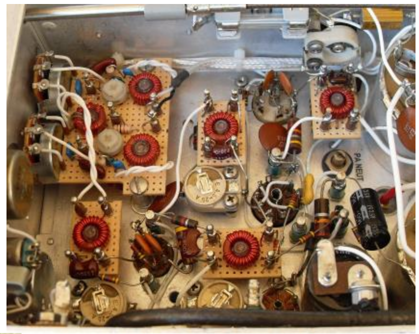
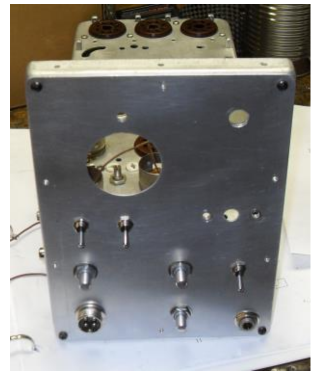
# Tips for Homebrewing Vacuum Tube Radios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## Overview

Information in the sections below is primarily based on the Octal Tri-Bander Transceiver, Power Supply/Speaker Unit, and 813 Linear, but a lot of it applies to my other radios as well. There are a series of articles on "The Joy of Building" by K8WPI in the May through August, 2008 issues of Electric Radio (ER) magazine. These articles provide comprehensive hints and kinks covering metal working and panel marking. Unfortunately I did not come across them in my ER collection until after my radios were completed! Reprints of these issues are available from www.ermag.com.

## Metalworking Techniques

I have been asked how I got my sheet metal work to turn out so nice. Some joke that I must have a well-equipped metal working shop and associated training. The answer is I don't have a shop with a brake press and shear, and I have never taken so much as a high school shop course. All work was done using commonly available tools and with lots of planning, patience and hand finishing. Any special techniques were learned by trial and error, and are not necessarily the best or fastest way to do things. Figures 1 through 4 show some of the typical work involved.

Those with proper tools and skills will likely scoff at my methods, and probably could have completed much of this work in a tenth of the time it took me. Sheet metal work is not one of my favorite endeavors. It's messy and tends to get very repetitious. But with any homebrew radio project that uses vacuum tubes it is an unavoidable necessity. And I hate to say it, but if you don't use some measure of planning, precision and craftsmanship the end product will look like some of the homebrew stuff you see at hamfests.

Below is a list of the principal tools and materials I used to work chassis, fabricate shields and make cabinets:

- 8 inch bench top drill press
- Variable speed rechargeable drill
- Variable speed corded drill
- Drill bits, 1/16 through 3/8 in
- Tap set, 4-40, 6-32, 8-32, 1/4-20
- Needle point scribe
- 3 inch C clamps
- High quality round and flat files
- Set of countersink bits
- Sanding sponges, assorted grits
- 2 x 4 foot sheet of plywood
- Black & Decker Workmate
- Variable speed saber saw
- Metal cutting blades (Bosch brand)
- Digital calipers
- Pop rivet tool
- 1/8 inch steel pop rivets
- Automatic center punch
- Steel rulers, 6, 12, 18 and 36 in
- Steel combination square, 12 in
- Chassis punch for sockets
- Chassis punch for meters
- Nibbling tool
- Masking tape

Obviously hand tools such as screwdrivers, pliers and wrenches are also needed. I have acquired several chassis punches for reasonable prices at hamfests and on eBay that make the job a lot easier and nicer looking. These are optional if you don't mind spending a few extra days filing holes that will almost be round when you're finished!

