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Home-brew this 800W amp

Build a hot 2m vertical!

Switching power supplies

Sunspot Cycle 23

The good news: Best DX ever
The bad news: Satellite killer?

Home-Brew a Customized HF Amplifier

Visualize, contrive, create!

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As many hams have discovered, building a vacuum tube-based RF power amplifier is still a good way to save money while creating a valuable station accessory. This project embodies a number of interesting ideas.

The amplifier described here allows me to substantially boost the output power of my HF station, yet my out-of-pocket expenses were a fraction of what I'd have needed to buy a commercial equivalent. I used all kinds of money-saving strategies.

On-the-air operation has resulted in comments of "very good" and "excellent" SSB signal quality. Some of the ideas I used in designing this amplifier may not appeal to everyone, but perhaps you will find one or more of these techniques helpful in your own project.

One money-saving strategy involves something other than the amplifier itself. Specifically, a transceiver or transmitter capable of 10 W or more can drive this amplifier to full output. I use it with a small multiband home-brew transceiver (described in my book, *Build Your Own Intelligent Amateur Radio Transceiver*, McGraw-Hill, 1997).

Other specifications of the amplifier include a maximum output of approximately 800 W. Input VSWR is very low, making it easy to drive with even the "pickiest" of exciters. It is capable of break-in keying (QSK) for CW, or reasonably fast turnaround T/R switching for data modes.

This is not a grounded-grid (cathode driven) amplifier. It uses a tetrode with the cathode bypassed to ground by capacitors. The cathode is 500-V negative with respect to chassis ground.

Other clues about the inner workings are apparent on the front panel in **Photo A**. Neon bulbs indicate the presence of grid-bias and plate voltage. Light-emitting diodes (LEDs) indicate control-grid and screen-grid current as well as filament voltage. Meters indicate plate current and RF output current.

Band-switching is accomplished with two separate switches for input and output circuits. Yes, this is a bit unsophisticated, but it's also simple and inexpensive. The jack labeled "KEY" at the lower left corner is a cost-related feature that ties in with issues related to T/R switching and relays.

The large pi-network coils and plate chokes in this project are fabricated by hand at a considerable savings over buying new ones. I even made the variable capacitors in the pi-network. If this seems too labor-intensive, wait until you see how they're constructed. The design is simple and easy to copy.

Circuit description

Except for the plate and screen supplies, the entire amplifier circuit including bias and control is shown in **Fig. 1**. Transmit/receive switching is accomplished by K1 and K2. The control-grid bias voltage changes from standby to operate mode when the contacts of K3 close.

The input signal is applied to the control grid. The screen grid is at RF ground as it would be in a conventional grounded cathode amplifier. An important difference here is that it is also at DC ground. I originally saw this idea in a VHF amplifier in the *1989 ARRL Handbook*. It offers the possibility of excellent input-to-output isolation because the screen grid sees a very low impedance to ground over a wide frequency range.

The control grid is supplied with bias through R8 which also acts as a load for the exciter. Loading the grid

