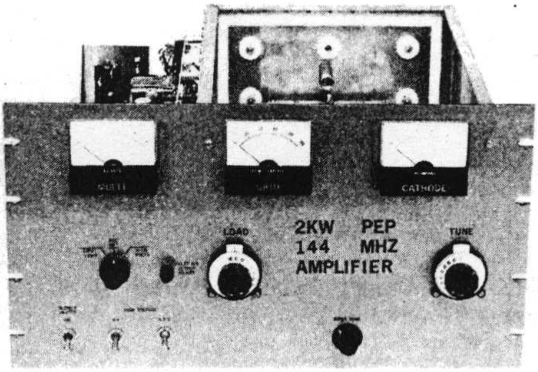
A 2-KW PEP Amplifier for 144 MHz



Part I

BY EDWARD L. MEADE, JR.,* K1AGB

ATTAINING a 2-kW PEP input level at 144 MHz is possible with a variety of tube types presently available. During the "slide-rule" design phase of the amplifier to be described, consideration was given to parallel operation of grid-driven tubes such as the 4CX250 series, or cathode-driven tubes like the more recently introduced 8874 series. Advantages or disadvantages notwithstanding, multiple-tube operation in a 2-kW PEP, 144-MHz power amplifier had the appearance of a "stop-gap" measure, rather than a state-of-the-art solution. The idea of multiple tube operation was set aside in favor of using a single tube.

Large external-anode triodes, in a cathode-driven configuration, offer outstanding reliability, stability and ease in obtaining high power at 144 MHz. The selection is somewhat limited and they are not inexpensive. Performance, on the other hand, is nothing short of spectacular. Data on the recently introduced 3CX1500A7/8877, a high-mu, external-anode power triode, appeared very promising. A reasonable heater requirement (5 V at 10 A) and an inexpensive socket and chimney combination made the tube even more attractive.

Several designs for 144-MHz amplifiers with large external-anode tubes have been presented to the amateur fraternity. Unfortunately, many of these employ tubes using expensive sockets which require modification to achieve amplifier stability – even when the amplifier is cathode driven. All of these amplifiers have one thing in common – a lack of true mechanical and operational simplicity.

The techniques employed in the design and construction of the cathode-driven 3CX1500A7/8877 amplifier described in this article have removed many of the mechanical impositions of other designs. Those remaining should be well within the capability of the vhf-er seriously interested in constructing a similar unit.

Plate-Tank Design

The primary objective of plate-tank design in this amplifier was mechanical simplicity in conjunction with satisfactory electrical performance. Typical "coil and capacitor" circuits are impractical at the frequency and power level involved. Cylindrical-coaxial tank circuits, although ideal, suffer from a lack of form flexibility and are difficult for the home builder to construct. Application of air strip-line techniques seemed to hold the most promise in achievement of the design objectives.

Air dielectric strip-line circuits have the advantages of lower attenuation, higher Q, smaller size, lower cost and greater ease of fabrication than coaxial circuits. The power handling capability of a strip-line tank is comparable to a coaxial tank with the same conductor separation. Strip transmission lines, in general, are designed to operate in the same electro-magnetic modes as round coaxial cable. Operation of strip lines in the "dominant mode" requires that two ground planes be employed, above and below the center conductor. The spacing between these planes must be less than one-half wavelength, if higher-order modes are not to be supported.

Design of an air strip-line plate-tank circuit at 144 MHz is somewhat straightforward. Complementing the traditional rules for the design of plate circuits employing resonant-line sections are approximations, formulas, and form factors governing the relationships between the physical and electrical parameters of air-dielectric strip lines. Electrically, the air-dielectric strip line is a section of transmission line, similar to coaxial cable, possessing a characteristic impedance (Z_o) and electrical length in degrees. In this amplifier we are dealing with a capacitively loaded quarter-wave line (less than 90 degrees long), short circuited at the receiving or "cold" end. Capacitive loading is the

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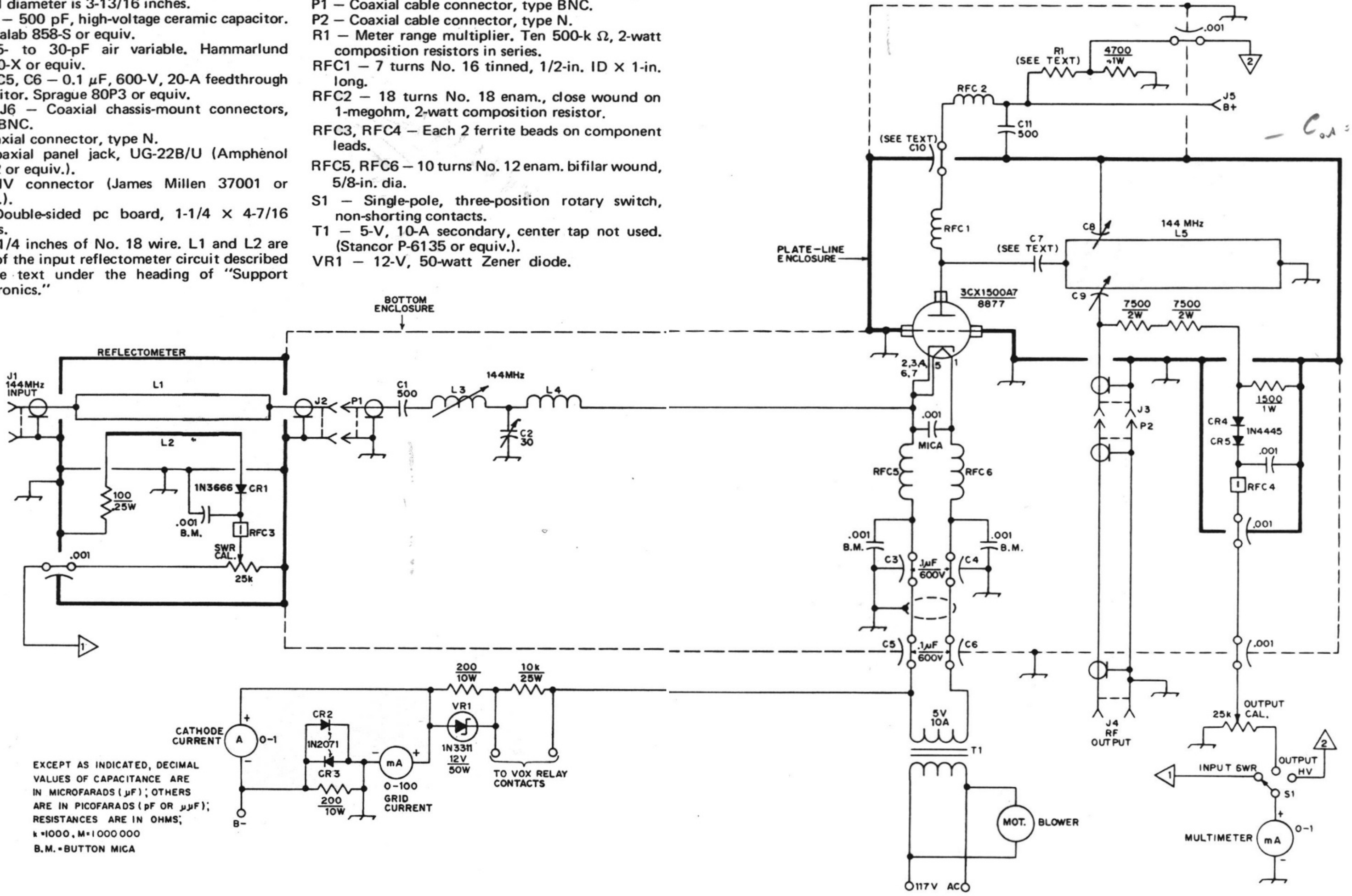

Fig. 1 — Schematic diagram of the amplifier. Included is information for the input reflectometer used as an aid to tuning the cathode circuit for low SWR. C7, C8, and C9 are fabricated as described in the text and Fig. 2.