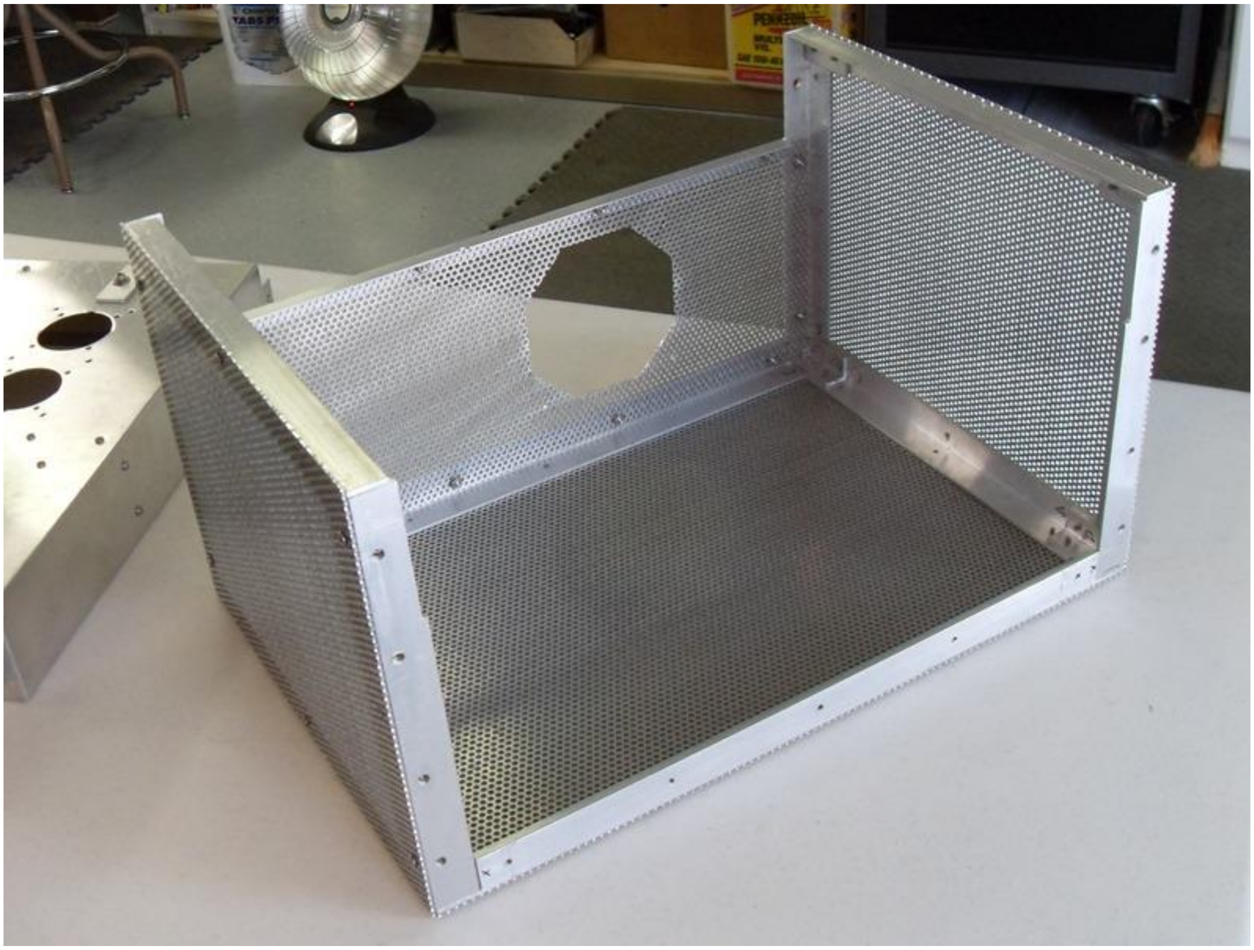

**Figure 1: Typical Cabinet Construction, 813 Linear Shown Here**

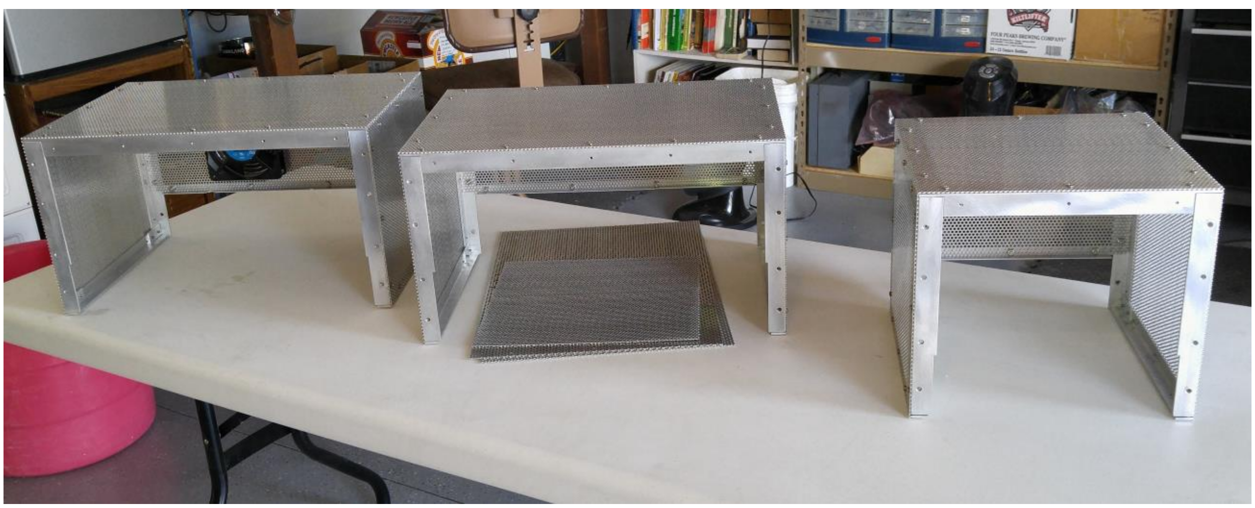

**Figure 2: All Three Cabinets**

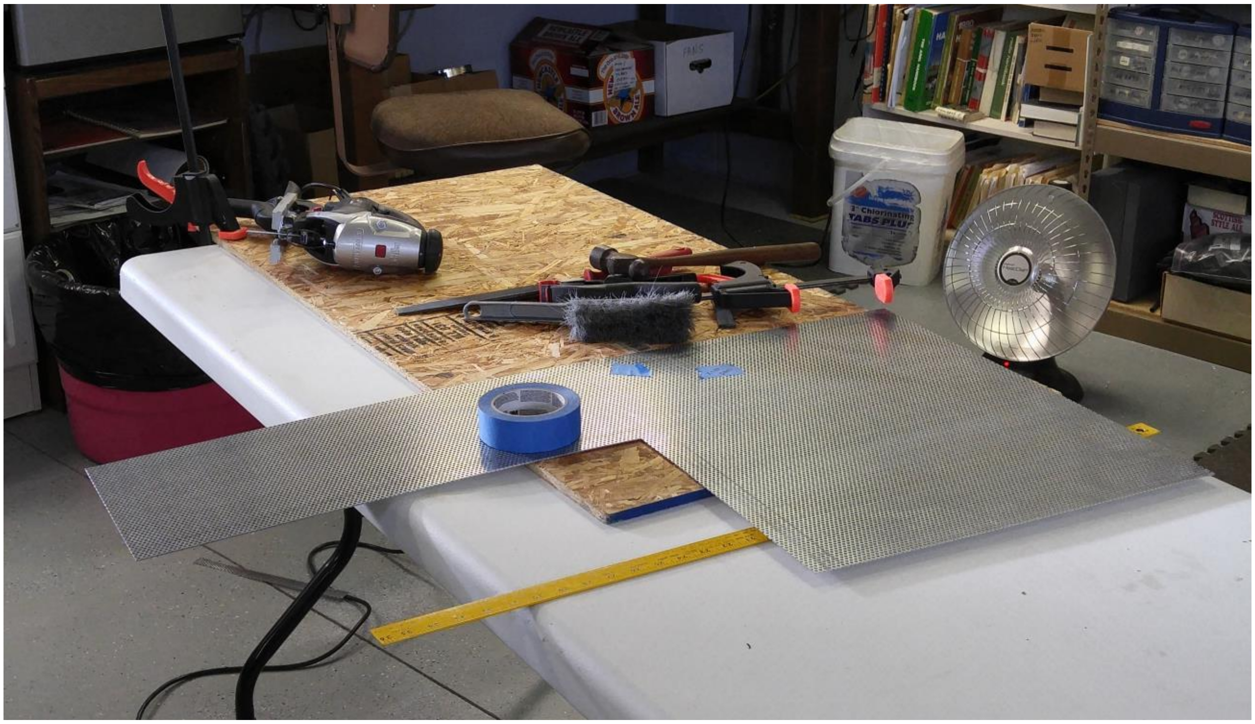

**Figure 3: Cutting Perforated Aluminum Sheet**

To cut sheet metal I first mark the desired cut on the piece using a needle point scribe run against a straight edge.  Then I clamp the piece to the Workmate or the plywood sheet, depending on size. You want to have the cut right next to the edge of the table so the sabre saw works against a solid surface and doesn't jump. Then I put an appropriate Bosch blade into the saw (the blade package tells you what thickness of soft metal the blade will cut) and cut just a little beyond the scribe line on the waste side. I mark the waste side of the cut first so I know which side of the scribe line to put the blade on. The whole idea is to not cut off too much – you can always file off excess but you can't put back what you didn't mean to cut off.

After cutting I clean up the piece to the scribe mark as required using one or more files, checking it as I go by laying a straight edge or square against it. Small pieces can be clamped in a vise, using pads to keep the vise jaws from marring the work.  Larger pieces can be filed by laying the edge of the piece along the edge of the plywood sheet.

The perforated metal sheets are a little more difficult to cut.  The saw works best cutting along the center line of a row of holes.  So I cut the piece maybe a 1/16 inch or more too big, and then use diagonal flush cutting pliers to cut very close to the scribe mark, one hole at a time. It's tedious but it's worth the trouble. The aluminum is soft enough and the spacing between holes is just right so that this method works quite well. After this the edges are cleaned up with files.

