation is shown at right. You can see construction details below.

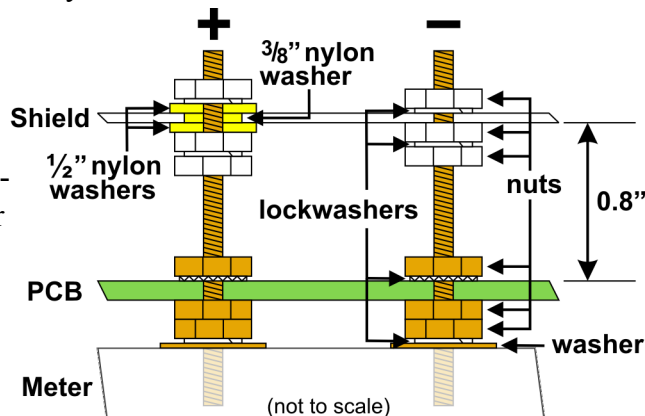


external leads. The hole can be seen more clearly on p.13. Trim the LED leads as shown (0.35"). Important: The top of each LED needs to be frosted to disperse the light evenly, as seen at left. Use 400-grit sandpaper to do that. Remember to get the polarity of the LED leads correctly oriented.

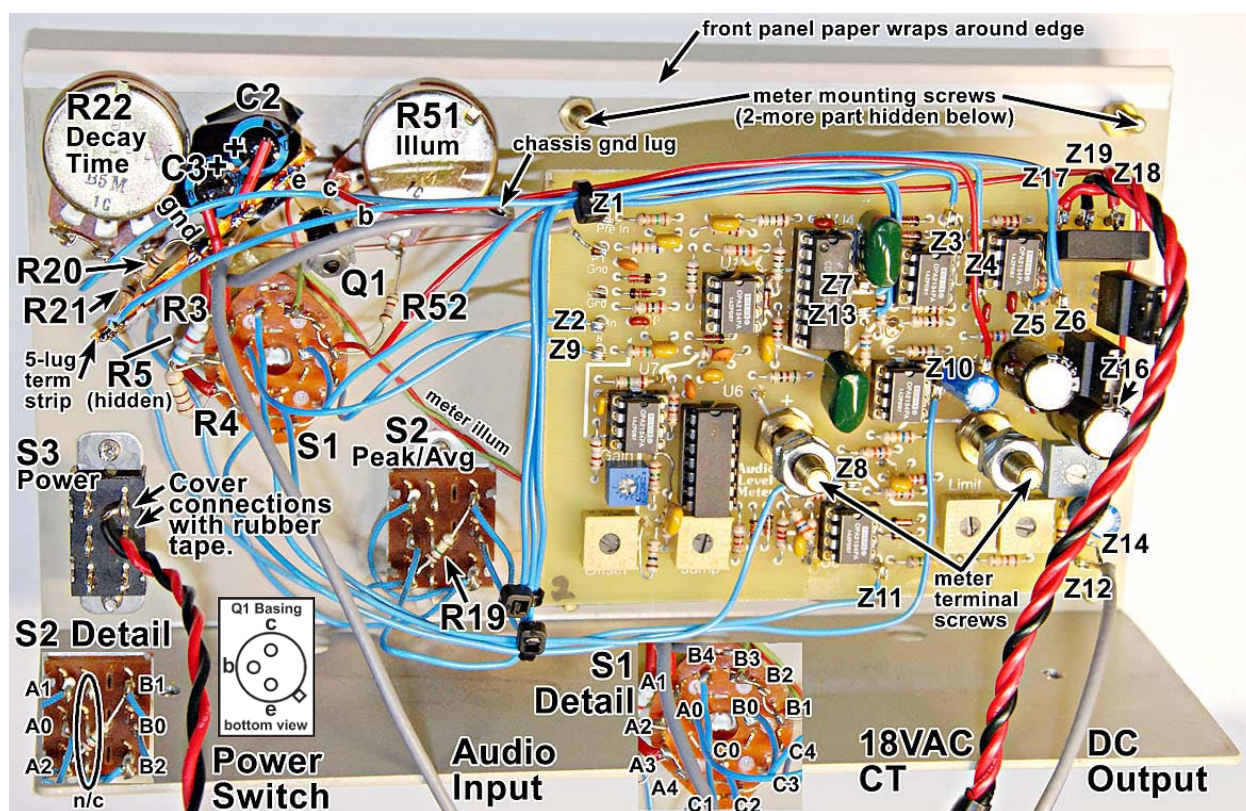
Assembling the Front Panel Subsystem (FPS)

The FPS contains all of the electronics of the ALM, except the power transformer, fuse and rear-panel jacks. You can refer to the photo on the next page for assembly and wiring details. The general steps in constructing the FPS are listed below.

- Mount the pots, switches and meter to the front panel (**FP**), as shown. Include a grounding lug around the bushing of pot R52, oriented as shown. Note that S2, S3 and the meter, along with their mounting hardware, are from the original IM-17. The other items are new.
- The PCB is mounted on the meter terminal screws. Use the six brass nuts, four lockwashers and two flat washers which were on the terminal screws in the IM-17. Refer to the diagram above right, for hardware details. Just the lower portion for the PCB mounting is relevant at the moment. We will refer back to this figure when it is time to attach the PCB shield.
- We need to mount a 5-lug terminal strip (center lug gnd) between R22 and S1. The mounting tab goes towards S1. To avoid adding an odd screw to the FP, I used a blob of 5-min

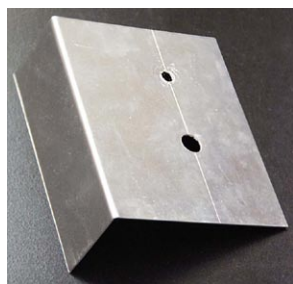


epoxy to cover the mounting tab and fasten the terminal strip. This does not provide a reliable connection to the chassis for grounding, though. The bushing lug of R51 is for that. In the photo, you can see the bare copper wire connecting that lug to the terminal strip lug.