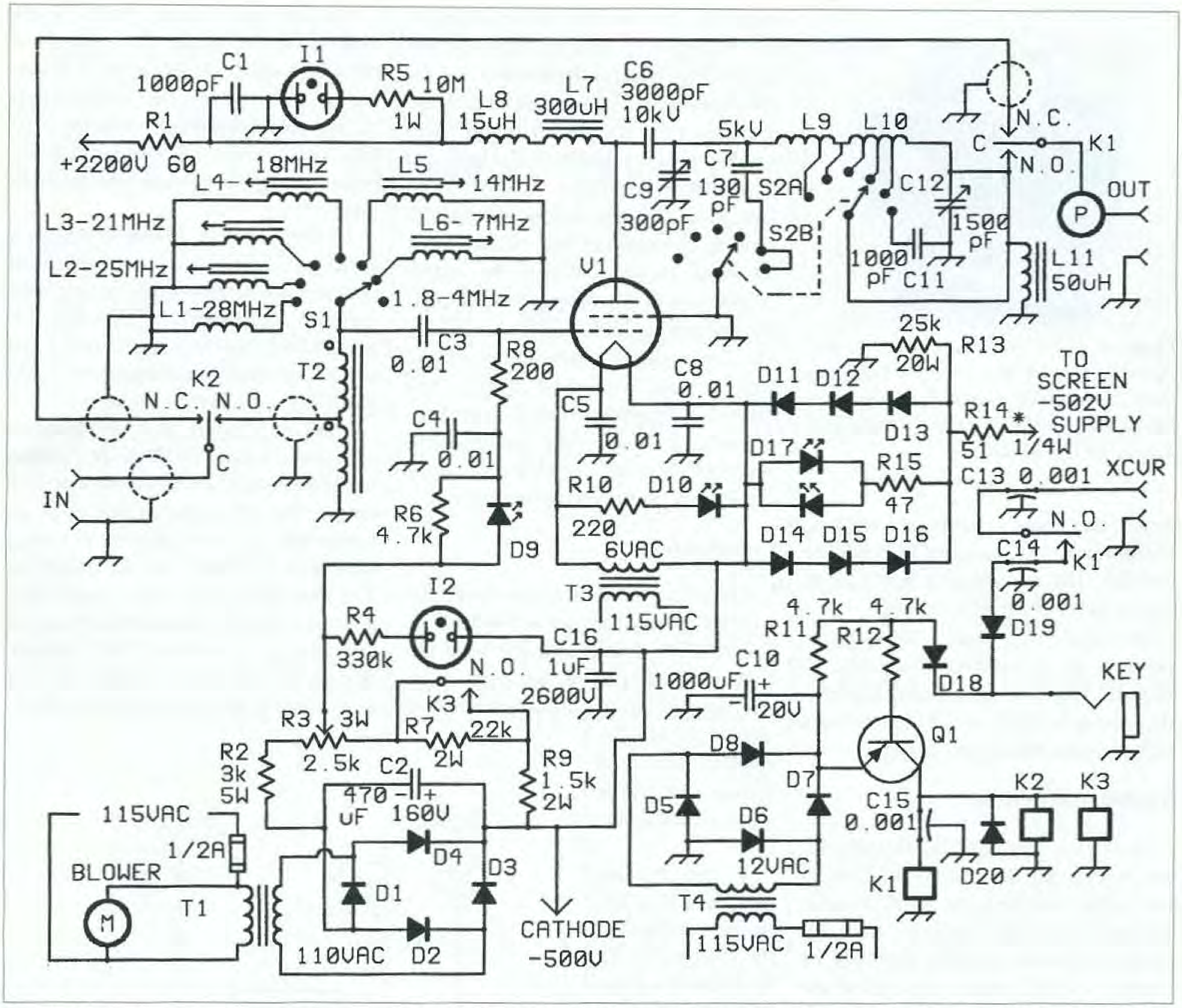

Fig. 1. For instructions on how to fabricate C9 and C12, see text. Diodes D11 through D16 are used only to protect the bicolor D17 LED from overloads. Values for L1 through L6 are chosen to form a parallel resonant circuit with the combined grid and socket capacitance of 110 µF. L9 is formed into a 1.7-inch (ID) coil. Wind six turns over a length of two inches.

helps dissipate the very small amount of output energy that finds its way back to the input. This also lessens the chances of parasitic oscillations occurring.

The 200-ohm load presented by R8 is transformed to one-quarter of that value by T2 for matching the 50-ohm output of an exciter. There is enough inter-electrode capacitance at the control grid and socket to cause an input mismatch on the higher bands. Coils L1 through L6 are switched in to cancel this capacitive reactance at 7 MHz and higher.

These input-coil values may have to be different if you use a different tube. Each forms a parallel resonant circuit with the combined tube and socket capacitances.

I used a low-current LED at D9 for grid current indication. It shows some illumination at 0.5 mA and is at almost full brilliance at 2 mA. When operating the amplifier in a linear manner, D9 lets me know if the drive level is too high. As soon as the grid is driven positive, D9 lights.

Screen current is supposed to be close to zero, or slightly positive, with the output properly loaded. D17 suffices for knowing if the screen current gets into a region high enough to exceed the screen dissipation rating. At least it will look excessively bright under such conditions. I have it connected to glow green with positive screen current, and red with negative screen current. This is one indicator where you should consider using a meter if you are paying very much for your tubes.

As for tubes, the 8791 is not really a common, inexpensive tube unless you happen to get some as "pulls" from a broadcast transmitter. A new socket for this coaxial-base tube is also rather expensive. I fabricated a suitable socket from sheet brass and PC-board laminate.

A number of tubes would be good candidates for use in this circuit. The 4CX800 and 4CX1000 are close to what I used, although you will need to get data about the necessary screen, control grid, plate and heater voltages.

I used a single transformer with two secondaries for the grid bias supply and

Photo A. *The U-shaped top cover is salvaged aluminum and was formed using steel angle stock clamped to the work bench. The final angles of the corners were hammered into shape.*

heater. You could certainly use separate transformers as shown in **Fig. 1** for T1 and T3. The control-grid bias supply uses a full-wave bridge rectifier.

The whole bias supply "floats" with no part of it connected directly to ground. Therefore, it is important that the insulation of T1 and T3 secondaries withstand the full screen voltage.

Timing and control

Controlling this amplifier in a slightly unconventional manner allowed me to use another low-cost part. Some amateur stations switch the amplifier from receive to transmit mode by a voltage or contact closure that comes from the exciter, usually a transceiver.

I think it makes more sense to have the amplifier control the exciter. That's the reason for the front-panel jack labeled "KEY." Regardless of the keying source (straight key, automatic keyer, computer, mike button, TNC, etc.), the amplifier has time to get its "affairs" in order before the exciter generates a signal on key-down (the start of a transmission).

The terminal in **Fig. 1** labeled "XCVR" keys the transceiver. This arrangement means that you can use a variety of ordinary relays for K1, K2 and K3.

Because of the seemingly unusual cathode and screen circuitry, I thought it might be helpful to clarify the amplifier supply requirements with **Fig. 2**. My setup is the (**a**) version. This is probably the easiest way to power the amplifier, because the screen supply is not required to deliver high current levels. The circuit at (**b**) requires that the full plate current, plus screen current, are available from the screen supply, with good voltage regulation. The screen grid in a tetrode amplifier is sensitive to voltage fluctuations. It does offer the advantage of requiring less voltage from the plate supply and may be worth considering if you happen to have parts for a very hefty (500-V in this case) supply. For a detailed description of the supply I'm currently using, see "Build a High-Voltage Power Supply at Low Cost" in the January/February 1998 issue of *QEX Forum for Communications Experimenters*.