B1 — Blower. Fasco 50752-IN or Dayton 2C610. Wheel diameter is 3-13/16 inches.
C1, C11 — 500 pF, high-voltage ceramic capacitor. Centralab 858-S or equiv.
C2 — 5- to 30-pF air variable. Hammarlund HF-30-X or equiv.
C3, C4, C5, C6 — 0.1 µF, 600-V, 20-A feedthrough capacitor. Sprague 80P3 or equiv.
J1, J2, J6 — Coaxial chassis-mount connectors, type BNC.
J3 — Coaxial connector, type N.
J4 — Coaxial panel jack, UG-22B/U (Amphenol 82-62 or equiv.).
J5 — HV connector (James Millen 37001 or equiv.).
L1 — Double-sided pc board, 1-1/4 × 4-7/16 inches.
L2 — 4-1/4 inches of No. 18 wire. L1 and L2 are part of the input reflectometer circuit described in the text under the heading of "Support Electronics."
L3 — 6 turns No. 18 enam., 5/8-in. long on 3/8-in. dia form (white slug).
L4 — 3 turns No. 14 enam., 5/8-in. long × 9/16-in. ID. Lead length to L3 is 5/8-in. Lead length to cathode bus is 3/4-in.
L5 — Air-dielectric strip line. See text and Fig. 2.
P1 — Coaxial cable connector, type BNC.
P2 — Coaxial cable connector, type N.
R1 — Meter range multiplier. Ten 500-k Ω, 2-watt composition resistors in series.
RFC1 — 7 turns No. 16 tinned, 1/2-in. ID × 1-in. long.
RFC2 — 18 turns No. 18 enam., close wound on 1-megohm, 2-watt composition resistor.
RFC3, RFC4 — Each 2 ferrite beads on component leads.
RFC5, RFC6 — 10 turns No. 12 enam. bifilar wound, 5/8-in. dia.
S1 — Single-pole, three-position rotary switch, non-shorting contacts.
T1 — 5-V, 10-A secondary, center tap not used. (Stancor P-6135 or equiv.).
VR1 — 12-V, 50-watt Zener diode.

— C_{out} = 6.2 p

combined effect of tuning, loading, stray, and tube output capacitance at the sending or "hot" end of the line. The combined value of these capacitances, 26 pF, represents a reactance (X_c) of 42.2 ohms at 145 MHz, which was chosen as the design center frequency for the amplifier.

There are two common types of air strip-line configuration. First is that of a center conductor with two equidistantly spaced ground planes. In this configuration, equal amounts of current flow on both sides of the center conductor and on both ground planes. The second form of air-dielectric strip line is that using a conductor of essentially zero thickness above a single ground plane of infinite width. Most of the current in this type of line is concentrated between the conductor and the ground plane. Formulas and graphs are available to calculate Z_o for both configurations.[1]

Several electro-mechanical parameters in this amplifier prohibit the use of equidistant ground planes, so the formula for a single reflecting ground plane was used in initial calculations. For obvious reasons, a cover is desirable on the amplifier. Thus we are faced with a compromise situation – a strip line with two ground planes of unequal spacing. To minimize the effect of this cover on the line, it was decided to limit the amount of current flowing on the top of the plate-tank strip line (and hence in the top cover) to no more than 25-percent of the total current in the tank. This was done by placing the top cover 4-1/2 inches above the strip line and fixing line height above the chassis ground plane at 1-1/2 inches. The total spacing of six inches between the top ground plane (the enclosure top cover) and the bottom ground plane (chassis base) is much less than one-half wavelength at 145 MHz, so the line should operate in its dominant mode. To be on the safe side, a "single-ground-plane" line width was calculated for a line Z_o of about 104 ohms, based upon the line height of 1-1/2 inches above the chassis. The 104-ohm value will be the highest possible impedance level that can be obtained, as the formula used for impedance calculations assumes a line of essentially zero thickness above a reflecting ground plane of infinite width. Line thickness and the addition of the second reflecting ground plane (enclosure top cover) will lower the line impedance to the 40- or 50-ohm range. The resultant line width (5-7/16 inches) was sufficient to provide circumferential contact around the tube anode cooler with room to spare. This wide line permits the distrubution of rf current over a large surface, resulting in a low current density and small line loss. Silver plating the line enhances the smoothness of the rf-current distribution and reduces surface resistance. Estimated line lengths were generated, based on several different line Z_o and the fixed value of X_c in operation in the tank. They were put on a graph to assist in the determination of an effective line Z_o in the operating amplifier.

Theoretically, when a tube is operated in a cylindrical-coaxial tank, the anode should be truly "equipotential" for rf and the electrical length of the tank center conductor will include the length of the anode cooler, up to the ceramic insulation. The air strip line presents an asymmetric load to the tube, and therefore it does not seem reasonable to consider the physical end of the anode cooler, near the grid ring, as the electrical terminating point for the strip line. The mechanical end of the line extends beyond the center of the tube by 2-3/4 inches This represents about 12 degrees of electrical length and is a significant portion of the total line length. It would seem more reasonable to assume that the mechanical end of the air-dielectric strip line is the effective electrical line-termination point, to be used in the calculation of effective line Z_o in operation in the amplifier. The importance of a high effective line Z_o is not as great with lines of one-quarter wavelength as it is with lines of multiple quarter wavelengths. Ideally, the ratio Z_o/X_c should be on the order of 1.5 to 2 for quarter-wavelength lines. This is a measure of frequency dependence, and wide deviations from these values are manifest by very wide or very narrow lines, inordinate values of tank Q and poor efficiency. In lines of multiple quarter wavelengths, the effects of frequency dependence become more noticeable.

Localized heating because of the possibility of asymmetric rf current flow on the tube seals and control grid does not appear to be a problem. This

