A Grounded-Grid Kilowatt Amplifier for 432 MHz

Stable, linear operation for tropo or moonbounce DX . . . that's the end result of this project.

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In the last few years I've built several high-power 432-MHz amplifiers that used tubes from the 4CX250 family. While they worked well in Class C, their performance when biased for linear operation left something to be desired. My previous experience with grounded-grid triode amplifiers on 2 meters was so good that I decided to try the same approach on 70 cm. An Eimac 8874 high-mu triode was selected for this design and a crude prototype was built in a few evenings. After the design was verified, the amplifier described in this article was built. It is stable, compact and delivers over 500 watts output while requiring only a high-voltage supply and a source of about 25 watts of drive. The amplifier has been trouble free in over three years of heavy usage.

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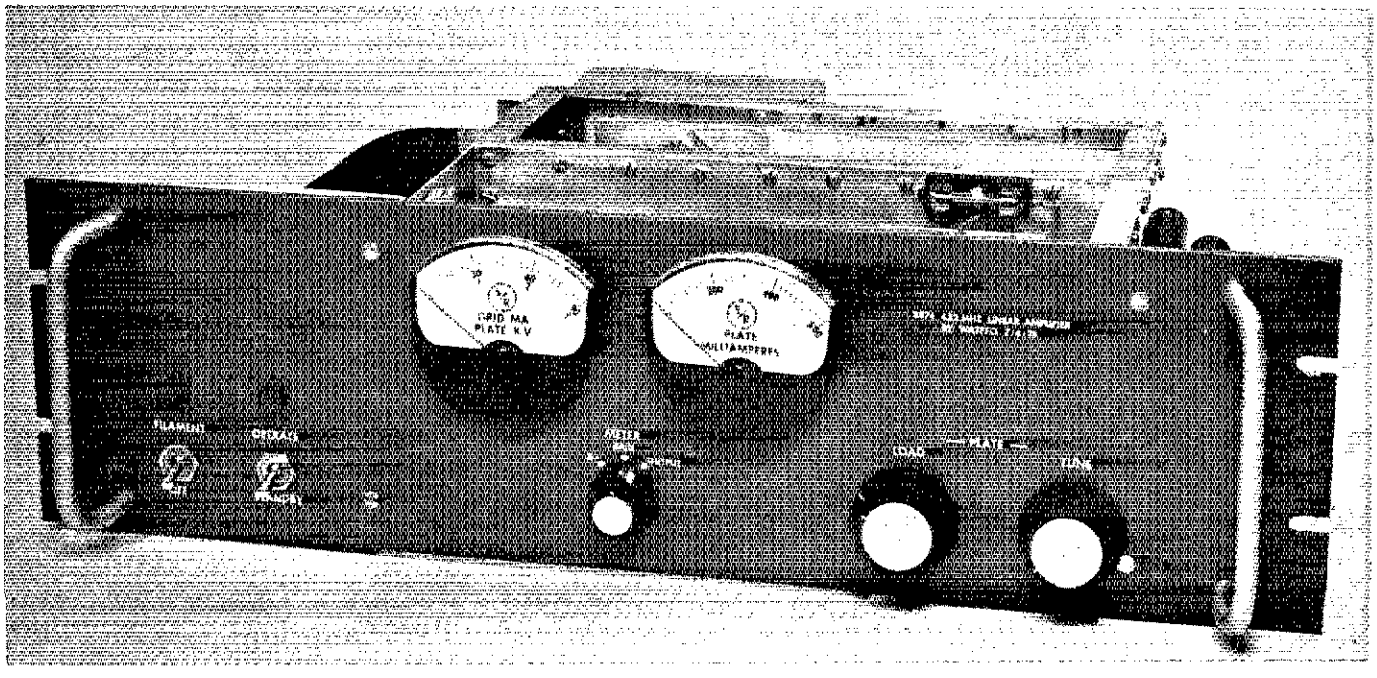
Circuit Description

A schematic diagram of the 432-MHz kilowatt is given in Fig. 1. W1 is a half-wavelength stripline which is tuned and loaded by C6 and C7 respectively. Plate choke RFC4 is connected at the approximate electrical center of the plate line. C8 functions as the plate-bypass capacitor. The half-wavelength cathode line is comprised of W2, L2 and C2. L1 and C1 serve to match the tube input impedance to the amplifier 50-ohm input. As the grid is grounded for dc as well as rf, D1 is used to develop operating bias at the cathode. R3 is switched in to supply near-cutoff bias

The high-power uhf amplifier. The toggle switches control filament power and standby/operate functions respectively. Multimeter function is selected with the switch located between the meters, while the plate tuning and loading controls are at the right. Modern knobs and homemade meter faces give the amplifier a commercial appearance.