Construction

Removing the bottom cover reveals a rather spacious layout in **Photo B**. In general, DC circuits and RF input circuits are contained in this area. Where conductors must pass through to the top side of the chassis, shielded cable and bypass capacitors are used for isolation.

At the bottom of **Photo B** is R3, the bias control on the back panel. To its right is a large hole for the blower. The large resistor running along the right edge of the photo is R1, used to give protection against tube flash over. Above the blower hole is T4 and its associated 12 VDC power supply components mounted on a copperclad board. I made the rectangular pads on the board by clamping it in a vise and raking a sharp marking punch along the straight edge of the vise jaws.

Another small circuit board below and to the left of the 12 V supply is the bias supply. At the upper left corner is the tube socket with various grid-circuit components mounted to its left. Input coils L1 through L6 are mounted at center top, next to the front panel.

A closer look at **Photo C** makes it easier to identify some of these input components. Components on the copperclad board include C3, C4, K3, R7, R8, and T2. Bypass capacitors C5 and C8 are the large mica units connected to the homemade tube socket.

All of the plate-circuit RF components are located topside in **Photo D**. I placed the blower and filament/bias transformer outside the RF-output enclosure in an apparently successful attempt to reduce unwanted feedback and RF radiation. The tube chimney is made from a food container that the manufacturer touts as "microwave oven-safe." The chimney diameter is larger at the bottom where it is attached to the chassis and tapers to a

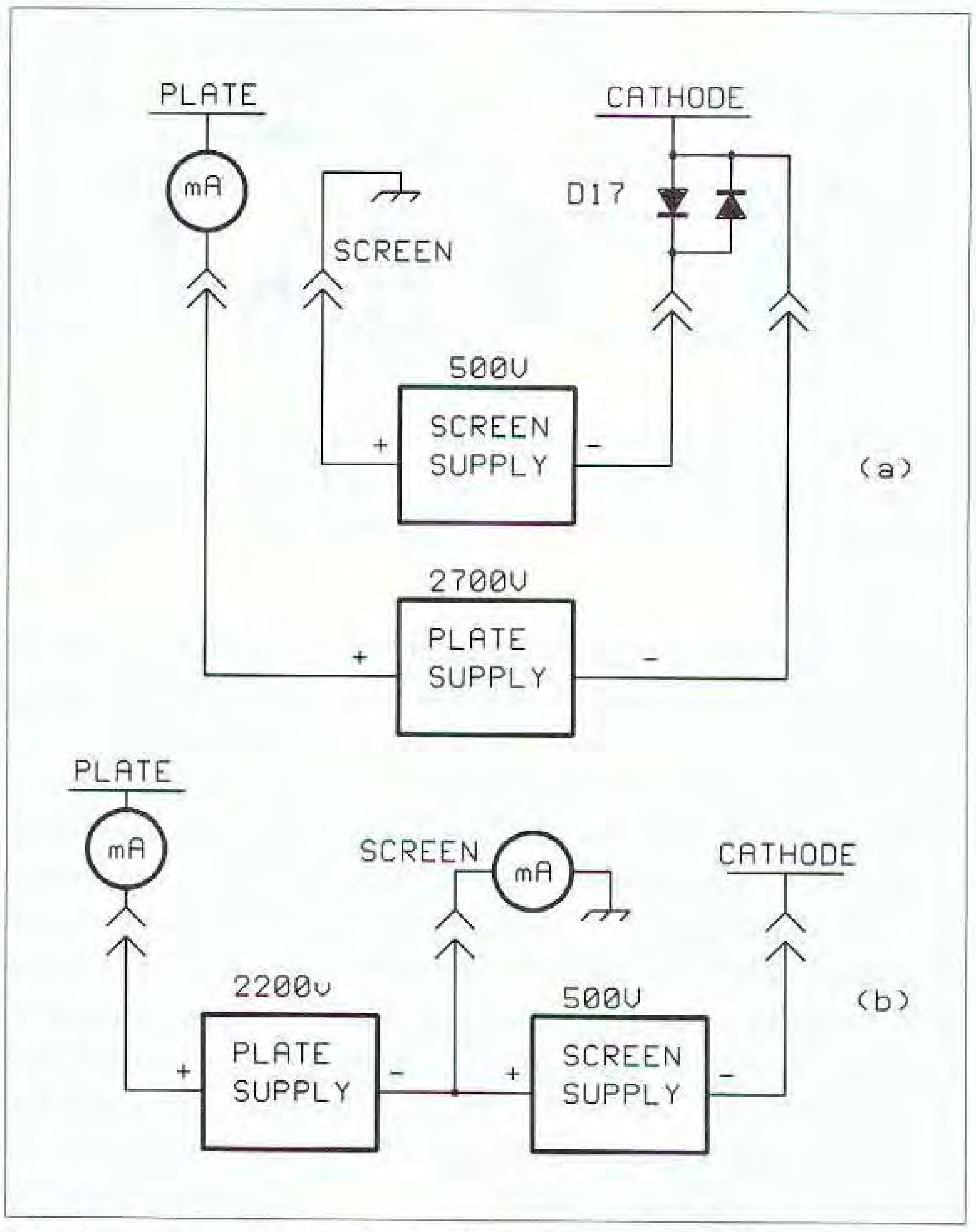

Fig. 2. *Two possible methods of powering the amplifier are shown here. You can substitute a meter for D17 if you wish. Plate current can also be monitored by putting the meter in the negative lead of the 2700 V supply in (**a**) or the 2200 V supply in (**b**). This reduces the insulation requirements of the meter housing and face.*

