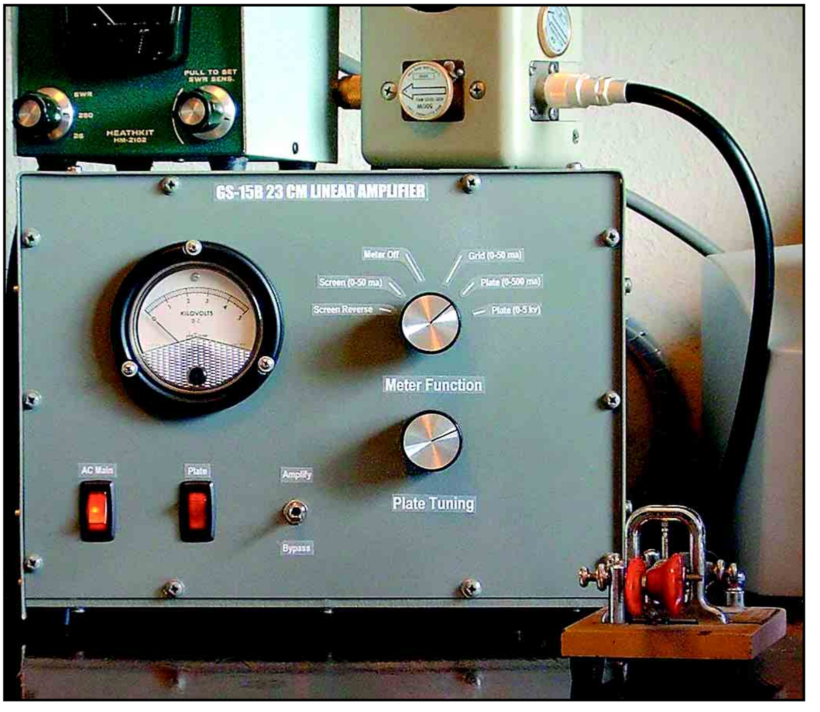
By Jim Klitzing, W6PQL

# A Water Cooled Amplifier for 23 cm




The Russian GS-15B tetrode may not put a full gallon in your shack, but how about a quart and a half? This 400 W amp is a compact, desktop package.

At the core of this 23 cm amplifier is a Russian tetrode, the GS 15B, modified for water-cooling as shown in Figure 1. This tube is modern, rugged, inexpensive and plentiful at the time of this writing. Prior to the appearance of the GS-15B, most power amplifiers on 23 cm were using the venerable 2C39/7289, pressing the envelope of performance to the breaking point. Amplifiers made with them almost always suffered from thermal drift above 150 W and the tubes have become scarce. Solid-state amps are expensive and most are limited to less than 100 W.

The GS-15B works well in a quarter-wave cavity, such as the one that was designed and built by Mats Bengtsson, KD5FZX. Complete information on this cavity, including plans on how to build it, can be viewed on the Internet at the Web site of Paul Goble, ND2X (**www.nd2x.net/kd5fzx-gs15s.html**).

You can construct the cavity yourself if you have a lathe and a mill. Fortunately for those of us without such tools, an assembled and tested cavity complete with a spare tube can be obtained at a reasonable price by contacting KD5FZX at **mgbpcs@swbell.net**.

## Building the Amplifier

This article gives an overview of the design and operation of the amplifier. The complete construction details, including numerous detail photos, can be found on the ARRLWeb.[1] The details include the TR switch, relay sequencer and all other controls necessary to operate the amplifier safely and reliably. The Web site also provides a set of operating guidelines and instructions. The complete schematic is downloadable as a PDF document.[2]

## Why Water Cooling?

Well, why not? Here are some good reasons: Fans are noisy and water cooling is quiet and very efficient. At this power level, the tube needs a superior cooling method for thermal stability. Water-cooling is safe, easy and clean if you do it correctly.

You'll need a flow rate of around half-gallon per minute, easily achieved with a small submersible fountain pump from your local hardware store or nursery. Use distilled water. The 4.5 gallon water tank and pump are shown in Figure 2. Quarter inch ID vinyl tubing brings the water to and from the RF deck. After an hour or so of making long transmissions, the temperature of the 3 gallon reservoir will elevate about 10°F, not enough to affect tuning.

I did plan to do a more elegant system later; the power supply chassis is oversized to house a copper heat exchanger, pump and reservoir. However, the present system is so easy to service and is working so well that I'll probably never get around to changing things.