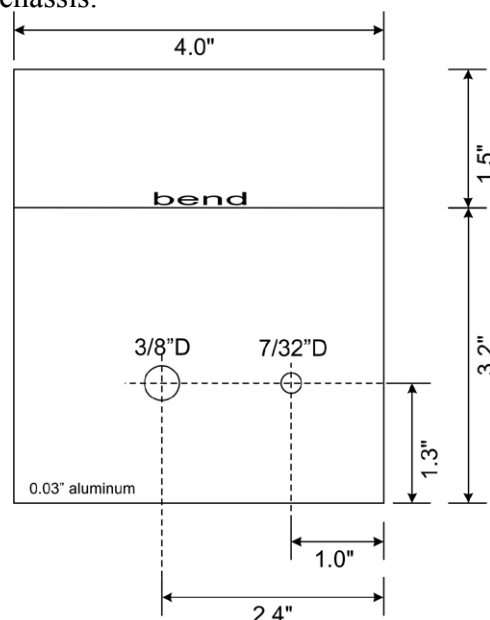


- The emitter, base and collector leads of transistor Q1 are labeled as “e, b, c.” Notice that what you can see of Q1 looks a bit odd because of its heatsink. I originally wanted it to be a TO-5 size package, for cooling. It came in a smaller TO-18 package so I added a tiny heatsink which has a screw mount (unused). A better idea would be to substitute a 2N2219, which is the same transistor in a TO-39 package (similar to TO-5). The pinout is the same.
- There is some tape under C2, C3 to prevent a short to the chassis.
- Install the other components and connections, using the photo and the schematic.
- Leave at least 12-inches of wire for the connections between the FP and rear panel. The Audio Input lead could use an additional 1-2-inches.

Making and Installing the PCB Shield



- Fabricate the shield as shown in the drawing **at right**, out of a 4.0” x 4.7” piece of 0.03” aluminum. The finished product is shown **at left**.
- Install the shield on the meter terminal screws as illustrated in the diagram on p.20. That uses six nuts, four lock-

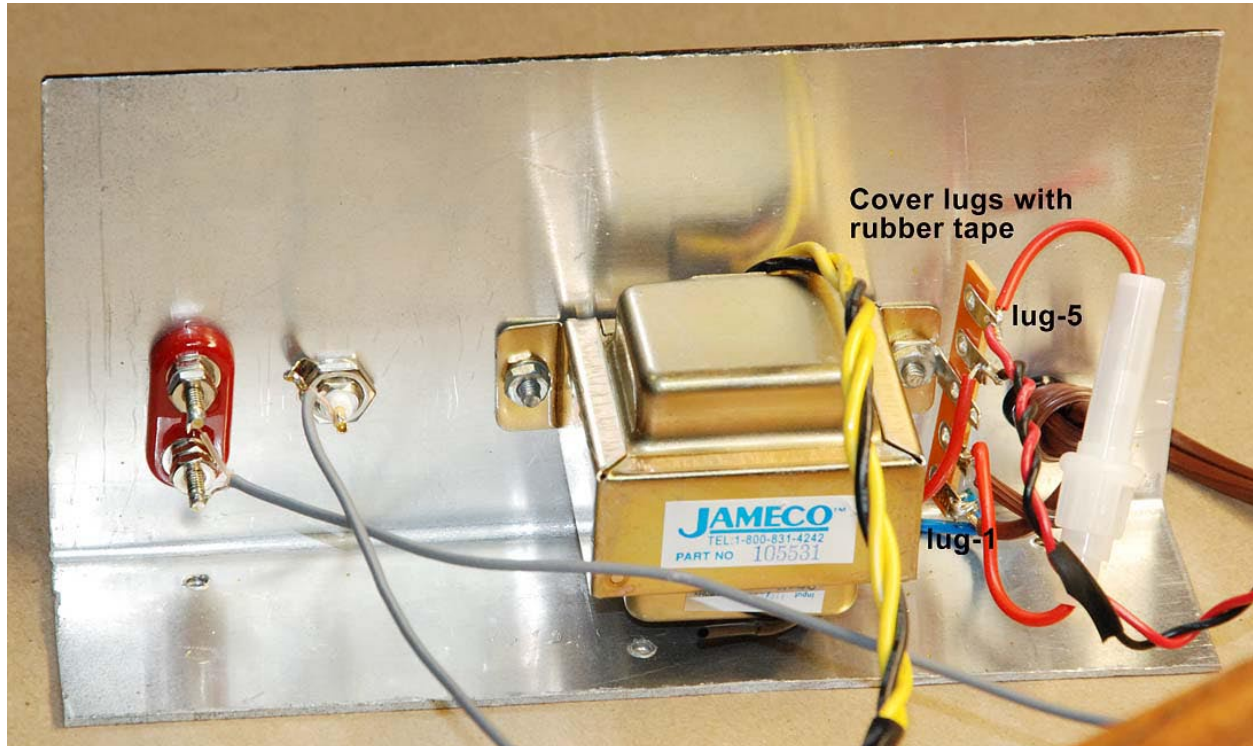


washers, two 1/2" nylon washers and one 3/8" nylon washer. The nylon washers insulate the positive meter terminal from the grounded shield. Press the 3/8" washer into the hole in the shield, so it is even with the metal. The pairs of nuts below the shield are tightened on each other to establish a fixed platform. Notice the nylon washer makes one side lower.

- The 1.5" flap is closest to the top of the ALM box. With the shield and the front panel in place, the board is covered on four sides.