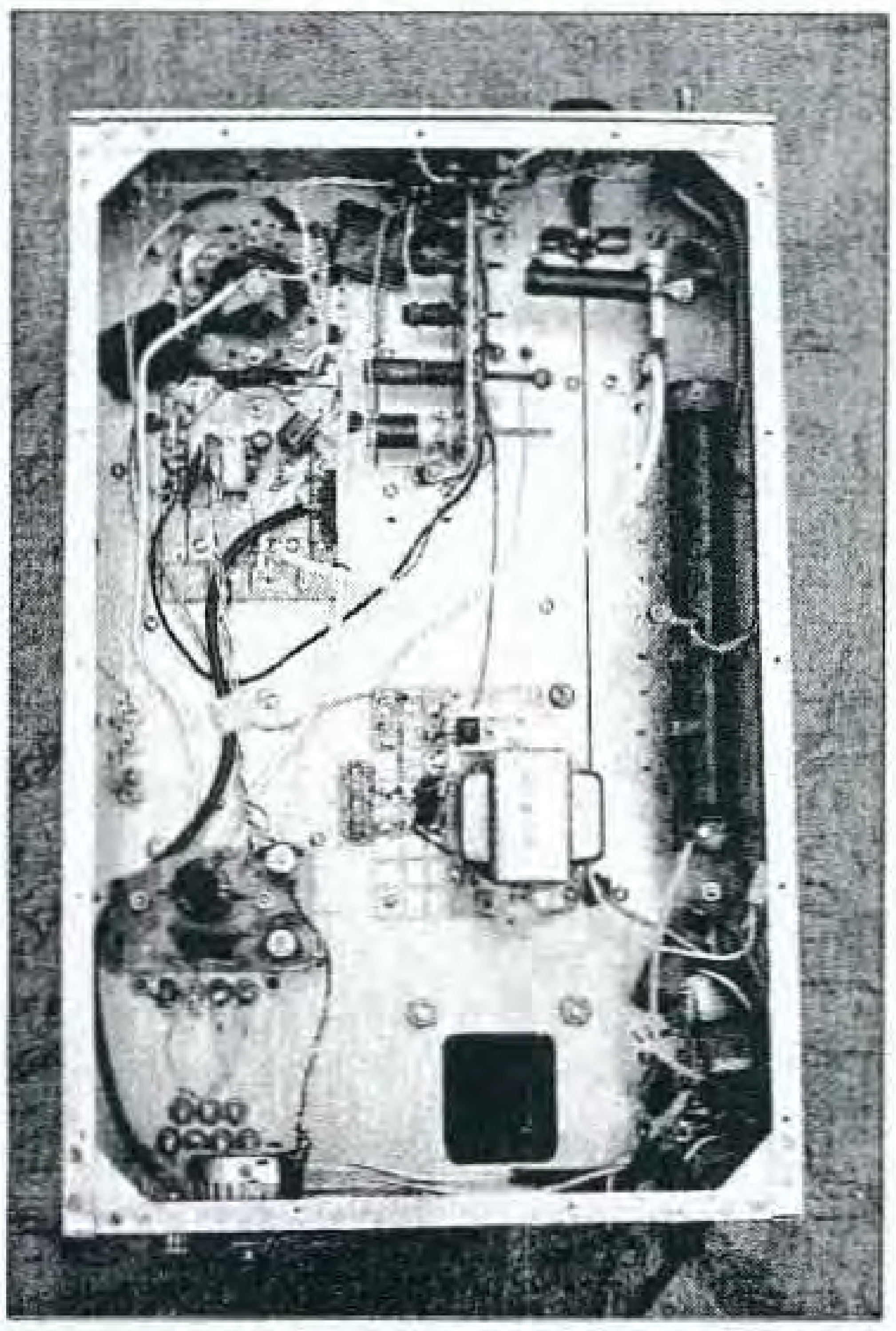

Photo B. The mechanism for the LOAD TUNE knob is near the front panel. Part of the knob can be seen alongside the toggle switch handle in this photo. The mechanism includes a small bracket made of sheet copper soldered to a 1/4-20 nut. The bracket bears against the chassis to prevent rotation of the nut. It also has a small hole drilled in it for attaching the dial cord. A washer has been fastened to the threaded end of the decapitated LOAD TUNE bolt and the PLATE TUNE bolt to act as a stop to prevent completely unscrewing the nut. I drilled and tapped the ends to accommodate a small screw for this purpose. R3 is mounted on the back end of the chassis for ease in adjusting control-grid bias.

