A PIN Diode T/R Switch for a 6M Power Amplifier Input

Joseph Haas
9/1/2012
joeh-*at*-rollanet-*dot*-org

I was interested in a 6M mobile rig, but to reliably work "local" stations or repeaters (local was not necessarily line-of-sight) you need some power. I had a UX-59 6M FM module from the ICOM IC-900/901 line, but it only runs 10W max. A co-worker mentioned to me once that a low-band MastrII mobile could be converted to a stand-alone PA without much difficulty and they were available in a 100W version. I located someone with a supply of low-band units nearby so I was able to obtain the one I wanted plus a couple of spares. The MastrII model codes that are applicable to this project are xx7xxxx33x. The "7" specifies the 100W PA, and the "33" specifies the low-band VHF split that best aligns to 52 MHz. The remaining characters are not important unless the transmitter and/or receiver sections of the radio are of interest.

The radio is very modular and the PA was easily removed with little difficulty. The only interconnects with the rest of the radio were the PA in/out and the relay drive. The cover, however, was part of the whole radio, so separating the PA meant that the PA circuits were exposed. The bottom of the PA was just bare cast aluminum, but the top was uncovered and the chassis was not configured to accommodate a simple cover plate. To address this, I fashioned a cover for the top using un-etched, double-sided FR4 stock that was cut to fit. I added some right-angle structures to stiffen the material and provide mounting access to the sides of the PA. The arrangement was hand-crafted to fit and is quite involved, but FR-4 is easy to work with, and the material is easily "welded" using solder seams. The copper plate also offered good shielding performance so it was a good choice in my opinion.

Since the PA had a T/R relay on the output, I only needed a transistor driver circuit to key the relay. An RF sense circuit was attractive since it didn't require that the T/R PTT be connected to the PA and any switching latency would simply mean that the antenna was directly connected to the T/R in transmit mode for a few ms until the relay was keyed.

However, another relay was required for the input side since the PA input needed to be separated from the T/R during receive. An actual relay would have been a simple choice, but I was in the mood to experiment so I looked into PIN diodes to construct a solid state T/R switch. Besides, I really don't like to use mechanical relays unless there is no other solution, so I wanted to at least give a PIN switch a go. This paper describes my 6M PIN diode T/R switch (project photos are presented in the Appendix).

I had tried my hand at a PIN based switch a long time ago in the VHF/UHF range and remembered that it hadn't been without issues (most of the issues dealt with PA instability, but that could have been exacerbated by the inadequacies of my PIN implementation).

I found some devices from Microsemi (LSP1004-454-0) and came up with the circuit shown in Figure 1. This circuit shows the PIN switches (one RX shunt and one TX pass switch), the RF detector, and a 6dB, 1W pad in the TX path. The RF detector simply provides a relatively high-Z sampling circuit to provide a DC voltage that is proportional to applied RF power. The 6dB pad is needed to reduce a 1W applied TX signal (low power for the UX-59 module) to 0.25W that is needed by the PA. This prevents the need to adjust the UX-59 to reduce its power just to meet the needs of the PA. The pad uses high power SMD resistors and can safely handle 1W of input power.

PIN devices are pretty simple to understand and use, but there are some limitations, the most prominent of which is that of power handling. PIN devices are generally used as current-controlled-resistances in RF applications. As the forward current is increased from zero, the device enters a region where the I-R curve gets rather linear. This curve generally extends to the maximum current that the device can safely conduct.

At I(PIN) = 0 with zero forward bias or reverse bias, the PIN device looks like a very high resistance with a very low capacitive footprint. These characteristics make the PIN diode very desirable for switching and attenuator designs.