Rear Panel Subsystem (RPS)

The RPS is shown in the photo below:



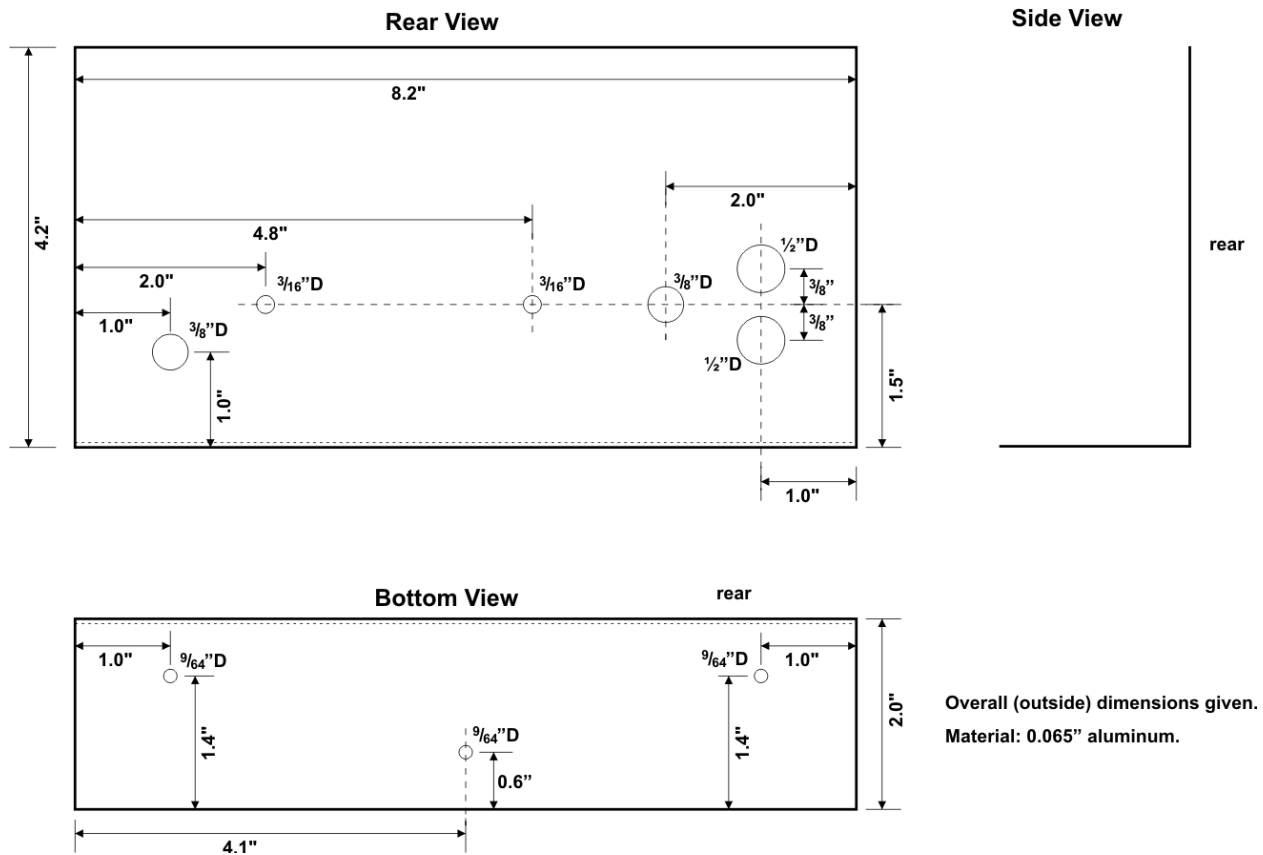
Fabricating the Rear Panel

- Cut, bend and drill a piece of 0.065" aluminum as shown in the drawing on the next page.
- Make sure that the panel fits properly in the box. Adjust, if necessary.
- Sand the outside with 220-grit. Spray paint with primer and then satin black.

Assembling the RPS

- Note: Although it is not shown in the photo, I would urge you to provide extra insulation around the AC wiring terminals, to lessen the likelihood of a short to the chassis or someone touching them. You could also use a three-wire AC cord and connect the mains ground to the chassis. In that case however, it would be advisable to float the electronics from the front and back panels. Else, if there is any other mains ground connection in the stereo system, there would be ground-loop hum.
- Mount the binding posts, BNC jack, transformer and 5-lug terminal strip (TS), as shown in the photo. Include a grounding lug with the BNC jack. Attach the transformer using two 8-32x3/8 pan-head screws, two nuts and two lockwashers.

Rear Panel



- Insert a grommet into the hole for the AC cord. Tie a knot in the cord to act as a stopper at the grommet, leaving 3-inches of wire on the inside of the panel. Connect the wires to lugs (1) and (2) of the TS.
- Connect the blue and red transformer leads to lugs (1) and (4).
- Connect the fuse holder between lugs (2) and (5).
- Twist the FP power switch wires and connect them to lugs (4) and (5).
- The end of the unused black wire of the transformer should be insulated with heatshrink, overhanging the end by at least 1/2". Lug-3 of the TS is not used.
- Splice the yellow and black leads from the transformer, to the red and black leads coming from Z17, Z18, Z19 on the PCB. Use heatshrink to insulate. Z19 is the black CT. The three-lead cable should be twisted.
- Solder the shielded cable from the FP TS to the dual binding post.
- Solder the shielded cable from Z12, Z14 on the PCB to the BNC jack.

Congratulations! That completes electrical assembly of the Audio Level Meter!

Final Assembly

- Drill six, 7/32" holes in the bottom of the box, for mounting the front and rear panels. This is shown **at right**.
- Position the holes so that each panel is set back from the edge of the box by 1/4". You can see this inset in the photos on p.1 and below.
- Countersink the holes so the screws are flush with the bottom. It is very important to have a definite way to set the depth of the countersink as it is very easy to penetrate too far.
- Attach four adhesive feet, as shown.
- Install the front and rear panels, securing them with six, #10x3/4" sheet metal screws.
- To label the rear panel, print the graphics file: "ALM labels.pdf" on inkjet label paper. It should align with Avery #5351 (1"x2-3/4") labels. You could also use full, letter-size label sheets (Avery #5165).
- Cut out the two labels, using a straightedge and X-acto knife. Darken the edges of the labels with quick sweeps of a black marker. Don't apply too much ink or it may seep far enough to mar the lettering.
- Apply the labels to the rear panel as shown **at right**. A view of the final rear panel is shown **below**.