The angle stock can be cut using the same basic methods.  Using a square, make sure the scribed mark is exactly perpendicular to the side.  The stock is then clamped between the blocks of the Workmate and cut one side at a time.  Again, cut the piece slightly longer than required and then square and clean it up using files.

**Figure 4: Tapping Holes in Cabinet Frame**

When it comes to drilling holes, first locate exactly where they go using calipers, rulers, or the actual component itself as a template. The automatic center punch (Harbor Freight) makes it easy to dimple the piece. Holes up to about 1/8 inch can then be piloted on the dimple and drilled directly. For larger holes drill a pilot hole first using a small drill. If the holes in two pieces must align very closely, try to clamp the pieces together and drill through both at the same time. You can also use masking tape to hold the pieces together, although it can be a little less secure. This technique is essential for countersunk holes mating up with tapped holes in angle or bar stock because there's no adjusting these afterwards. The countersunk screw will find its center precisely and you're stuck with what you get.

For drilling and tapping holes, try to use close to the recommended drill size for the tap. And keep the drill perpendicular to the piece. I find that a drop of oil on the tap helps make the cutting go smoother. Start twisting the tap into the hole and gently make sure it stays perpendicular to the work. After the tap has been run through and before backing it out, clean off the debris on all sides of it using a small wire brush. That way you won't drag the debris back into the hole and possibly damage the threads you just cut.