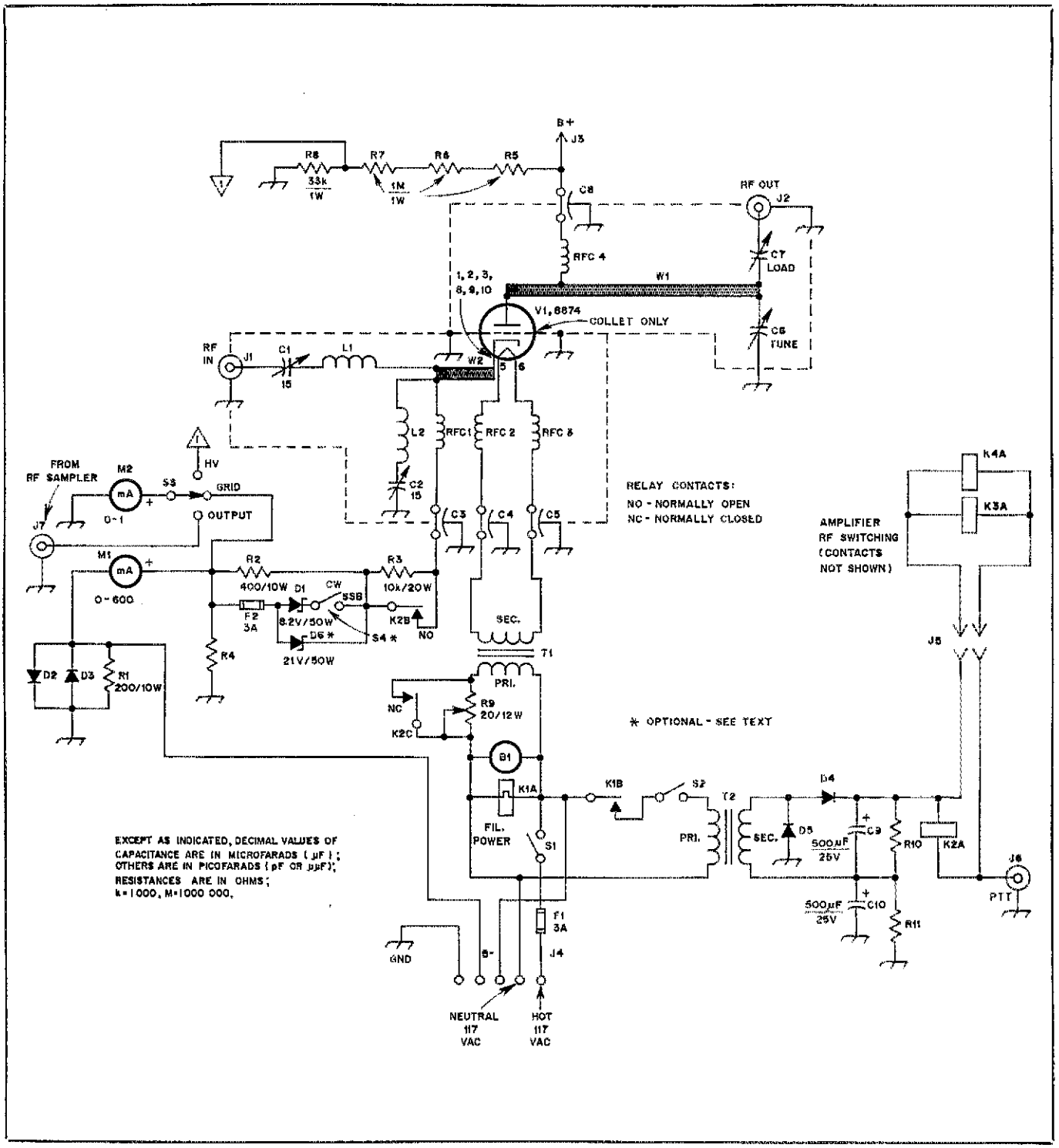


Fig. 1 — Schematic diagram of the amplifier.

B1 — 50-ft^3 (1.4-m^3)/min blower, Ripley Sk2754-2A or equiv.