Final Testing

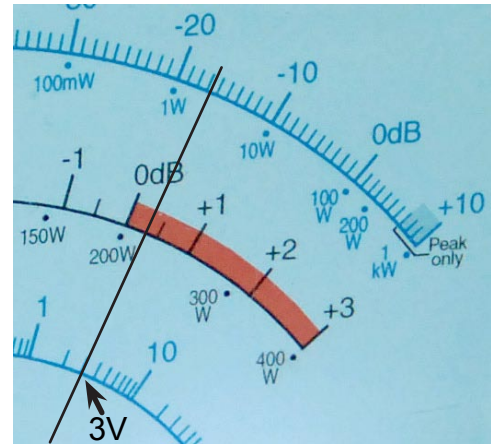
To verify that the ALM works correctly:

- Attach an audio generator to the Audio Input of the ALM.
- Set the Range to **1kW Log**, AVG, Decay at min and Illum at max. Plug-in the AC cord and turn ON the Power switch.
- Verify that all four LED's are lit and the illumination is fairly even. Vary the Illum control.

Brightness should fade to black, well before the min position of the control. Return it to max.

Log Scale Tests

- Set the audio gen for 1kHz and its highest integer output value, as measured with a DVM. Verify that the voltage reading on the bottom blue scale is correct $\pm 15\%$. For example, in the reading **at right**, the bottom scale indicates 3Vrms. On the top scale, we see that the level is a bit over 3dB above 1W, or a bit over 2W. Calculating the power of 3Vrms in 4-ohms, we get $P = (3)^2/4 = 2.25W$, which agrees.
- Adjust the generator for 2Vrms. You should read about -20dB on the top scale. Switch from AVG reading to PEAK. Verify that the indicator increases by 3dB. Then switch back to AVG reading.
- Adjust the generator to read exactly -20dB on the top scale. Now use the generator's 10 or 20dB step attenuator to check tracking as far down as it will go. It should be within 1-2dB.
- Remove the generator connection and short the Audio Input of the ALM. It should read -90dB or below. Reconnect the generator.



Variable Decay Test

- Reset the step attenuator to read -20dB. Loosen the generator hot lead, so you hold it connected and can break the connection quickly. Ideally, with Decay time set to minimum, the circuit will slew at 65dB/sec. So pull the signal and it should be near the bottom in 1-2-sec. At maximum Decay time, it slews at 2dB/sec, so it would be near the bottom in 35-sec.
- However, even tiny amounts of leakage in the circuit can upset that. The effect of the leakage becomes 300-times less when the auto-ranging point is reached at about -50dB, though. So you may see the decay start slowly ~ 2 dB/sec, speed-up as it approaches -50dB, then slow down there, speeding-up again as it approaches the bottom.

Linear Scale Tests

- Next, we will check the linear scales. Select the 400W Range. The average audio gen doesn't offer enough voltage to do much of a test on that scale. If you can get 28.3Vrms (perhaps from a variac), that should read 0dB (200W). A value of 10Vrms should read -9dB (25W). 6.32Vrms should read 10W.
- Switch to the 40W Range. Now the marked power values are divided by ten. The 0dB (20W) mark should result from 8.94Vrms. The -3dB (10W) mark is at 6.32Vrms.
- Switch to the 4W Range. Now the marked power values are divided by 100. The 0dB (2W) mark should result from 2.83Vrms.

If all of the tests are satisfactory, your new Audio Level Meter is good to go!

Installing and Operating Your ALM

The ALM is designed to rest on top of a speaker enclosure. It can be connected across the speaker terminals with shielded cable or thin twisted pair wire. I switch my stereo system on and off using an X10 wireless remote control. An extra appliance module on the same channel switches the ALM's on, at the same time as the stereo. The illuminated meters make a nice indicator that the system is on.

Built-in input and meter protection insures that your ALM will not be damaged on any scale, by even the most powerful home stereo amplifiers.

Please refer to the coverage of the scales and basic operation of the ALM on p.2 of this article. We add some additional notes here:

- Use the Avg mode for the best measurement of continuous power and residual noise levels.
- For the most accurate indication of power levels above about 0.4W, use the lowest linear range which will accommodate the reading.
- For the best indication of low power levels and residual noise, use the log scales. The lower blue scale reads directly in Vrms (though it uses an averaging detector, rather than true RMS).
- Be aware that the Decay time control only affects Peak mode. In Avg mode, the filter time constant is fixed at 33ms.
- Use the Peak mode with maximum Decay time to show whether an amplifier is in danger of clipping.
- Use minimum Decay time for fast indication of music dynamics.
- If you find that Peak mode shows noise levels more than say, 10dB higher than Avg, there may be short, 60Hz transients present. These can come from lamp dimmers, such as those found in X10 remote control lamp modules. Any equipment switched with X10, should use appliance (relay) modules, rather than the dimmer-type lamp modules.
- The DC output offers a voltage which is proportional to the meter indication. It lets you use the signal detection capabilities and log processing feature of the ALM with other equipment. Examples include:
 - » Using the auto-logging feature of a digital multimeter to record noise or power level readings over a period of time.
 - » Plotting frequency response in dB on an XY-plotter or digital oscilloscope.
 - » Using a computer to measure a wide dynamic range of AC levels, with a digital multimeter having a computer interface.



Schematic Discussion

The basic theory of operation of the ALM was covered on pp. 3-5. Now we will get into the individual circuits of the ALM in greater detail. Please refer the **schematic on the next page**.

High Range Input Circuits

The speaker-level audio from the Audio Input is AC coupled through C2, C3 to the input attenuator and the 30dB preamp. The preamp path is only used in Log mode and only when the auto-ranging activates the low range. At all other times, the path through the input attenuator is employed.

AC coupling is used to eliminate any DC offset that the power amplifier might have. The input attenuator sets the input impedance of the ALM at 10Kohms. Low frequency rolloff resulting from the AC coupling breaks at only 0.32Hz. The reason that it is so low is to minimize transient DC offsets which would result from the presence of asymmetrical or low frequency material in the audio. Such offsets would reduce the validity of using the ALM as a clipping indicator. That's because the meter would be reading something different than the true peak audio levels.