Continued on page 14

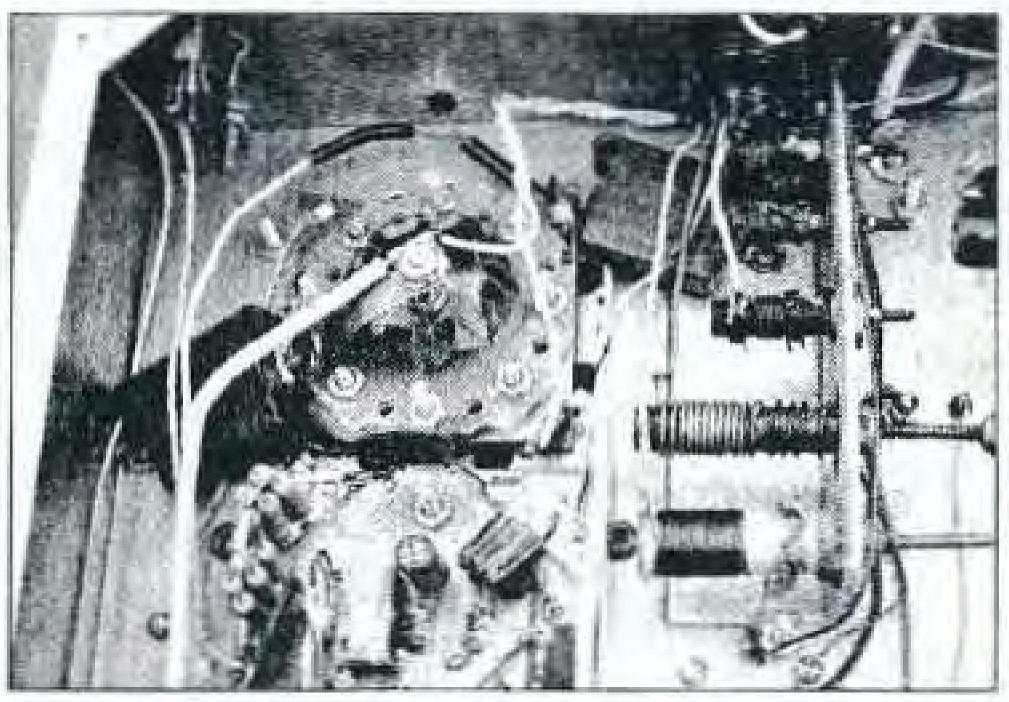

Photo C. This is a closer look at the surroundings of V1. The homemade tube socket is a story in itself. Alternating layers of 0.010-inch sheet brass and unclad glass-epoxy board are used to make the supporting structure and contacts. The ventilated brass sheets and a small finned heat sink help cool the tube base.