C1, C2 — Air-variable capacitor, 15 pF, E.F. Johnson 189-0565-001, 160-0107-001 or equiv.

C3-C5, incl. — Feedthrough capacitor, 500 pF, 300 V.

C6-C8, incl. — Homemade "flapper" capacitor. Details of construction in text and Fig. 3.

C9, C10 — Electrolytic capacitor, 500 µF, 25 V.

D1 — 50-watt, 8.2-volt Zener diode, IR Z-3307-C or equiv.

D2-D5, incl. — 1-A, 1000-PIV diode, 1N4007 or equiv.

D6 — 50-watt, 21-volt Zener diode (optional — see text).

F1, F2 — 3AG fuses.

J1 — Chassis mount BNC female connector, UG-1094/U.

J2 — Chassis mount N female connector, UG-58A/U.

J3 — High-voltage connector, Millen 37001.

J4, J5 — Power connectors, as available.

J6, J7 — RCA phono jacks.

K1 — Time-delay relay, 90 second, normally open contact, Amperite 115N090T.

K2 — Control relay, 28-volt coil, 1-A 4pdt contacts.

K3, K4 — Coaxial relays equipped with suitable connectors. K4 should have N connectors, K3 may be BNC or N.

L1 — 3-1/2 turns no. 16 enam. wire, 3/4-inch (19 mm) long, 1/4-inch (6 mm) diameter.

L2 — 1-1/2 turns no. 16 enam. wire, 5/8-inch (16 mm) long, 1/4 inch (6 mm) diameter.

M1 — 1-mA meter movement with shunt to provide 600-mA full-scale deflection.

M2 — 1-mA meter movement with shunts to provide 90-mA (grid current) and 3-kV (plate voltage) full-scale deflection.

R4 — Grid-current shunt.

RFC1 — 10 turns no. 18 enam. wire, close wound, 1/4 inch (6 mm) diameter.

RFC2, RFC3 — 10 turns no. 16 enam. wire, close wound, 1/4 inch (6-mm) diameter.

RFC4 — 5 turns no. 16 wire, one inch (25 mm) long, 1/4 inch (6 mm) diameter.

S1 — Toggle switch, spst.

S2 — Toggle switch, spst.

S3 — Rotary switch, single pole, three position.

S4 — Toggle switch, spst (optional, see text).

T1 — Filament transformer, 6.3-volt, 3-A, Stancor P-6466 or equiv.

T2 — Transformer, 12.6 volts, 1 A.

during standby periods. M1 is used solely to monitor plate current in the high-voltage supply negative-return lead. M2 is switched to read grid current, high voltage and relative output. The latter function is by means of an external line sampler.[1] With the exception of the multimeter functions the metering and bias circuits are similar to those in a 220-MHz amplifier.[2]

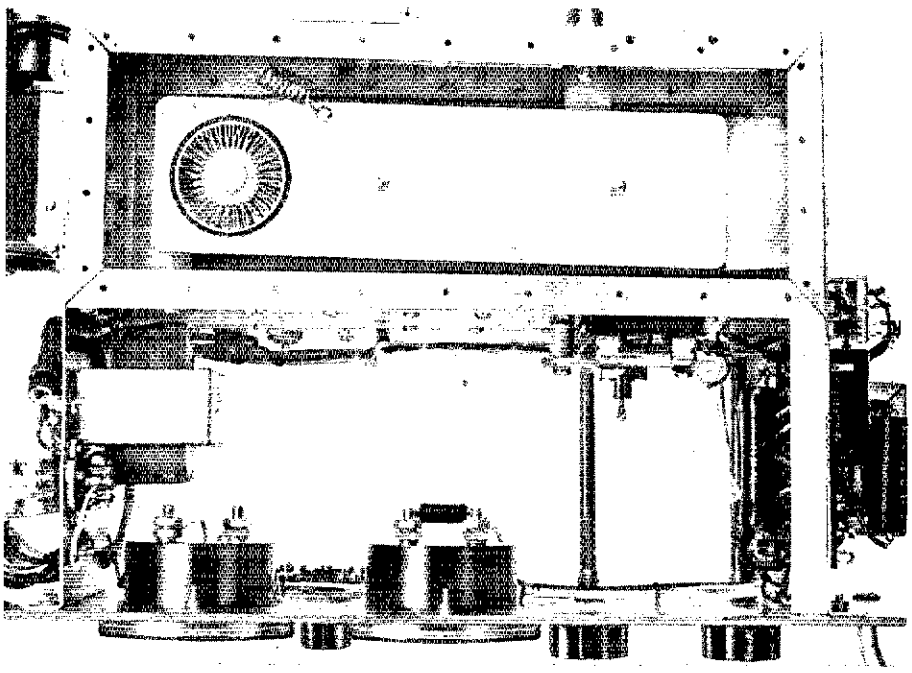
Separate coaxial relays attached to the input and output terminals allow the amplifier to be switched in and out of the line in a manner popular with ht amplifiers. Time-delay relay K1 prevents the amplifier from being switched into service for 90 seconds after the tube heater is energized, allowing the element to reach operating temperature. A normally closed contact of K2 applies full voltage to the heater during standby periods. The voltage is reduced during operation as recommended by the manufacturer.