The input attenuator is switched between 0dB, -10dB and -20dB by the Range switch. 20dB attenuation is used on the log range. Output from the attenuator is lowpass filtered (**LPF**) at 20kHz by R6, R7, C5, C6. Note that C6 is only part of the capacitance on that node, as diode and other caps are significant there. This is a 12dB/oct filter, 2dB down at 20kHz. Somewhat aggressive filtering is used to minimize the degradation which RF and transient interference might cause for the use of the ALM in measuring residual noise.

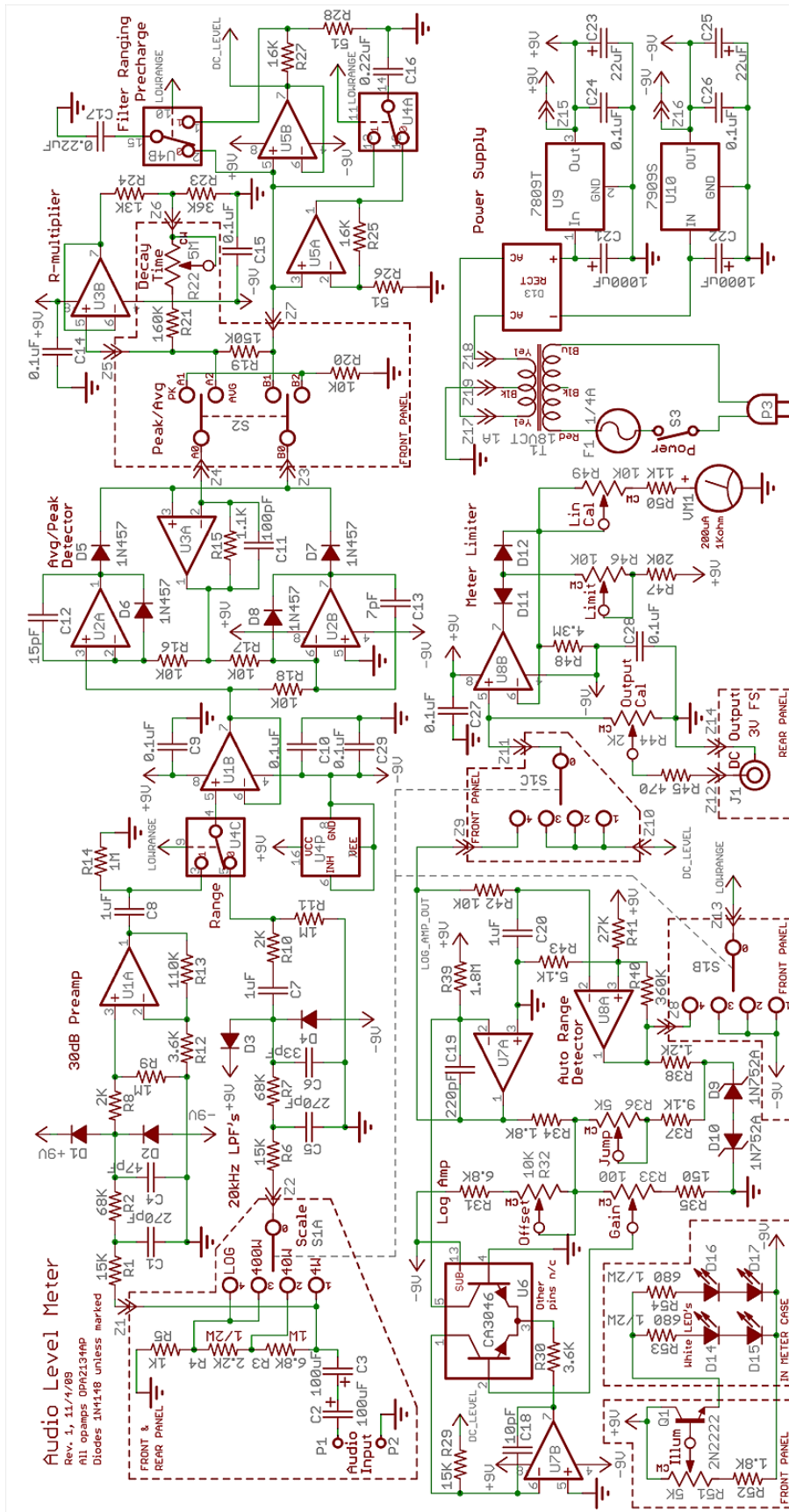
Following the filter, clamp diodes D3, D4 protect the ALM from high voltages which might be present at the Audio Input. The series resistance in the LPF limits current into the diodes. AC coupling cap C7 is present only to match the high-range input circuit to the low-range input circuit. R10 insures that the clamp diodes, rather than parasitic diodes in U4, take most of any fault currents. Such current in U4 could cause latchup. R11 keeps C7 charged to match C8. Notice that due to the loading of R11 on R6,7, there is a small amount of loss in this path.

Low Range (Preamp) Input Circuits

The characteristics of the low range and high range input circuits must match as closely as possible, so that when the auto-ranging switches, the reading on the meter is not affected. The same LPF and input protection circuitry is used in the preamp, including R1,2,8, C1,4, and D1,2. R9 is added to provide a DC return path for U1A. This opamp, with R12,13, provides 30dB of gain. AC coupling cap C8 is needed to eliminate any DC offset of U1A, which would otherwise be multiplied by the gain of the preamp. The Avg/Peak Detector is vulnerable to DC offset, since it must accurately rectify signals down to 50dB below max.

Range Switching and Avg/Peak Detector

In Log mode, analog switch U4C selects either the low range path (which has 30dB gain) or the high range path (which has 20dB attenuation in the Log position), according to the $\pm 9V$ logic signal, LOWRANGE. In linear modes, the logic signal is forced low by S1B, selecting the high



range path only. The selected input signal is buffered by U1B so that the loading of R18 will not affect low frequency response.