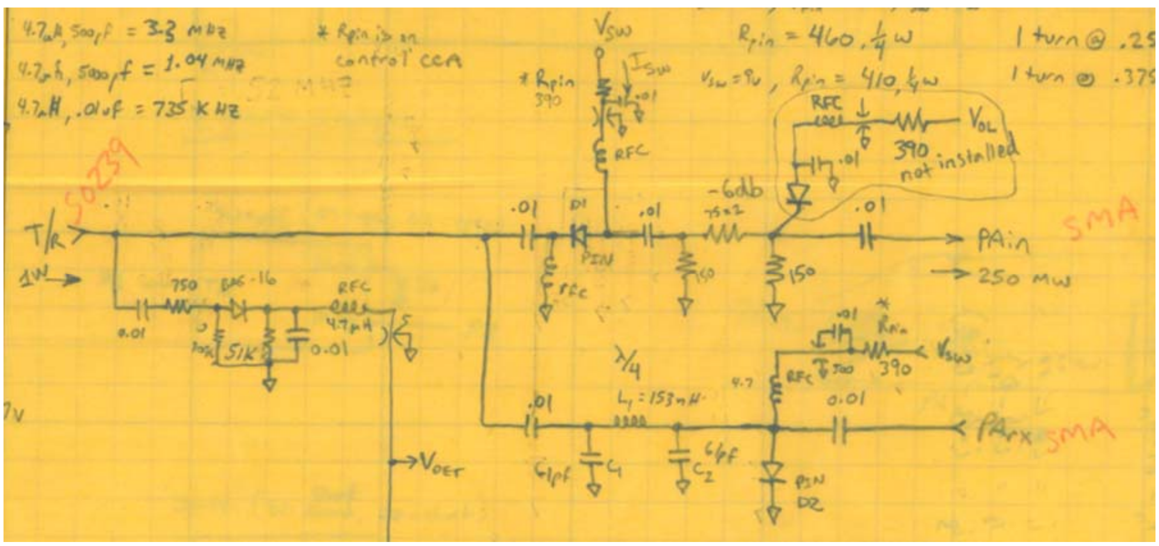

Figure 1. 50 MHz T/R switch circuit

A typical T/R switch generally has two switch elements. One is a pass element that connects the TX path while the other is a shunt element that is located along the RX path. The idea being that you want to allow the TX power to conduct along the desired path while protecting the RX path by shunting it to ground. For receive, you open the TX and RX switch elements to allow the RX power to flow to the receiver. For higher frequency ranges, stub length get increasingly important, but at 52 MHz, stubs of up to 1 inch don't offer much of a disturbance to the RF paths. Still, I made an effort to keep the stubs short.

However, the RX shunt element needs to be isolated from the TX path or the shunt element will simply short out the TX path. This is accomplished by inserting a 1/4λ transmission line between the RX shunt element and the common switch point. The 1/4λ element transforms the short at the RX element to an open at the common switch point. At UHF and above, 1/4λ transmission lines become very short and can easily be implemented in microstrip or micro-coax. However, at VHF and below, the line lengths become ungainly at best. At 6M, you need about 60 inches of coax to create a 1/4λ transformer. However, a 1/4λ transformer can also be approximated using an LC network. This approach was used here with a 153nH coil (5T on a 0.375" drill bit) and a pair of 62pF silver-mica caps. L and C are calculated from:

$L = Z_o/2\pi F_o$ & $C = 1/2\pi F_o Z_o$; where $Z_o = 50\Omega$ and $F_o = 52.525$ MHz

Of course, the 1/4λ transformer aspect of solid-state switches is the Achilles heel of this method of T/R switching. It forces the T/R switch into a narrow band of operation. Generally, this isn't a serious issue since T/R systems at VHF and above are typically not broad-band. However, the LC 1/4λ transformer is generally preferable in systems that will or might cover an entire band since transmission line transformers are very narrow band and their performance will suffer for even modest excursions from the design frequency.