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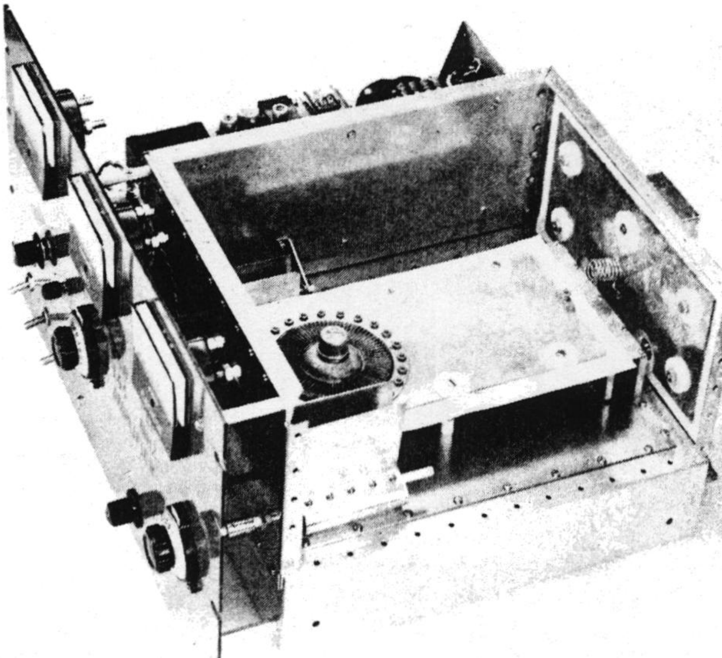
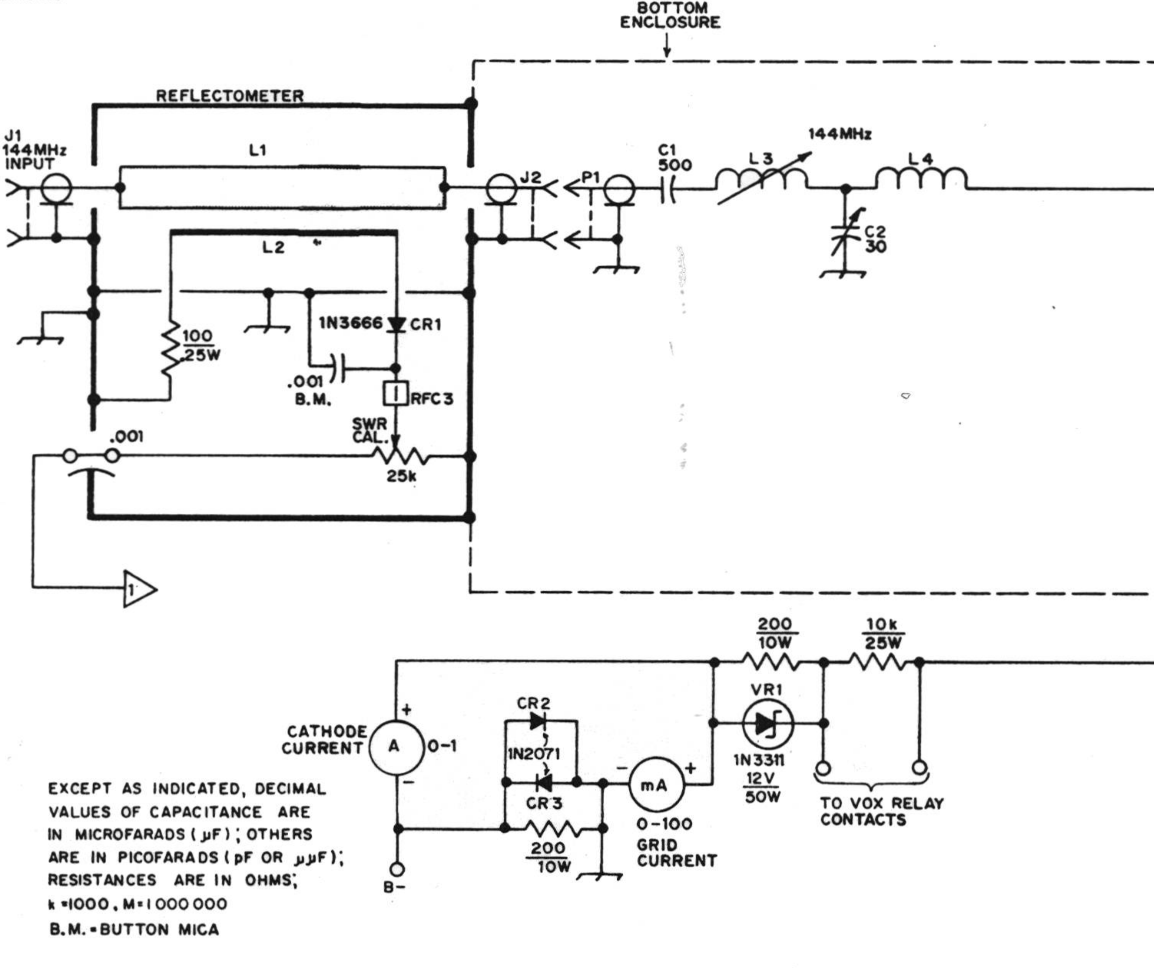
[1] This and all subsequent references are given at the end of this article.



Here the tube and plate line is in place, with the top and side of the compartment removed for clarity. The plate-tuning vane is at bottom center. A bracket is attached to the side panel to support the rear of the Teflon rod supporting the tuning vane. The coil at the opposite end of the plate line is RFC1, connected between the high-voltage-bypass plate and the top section of the plate-line sandwich. Items outside the tube enclosure include the filament transformer, blower motor, relays, and a power supply to operate a VOX-controlled relay system.

subject was discussed with colleagues during the initial design phase and the general consensus was that, even though the tank was not cylindrically coaxial in structure, the effect of tank asymmetry should be minimal, as the current return path is different by much less than one-eighth wavelength circumferentially from one side of the tube to the other. The effects of an asymmetric tube tank relationship will probably become more noticeable with this tube if the frequency of operation is increased appreciably. The use of tubes of smaller physical dimensions, such as the 4CX250 or 8874 series, in similar circuits at higher frequencies, is an effective method, as demonstrated by Knadle,[2] of circumventing this current flow/return path problem.

In an effort to determine the amount of heat transferred from the tube anode cooler to the tank circuit, a direct tank-temperature measurement was made at the tube end of the line. The amplifier was operated with zero bias and no drive, at about 850 watts anode dissipation for a period of 3 minutes. At the end of that period, the tank circuit temperature had stabilized at +65°C. At 2-kW PEP