Precision Rectifier

The Avg/Peak Detector consists of a precision rectifier (U2A,2B,3A and associated components), followed by a complex filtering circuit. The precision rectifier operates like a perfect, fullwave, diode rectifier and can be viewed independently from the peak/averaging filter which follows. The output of the precision rectifier is at Z3. For the moment, let's ignore the filtering circuits and just imagine a resistor load there.

U2A is a non-inverting, unity-gain, half-wave, precision rectifier. U3A buffers the feedback (**FB**) for both U2A and U2B, so that the FB networks do not load the subsequent filtering circuitry. U2A is a precision rectifier because D5 is within the FB loop. D6 provides clamping so that when a negative voltage is applied to the non-inverting side, the opamp will not slew all the way to the rail as D5 blocks FB. Keeping U2A clamped maintains FB, preventing internal circuits from saturating and minimizing the amount of voltage that the opamp must slew. That greatly reduces recovery time as the input signal becomes positive again.

U2B is an *inverting*, unity-gain, half-wave, precision rectifier. When input signals are negative, it delivers a positive, rectified voltage to the output. When the input goes positive, D8 clamps the opamp, speeding recovery as in the non-inverting case. Together, the inverting and non-inverting rectifiers produce a positive, fullwave-rectified waveform on a resistive load. They operate in parallel, each providing output current for a half cycle.

This parallel-type full wave rectifier approach minimizes DC offset and dependence on resistor matching. Referring to the levels given on p.10, we have the max level out of the rectifier/filter as 3.33VDC. The minimum significant signal level is then 50dB lower, or about 10mV. So we want DC offset to be far less than that.

Notice that the precision rectifier cannot draw current back from the load. It acts like a perfect diode, only conducting current in the forward direction and only when the input is higher than the output. Since even tiny leakage currents can upset the long time constant filtering, the diodes are special, low-leakage types. The opamps all have JFET inputs, minimizing input currents.

Avg/Peak Filtering

For all its parts, the filtering function pretty much boils down to a cap from Z7 to ground and a resistor load to discharge it. Either C16 or C17 is connected to Z7 by analog switches, U4A or U4B. In Peak mode, the output of the precision rectifier at Z3 is connected directly to the filter point, Z7. That does the job of rapidly charging the filter cap to the peak level of the input signal. The full output of the rectifier opamps is available to charge the relatively small 0.22uF filter cap.

Since the output of the filter is buffered by U5B, the only non-leakage path which discharges the filter cap is through R21,22. If we could get it, R22 would simply be a 20M pot going to ground. But the highest value pot we could find is only 5M. The solution is use buffer U3B to bootstrap the end of the pot which would normally go to ground. The gain from Z5 to Z6 is 0.73. This

makes the voltage drop across the pot only 27% of what it would be if it were grounded. The current is reduced proportionally. In effect, we have multiplied the resistance load of the pot (and R21) by 3.77X, making them appear to be 19.4M. That achieves the max time constant needed of about 4.3-sec.

Let's take a look at how sensitive the circuit is to leakage current. As mentioned, the max level out of the rectifier/filter is 3.33VDC. At the longest Decay setting, the discharge current at full scale then, is $3.33/19.4\text{M} = 172\text{nA}$. When this has decayed 50dB (just before the auto-ranging point), the current is reduced to $172\text{nA}/316 = 0.54\text{nA}$. So leakage must be kept well below this. Checking a 1N457 diode in the lab, I measured the leakage at 0.074nA, which should be adequate. The opamps have a typical input current of 0.005nA. A film filter cap was chosen because those have a typical insulation resistance spec of 10Gohm/uF. Conclusion: The diodes are by far the limiting factor and those should meet the requirement. Connections and the board near the sensitive nodes should be kept clean, though.

In Avg mode, the cap on Z7 is driven through R19. To get proper averaging, we need the signal which is driving R19 to be a full-wave rectified waveform which can sink as well as source current. That is, we need it to be effectively a voltage source, regardless of whether the voltage on the cap at Z7 is higher or lower than the input signal. In Avg mode, R20 alone loads the output of the precision rectifier at Z3. So the waveform there, is indeed the full-wave rectified waveform. Notice that the voltage at U3A-2 follows that waveform exactly. That is where we take the signal to drive R19 in Avg mode.

What we have then, is a full-wave rectified waveform which is lowpass filtered by 150K (R19) and 0.22uF (C16 or C17). That gives us a fixed time constant of 33ms or 260dB/sec in Avg mode. It will be able to discharge the full 100dB range in less than 0.4-sec. Notice that the Decay control has no effect in Avg mode because it loads only the voltage source drive.

As mentioned before, U3A buffers rectifier feedback. So what is the purpose of R15? Notice that R20 is connected to U3-2 in peak mode. With R15, this gives the feedback a gain of 1.11, reducing the gain of the rectifier by this factor. This is needed because we want the meter to be calibrated to read RMS voltage in average mode. For a sine wave, the ratio of peak to RMS voltage is 3dB, while the ratio of peak to (fullwave) average is about 3.9dB. The difference of 0.9dB is a factor of 1.11 in voltage. Reducing the rectifier gain in peak mode lets us calibrate the meter to read both RMS voltage and peak voltage correctly (for sine waves).

The filtering gets complicated by the fact that we need to keep a second filter cap in reserve, which is charged to a level 50dB different than the current cap. That technique is discussed in detail on p.5. For our purposes now, suffice it to say that C16 is used as the filter cap in low range and C17 is used in the high range. When not in use, C16 is kept charged for low range action by the 50dB amp U5A, R25,26. When C17 is not in use, it is kept charged for high range action by the 50dB attenuator R27,28, which is buffered by U5B.