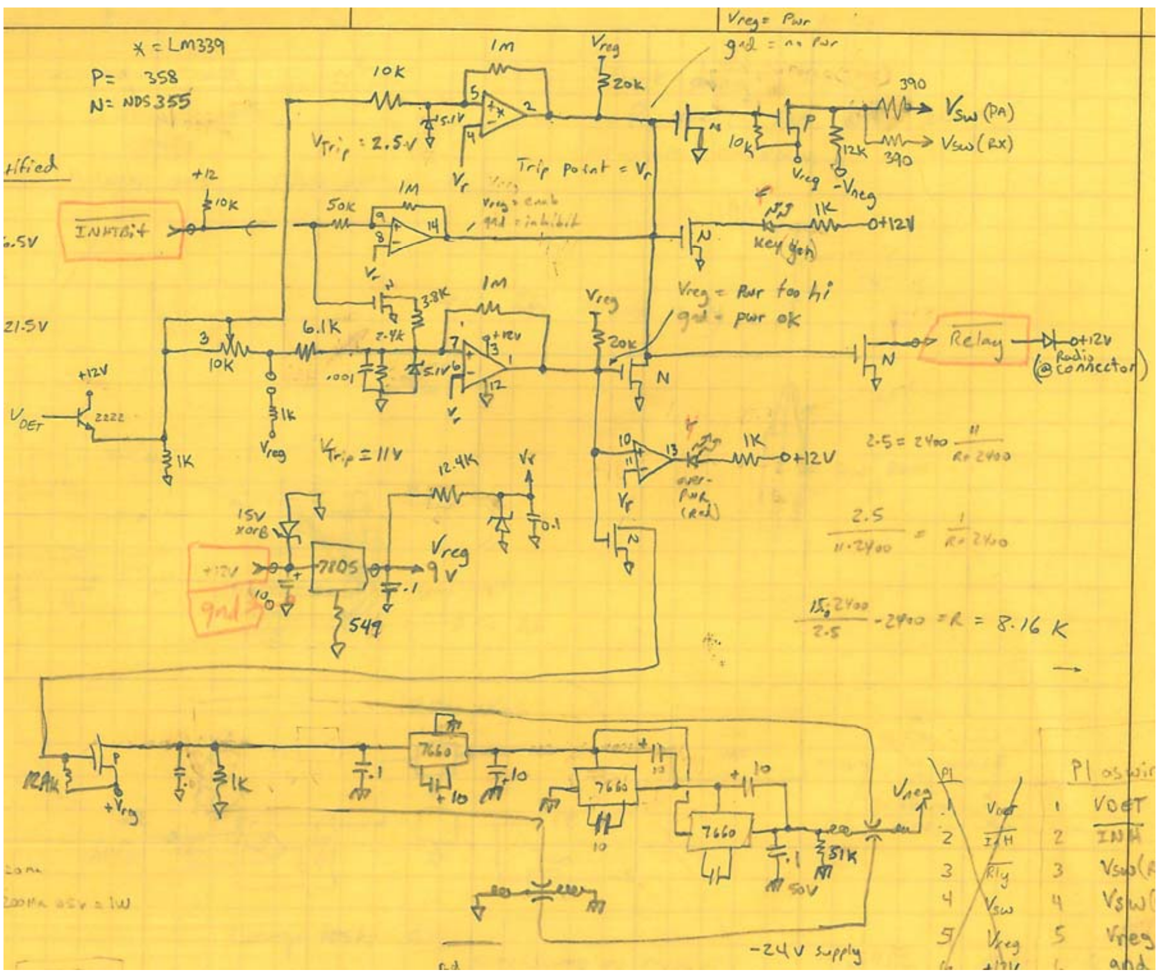

Figure 2. Bias supply and switch logic

For this application, the RX path isn't really necessary since it simply connects to the T/R relay on the PA. However, I was in experimentation mode, so I wanted to construct a T/R switch that could be used on a separate TX/RX system if the need later presented itself. Besides, the idea of having a stub of coax connected to the PA input during TX didn't feel right, even if it was a short length.

The diodes I chose were LSP-1004 which have an on resistance of about 0.6 ohms at If = 10mA. I chose to bias them at 23mA to overcome the influence of the TX power when present to make sure they stayed on. In addition, I reverse biased the devices when they were to be turned off to increase the off resistance and reduce insertion loss. To accomplish this, I designed the circuit of figure 2 to produce the negative bias source and perform switching functions.

The reason that the reverse bias was important to this application is that I wanted a low-power mode that would allow the PA to be disabled. To do this, the T/R switch simply needs to remain in the RX state, which allows the exciter T/R to be directly connected to the system antenna through the RX path to the output T/R relay. However, the power levels (1-10W) present in this mode could be sufficient to cause the PIN devices to start conducting (10W into 50 ohms is about 22V of RF). Thus, the reverse bias keeps the PIN devices off in the presence of med-power RF and needs to be a voltage of at least the maximum expected at Pmax for a matched load.