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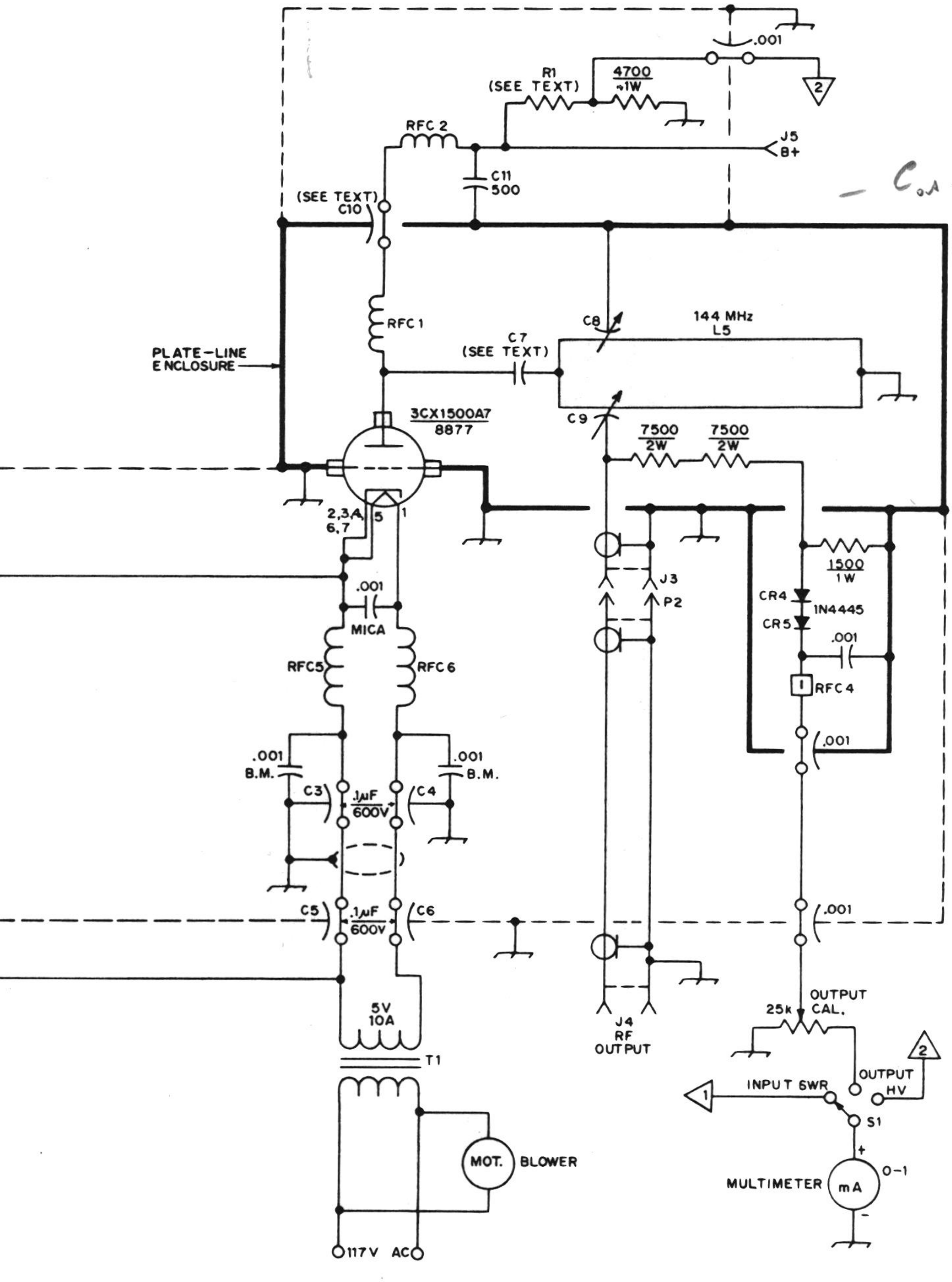
S1 — Single-pole, three-position rotary switch, non-shorting contacts.
T1 — 5-V, 10-A secondary, center tap not used. (Stancor P-6135 or equiv.).
VR1 — 12-V, 50-watt Zener diode.

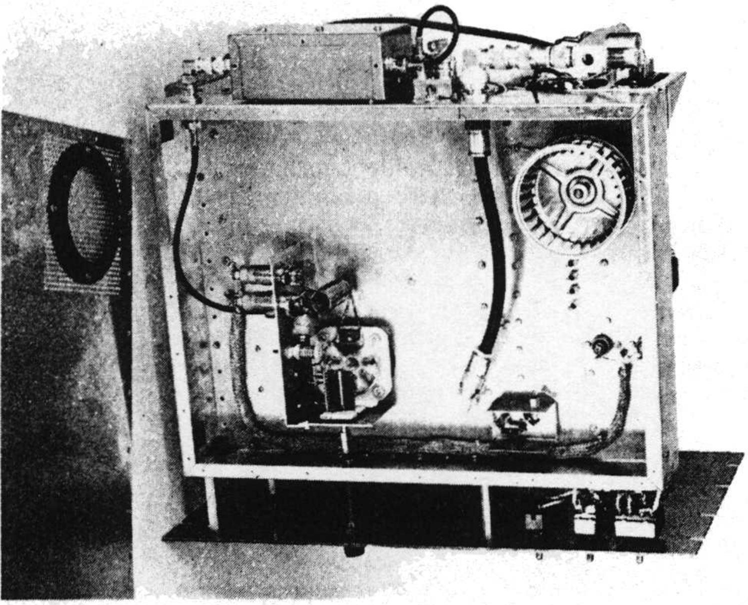
EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF); OTHERS ARE IN PICOFARADS (pF OR μμF); RESISTANCES ARE IN OHMS; k = 1000, M = 1 000 000
B.M. = BUTTON MICA

input, taking into account voice duty factor, this would represent a tank-temperature rise of approximately 15°C above typical blower air-input temperature. This small thermal rise should have negligible effect on the mechanical or electrical operating parameters of the tank, if rf heating is kept to a minimum.

The plate tank operates with a loaded *Q* on the order of 40 at 2-kW PEP and 80 at 1-kW. Typical loaded *Q* values of 10 to 15 are used in hf amplifiers. In comparison, we are dealing with a relatively high loaded *Q*, so losses in the strip-line tank-circuit components must be kept very low. To this end, small diameter Teflon rods are used as mechanical drive for the tuning capacitor and for physical support as well as mechanical drive for the output-coupling capacitor. The tuning vane or flapper capacitor is solidly grounded, through a wide flexible strap of negligible inductance, directly to the chassis in close proximity to the grid-return point. A flexible-strap arrangement, similar to that of the tuning capacitor, is used to connect the output coupling capacitor to the center pin of a type N coaxial connector mounted in the chassis base. Ceramic (or Teflon) pillars, used to support the air strip line, are located under the middle set of plate-line dc isolation bushings. This places these pillars well out of the intense rf field associated with the tube, or high-impedance end of the line. In operation, plate tuning and loading is quite smooth and stable, so a high-loaded *Q* is apparently not bothersome in this respect.



— $C_{oA} = 6.2$ pF



The placement of input-circuit components and supporting bracket may be seen in this bottom view. When the bottom cover is in place, the screened air inlet allows the blower to pull air in, pressurizing the entire under-chassis area. The Minibox on the rear apron is a housing for the input reflectometer circuit.

In this amplifier, output coupling is accomplished by the capacitive probe method. As pointed out by Knadle[2] "Major advantages of capacitive probe coupling are loading linearity and elimination of moving contact surfaces."

Capacitive-probe coupling is a form of "reactive transformation matching" whereby the feed-line (load) impedance is transformed to the tube resonant-load impedance (R_o) of 1800 ohms (at the 2-kW level) by means of a series reactance (a capacitor in this case). At the 1-kW level, R_o is approximately twice that at the 2-kW PEP level. Therefore, the series coupling capacitor should be variable and of sufficient range to cover both power levels. Formulas to calculate the transformation values have been presented in *QST*.[3]

The electro-mechanical method of probe coupling used in this amplifier is easy to assemble and provides good electrical performance. Also, it has no moving-contact surfaces and enables placement of the output coupling, or loading, control on the front panel of the amplifier for ease in adjustment.