For deburring drilled holes I bought a set of deburring tools. These work ok where you can get 360 degree access to both sides of the hole. But inside the chassis this becomes difficult. So in these cases it was back to twisting a larger drill in the hole with my fingers. Hard on the fingers, but it works. You can install an old radio knob on the drill to make it easier on the fingers. And by the way, tempered aluminum deburrs much cleaner than the soft stuff.

When all pieces of aluminum are completely finished, I sand them using a medium or fine grit sanding sponge and a circular motion to get rid of the mill marks. Then they are cleaned with isopropyl or 409 type cleaner to remove the ultra-fine dust.

Sometimes I use pop rivets where at least one surface of the work needs to be precisely located and will never have to be disassembled. They are very useful for fastening one side of angle stock to a shield. The 1/8 inch diameter rivets are just right for this application. Here the two pieces were secured together with masking tape and 1/8 holes drilled through both on the drill press. After deburring, a rivet was then inserted; making sure it was on the desired side of the two pieces. It was then pulled with the tool until it popped. As a final step, the small steel ball inside the rivet was driven out using the rod that popped from the rivet. The ball is no longer needed after setting the rivet, and if you don't remove it, it can fall out later and become FOD (foreign object damage). Note that this technique for shields takes the place of a right angle bend that I can't do because I don't have a brake press. Plus the tempered sheet I used can't be bent at a usable radius anyway. Furthermore, if I did have a brake press, I imagine it would be hard to make the bend at just the right dimension so that the finished piece would fit properly.

So that's my story. There's nothing magic to this. It is tedious work but the reward is a radio that looks like you took your time to do it right. I liken it to prepping and painting a car. If you rush the job and skip steps, it will probably look like it.

## Fasteners

My later radios use stainless steel, Phillips head fasteners throughout. If you look at military gear, that's what they use. This hardware is durable, strong and obviously corrosion resistant. Phillips heads allow for positive mating with driving tools. And in most locations I used nuts with built-in star type lock washers. These are called "K-Lock or "KEPS" nuts". This makes it much easier to assemble a screw and nut because you don't have to fuss with a separate lockwasher. And you can usually tighten either the screw or the nut by itself without holding the other part – a real bonus in tight spaces.

All fasteners were procured from Albany County Fasteners (albanycountyfasteners.com). The prices for this hardware are very reasonable, and they offer free shipping for orders over $25.00. The prices were so low that I ordered plenty of extra stock. For example, if I estimated needing 80 screws, I ordered 250. Better to have too many than have to place another order. And if you have plenty of extras you won't have to waste time crawling around on the floor with a flashlight trying to find the one you dropped!

For blind nut applications, there are also "self clinching nuts" that are pressed into place. The commercial name for these is PEM® nuts, from the U.S. company that makes them. They were used in a lot of military gear and Collins amateur gear. They are available from PEM in SAE sizes, but are quite expensive. Plus you need to carefully select them for the thickness of materials used, and will have to press them into place with a tool or just plain tightening them in place with hard steel screws. There are also inexpensive Chinese made fasteners of this type, but typically only in metric sizes.

## Panel Finishing

I started with natural finish aluminum rack panels. Although painted panels are about the same price, I reckoned that by the time I finished construction a painted panel would be so beat up I'd have to paint it anyway. Plus the rear of the panel should be bare for best electrical contact. Finally, the PSSU panel was a custom size cut from a 12 inch square piece of 1/8 inch tempered sheet that was, of course, unpainted. After construction was complete, the panels were removed, sanded, cleaned and then primed with Rustoleum light gray primer from a spray can (aka "rattle can"). The decals were applied next, as covered in the next section. After the decal process, the panels were sprayed with a couple of coats of Rustoleum clear matte finish, also from a spray can. This produced a very nice looking finished product.

The perforated sheet used for the cabinets has a semi-gloss "mill" finish on one side and a rougher finish on the other side that is not exposed. I found the mill finish to be a bit shiny compared to the front panels, plus there were some irregularities in the finish. So the mill sides of all the perforated sheet pieces were wet sanded with fine grit sanding sponges, washed with 409 cleaner, rinsed and thoroughly dried.

## Labeling with Water Slide Decals

Many different methods of marking the front panels and chassis were considered. I even looked into products available from Panel Express. This company offers free CAD software to design a panel. You then send them a data package and they will produce a professional laser cut and powder coated panel, complete with engraved and filled panel markings. But I had already invested in panels and had everything cut and drilled to exact fits. To use the Panel Express method I would have had to reverse engineer all my dimensions, create a CAD drawing and hope that I didn't make any mistakes, because if I did the now useless piece of pricey scrap metal would be on my nickel.

I've used rub-on dry transfers for earlier projects, but they are now very difficult to find with the right kinds of labels for tube radios. Another method involves printing labels on semi-gloss clear label stock. This was originally used with my Octalmania radios. While it works ok, it does not result in a professional look.

In searching the web for other techniques I came across water slide decals from a company in Texas called Papilio (papilio.com). These folks offer a variety of water slide decal products at reasonable prices. These decals are basically the same things you remember as a kid building plastic models. You cut the decal out from a preprinted sheet, soak it in water, slide the decal off its backing, apply it to the target object, slide it into position and tamp dry with a paper towel. Of course for the models they were already printed on a sheet. For homebrew radio projects we design the decals on a computer and print them on decal paper stock.