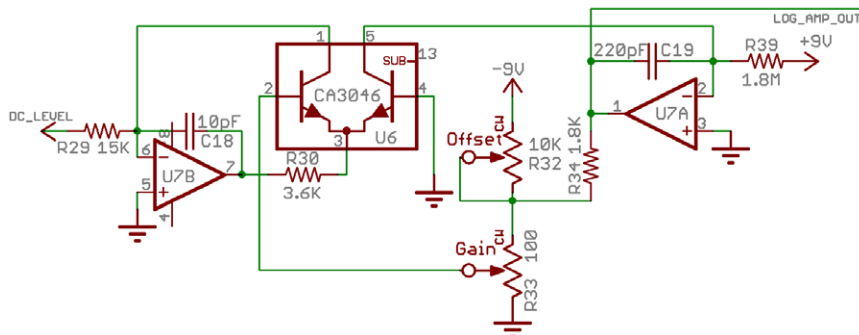
That buffer also delivers the final result of the Avg/Peak Detector, to the subsequent circuits. The signal at that point is called DC_LEVEL. Depending on whether a Linear or Log range is selected, DC_LEVEL may go on to the meter or it may be processed first through the Log Amp.

Log Amplifier

The purpose of the Log Amp is to produce a voltage which is proportional to the logarithm of the input voltage. This presents a display which can be linearly calibrated in decibels. A given percentage change is a constant distance on such a scale, regardless of the absolute amplitude.

Before getting into circuit details, here's an overview of how the log amp works: The basic idea is to use the fact that the voltage across a diode is the log of the current through it. In the ALM, the diode is the base-emitter junction of a transistor. We set the emitter current from the input signal and use the base-emitter voltage as the log value.

Please refer to the simplified schematic of the log amp, **at right** (which does not have the auto ranging circuit). The input to the log amp is at left and the output is at the right, above the +9V arrow. The two transistors are matched.



U7B adjusts the current feeding both emitters, to make the collector current of the left transistor track the input signal. So the base-emitter voltage of the left transistor is basically the output value we want.

U7A adjusts the base voltage of the left transistor to keep the collector current of the right transistor at a fixed value. Since its base is grounded, that reference current determines the emitter voltage of both transistors. It will be at a baseline value which compensates for temperature and device characteristics. When the input signal current matches the reference current, the collector currents will match and the base voltages will match (and be zero). The output of U7A is the log value with scaling and offset. R32 and R33 let us adjust that scaling and offset, to calibrate the output of the log amp.

Referring now to the auto-ranging version in the schematic on p.28, you can see that it adds a comparator to detect a certain threshold voltage at the log amp output. When it switches, the logic output of the comparator (regulated by zener diodes) offsets the log amp output by the equivalent of 50dB. That cancels the 50dB change in gain in the input system, which the comparator also controls. The Jump adjustment adjusts the amount of offset supplied by the comparator so that the cancellation is accurate. If it is set correctly, the output of the log amp should not change when the comparator switches. If it is incorrect, the output will jump when the comparator switches. Hence the name.

The result of the range switching is that the log amp output accurately spans 100dB of dynamic range, while the basic logging circuit only has to work over a 50dB range. The basic logging circuit here is good for about 60dB range. Please refer to p.10 for some detailed values of levels and range switching thresholds. You can also gain some insight into the Log Amp from the discussion of its adjustments on p.14.

Meter and DC Output Circuits

Section S1C of the Range switch selects whether the panel meter is driven from the Log amp or directly from the Avg/Peak Detector. In addition to driving the meter, the selected signal is routed through a calibration pot and limiting resistor to become the DC Output on the back of the ALM. Since the nominal max level to the meter is 3.33VDC, the calibration pot will have about 10% adjustment range around the target level of 3.0VDC out for max scale.

U8B, D11,12, R46,47,48 form a precision limiter which protects the meter from severe overloads which could damage it. Remembering that the log amp can put out negative voltages as well as positive ones, the limiter must work on both ends of the scale. On the negative end, R48 supplies the only negative current which is allowed into the meter. This is easy to control precisely, since it's close to zero. Hence, a fixed resistor is used to insure that the meter range easily includes zero (-90dB on the Log scale). The max negative current is 2uA, which is 1% of full scale. So the meter can be pulled up to 1% negative.

R46,47 supply the only positive current which is allowed into the meter. The limit in the positive direction should be set to just beyond the full scale marking, to insure that the meter can easily make full scale. Thus, no matter how high the overdrive is, the meter will only see peaks just past the ends of its scale.

R49,50 calibrate the meter so that on the highest linear range, 0dB corresponds to 28.3Vrms (200W in 4ohms) at the Audio Input. The log amp is then adjusted for log calibration.

Power Supply

A conventional center-tapped transformer and bridge rectifier develops about $\pm 11.8\text{VDC}$ at the inputs of positive and negative, 9V, three-terminal regulators. The 12-opamps of the ALM pull typically 48mA. The illumination circuit brings the total to about 81mA, dissipating about 1/4W in each TO-220 regulator package. The $\pm 9\text{V}$ supply voltages were chosen as the highest values which are compatible with the low-cost and plentiful, 4053B analog switch. The opamps work well on those voltages, too.

Illumination Circuit

The four LED's in the meter are arranged in two parallel strings, pulling 15mA each. Each LED drops about 3.4V at max current. My unit had 10.3V dropped across the current limiting resistors, yielding about 160mW dissipation in each. This seemed just a bit high for 1/4W resistors, so I went to 1/2W for reliability. Illum control R51 varies brightness, with R52 there to take up some of the slack of the LED threshold voltage. Q1 saves the wiper from having to pass the 30mA of LED current. Max dissipation in Q1 is about 100mW.

Contact

I sincerely hope that your project turns out well or that at least, this article has been of some interest. If you have questions or problems, I will try to help. Comments are welcome. (particularly compliments :) You can reach me at: slafferty@bellsouth.net

Parts List

Most electrical parts should be available at Mouser, except where noted.