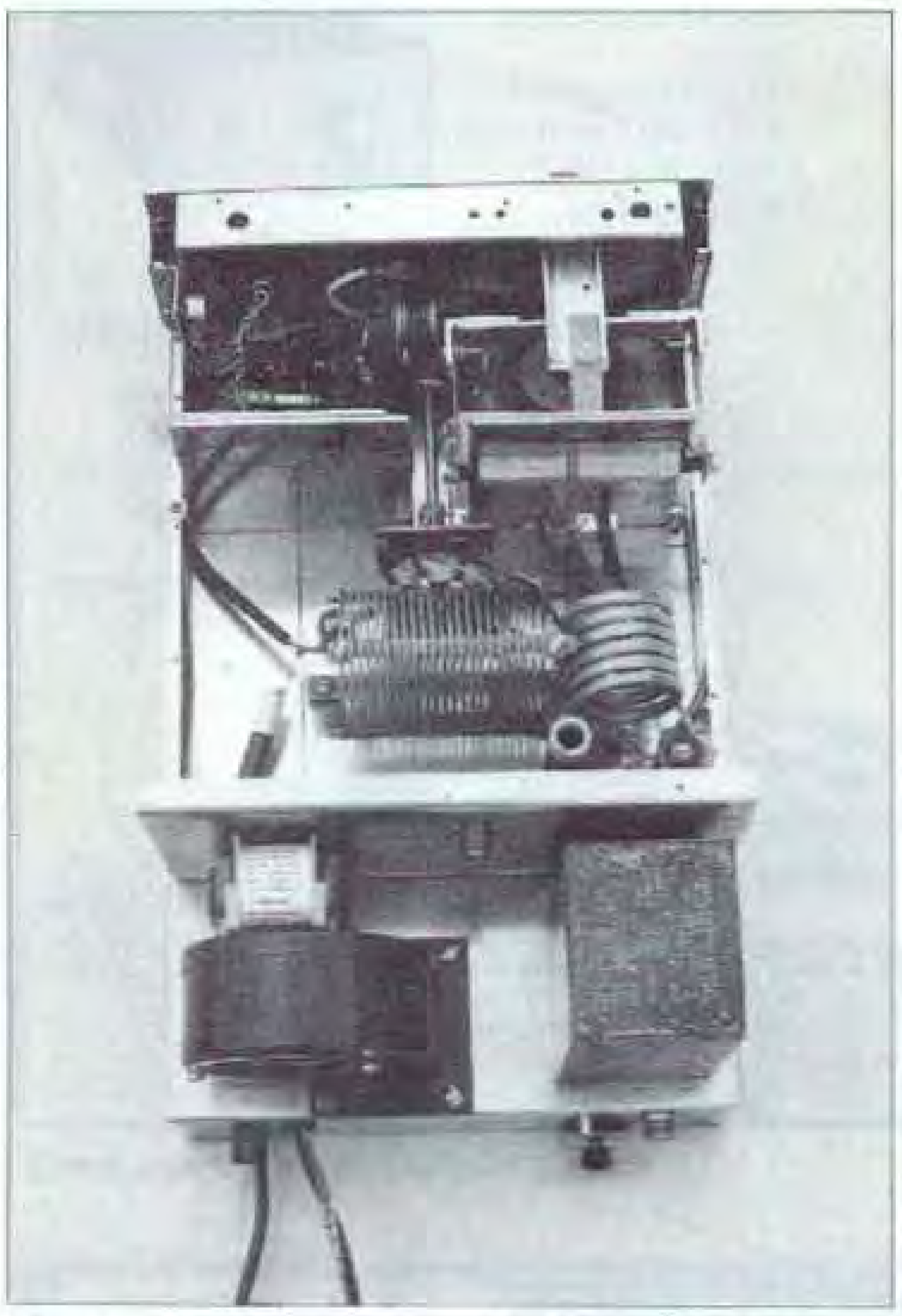

Photo D. Copper braid from RG-59 coaxial cable is used for connections between the tank coils and band switch. A long shaft extension from the band switch is used to make part of S2B. A movable contact made from brass sheet soldered to a knob insert is mounted on the shaft extension. It rotates against a fixed brass contact mounted on a standoff insulator connected to C7.

smaller diameter at the opening around the tube cooling fins, allowing me to place holes in the chassis around the tube socket for decreased back pressure and increased air flow.

Pi-network components

Both plate tank coils are handmade. The smaller L9 is made of quarter-inch copper tubing. The strips you see in **Photo D** supporting the coil turns in L10 are made of epoxy-glass circuit board material with the copper foil removed. Polyester resin, available in hobby stores and auto-supply houses, holds the wire in place on the strips.

Another money- and space-saving feature in this amplifier includes C9 and C12, the output pi-network capacitors. You have probably seen small compression trimmer capacitors that squeeze together two metal plates separated by a solid dielectric. Well, C9 and C12 are sort of an overgrown version. They are the large metal plates standing vertically and parallel to the front panel in **Photo D**. The variable capacitor at the upper edge is C12. Minimum capacitance for these capacitors is lower than values attainable with conventional air-dielectric variables.

An edgewise view of this capacitor in **Fig. 3a** shows how one plate is pivoted away from the other by tension from a dial cord. The dial cord for C12 passes to a small pulley at the back of the tank circuit enclosure, through the chassis deck and returns underneath to a threaded nut near the front panel. A 1/4-20 bolt, threaded into this nut, passes