The bias supply is simply a chain of ICL7660 devices that invert the applied DC voltage. Inverting -9V * 3 = -27V, which is more like -24V in practice. This supply is built on the bottom of the control circuit card proto board.

The control logic is build on the top of the proto board and follows two main paths starting with the Vdet input. Vdet is simply the rectified and filtered RF sample. It is buffered with an emitter follower and fed to two comparator circuits. The top comparator simply looks for Vdet > 2.5V at which point, the PA relay is keyed, and the Vsw outputs are set to 9V (with 390 ohm Ilimit resistors for each PIN device).

The Inhibit input (the middle comparator) is an open/ground input that will disable the switch function when grounded. In this state, the PA is switched out regardless of the Vdet voltage.

The bottom comparator is designed to trip when Vdet > 11V which is about 2.5W of RF input power. This condition has the same effect as the inhibit input in that it disables the PA and passes the T/R power directly to the antenna. The last comparator is used to drive an LED to indicate the over-power condition. This protection mechanism keeps the 6dB pad in the TX path from being damaged by excessive input power.

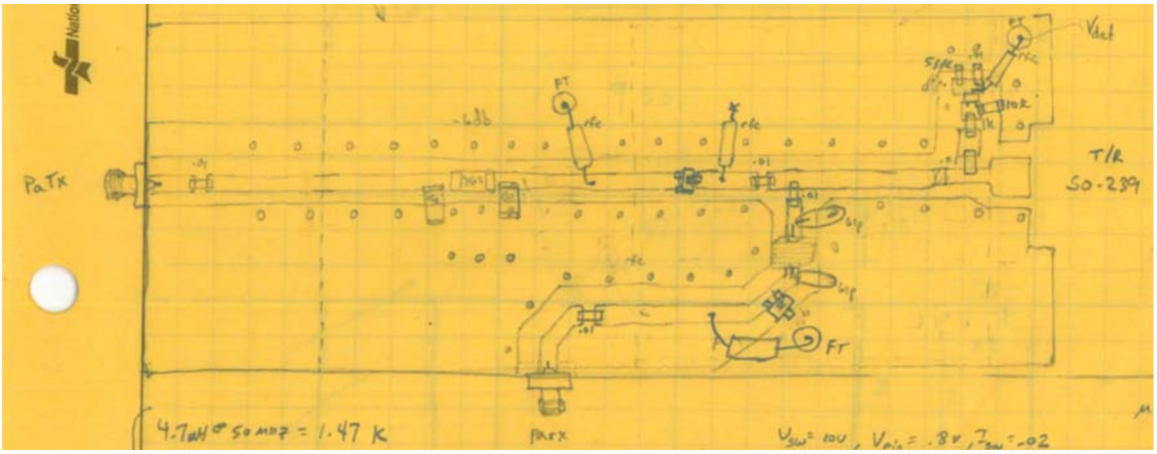

Figure 3. Layout sketch of the RF paths

I fancy myself to be pretty adept at building structures with un-etched, double sided FR-4 PCB stock. This project remains one of my best examples of the craft.

I started with the RF layout on a single piece of 0.063" FR-4. I measured out the microstrip routes (50Ω on my substrate was about 0.1") and peeled back a 0.1" relief from either side of the microstrip lines. I also peeled out the RF detector pads (upper right of Figure 3) and drilled fencing holes along the periphery of the traces and drilled holes for the 3 feed-thru caps. I then soldered feed-thru wires to connect the top ground to the bottom ground plane. I used bulkhead-style SMA connectors for the PA connections since they were small and didn't need to carry much power. I used an SO-239 for the TR since that is what most 6M radios use and makes the patch cord easy to come by.

From here, I went on to cut the sides of the enclosure that would surround the RF card as two sets of identical rectangles. The RF card would sit roughly mid-way between the top and bottom of the enclosure and the connector mounting holes were drilled accordingly to match up with the RF card connections.