There are two basic product types available from Papilio, one intended for inkjet printers and the other for laser printers. I ditched all my inkjet printers years ago after figuring out that once installed, the overpriced ink cartridges dry out in six months whether you use them or not. So now I have only a monochrome laser printer.

An advantage to inkjet printers is that you can make color decals. A distinct disadvantage is that with inkjet decal stock, you have to spray the printed sheet of decals with clear Krylon or a similar coating. Otherwise the water used to activate the decal will dissolve the unprotected ink.

Of course if you have access to a color laser printer you can also print color decals that way. Since I was not about to make that investment I decided to be content with monochrome.

Note that all of this discussion is based on using black text and figures that will be visible on a light background. Making white lettered decals for use on black or dark backgrounds typically involves something called an ALPS printer, which if you can even find one anymore or someone who has one, is cost prohibitive. There are people working on white ink cartridges for inkjets, but so far the results are sketchy. Making satisfactory white ink is more complicated than you might think. So I won’t discuss white decals any further here.

Figures 5 through 9 show some typical steps and end products for the decals I used. I was basically starting from scratch with this technique. Since the decal paper was so inexpensive I bought two ten sheet packs and decided to do some experimenting. One pack was Papilio’s basic “Laser Clear Waterslide Sheets – 8.5 x 11 In.”. The other was their “Laser Bake-On Waterslide Sheets – Clear - 8.5 x 11 In.”. With the latter you bake the applied decal in an oven for a more durable result.

As far as computer design of decals, for just plain text one could use any word processor. I used Microsoft Visio because it is a form of a drawing program that, in addition to text, allowed me to make custom dial scales for the variable capacitors and meters. If you would like a copy of one of my Visio files to experiment with, send me an email.

When printing out laser slide decals, Papilio specifies use of the plain paper setting to minimize heat used by the printer’s diffuser. They also state their laser stock is compatible with any color laser printer but say nothing about a monochrome printer. I was a little bit concerned about ruining my printer cartridge, but decided to go at risk, used plain paper settings on my bottom end HP monochrome laser printer, and had no trouble whatsoever. And the toner did not smear or run at all when immersed in water.

Experiments showed that after a decal was applied there would be a slight raised edge even after spraying a coat or two of clear over it. Some people have had success by applying several coats of clear and wet sanding between coats until the edge was blended in. This seemed like a lot of extra work to me, plus each sanding/spraying cycle invited more risk for dust specs, sanding too deep or other disasters. So I decided to make boxes around every decal to provide a clear transition at the decal’s edge. In addition, the boxes provided a clear border for cutting the decal out of the sheet and for lining it up parallel or perpendicular to the panel edge. If the decal is cut right at the edge of the line (see Figure 9), the transition is imperceptible.