## Power Supply Circuit

The "grounded screen" may be a bit confusing to those of us used to using a tetrode in the more conventional manner, with the cathode at chassis potential. Due to the design of this cavity, the screen is indeed at "ground" for RF. For dc, it can be more precisely described as being connected directly to the chassis and at a potential of +350 V with respect to the cathode. It is the cathode that floats below chassis potential at –350 V. This requires a change from traditional thinking in the design of the power supply.

Figure 3 shows the power supply circuitry required to operate the tube. The Variac transformer isn't needed unless the

[1]Notes appear on page 32.

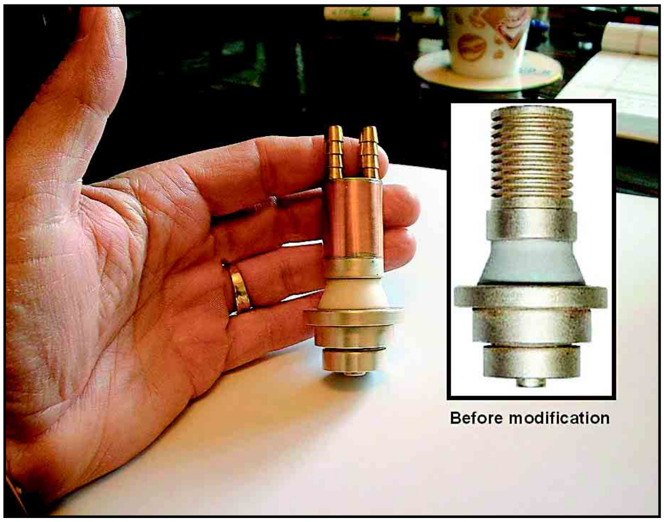



**Figure 1—The Russian GS-15B tetrode is modified for water cooling by attaching a watertight sleeve around the anode cooling fins.**

**Figure 2—A small reservoir of water and submersible pump are all that is required to provide cooling for the GS-15B. The amplifier power supply is directly below the container. Be sure to keep the water system safely away from any power sources.**

HV transformer is out of range, or you wish to experiment with different anode supply voltages. As you can see, even though the dc voltages are described in reference to the chassis potential, no connections are made to the chassis in the power supply; that happens in the RF deck. The full schematic on the ARRLWeb shows all of the necessary power circuitry needed for the complete amplifier.

I used power transformers I had on hand; if you have something that has all of the necessary windings on one unit, so much the better. My particular plate transformer and rectifier stack produced a little more than the recommended voltage (about 2 kV under load), but I did not find this to be a problem; I just reduced the idling current a bit, and all was well.

Normal operating voltages (referenced to the cathode) are:

Anode: +1600-1800 V dc @ 350 mA
Screen: +350 V dc @ 1 mA
Grid: –30 V dc @ 5-20 mA
Filament: 5.5-5.8 V ac @ 2 A

Note that the screen voltage is derived from the half-voltage point of the voltage doubler, eliminating the need for a separate screen supply. The Zener diode connected across the screen supply regulates the screen voltage and provides clamping protection for reverse screen current as described in the operating instructions. Any shunt regulator circuit would work well here (active or passive), but I found this to be the simplest way to satisfy the circuit requirements. I didn't have a 350 V Zener handy, so I used a series of 1 W diodes—10 at 33 V and one at 20 V.

Figure 4 shows the schematic for the low voltage supplies for the control circuits and antenna relays. I needed 28 V at 700 mA for relays, and 12 V at <500 mA for the sequencer and fans. I used a 25.2 V @ 2 A filament transformer, a full-wave bridge, and an LM317 regulator IC for the 28 V supply, which feeds a simple 7812 regulator for 12 V. If you will be using only 12 V relays, you can use a 14-16 V transformer, eliminate the LM317 circuit, and obtain 12 V from the 7812. I dislike noisy fans, so I used a simple speed control circuit to run the computer-type muffin fan at half speed. It's a lot quieter, yet it moves enough air to keep the entire power supply cool.

The chassis for the power supply was designed so that a sheet metal bending brake was not required; just one way of doing things if such a tool is not available. Dimensions for the power supply chassis are not critical; just make it large enough to house all of the components. Mine measures $8\frac{1}{2}$×12×19 inches (HDW). All of the pieces for the top, bottom and sides were cut from 0.060 inch aluminum sheet and connected with 0.375 inch square aluminum bar stock, drilled and tapped for 8/32 machine screws.