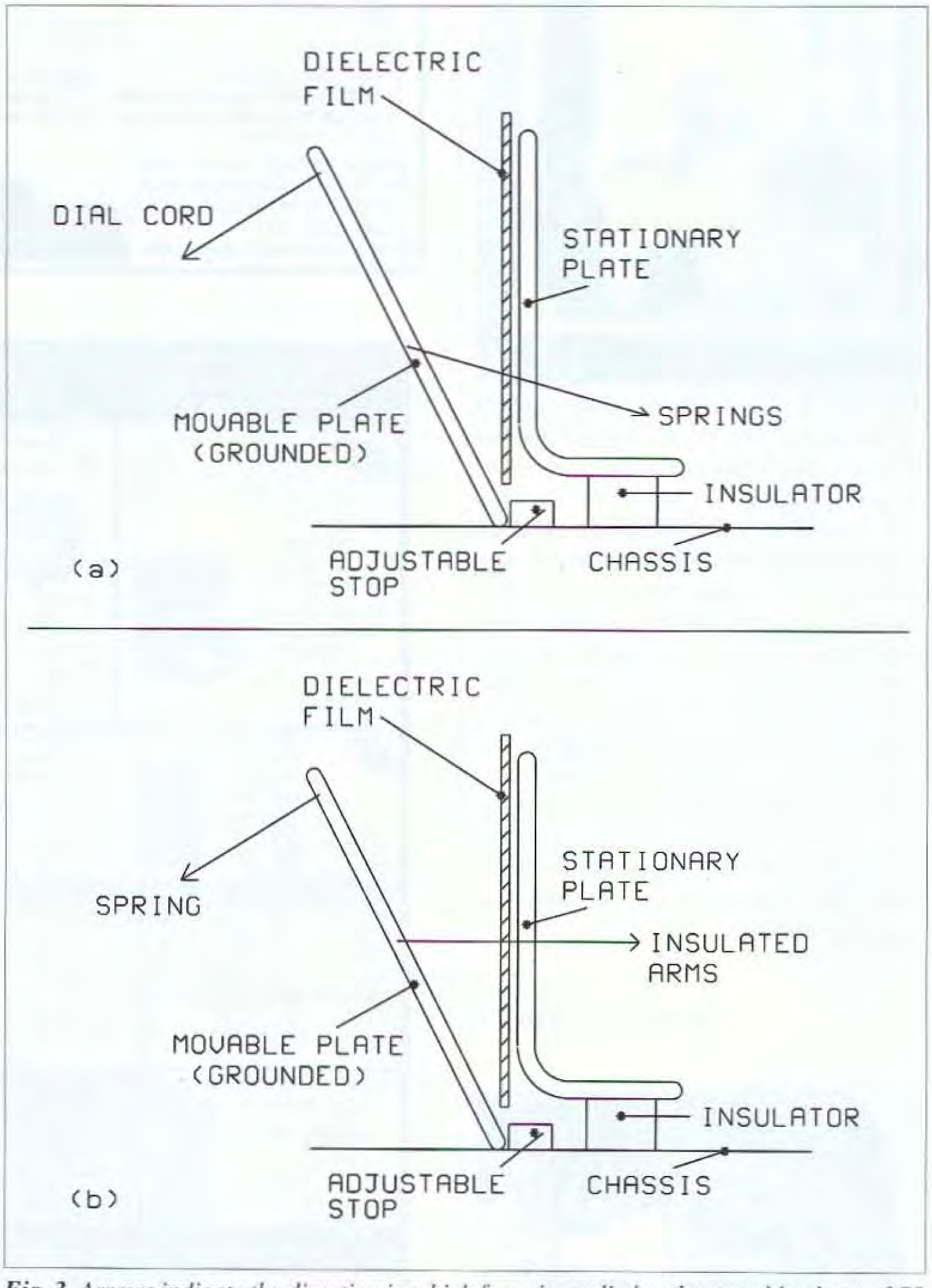

Fig. 3. Arrows indicate the direction in which force is applied to the movable plates of C9 and C12. The adjustable stop is simply a small block of aluminum with an oversized hole (or undersized bolt) that can be positioned as needed and tightened in place. Tension from the springs and linkage hold the movable plates in a 90° corner formed by the chassis and stops. The short horizontal section of the stationary plate is actually two three-quarter-inch-wide "ears" because a "U"-shaped section is cut from the plates before bending them in a vise. This makes bending them easier. Be careful not to deform the plates. With both plates closed, the area contacting the dielectric at C9 measures four by four and one-quarter inches. The area for C12 is four by five inches. I have added a thin (0.010-inch) brass sheet between the grounded plate and dielectric sheet of C12. It is slightly bowed, which provides a less abrupt change of capacitance as the grounded plate moves.

Parts List

D1–D4	400 PIV, 1 A units or equivalent bridge
D5–D8	50 PIV, 1 A units or equivalent bridge
D9	RS #276-044
D10	any 20 mA LED
D11–D16, D20	1N4002
D17	RS #276-012 or Mouser #351-5101
D18	1N4007
D19	1N5819 Schottky
I1, I2	NE-48 neon lamps
K1	10 A DPDT RS #275-218
K2	SPDT relay RS #275-241
K3	reed relay, RS #275-233 or Mouser #431-1412
L1	0.28 µH
L2	0.37 µH
L3	0.5 µH
L4	0.7 µH
L5	1.15 µH
L6	4.5 µH
L7	loaded w/ferrite rod
L8	15 µH
L9	1.4 µH 1/4" copper tubing, 1.7" ID coil, 6 turns over 2 inches
L10	20.4 µH, 23 turns of #12 wire on 2.7" diameter form, 6 turns per inch
Q1	TIP106 or similar
R1	60 Ω, 30 W or higher
R8	10 carbon comp or non-inductive 2000 Ω resistors, 2 W each, in parallel
R14	1/4 W carbon film resistor used as fuse
T1	14 bifilar turns of #26 plastic-insulated hookup wire wound on FT50B-61 toroid, Amidon Inc.
V1	8791 (see text)

Note: L1–L6 to resonate with the combined grid and socket capacitance.

Table 1. *Parts list.*

through the panel where a knob is attached for the "LOAD TUNE" control. The dielectric film is two-mil-thick polyethylene film, a fancy description of a piece of sandwich, garbage or recycling bag.

The other variable capacitor, C9, uses the dial cord and spring arrangement in **Fig. 3b**. Its Fiberglas™ arms and linkage are above V1. The ends of the Fiberglas arms are joined by a metal bar fastened to a threaded nut. It is attached to another 1/4-20 bolt turned by the "PLATE TUNE" knob. The dielectric film for this capacitor is two layers of 0.010-inch (10-mil) Teflon™. I purchased the Teflon sheet from Regal Plastics, 9342 West Reno, Oklahoma City OK, phone 1-800-444-7755.

The Teflon sheet in C9 is rigid enough to stand in place if its bottom edge rests on the chassis. The small sheet of polyethylene film in C12 is draped over the top of the stationary plate and secured to the back side of the plate with cellophane tape.

I'm using three-quarter-inch-long threaded ceramic standoff insulators to support the stationary plate of C9. Circuit board material is sandwiched between the stationary plate of C12 and the chassis. The three layers are drilled for nylon screws and nuts.

All surfaces near or in contact with the dielectric film of these variable capacitors should be smooth and polished. Instead of square and sharp, the edges of the plates should be rounded. Holes drilled for attachments should also be countersunk, smoothed and polished. This is easy to do by using several grades of sandpaper or emery cloth. Start out with a coarser grade for rounding and smoothing. Wipe off any grit residue from the coarser grade and repeat the operation with a finer grade.