Qty	Reference	Description
9	C9,C10,C14,C15,C24,C26,C27,C28,C29	0.1uF CAP, cer, 50V
2	C16,C17	0.22uF CAP, film, 50V
2	C21,C22	1000uF CAP, alum, 25V
1	C11	100pF CAP, cer
2	C2,C3	100uF CAP, alum, 25V
1	C18	10pF CAP, cer
1	C12	15pF CAP, cer
3	C7,C8,C20	1uF CAP, cer, 50V, Z5U
1	C19	220pF CAP, cer
2	C23,C25	22uF CAP, alum, 25V
2	C1,C5	270pF CAP, cer
1	C6	33pF CAP, cer
1	C4	47pF CAP, cer
1	C13	7pF CAP, cer
4	D5,D6,D7,D8	diode, 1N457, low leakage
2	D9,D10	zener diode, 1N752A, 5.6V
1	D13	bridge rectifier, Taitron BR88D/TP208, Jameco
4	D14,D15,D16,D17	LED, white, Rohm SLA560WBC7T2XM
6	D1,D2,D3,D4,D11,D12	diode, 1N4148
1	F1	fuse holder, inline, with 1/4A fuse
1	J1	panel jack, BNC female
1	P3	AC cord, 8-ft, 16AWG
2	P1,P2	dual binding post Radio Shack# 274-718
1	Q1	bipolar transistor, Use 2N2219 instead of 2N2222
2	R26,R28	resistor, 51ohm, 1/4W
1	R33	resistor, 100ohm, 1/4W
1	R35	resistor, 150ohm, 1/4W
1	R45	resistor, 470ohm, 1/4W
1	R15	resistor, 1.1Kohm, 1/4W
1	R38	resistor, 1.2Kohm, 1/4W
2	R34,R52	resistor, 1.8Kohm, 1/4W
1	R39	resistor, 1.8Mohm, 1/4W
5	R16,R17,R18,R20,R42	resistor, 10Kohm, 1/4W
3	R32,R46,R49	resistor, 10Kohm, 1/4W
1	R13	resistor, 110Kohm, 1/4W
1	R50	resistor, 11Kohm, 1/4W
1	R24	resistor, 13Kohm, 1/4W
1	R19	resistor, 150Kohm, 1/4W
3	R1,R6,R29	resistor, 15Kohm, 1/4W
1	R21	resistor, 160Kohm, 1/4W

2	R25,R27	resistor, 16Kohm, 1/4W
1	R5	resistor, 1Kohm, 1/4W
3	R9,R11,R14	resistor, 1Mohm, 1/4W
1	R47	resistor, 20Kohm, 1/4W
1	R41	resistor, 27Kohm, 1/4W
1	R44	resistor, 2Kohm, 1/4W
2	R8,R10	resistor, 2Kohm, 1/4W
2	R12,R30	resistor, 3.6Kohm, 1/4W
1	R40	resistor, 360Kohm, 1/4W
1	R23	resistor, 36Kohm, 1/4W
1	R48	resistor, 4.3Mohm, 1/4W
1	R43	resistor, 5.1Kohm, 1/4W
2	R36,R51	resistor, 5Kohm, 1/4W
1	R22	resistor, 5Mohm, 1/4W
1	R31	resistor, 6.8Kohm, 1/4W
2	R2,R7	resistor, 68Kohm, 1/4W
1	R37	resistor, 9.1Kohm, 1/4W
1	R4	resistor, 2.2Kohm, 1/2W
2	R53,R54	resistor, 680ohm, 1/2W
1	R3	resistor, 6.8Kohm, 1W
1	S1	switch, rotary, 3P4T
1	S2	switch, DPDT, from Heathkit IM-17
1	S3	switch, SPST, from Heathkit IM-17
1	T1	transformer, 18VCT 1A, Jameco #105531
1	U4	IC, CD4053B, analog switch
1	U9	IC, KA7809AETU, positive 9V reg, TO-220
1	U10	IC, KA7909TU, negative 9V reg, TO-220
1	U6	IC, CA3046, transistor array, avail at MCM
6	U1,U2,U3,U5,U7,U8	IC, OPA2134PAG4, Mouser
1	VM1	Meter, 200uA 1K, from Heathkit IM-17 w/hardware
19	Z1-Z19	Terminal, flea clip, Keystone, Mouser#534-1500
1		PCB, 4.1x3.1", fabricated
1		grommet, OD-0.5", ID-0.25", hole-0.375"
4		plastic foot, brown, with adhesive
1		Knob, Range, 1.3", Mouser 506-PKES120B1/4
2		Knob, Illum/Decay, 0.5", Radio Shack 274-403
1		IC socket, 16-pin, machined, hollow floor
2		terminal strip, 5-lug
6		#10x3/4" sheet metal screw, pan-head, philips
2		8-32x3/8, machine screw, pan head
2		8-32 nut
2		#8 lockwasher
6		12-32 nut
4		#12 lockwasher
2		1/2", #12 nylon washer

1	3/8", #12 nylon washer
1	3/8" ground lug for R51
1	aluminum sheet metal, 4.7x4.0", 0.03"
1	aluminum sheet metal, approx 8.2x6.3", 0.065"
1	front panel from Heathkit IM-17
1	walnut board, 30x7x0.5"
1	tung oil, pre-thinned
1	3M Super-77 spray adhesive
1	rubber cement

File List

The following files are supplied separately to support this project. You can find them at:

<http://www.tronola.com>

They are packaged together in: ALM files.zip (2.5MB). There is a high-resolution schematic file (ALM schematic.gif) also downloadable at the website.

- ALM pcb.cdr - All PCB layers in CorelDraw-12 format.
- ALM pcb top.bmp - PCB top side metal in standard graphics file format.
- ALM pcb bottom.bmp - PCB bottom side metal in standard graphics file format.
- ALM pcb silk.bmp - PCB "Silkscreen" and info layer in standard graphics file format.
- ALM mtr4.cdr - CorelDraw-12 format.
- ALM mtr4.png - Panel meter art in standard graphics file format.
- ALM FrontPanel.cdr - Front panel art in CorelDraw-12 format
- ALM FrontPanel.png - Front panel art in standard graphics file format.
- ALM labels.pdf - Rear panel labels in Adobe Acrobat format.