The connectors on the power supply (a separate unit from the RF deck) are female and the ones on the RF deck male. The ac power switches are in the RF deck, providing additional safety. Despite all of these precautions, under no circumstances should the interconnect cables be connected or disconnected while main ac power is on. Be safe!

### The RF Deck

I made the RF deck chassis 12×12×8.5 inches high, using the same method of construction as the power supply with one exception: the sides and top are a one piece U-shaped hood instead of flat panels. It looked a bit nicer that way, and all pieces were painted with good quality spray enamel.

### Safety First!

Remember that lethal voltages are present in this amplifier. Take extreme care when tuning or adjusting the cavity while in operation. *The ARRL Handbook* contains a section on working with high voltages. Some excerpts:

- If at all possible, troubleshoot with an ohmmeter.
- Keep a fair distance from energized circuits.
- If you need to measure the voltage of a circuit, install the voltmeter with the power safely off, back up and only then energize the circuit. Remove the power before disconnecting the meter.
- If you are building equipment that has hinged or easily removable covers that could expose someone to an energized circuit, install interlock switches that safely remove power in the event that the enclosure was opened with the power still on.
- Never assume that a circuit is at zero potential even if the power is switched off and the power cable disconnected.
- If you must hold a probe to take a measurement, always keep one hand in your pocket.