To attach a top and bottom lid, I cut 3 rectangular pieces of FR-4 that were about 0.75" larger than the RF card (the bottom lid is the top-cover of the PA, so it serves as the 4^{th} piece in this situation). I then cut out a rectangular opening that was the same size as the RF card centered on the top flange piece. For the bottom flange piece, I cut an irregular opening that was smaller than the opening for the box. This allowed me to solder a full bead on both the inside and outside seams between the enclosure sides and the bottom flange.

Next, I match-drilled 1/8" mounting holes around the periphery of the 4 pieces (10 holes for each piece). Finally, I soldered brass, 4-40 nuts at each hole on the flange pieces. This was easily accomplished using a stainless steel screw to hold the nut in place and soldering with water-clean (i.e., acid) flux – I highly recommend this when working with FR-4 enclosures and RF cards, just be sure to wash and dry thoroughly when the structural soldering is complete. The result was a set of lids and flanges with threaded holes that can then be attached to the top and bottom of the enclosure (assuming that all of the cuts are accurate).

The enclosure had to be assembled in a particular order starting by tack soldering the sides to form a 4-walled structure that was planar on the bottom edges and square. Next, this structure was soldered to the bottom flange with 100% solder coverage at each seam. The inside corners of the enclosure were then soldered to 100%, and the RF card was positioned to line up with the connector holes and the edges were soldered as close to 100% as possible. Lastly, the top flange was attached along with several small pieces of triangular FR-4 to help brace the top flange against the box frame. .

The box is finished off by using copper tape to cover all of the internal exposed fiberglass edges and soldering the copper tape seems to the enclosure walls. I used an Exacto knife to carefully clear the copper tape over the flange holes. This same copper tape method was used to cover the exterior corners of the box as well. I attached an external bracket for the INH connection (RCA connector) and also placed the 9V regulator on the exterior and fed all of the power and control signals into the bottom cavity of the box (the under-side of the RF card where the control card was located) using feed-thru caps.

The result is a continuous metallic surface over both the inside and outside of the enclosure that could be made very RF tight with the lids attached, but still be disassembled for repair if needed.

When completed, I ran a series of tests using my UX-59 as a signal source and found very good results. The insertion loss in the RX path was only about 0.2 dB and in the TX path the loss was about 6.2 dB (which includes the 6 dB pad). The isolation from T/R to RX in the TX mode was about 50 dB, and the isolation from RX to TX in the RX mode was about 33 dB.

I was very pleased with the performance of this project. The cost of the MastrII radio was under $40, and most of the remaining parts were either scraps or samples. Under $50 for a 100W PA is hard to beat and I learned a little bit about PIN diode RF switches as well.

Project Images:

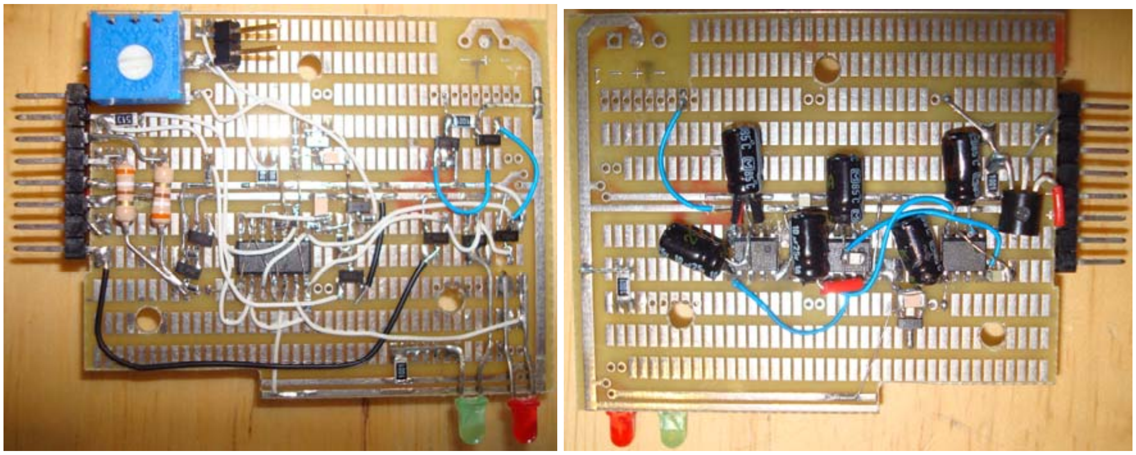

Photo 1 (a & b). Control card. Left (top of card) is the comparator switch circuit. The right image (bottom of card) is the -24V bias supply. The proto-board is a custom design that I produced specifically for SOIC/0603 prototype circuits.