After progressing through a sequence of perhaps 100-, 220-, 350-, to 600-grit, finish with metal polish. Be careful not to scratch the plates when installing them. Smooth, round surfaces are important at C9 because sharp corners and protrusions result in a concentration of the electric fields that may cause arc-over or insulation breakdown. The elimination of mechanically piercing or weakening the thin dielectric film at C12 is also a good reason for having smooth surfaces there.

I used one-eighth-inch-thick aluminum to make all four plates. Anything thinner may warp and not maintain a flat surface while you are working with it or when under tension from the control linkages. A Fiberglas stop between the front panel and stationary plate of C9 adds additional support when the movable plate is pulled against the Teflon sheets.

Setup

Before trying to operate an amplifier such as this, you should make sure the input and output circuits are set up correctly. You can do so without powering up the amplifier. Align the input coils by measuring reflected power seen by the exciter. Either energize K2 or jumper past its normally-open contacts. The dip in reflected power is very broad and should reach a low value.

To find the correct places to tap L9 and L10 in the output network, temporarily install a resistor between the tube anode and ground. This can be a single 1/4 W or 1/2 W resistor if you have some low-power method of measuring reflected power. If all you have is a regular SWR meter that requires a few watts of RF, you may have to cobble together some combination of resistors rated at one or two watts each. Don't use wire-wound power resistors. They have too much inductance.

For this amplifier, the temporary resistor should be approximately equal to the plate load resistance. For example, an amplifier operating class AB1 with a plate current of 500 mA will have a plate load of

$$R = \frac{\text{plate voltage}}{(1.5 * \text{plate current})}$$

or 3600 ohms. The units used here are amperes, volts and ohms.

Remember to leave the plate and screen supplies off and disconnected. To test the output tuning, you will be sending a signal from an exciter or other generator to the amplifier output circuit. This time, connect your SWR meter (or other instrument) to the output connector and energize K1. Alternatively, you can connect the SWR meter directly to C12. Again, you are looking for a low reflected-power reading.

Output tuning capacitors C9 and C12 should be adjusted to the value which produces the network-loaded Q needed for the frequency under test. When you find the position on the coil that results in the lowest SWR, that's where you tap it for the appropriate switch position—a lot safer than trying to find the correct tap with the high voltage on.

I used this procedure on my amplifier and it works well. Just don't forget to remove the temporary resistor when you apply plate voltage. If you don't have a method of measuring C9 and C12, it's probably better to err on the side of setting their capacity too high than too low. This can cause a loss in efficiency but it will result in lower levels of harmonic emissions. A loaded Q of 14 with a plate load of 3600 ohms results in the following values in picofarads. These values include tube and stray circuit capacitance.

1.8 MHz: C7 + C9 = 344, C11 + C12 = 2330
3.5 MHz: C7 + C9 = 177, C12 = 1198
7.0 MHz: C9 = 88, C12 = 599
10.1 MHz: C9 = 61, C12 = 415
18.068 MHz: C9 = 34, C12 = 232
21.0 MHz: C9 = 29, C12 = 200
24.89 MHz: C9 = 25, C12 = 169

A Q of 16 for 10 meters results in

28.0 MHz: C9 = 25, C12 = 182

It's probably a good idea to make these pi-network adjustments with the plate end of RF choke L7 disconnected. Try to arrange the disconnected lead so that it's resting very near its connected position. When you reconnect it after each adjustment, the reflected power reading should not change too much.

If the meter suddenly shows a big mismatch, the L7-L8 combination probably has a series self-resonance on or near the band you're testing. High-power operation in this condition will likely cause poor performance or destruction of the RF choke. Tune L8 by removing or adding turns to move the self-resonant frequency away from any of the desired amateur bands.

Use and operation

The only evidence of instability that I have detected in this amplifier has been a tendency toward a fuse-blowing low-frequency oscillation until I installed C16. It was not installed when **Photo B** was taken. You can use a larger value than 1 μF if necessary. After installing C16, I've experienced months of reliable operation.

Be sure to install covers over any areas with hazardous voltages. I've seen some home-brew amplifiers that work well, but they need safer enclosures and connectors. Connectors for the plate and screen supply cables are inside my power-supply enclosure and hard-wired at the amplifier chassis.

Increasing the output power of my station often allows me to use my operating time more efficiently. Operating on the lower bands often means contending with atmospheric noise when vying for the attention of another station. Single sideband signals seem to suffer from the effects of noise more than other modes such as CW and data modes that concentrate their power into a narrower frequency spectrum.

I'm pleased to find that this amplifier operates reliably, especially considering the unusual nature of output network capacitors C9 and C12. It is possible to break down the insulation of C12 by driving the amplifier hard into a large load mismatch. However, it is also very easy to repair it. Be aware that a slight detuning effect may occur as the capacitors heat and cool during operation. Most of this could probably be eliminated by using better placement, ventilation or nonconductive baffles to redirect the hot exhaust air.

Having extra power is nice, but remember to use it wisely. If you don't need the extra power to overcome path loss, noise or QRM, turn down the "wick." I hear too many operators trying to punch through QRM and annoying everyone (including themselves) when they could easily reduce power and move to nearby vacant frequencies.

Building an inexpensive well-made amplifier is a worthwhile experience. However, when it comes to being a considerate, competent operator, don't scrimp. Be a big spender and invest your best efforts.

Many thanks to Henry Just (K5SAM) and other generous amateurs whose former parts and materials are now part of this amplifier. 73