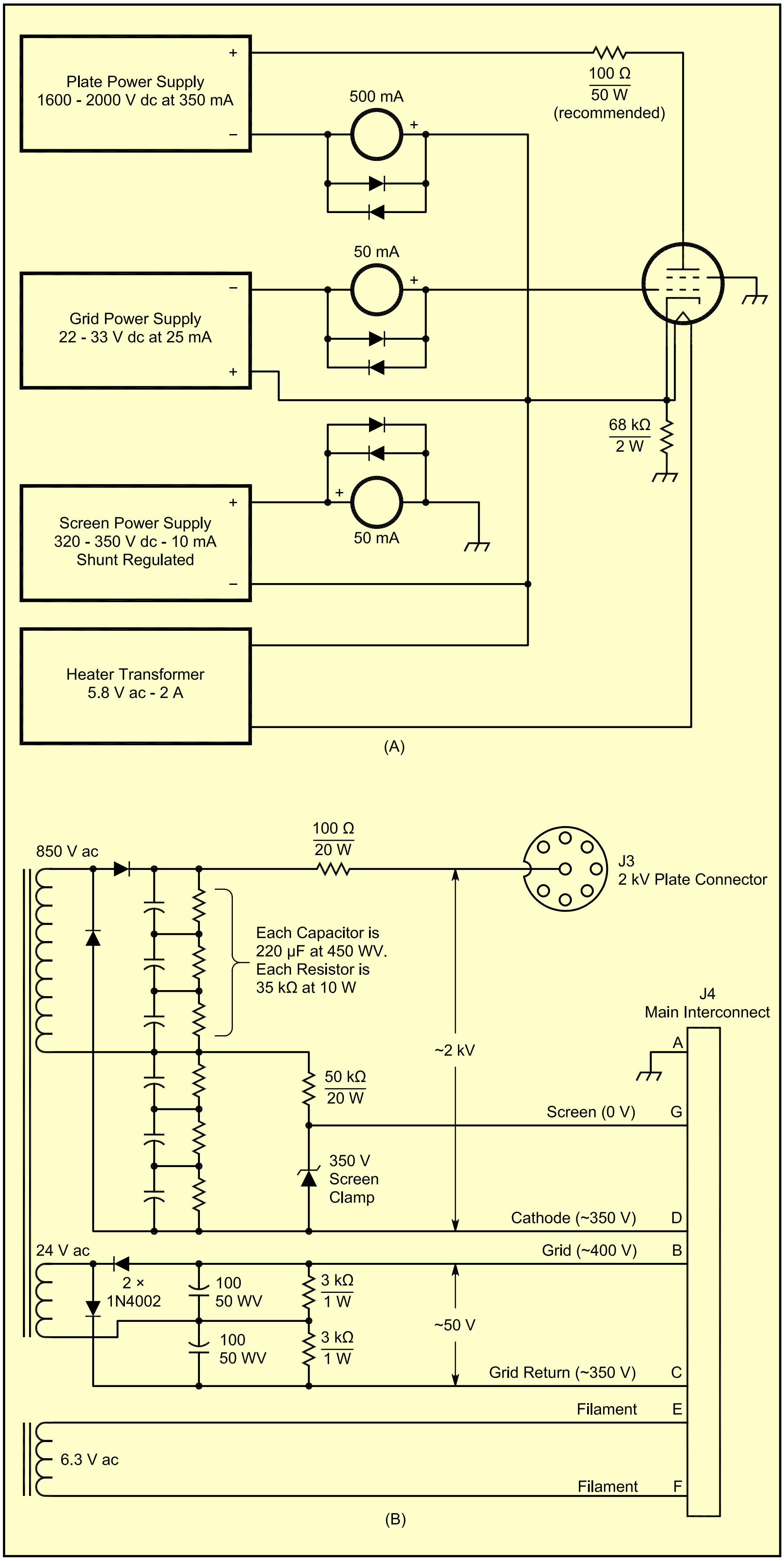



**Figure 3—The power supply has four major sections to supply the plate, grid, screen, and heater. The screen is grounded, an unusual configuration, and the cathode is maintained at approximately –350 V dc. All chassis connections are made in the RF deck.**

## Metering and Bias

Figure 5 shows the circuit that regulates the grid bias—a simple Zener/Darlington combination. [Some components mentioned in the text appear in the detailed schematic available on the ARRLWeb. —*Ed.*] The load resistor (600 Ω @ 4 W) must draw at least enough current from the bias supply to at least equal maximum grid current (20 mA or so at 30 V bias). This particular resistor draws 50 mA. The tube is cut off during standby with a 35 kΩ cathode resistor, which is bypassed by the cutoff relay during transmit. The 10 kΩ bias adjust control sets the idle current for the tube.

Metering shunts in the screen and grid circuits develop about 250 mV for full-scale deflection. Variable resistors are employed to calibrate the various meter ranges. The only exception is a high voltage metering resistor; this is actually five 1 MΩ 1% resistors in series, providing a full-scale deflection at 5 kV.

A number of low-value 2 W resistors are placed in series with the filament supply. These can be switched in or out of the circuit with jumpers to set the minimum filament voltage required for proper emission. This helps extend tube life by minimizing the effects of cathode back-heating.

A 50 kΩ, 20 W resistor is connected between the cathode and screen to eliminate the possibility of the tube generating self-supplied screen voltage, should the connection to the screen supply and clamp fail.

## Relay Sequencing

A sequencer circuit protects those expensive RF relays from damage by operating the relays in order, allowing the contacts enough time to close and be ready for all that RF coming their way. It happens like this:

- Key down, antenna relays close first, 100 ms later the cutoff relay turns on the tube, 100 ms later the transverter is keyed. If you are not using a transverter, you need not use this last connection.
- Key up, the transverter is released, 100 ms later the cutoff relay cuts off the tube, 100 ms later the antenna relays are released.

Do not change amplify/bypass switch setting while transmitting, as this will defeat the sequencing.

## Antenna Relays

I rebuilt a couple of used Microwave Associates relays for the antenna switch seen in Figure 6. They have extremely low loss, switch over quickly, and can withstand the power levels developed by the amplifier. Similar units are available