Metric Equivalent of Some Dimensions Used in the Text

1/32	.78 mm	2-5/8	6.66 cm
1/16	1.58 mm	2-3/4	6.98 cm
3/16	4.76 mm	3-9/16	9.04 cm
1/4	6.4 mm	4-1/4	10.79 cm
3/8	9.52 mm	4-3/8	11.11 cm
13/32	10.31 mm	4-1/2	11.43 cm
7/16	11.11 mm	4-5/8	11.74 cm
1/2	12.7 mm	5-7/16	13.81 cm
3/4	19.05 mm	6	15.24 cm
15/16	23.81 mm	9-1/8	23.17 cm
1-1/16	2.69 cm	10-1/2	26.67 cm
1-1/2	3.81 cm	11-1/4	28.57 cm
2-1/4	5.71 cm	13	33.02 cm

Input Circuit Design

The input matching circuit consists of a T network which matches the 50-ohm driving source to the complex input impedance of the tube (about 54 ohms at the 2-kW level, in parallel with 26 pF). One might be tempted to drive the amplifier with 50-ohm line through a coupling capacitor, directly into the tube cathode. Doing so neglects the shunting effect of the 44 ohm parallel capacitive reactance represented by the 26 pF. Also, the 54-ohm "real" component of the tube input impedance is a function of cathode current and is realized only when the amplifier is operating at the 2-kW PEP level. Thus, a widely varying load would be presented to the exciter as the amplifier goes from idle to full power. A properly designed matching network will serve as a "storage tank" for drive power, because of the inductive "flywheel" effect, and compensate for the 26 pF as well. In presenting the driving source with a relatively constant load, not necessarily a purely resistive 50-ohm load, somewhat less drive power will be required. Intermodulation distortion will be reduced to some degree if an input matching circuit with an operating Q of two or greater is used. A low-Q matching circuit offers the advantage of reasonable bandwidth and component values which do not make the network appear very sharp in tuning. The nominal circuit values employed were computer derived,[4] based on the tube input characteristics mentioned above.

The second part of this article will appear in a subsequent issue. Construction of the input circuit and the plate-line assembly will be explained, as well as some notes on the operation and performance of the amplifier. QST

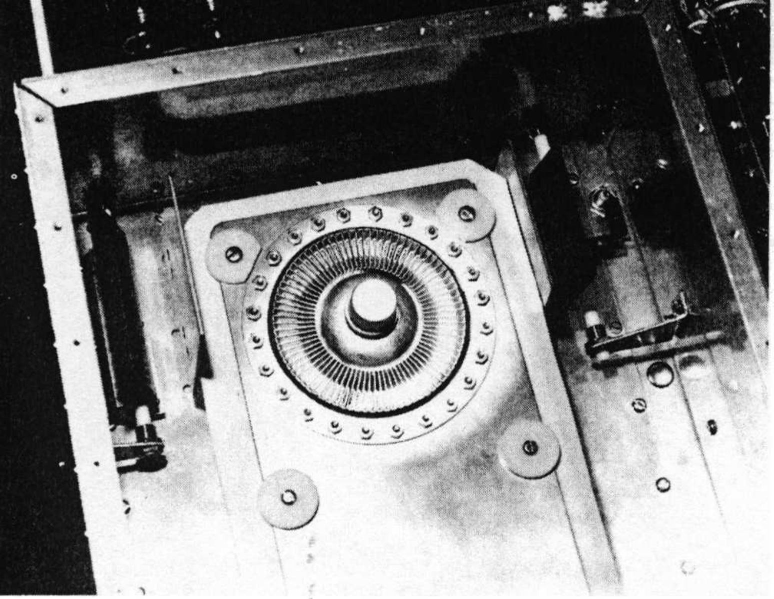
References

1) *Reference Data for Radio Engineers,* ITT, 5th Edition, Chapter 22, p. 26-27.

2) Knadle, "A Strip-Line Kilowatt Amplifier for 432 MHz," *QST*, in two parts; Part I, April, 1972, p. 49; Part II, May, 1972, p. 59.

3) Belcher, "RF Matching Techniques, Design and Example," *QST*, October, 1972.

4) Davis, "Matching Network Designs with Computer Solutions," Motorola Semiconductor Products, Inc. Application Note AN-267.



A 2-KW Amplifier for 144 MHz

Part II

BY EDWARD L. MEADE, JR.,* K1AGB

Plate Tank Assembly

THE STRIP-LINE plate tank is fabricated from two pieces of 1/16-inch thick brass sheet, with dimensions and hole-center positions as shown in Fig. 2. Once the sheets have been cut to size, the center points of all holes in both sheets are marked and checked for positioning accuracy. A small pilot hole (No. 28 bit to pass a 6-32 bolt) is drilled in the center of the large tube clearance holes on both sheets. Then both sheets are aligned as they would be for final assembly, and are bolted together through the two pilot holes and clamped together at the shorted end of the line. The dc-isolation bushing-hole centers are drilled through both sheets, using a small pilot bit (No. 55 or so). Doing this provides reasonable assurance of concentricity of common holes in the two sections of the plate line when the time comes to assemble the tank circuit. Burrs are removed from all holes before continuing, to prevent scratching or gouging the lines.

Holes for mounting the capacitor stator plates and the line-shorting bar are now cut in the bottom sheet, in accordance with Fig. 2B. At this point, consideration should be given to mounting-position requirements of the line on the chassis top. If skewing of the tube in the socket and attendant tube-seating difficulty is to be avoided, careful attention must be given to assuring concentricity of the tube-clearance hole in the plate line and the socket-mounting hole in the chassis. The tube socket is centered in the plate compartment, 3-9/16-inch back from the front edge of the chassis. The bottom half of the plate line is placed flat on the chassis, with the tube-socket hole and the plate-line tube-clearance holes aligned. Using the line as a template, the position of the hole centers for the supporting insulators and the line-shorting-bar drilling points can be marked on the chassis.

The large tube-clearance holes are cut in each plate-line sheet independently, as they are of different diameters. A circle or fly cutter will work, but better accuracy will be obtained if a series of small, very closely spaced, holes are drilled inside the desired hole circumference and the center removed by cutting away the small bits of brass holding the center to the edges. A medium-grade, half-round file will finish off the hole. This may sound like a lot of work, but it is far easier than trying to control a circle or fly cutter in a hand-held drill.

Holes for the dc isolation bushings are now cut in the top sheet. These holes can be moved somewhat closer to the center of the line if desired. The diameter of these holes will be dependent on what the builder uses for bushings. The author had some surplus Teflon bushings on hand, so they were used. Suitable substitutes are available in the form of one half of a ceramic feedthrough insulator. Shape and size of the insulator is not overly important, but the clearance-hole diameter should be on the order of 1/2 inch or greater. The four outer holes in the bottom sheet should be drilled and tapped to fit the screws available with the insulating bushings. Similarly, the fit of these screws to the ceramic pillar insulators should be checked.

High voltage is fed to the upper sheet, near the shorted end of the line, through RFC1. A countersunk No. 4-40 flathead bolt and a short piece of tapped 1/4-inch brass bar stock facilitate this connection. The common dc and rf connection to the tube anode is made via this top sheet. To eliminate some expensive finger stock and the difficulty of soldering it into a large hole, I decided to try a little different mechanical method of connecting this sheet to the anode cooler. This connection is accomplished by twenty-four strips of thin (.010-inch) springy brass or beryllium copper, about 13/32-inch wide and 3/4-inch long. A No. 33 hole is drilled in each "finger" about 3/16-inch from one end, to match the holes in the upper plate line around the circumference of the tube-clearance hole. The fingers are bent in the middle and about 3/8-inch of each strip protrudes