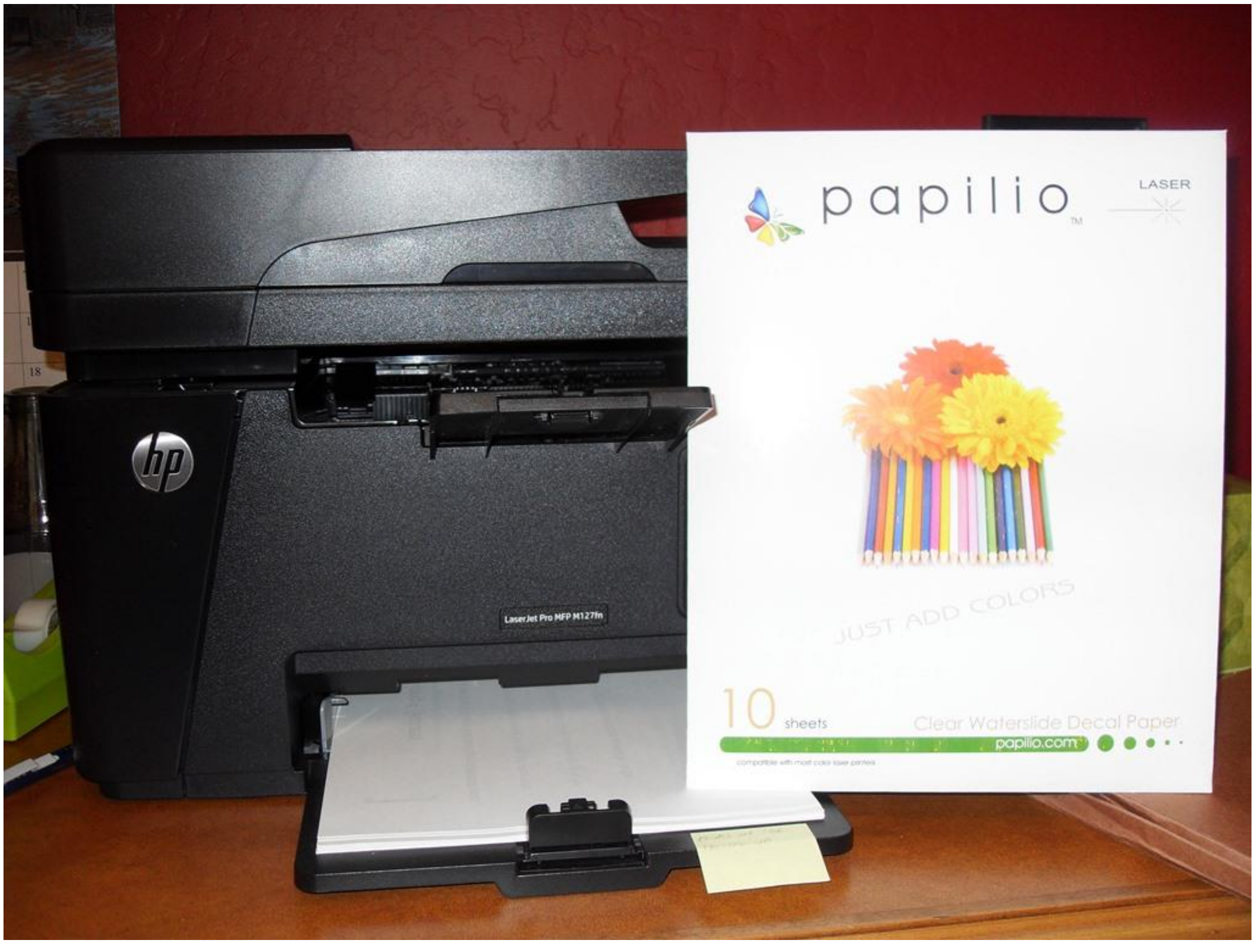


**Figure 5: Decal Product and Laser Printer That Were Used**

Test samples also showed that there was no advantage using the bake-on decals. The paper itself has a more coarse texture, which results in less resolution. And with clear coat applied to the plain decals, durability is satisfactory.

After printing, decals were carefully cut out using a pair of new, high quality scissors. To apply a decal I warmed some distilled water in a small dish, submerged the decal and let it sit for about 30 seconds. I also put a drop of water on the surface where the decal was to go. The decal was then slid into place and lined up. Then a paper towel was pressed over it to squeeze out and absorb excess water.

After drying, some of the larger decals on the front panels had some splotchy, shiny areas. I wasn't sure if this would disappear with the clear coat. However, during testing I had put some specimens in the oven for a while and noticed these splotches were not present. So I popped the completed panels into a 275° oven on the middle rack for 15 minutes. Voila! No splotchy areas.

As mentioned before, after the decals were applied the panels received two coats of clear Rustoleum finish. Like any spray painting, there is a knack to getting an even coat. It's a little less critical with a matte finish, but you still have to decide when to call it done. If you keep spraying more paint on you can end up with a mess. Remember the old saying: "The enemy of good enough is better".


**Figure 6: Close-up of Typical Panel Decal When Completed**

Decals were also applied to the chassis to label controls and jacks at the rear as well as the tube sockets. For these I ran into a couple of adhesion problems where the decals came off after drying. I'm not sure if it was because I was doing these in a cold garage or because they just don't stick to bare aluminum as well. In any case, I used a small brush and applied a coat of clear polyurethane over each one and now they are fine. I used Mini-Wax Polyurethane Semi-Gloss because I had an old can lying around from a furniture refinishing project. From experiments, I do know that you can't use clear nail polish. It will dissolve and wrinkle the decal, and smear the toner. I imagine any kind of lacquer would do the same.

The finished panels look great, and using the water slide decals allowed me to make custom patterns not available with any preprinted transfers.