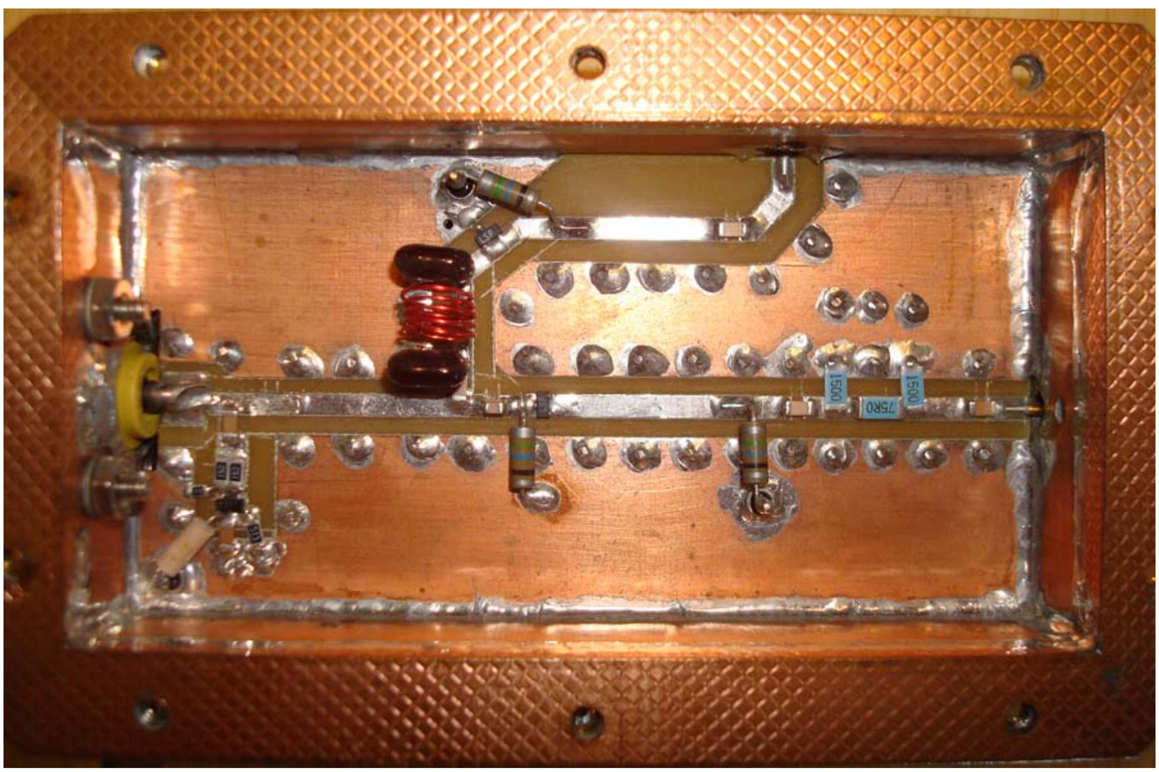

Photo 2. RF Section. T/R connection is on the left, TX out to PA is on the right, and the T/R relay (RX) connection is at the top. The RF detector is in the lower left corner.