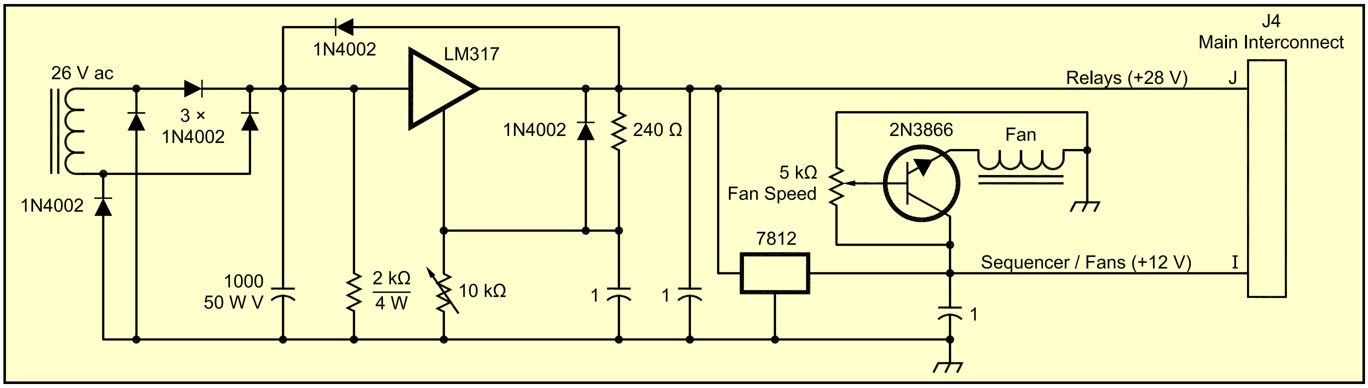



Figure 4—A low voltage transformer is used to generate the necessary voltages for the relays and control circuits.

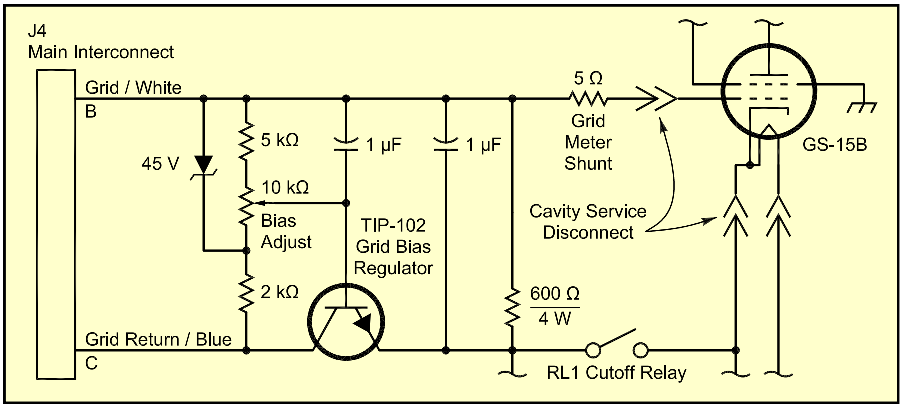



Figure 5—The bias regulator circuit for the grid of the amplifier.

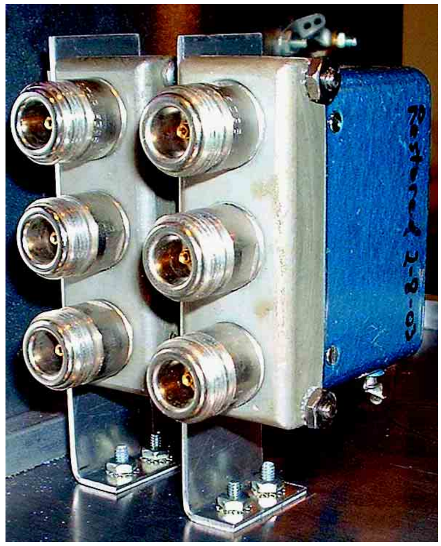


Figure 6—Commercial relays were rebuilt and used for antenna switching.

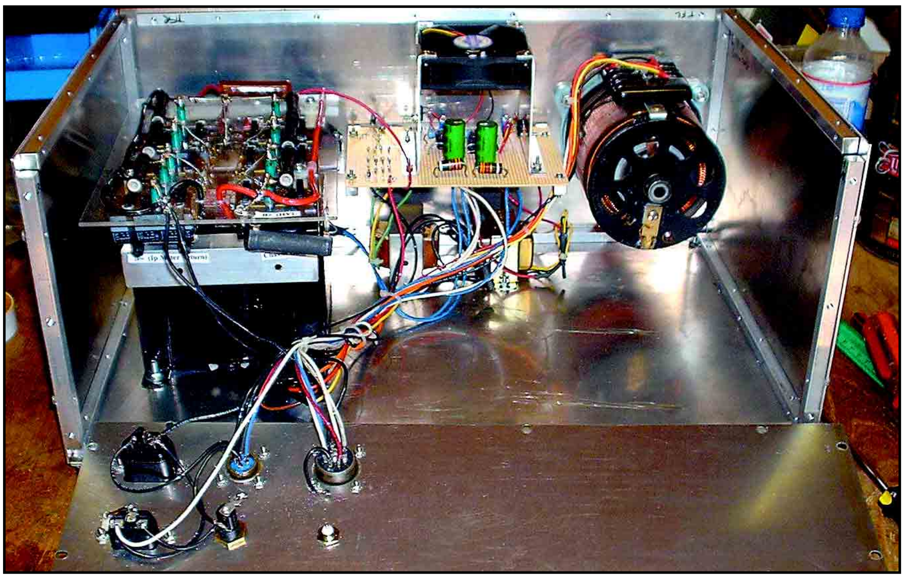


Figure 7—The general layout and wiring of the power supply.

from a number of sources. New ones sell for around $100 each at the time of this writing, so if you have them already, or can trade for them, you can save a bundle here. The mounting brackets are made from 0.060 aluminum scraps.