**Figure 7: Chassis Decal**

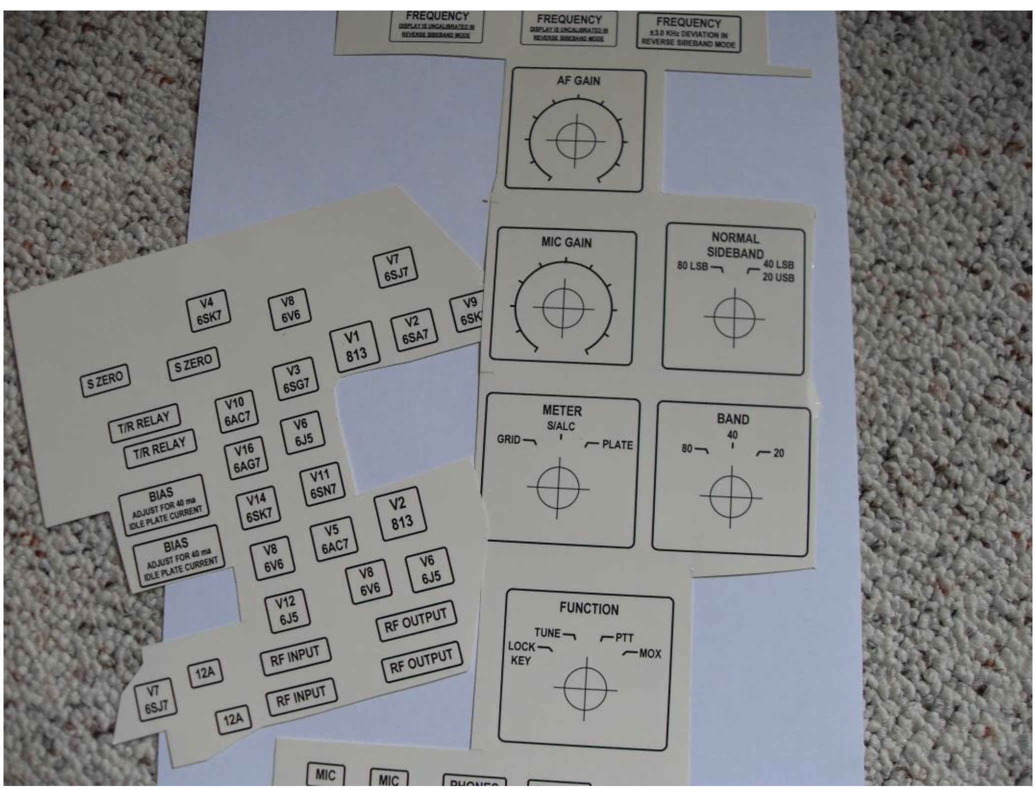


**Figure 8: Printed Decals Being Cut Out**

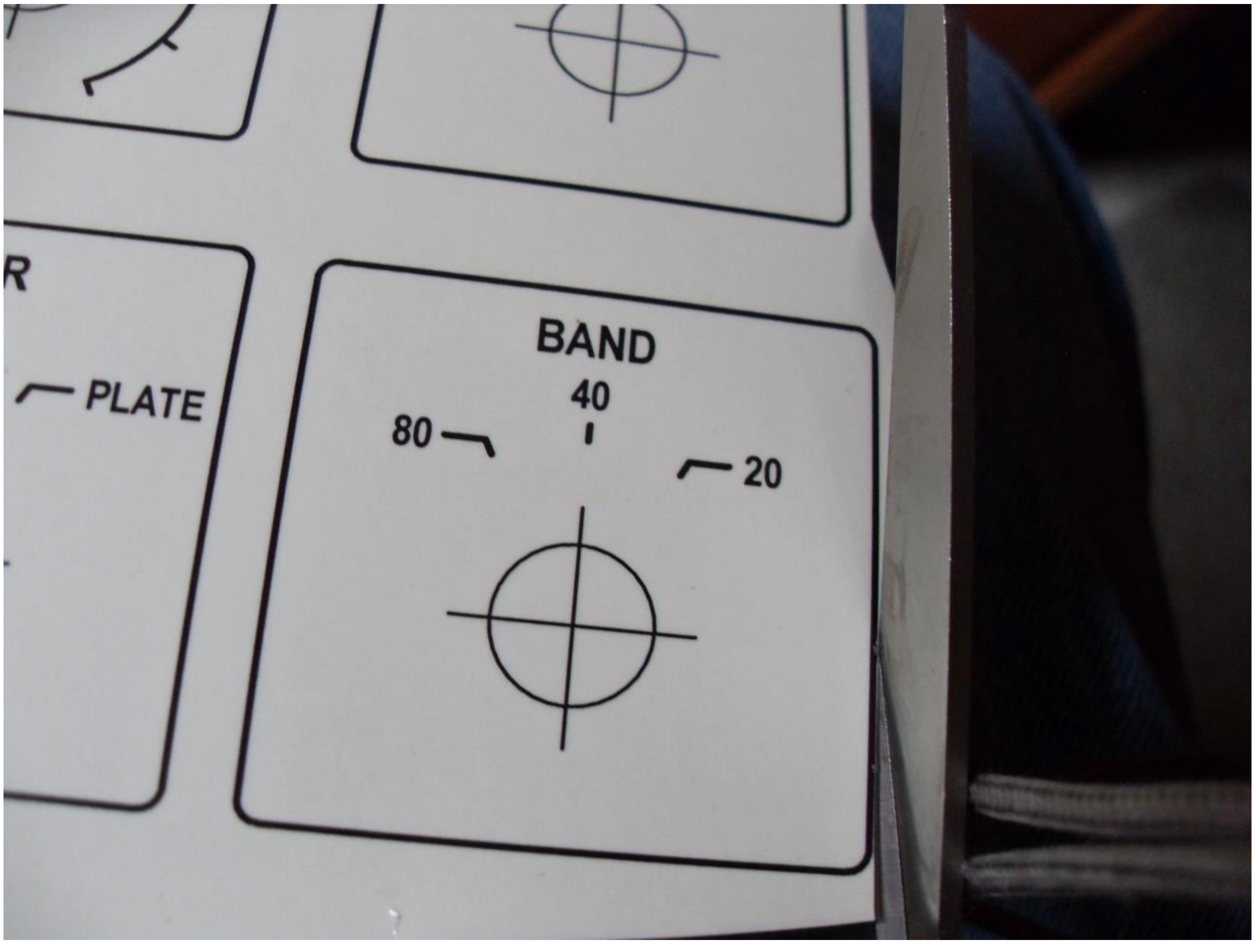


**Figure 9: Cutting Right to Decal Edge With Good Scissors**

## Meter Scales

For the transceiver and linear projects I procured some matching NOS Triplett panel meters. I also found some beat up used meters of the same type to experiment with. To make custom meter scales, the first order of business was to make sure I could remove the front covers without breaking any plastic. What I finally ended up with was a tool made by grinding the edge of a 2 inch putty knife into a very sharp edge. This edge could then by carefully inserted between the edge of the cover and the meter body, and worked back and forth to release the plastic catches.