Construction

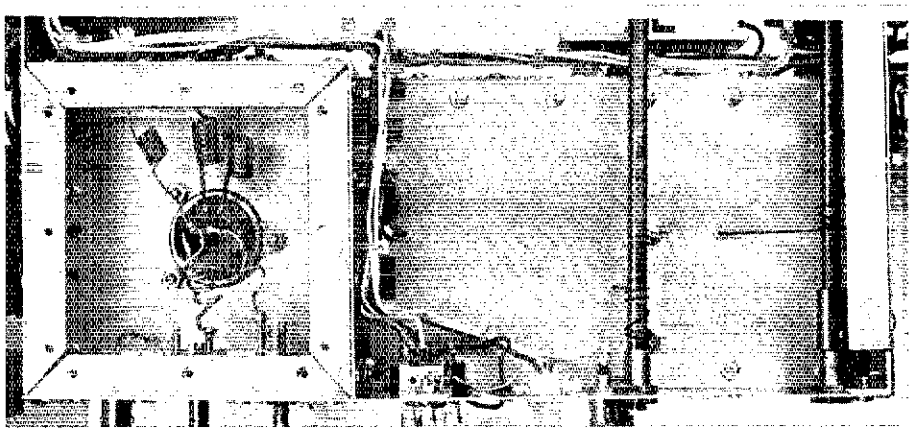
Plate and cathode-compartment construction is from 0.032-inch (0.8-mm) thick aluminum sheet attached to 1/2-inch (13-mm) aluminum angle stock. Some angle stock may be anodized, giving the surface a dull appearance. This material must be lightly sanded to remove the anodized metal, which is a poor conductor. Holes are drilled in the angle stock to allow attachment of the covers; these are tapped for no. 4-40 screws. Details of the 10.5 × 4 × 3-inch (267 × 102 × 76-mm) plate compartment may be seen in the top view photo. Construction of the cathode compartment is similar, and may be seen in the photo of the underside. It measures 4 × 4 × 1-3/4 inches (102 × 102 × 44 mm). The aluminum brackets holding the rf enclosures to the front panel also serve as end covers for the compartments. Compartment spacing from the panel is four inches (102 mm). A 5-1/4 × 19-inch (133 × 483-mm) rack panel is used.

The plate line was fabricated from a piece of 1/16-inch (1.6-mm) thick brass. Fig. 2 gives detailed information for making the line. In addition to brass, lines were made from copper, both unplated and silver plated, with no discernible difference in efficiency. Double-sided G-10 printed circuit board would probably work as well. Best thermal stability was obtained with the unplated solid-copper line. The line is supported by 1.5-inch (38-mm) long ceramic insulators, although standoffs made of Teflon will also serve. C6 and C7 are made from beryllium-copper sheet. Details of their construction appear in Fig. 3. These "flappers" are moved with fishing line which is tied to 1/4-inch (6.4-mm) fiber shafts. These shafts may be seen in the underside view.

[1]Notes appear on page 14.



Top view of the amplifier, with the plate compartment cover removed. The tube, plate line (W2) and RFC4 may be seen at the top of the photo. Note the large number of holes drilled in the plate compartment to receive the cover hold-down screws. A tight seal is required to prevent rf and air leaks.



This bottom view shows the cathode compartment and the shafts for C6 and C7. A cover is placed over the cathode compartment during tuneup and operation.

The anode collet (Eimac no. 008294) is secured to the bottom of W1 with standard 60/40 solder. Use no. 4-40 screws and nuts to hold the collet in place during the soldering operation. The grid collet (Eimac no. 882931) is attached to the chassis with eight no. 4-40 machine screws and nuts. A poor ground connection for the grid will greatly increase the amplifier drive requirements or make the unit totally inoperative.