## Tune-up

Mats recommended the following tune-up procedure. He did such a good job of tuning the cavity before sending it to me, I found that the only adjustments I needed to make were to peak the cathode and anode tuners. I did not experience large variations relating to reverse screen current, but the caution is certainly valid.

Naturally, if you experiment a bit and change the plate voltage, you'll need to reset the idling current (I set mine at 50 mA) and re-peak the anode tuner, which is why it's a good idea to have a front panel control for it. The cathode tuner can be set and forgotten unless the tube is replaced.

- Set idle current for 60-80 mA
- Monitor screen current. If the screen current goes more than 4-5 mA negative during tune-up, then stop immediately and turn the plate tuner slightly CCW before continuing.
- Apply 3-4 W drive to the input.
- Adjust input and output tuners for maximum power.
- Increase power 2-3 W at a time and repeat step 4 until 10-12 W drive is reached.
- Turn the plate tuner CCW until the output power drops 10-20 W to prevent negative screen current.
- Loosen the hose clamp for the input coupler.
- Apply drive and adjust the coupler depth and input tuner alternately for best

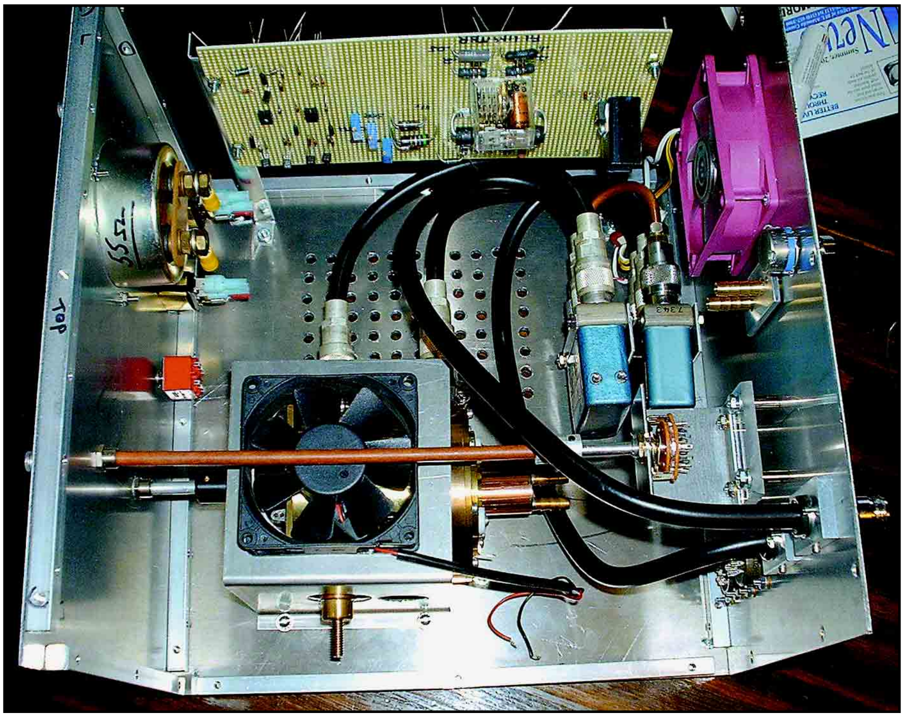



Figure 8—Taken prior to completing the high-voltage and control wiring, this photo shows the layout of the cavity, RF cables and all major assemblies in the RF deck.

input SWR.

• Tighten the hose clamp. Input tuning is completed.

• Loosen the hose clamp for the output coupler.

• Apply drive and alternately rotate the output coupler in small steps and tune the plate tuner until max output is reached. Monitor the screen current while doing this adjustment.

• Tighten the hose clamp. Loading tuning is completed

• Turn the plate tuner counterclockwise until power drops 10-20 W to prevent negative screen current.