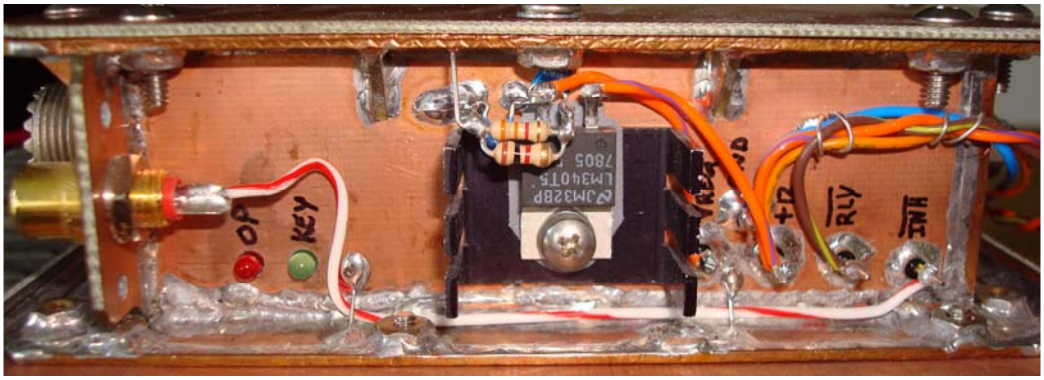

Photo 3. Close-up of the side of the switch enclosure. The INH connection and status LEDs are shown on the left, the 9V regulator is in the center with the signal feed-thrus on the right.

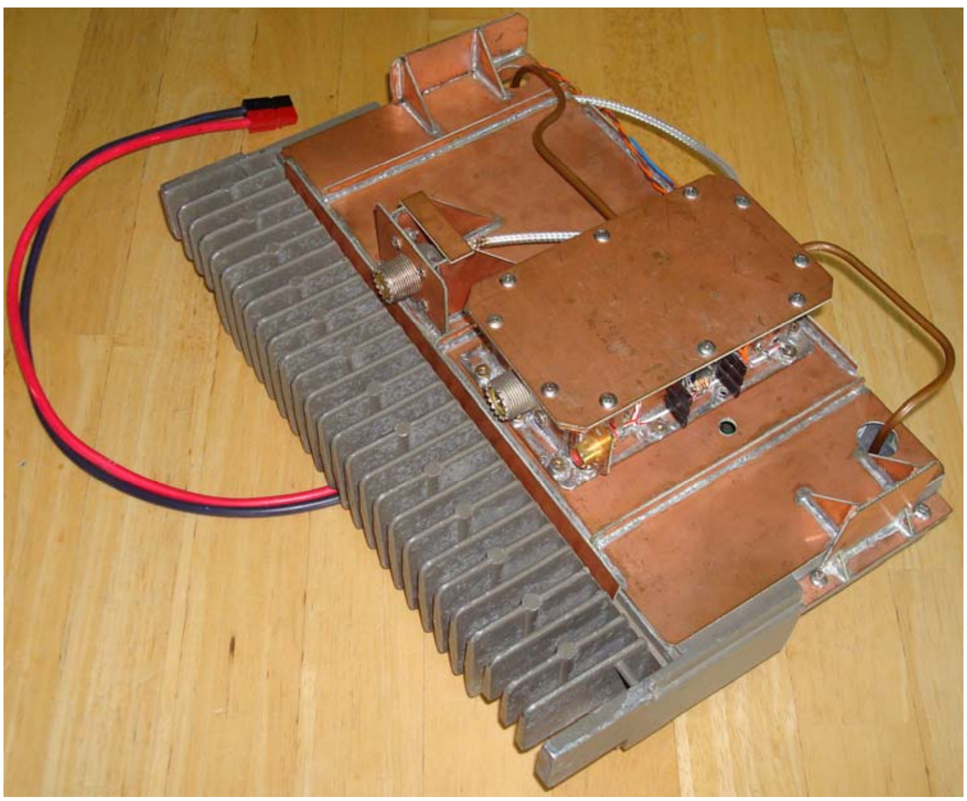

Photo 4. The completed, transceiver-ready, 100W PA for 6M. The gold plated INH RCA connector is in the forward corner of the T/R-switch enclosure. Just above is the T/R radio connector, with the antenna connector (SO-239) just above that (the antenna connector and cable are salvaged from the original MastrII radio). The SMA connectors for RX in and TX out are on the far side of the switch enclosure shown connected with 0.141 semi-rigid coax patch cables.

Bibliography:

Datasheet for LSP1000 – LSP1012, www.microsemi.com
Rev: 2009-09-10

PIN Diode Fundamentals, MicroNote Series 701, by Bill Doherty, www.microsemi.com
(no date)

Application Note 922, Applications of PIN Diodes, Avago Technologies
July 13, 2010