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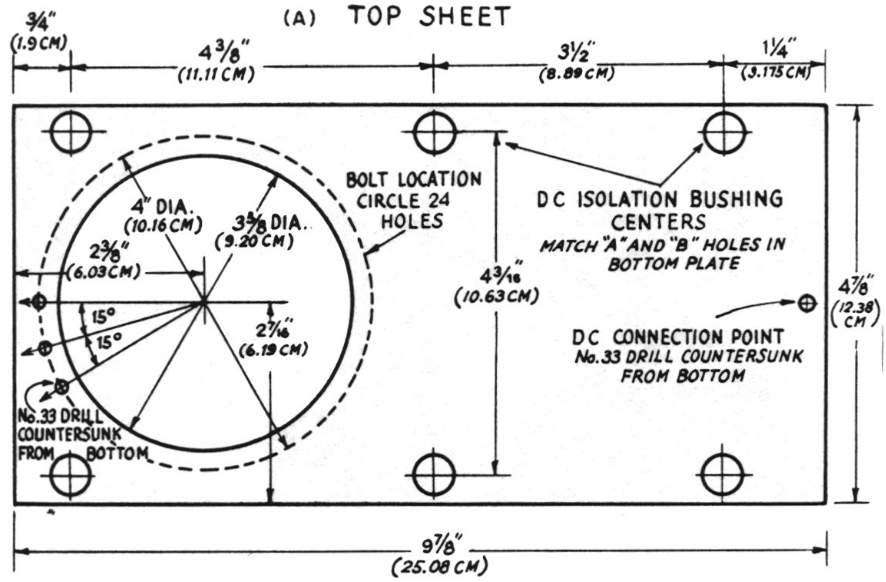


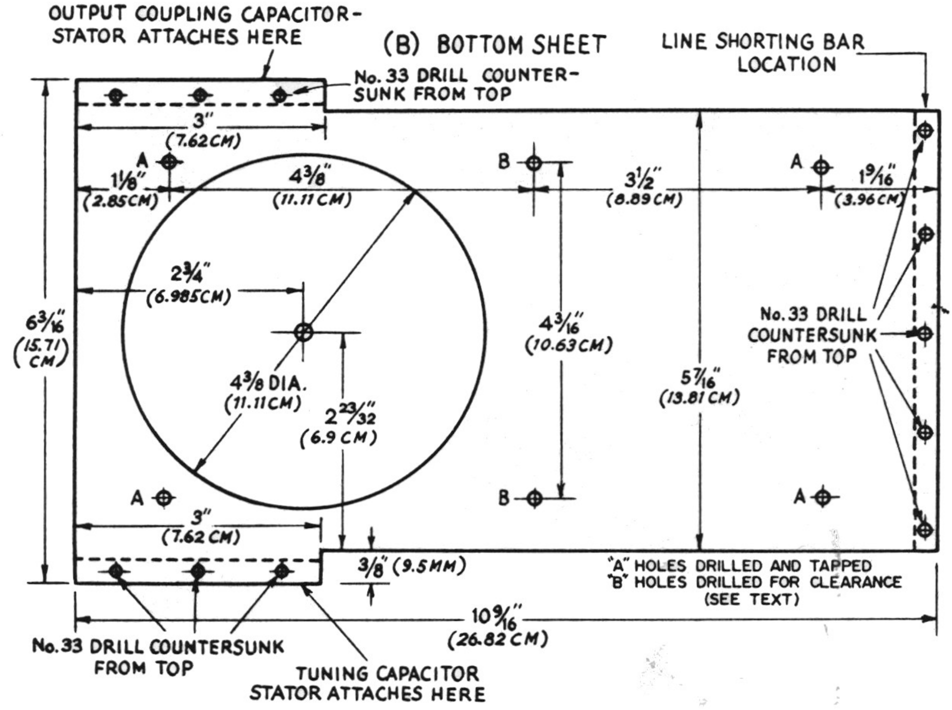
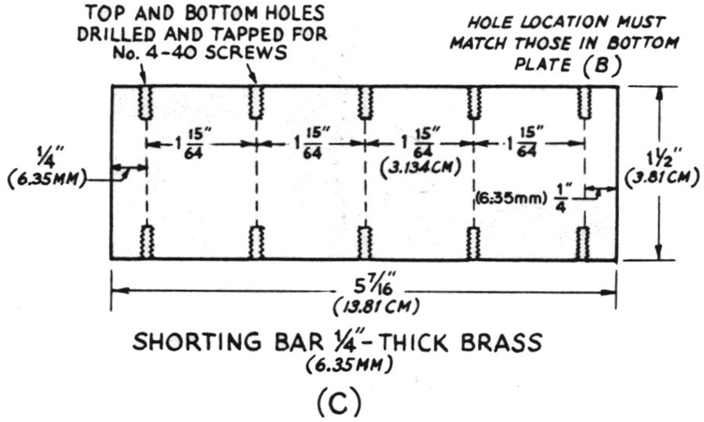


Fig. 2 — Dimensions and layout information for the plate line. The two brass plates and a Teflon sheet form a sandwich with the plate nearest the chassis being at dc ground potential. The top plate carries high voltage and is connected to the tube anode. The shorting bar (C) is permanently attached between the bottom plate and the chassis, replacing the sliding short that is visible in the photographs.



through the tube-clearance hole in the upper sheet, downward toward the chassis. The 4-3/8-inch diameter hole in the lower sheet of the plate line assembly provides ample clearance for the tube and the anode contact fingers. No. 4-40 × 1/4-inch flathead brass bolts and nuts attach these fingers to the top of the upper sheet. A copper ring was used to cover the junction of these fingers with the upper sheet, but small brass washers will serve as well.

Four of the six holes previously drilled in the lower sheet – those concentric with the holes for the upper sheet dc isolation bushings – are tapped for ease of line assembly. The two holes near the middle of the plate line are not tapped, so that screws from the top can be run through the dc isolation bushings and into the 1-1/2-inch ceramic line supports.

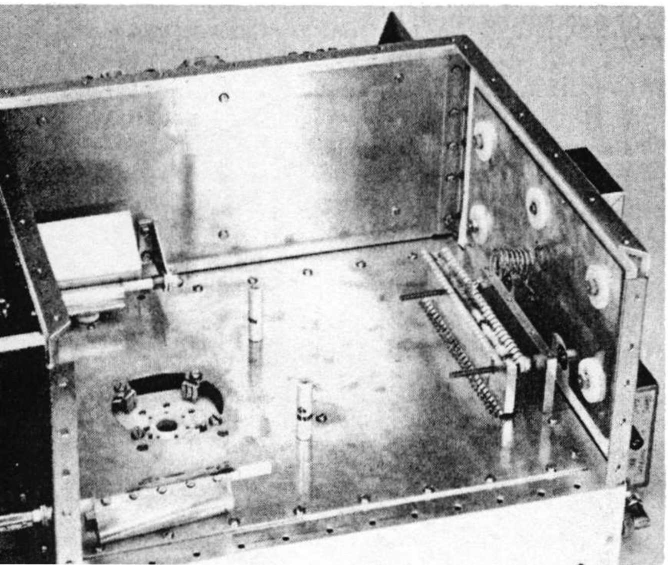
The stators of both the tuning- and output-coupling capacitors are attached to the lower sheet, at the tube end of the line, with brass bar stock and countersunk flathead 4-40 × 1/4-inch brass screws. Using the bar stock and countersunk screws eliminates the need for silver soldering these stators to the tank circuit. Variable capacitor dimensions and assembly information are given in Fig. 3 and 4. The movable vanes of the tuning (C8) and output coupling (C9) capacitors are made of 1/32-inch thick brass sheet, formed as specified. The flexible portion of both capacitors is made of .005-inch thick brass shim stock. The grounded end of the tuning capacitor (C8) movable vane is fastened to the chassis by a length of square brass bar stock pinned to the chassis with No. 4-40 screws entering the plate-tank area from the bottom of the chassis. The junction between the shim stock and the capacitor vanes is soft soldered to provide solid rf contact. Both movable vanes are secured to 1/4-inch diameter Teflon-rod drive shafts with No. 4-40 binder-head screws. A small hole is cut in the shim stock end of the output-coupling capacitor movable vane to accept the centerpin of the type N output connector. A Teflon bushing, made of two or three small pieces of scrap Teflon sheet placed on the center pin of the output connector between the shim-stock portion of the output capacitor and the chassis, serves as insulation "insurance" for the shim stock in the unlikely event the solder at this joint should soften.