• Leave carrier on for 1 minute or more to reach a stable temperature.

• Monitor screen current and turn plate tuner clockwise until you see a 1-2 mA current decrease. This should be about 10 W below maximum output.

Tune-up is completed.

As long as all voltages remain the same, you will not need to touch the tuning again. The screen current and output power is the only thing you need to watch during tuning. If you turn the plate tuner too far CW, then the screen current will go drastically negative, which could harm the tube and your screen stabilizer circuit.

### The Completed Amplifier

Figures 7 and 8 show the general layouts of the power supply and RF deck. Figure 9 shows the rear panel of the amplifier with all electrical and coolant connectors. The amplifier delivers more than 300 W with 10 W of drive. At this power level it is free of thermal drift in all modes. I often drive it with 15 W to over 400 W output in SSB and CW service where the duty cycle is lower, also without thermal drift. It is stable and robust, and tunes very smoothly.

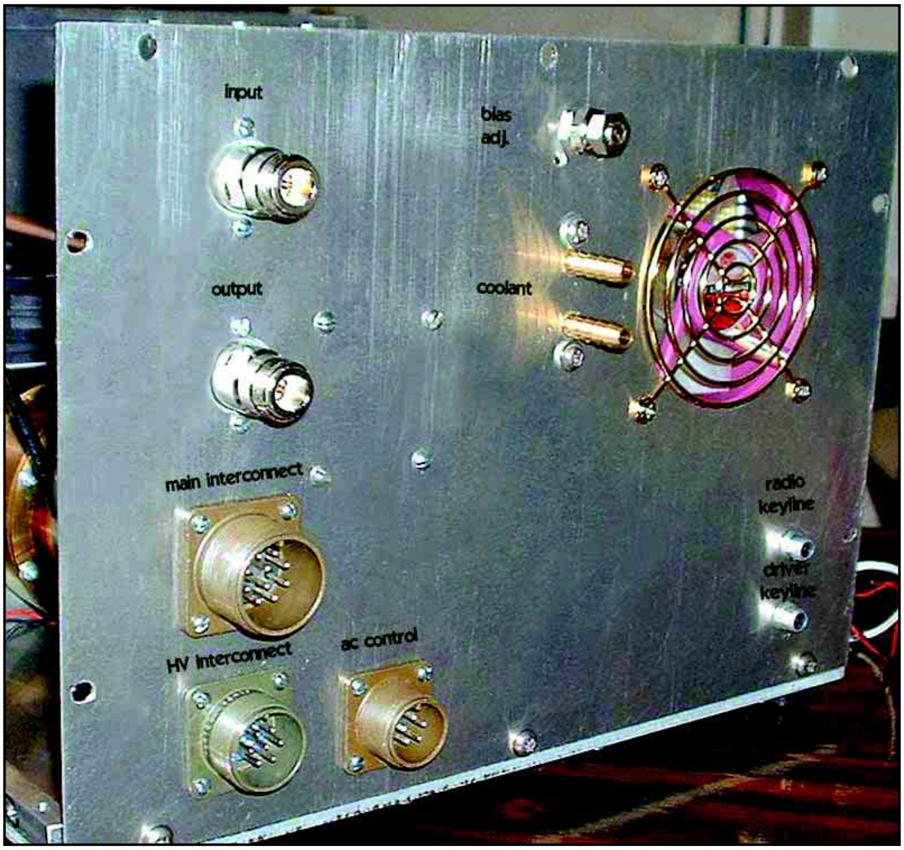



Figure 9—The uncluttered rear panel provides easy access to all connections. Note the use of male power connectors for safety and different styles to prevent connection errors.

#### Notes

[1]A detailed schematic diagram and other resources can be found at **www.arrl.org/files/qst-binaries/23cm_amp.zip**.

[2]See Note 1.

[3]RadioShack part no. 273-1512.

[4]Tohtsu relays are available at RF Parts (**www.rfparts.com/coaxial.html**).

*Jim Klitzing, W6PQL, was first licensed in 1964 as WB6MYC. He has been a metrologist for both the US Air Force and Hewlett-Packard Co, and has designed, manufactured and sold a line of solid state VHF/UHF linear amplifiers. He is currently engineering services manager for Agilent Laboratories in Palo Alto, California. You can reach the author at 38105 Paseo Padre Ct, Fremont, CA 94536;* **qrz@w6pql.com**.