Once inside, the original aluminum meter face was carefully removed, flipped over and spray painted white. Custom scales were designed using Visio and printed on plain white paper. Critical to the design was accurately locating the two screw holes, the end points of the scale, and the pivot point of the movement. A surprise to me was that some movements rotate 90° and others 100°.

As an alternative to Visio, there are some meter face drawing programs available on the internet for making your own custom scales.

The new scales were cut slightly oversize and glued to the newly painted faces using spray adhesive. Before spraying the adhesive, the paper scale and the metal face were carefully lined up, secured along the bottom edge with Scotch tape, and then opened up like a butterfly and laid flat. The adhesive was then sprayed on both pieces, and they were folded together. The edges of the paper were trimmed flush with the aluminum using a hobby knife, and the new face carefully installed. Extra care was taken to ensure there was no FOD left inside the meter, which typically gets caught between the armature and magnet, and causes the meter needle to stick. A little practice with the junk meters paid off – there were no disasters with the four meters that finally went into the radios.

These methods were also used for other meters in my projects. They can be applied to virtually any meter where the case can be removed. Note that there are military meters that are hermetically sealed (typically soldered shut), so with these you are out of luck.

## Wiring and Soldering Practices

I approach wiring and soldering with the same philosophy as my mechanical work. Someday, somebody is going to look inside my radios, maybe after I'm long gone, and I want them to be impressed with what they see.

First off, I always use Teflon insulated, silver coated, stranded copper wire. It's expensive to buy new, so I keep my eye out for surplus wire at hamfests. Beware of nickel coated wire typically used in aircraft wiring harnesses. This wire is intended for crimp connections only, and won't solder very well. You can tell the difference when stripped – silver coated wire is shiny bright and nickel coated is duller.

The cost of the silver coated Teflon wire has also forced me to use the same color of wire everywhere. In the Octalmania and previous homebrew radios the wire was white. For the Octalmania, PSSU and linear I used blue wire. Of course using the same color makes wire tracing more difficult, but I have not found that to be a big problem. It does take a good pair of wire strippers to avoid damage to the strands. And I always tin the stripped wire first to keep the strands from flaying apart when making the connection.

I also completely wire the radio first, and then when everything is working properly the wires are bundled into harnesses using ty-wraps (aka zip-ties). I try to visualize ahead of time what the finished harness will look like and leave enough extra wire to work with. Unless a wire carries a critical signal and needs to be short, it is tucked along a chassis edge or run parallel to a chassis edge. The results look professional instead of like a 1950s TV set. Sometimes it gets a little tight to work the ty-wrap into place, but dental picks, hemostats and patience can usually get the job done. Of course in a production radio the harnesses would be built separately and then installed (like a Heathkit). There's no way that is feasible for one-off radios like these.

These radios are built with some very old, used parts. As such, getting a good solder joint can present a challenge. If there is any doubt as to the condition of terminals, I always clean and tin them before mounting the part in place. Working in tight spaces with a lot of stuff in the way is not the time to find out that old terminal just won't take solder. And the last thing you want is a cold solder joint to go intermittent and drive you nuts. Sometimes just reflowing the terminal with some fresh solder and maybe liquid flux will do the job. Other times you may have to scrape it clean with a hobby knife or sand paper.

Many old parts are silver plated and severely tarnished. This includes variable capacitors, coils and wafer switch contacts. I have had good luck restoring these parts using Connoisseurs brand liquid silver polish. It comes in a maroon colored jar, and I found it in the Walmart jewelry department. The parts are submerged in the liquid and if necessary, a small brush used to help the cleaner do its work. Then you just rinse them in clean water and blow them dry.

For rework or modifications it's almost always necessary to remove parts or wires. This in turn means removing solder. As told in the short story on kg7tr .com, my dad invented the original Solder Sipper, so out of respect I try to use one whenever possible. But the truth is that in tight spaces you just can't get in there with one of these tools to suck the solder away. So I switch over to solder wick. Each method has its place. To get the old wires unwrapped and removed I work into them with a dental pick with the joint heated. Alternately, you can wiggle the wire or component while the solder is cooling and it will be loose afterward.

More recently, I finally acquired a Hakko desoldering gun. It is a solder removal tool that uses a hollow soldering iron tip and built-in vacuum pump. There are less expensive clones available all over the internet. It works great, especially on through-hole PC boards. But again, when working inside a chassis, you have to have enough room to get the tool's tip onto the target connection.

I hope these hints are useful. If you have any questions or suggestions send me an e-mail.

Mike