Small brackets are attached inside the plate-circuit enclosure, on the right and left hand walls, to serve as bearing points for the Teflon drive shafts of both capacitors. These shafts are about 6-inches long, and go through bushings in the front wall of the plate-tank enclosure. They are directly coupled to planetary-drive knobs. Planetary drives are necessary in this application to provide positioning tension for the shafts as well as a smooth tuning ratio.

Because the entire lower plate-line sheet, including the stator of both capacitors, is at dc ground there is no chance of damaging the power supply or having a high dc potential appear across the output connector if one of the movable vanes touches a stator while tuning. Of course, the travel of the movable vanes should be restricted to prevent rf breakdown. This is accomplished by the end stop in the planetary-drive knob.

The insulation between the lower and upper sheets of the plate line is a piece of 1/32-inch thick Teflon sheet. This forms the dielectric of a sandwich capacitor with a value of about 450 pF. It has been tested to 5500 V dc, but will go much higher. The large hole in this Teflon sheet was cut while using the hole in the upper brass sheet as a template. The smaller holes were marked, using the same template, and punched with a small diameter paper-hole punch. Note that the holes in the Teflon sheet for the dc isolation-bushing bolts are small – just large enough to pass the bolts used to hold the bushings in place. The insulation overlaps the "hot" side of the plate line by at least 3/8-inch on all edges.

Prior to assembly, all plate-tank components, including the movable capacitor vanes, can be silver plated, using Cool Amp silver salts.[5] Brass accepts plating quite readily. Before plating, inspect the plate-line sheets for burrs or metal chips. All edges should be smoothed and the countersunk flathead screws used in line assembly should be free of burrs and sharp edges. A little fine grade sand paper will do the job nicely. Inspect the Teflon sheet for metal chips. If there are any metal chips in this sheet, disaster will surely result. The same procedure applies to the high-voltage decoupling capac-



The plate compartment with the tube and plate line removed. Note that the grid clips are on the socket side of the chassis, attached to tabs formed for that purpose when cutting the hole. The output-coupling capacitor (C9) movable vane may be seen to the upper left. The sliding short (right, with finger stock) should be replaced with a fixed short as described in the text. The insulating washers on the rear wall of the enclosure are to secure the "hot" plate of the high-voltage bypass capacitor.

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[5] This and all subsequent references appear later in this section.

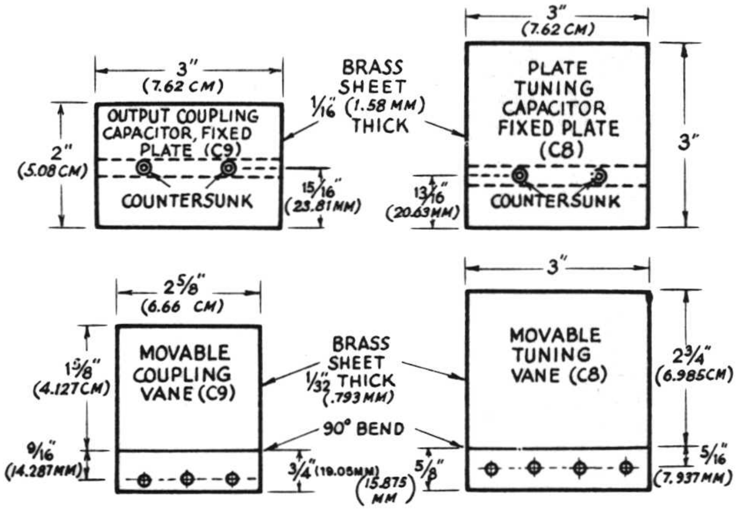


Fig. 3 – The fixed and movable portions of C8 and C9 are fabricated from brass sheet to the sizes indicated. Parts should be free of burrs and corners should be slightly rounded.

itor on the rear wall of the plate tank enclosure. All these components should be cleaned thoroughly with isopropyl or rubbing alcohol and reinspected before final assembly.

The sliding short, although still installed in this amplifier, is not recommended for duplication. I have had no cause to use it since setting up the amplifier for high power operation. It represents a "moving contact surface," ultimately subject to galvanic action. The line dimensions given in Fig. 2 do not include the distance between the sliding and fixed shorts. The line is 15/16-inch shorter than is apparent in the photographs.

For tube cooling, the Eimac SK-2216 chimney is recommended, as it is made of low-loss Teflon. The SK-2216 is held in place with four toe clamps which are supplied with the chimney. The plate-line to anode-cooler contact fingers may protrude a bit too low (1/32-inch or so for the SK-2216). However, a sharp knife will pare down the soft Teflon chimney with ease if height problems develop. Drilling points for the chimney toe clamps are best marked with the chimney in place around the tube seated in the socket. Holding the chimney in place with the toe clamps makes tube removal and subsequent reinsertion in the socket much easier than if the chimney were "floating."

Input Circuit Construction

The input circuit, by definition, includes the tube socket assembly. An E. F. Johnson 122-247-202 ceramic wafer socket is centered 3-9/16 inch from the front edge of the chasis, on a line dividing the plate compartment in half. The position of the plate line in the upper compartment is dependent on accurate location of the socket, so reasonable care should be exercised in socket positioning. Using the socket itself as a template, the location of the four mounting holes can be marked. These holes can be scribed on the chassis through the socket holes when any flat side of the socket is on a line parallel with the front of the chassis. With the center located and the mounting holes marked, two concentric circles are drawn on the chassis, using the socket center point as a reference. The smaller circle, 2-1/4 inches in diameter, will fit entirely within the confines of the already scribed mounting holes. A second circle, 2-5/8 inches in diameter, is drawn around the first. This circle will intersect the socket mounting holes. Four 7/16-inch wide "tabs," encompassing each of the socket mounting holes, are then drawn between the inner and outer circle. When the metal is finally cut, the result will be a hole, 2-5/8 inches in diameter, with four tabs protruding into the center, toward the tube stem. These tabs serve as mounting points for the socket and the grid-grounding clips[6] When the hole is finished, the socket, with grid-grounding clips and the bracket for C2, can be mounted 7/16-inch below the chassis plate on metal spacers trimmed to accommodate this depth. Socket pin No. 4 (large pin) is positioned toward the front of the chassis. The spacers on the front mounting bolts should be shorter than those on the rear if the mounting feet of the bracket for C2 are attached to these points. The vertical portion of this bracket is spaced 1/4-inch from the tube socket, toward the front edge of the chassis. A 1-1/4-inch wide 1/2-inch high section is removed from this bracket, near the chassis, to provide proper air flow.