C8, the plate-bypass capacitor, is made from two brass plates, one mounted on either side of the plate compartment. A 0.005-inch (0.13-mm) thick piece of Teflon sheet is used for the dielectric material. While this Teflon thickness may seem inadequate, it is rated at 1000 volts per mil (0.03 mm) thickness. It is necessary to coat the dielectric with Dow Corning type DC-4 silicone grease to fill in

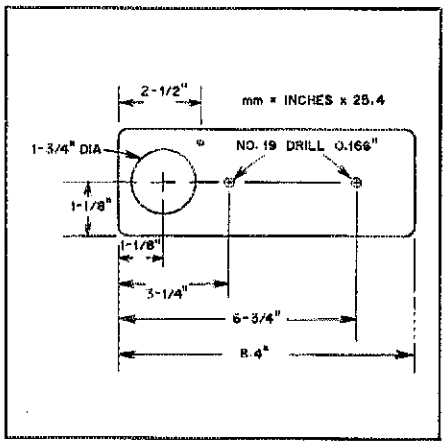


Fig. 2 — Dimensions of the plate line are given here. The line may be constructed from 1/16-inch (1.6-mm) thick copper or brass. Corners of the line should be filed to give a 3/16-inch (5-mm) radius.

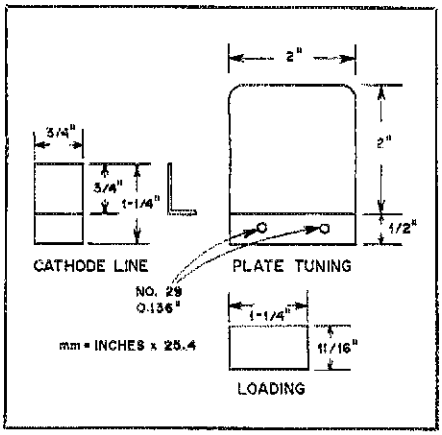


Fig. 3 — Dimensions of the cathode line and the flappers used to tune and load the plate circuit are given here. Additional information is contained in the text.

any imperfections in the surface that might allow a leakage path and subsequent capacitor breakdown. This silicone grease has dielectric properties similar to Teflon.* A no. 8 (4-mm) brass screw is used to hold the plates in place, and also acts as the high-voltage feedthrough terminal. A 3/8-inch (10-mm) diameter washer was sliced from a Teflon rod and used to center the screw in the hole. Fig. 4 gives details of the remaining metalwork.

An enclosure attached to the rear wall houses the meter dropping resistors and provides a protective hood over the high-voltage terminal. I made this cover 3 × 4 × 1.5 inches (76 × 102 × 38 mm) in size, but the dimensions are not critical. As a final note on construction, it is necessary to isolate the shaft of C1 from ground, if the rotor is connected to the shaft of the capacitor. Rf potential at this point is low, allowing the capacitor to be mounted on a small piece of plastic if an insulated unit is not available.

Cooling the Amplifier

This amplifier is thermally stable; that is, heat-induced warping of tuned-circuit components and the resulting decrease in power output is minimal. A major reason is no doubt the effective cooling system used. The cathode compartment is pressurized with a medium-sized blower. Any convenient unit capable of supplying 50 ft^3/min. (1.4m^3/min.) may be used. A piece of copper window screen is attached to the side cover with aluminum solder, to shield the air inlet. Air flows from the cathode compartment through the socket and into the plate compartment, providing some cooling of the grid area of the tube as well. A chimney is made of 0.01-inch (0.25-mm) Teflon sheet, 1.5 × 12 inches (38 × 305 mm) in size. A piece of 1-5/8-inch (41-mm) OD copper pipe was used as a form to make the chimney. The Teflon is held together with RTV (room-temperature vulcanizing) adhesive. Air in the plate compartment must now flow through the anode cooling fins to escape. The air outlet is built on a 2-1/4-inch (57-mm) square copper plate. A 1-5/8-inch (41-mm) diameter hole is made in the plate and a piece of copper window screening is soldered over it. On the side opposite the screening is soldered a 3/8-inch (9.5-mm) long piece of 1-1/2-inch (38-mm) copper pipe. This pipe has an outside diameter of 1-5/8 inches (41 mm) and should fit snugly into the hole. The Teflon chimney will be held firmly in place and no air should leak from the box without passing through the anode cooler.

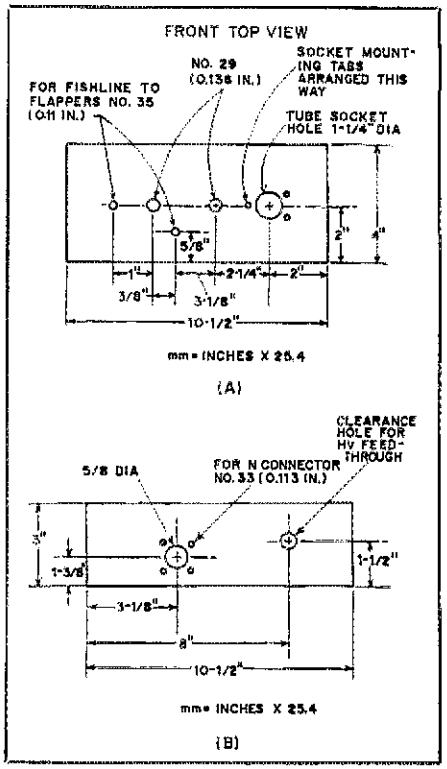


Fig. 4 — At A, dimensions of the plate compartment bottom cover. At B, dimensions of the rear panel of the amplifier.

Operation

Adjust R9 to place maximum resistance in series with the tube heater. Apply heater power and allow two minutes for the element to reach operating temperature. Now energize K2 and adjust R9 to place 5.7 volts at the socket pins. Apply plate voltage (about 2000 volts). Idling plate current should be approximately 30 mA. Apply drive and adjust its level to bring the plate current up to 150 mA. Adjust C6 (plate tuning) for maximum output. Input capacitors C1 and C2 may then be coarsely adjusted for maximum plate current. Simultaneously increase drive and adjust plate tuning and loading for maximum output until input power reaches one kilowatt or the desired level. The input circuit may be adjusted for minimum reflected power when the proper drive level is established.

An accurate wattmeter is strongly recommended for use during intitial adjustments. It is very easy to overload and underdrive an amplifier of this type, resulting in an efficiency of only 20 to 30 percent. If a wattmeter is not available, tune for maximum forward power as indicated on the line sampler. For one-kilowatt input, drive power must be at least 20 watts. Grid current will vary from 30 to 70 mA as a result of tube differences. Less grid current is a sign of insufficient drive and too much loading. Decreasing the load capacitance should result in reduced plate current and increased grid current. Slight readjustment of the plate-tuning capacitor should also be required. Table 1 contains a summary of amplifier operating conditions at the one-kilowatt level. If 40 watts or more of excitation are available, the cw plate efficiency can be boosted to about 59 percent by means of increasing the bias to 21 volts. I later installed a switch on the front panel to select another diode in place of D1 when operating cw.**

Conclusions

From a cold start, the amplifier reaches full output five seconds after drive is applied. After the first transmission, full output is obtained in one second, with no further drift noticed. This amplifier has been operated for several months without need for retuning. This amplifier represents one of the easiest, most reliable methods of becoming a big gun on uhf.

*Alternatively, an Erie 2498-001-X5U0-102M 1000-pF 4-kV feedthrough capacitor may be used. This component is available from ARCOS, P. O. Box 546, East Greenbush, NY 12061.

**[Editor's Note: When computing the input power of a grounded-grid amplifier, the rf drive power must be added to the dc plate power because some of the drive appears at the output. With 42 watts of drive, the unit can be loaded to a plate current of 496 mA for a power input of 1 kW at 1950 volts. The actual plate voltage is less than the value indicated by the meter by an amount equal to the drop across the cathode-biasing diode. The actual PEP input under the conditions listed in Table 1 is 1026 watts, which is suitable for ssb service.]

Table 1

Operating Conditions, 432-MHz Linear Amplifier

Plate voltage, key down:	1950 volts
Bias:	8.2 volts
Heater voltage:	5.7 volts
Plate current, key up:	30 mA
Plate current, key down:	515 mA
Power input:	1000 watts
Power output:	530 watts
Efficiency:	53 percent
Grid current	40 mA
Drive power:	26 watts
Input SWR:	1.2:1
Power gain:	13.1 dB

Notes

[1]McMullen, "The Line Sampler," *QST*, April 1972.
[2]Sutherland, "High Power Linear Amplifier For 220 MHz," *Ham Radio*, December 1971.