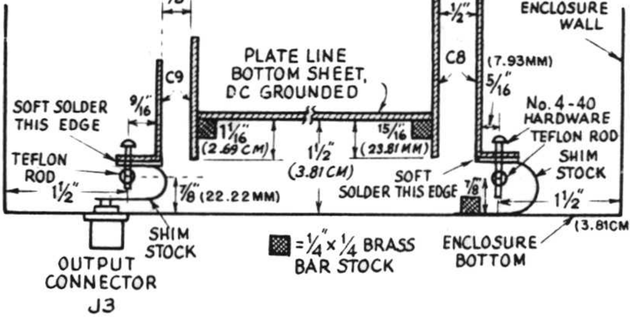


Fig. 4 – Relative positions and assembly information for the output coupling capacitor (C9) and the plate tuning (C8). Note that the shim stock is soldered to the movable vanes, and that the assembly is fastened to the Teflon shafts with No. 4 screws. The brass bar stock helps to provide a good ground connection between the shim stock of C8 and the chassis.

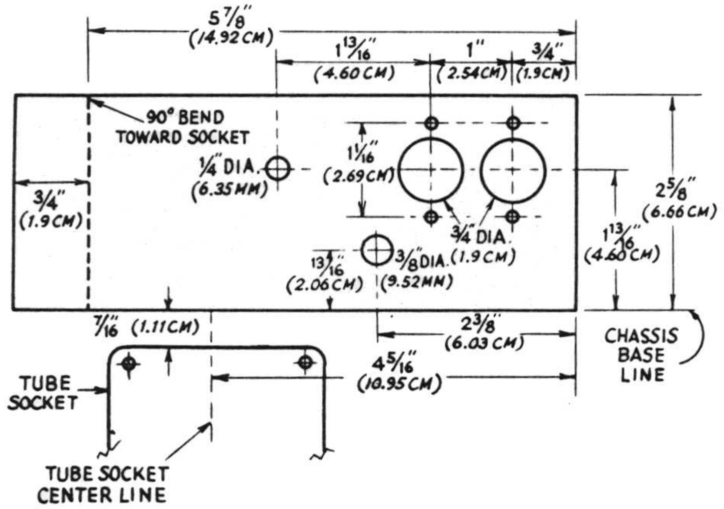


Fig. 5 – A sheet-aluminum bracket is used to mount components for the input circuit. The position relative to the tube socket is shown. The bracket may be fastened to the chassis by pieces of angle stock, or a lip may be formed along the bottom if the material is cut slightly larger in height.

The grid-grounding clips are mounted between the spacers and the bottom side of the chassis. Although placing the clips on the plate tank side of the chassis is easier and provides proper mechanical contact with the grid ring, an undesirable coupling loop is created between input and output. This causes circuit instability which cannot be cured except by moving the clips to the socket side of the chassis. One-inch long, 8-32 bolts are used to fasten the socket and associated components to the chassis. Tapped spacers may be used to hold the bolts and grid-grounding clips captive. Do not use excessive torque on the nuts, or damage to the socket may result.

Once the socket is mounted, pins 2 through 7 are connected together. with pin 4 forward, the free heater pin (No. 1) and one end of the cathode/heater bus (pin No. 7) will be available on the side of the socket facing the rear of the chassis. Holes in the tabs on pins 1 and 7 are enlarged slightly to accept the heater choke leads. A 1000-pF silver-mica capacitor is soldered between pins 1 and 7 with short leads. It is wise at this time to check the tube for proper seating and for even ground-clip contact with the grid ring.

All of the input circuit components except C2 are assembled on a separate sub-panel attached to the chassis near the tube socket. The button-mica bypass capacitors and high-current feedthrough capacitors supporting the cold end of the heater chokes are visible in the left corner of the photograph. Number ten solder lugs extend from the feedthrough capacitors to the button-mica capacitors. No. 3-48 × 1/4-inch bolts passing through one flange-mounting hole of each high current feedthrough capacitor secure the button mica capacitors to the panel. A 6-32 bolt secures the other side of the flange. The button mica capacitors are oriented to provide a very short lead length when solder connections are made to the lugs and choke leads. Insulated No. 12 wire, run through a length of sheild braid, is used to connect the outer end of the feedthrough capacitors to the heater transformer. The shield is solder-tacked to ground at several points. A second pair of high-current feedthrough capacitors is mounted in the vicinity of the heater transformer. If the builder desires, the heater transformer may be placed under the chassis and lower current feedthrough capacitors may be used to apply primary voltage to the transformer.

Rf input is via a BNC jack, below and just to the left of the input coupling capacitor, C1. L3 is mounted just to the right of C1. The connection between C1 and L3 (not visible in the photograph) is made to the coil-form lug nearest the sub-assembly plate. The junction of L3, C2 and L4 is visible. One end of L4 is connected to the cathode/heater bus under C2, near pin 5 (heater pin). The extension shaft from the rotor of C2 through the chassis and front panel is a length of bakelite rod. Component positioning and dimensions for the input circuit sub-assembly are given in Fig. 5.

Input Circuit Tuning

Initial "cold tube" input tuning was done with the tube in the socket, grid grounded and the cathode-matching network completely installed (including heater chokes and bypass capacitors). The tube heater remains off. A 55-ohm load, consisting of four 220-ohm 2-watt resistors in parallel, is connected with nearly zero lead length between the cathode bus and a ground lug temporarily installed on one of the tube mounting studs. The ARRL *VHF Manual*[7] describes satisfactory methods of attaining nearly zero lead length with carbon resistors for low-power dummy loads. A fairly sensitive VSWR indicator (or the reflectometer described in this article) and an exciter of 5-watts output can be used to perform the "cold tube" check of the input circuit. If the coil dimensions and positions given in the text and drawings are followed, you should have no trouble tuning the input circuit. Be sure to remove the resistors when you finish.

The objective in tuning the cathode circuit is not to couple maximum drive power to the amplifier, but to provide a relatively constant load to the exciter. Therefore, tuning in the cathode circuit should be done for best VSWR when the amplifier is operating at the desired power level. For this reason, C2 was made adjustable from the front panel. This capacitor has sufficient latitude to cover a wide range of match conditions. Power transfer to the cathode is only slightly degraded, if grid current is any indication, when VSWR is optimized and everything behaves nicely.

Plate-Line Enclosure Assembly

The plate-line enclosure, 6-inches high 11-1/4-inches wide and 13-inches deep, is made of sheet aluminum and aluminum angle stock. A standard 13 × 17 × 3-inch aluminum chassis serves as a base and the enclosure is positioned all the way to the right side, when viewing the amplifier from the front panel. Although I bent the aluminum sheet to form some of the enclosure corners, the angle stock will serve nicely. Copious amounts of No. 6-32 bolts, nuts and lockwashers are used to assure mechanical and electrical integrity of the enclosure. Do not skimp on the bolts or you may have electrical problems.

High voltage for the tube is fed through the rear wall of the enclosure via a bolt and one half of a ceramic feedthrough insulator. A bypass capacitor, similar in construction to the plate-line sandwich capacitor, is employed to decouple the high-voltage line. A piece of 1/16-inch thick brass sheet, 4-5/8 × 9-1/8-inches, is used to form the "hot" side of the capacitor. Teflon sheet is used as the capacitor dielectric and the enclosure rear wall serves as the grounded side of this bypass capacitor. The dielectric extends beyond the "hot" capacitor plate by at least 3/8-inch in all dimensions. High-voltage connections outside the enclosure are covered by a small Minibox. Additional rf decoupling and the plate-voltage meter-multiplier resistors are enclosed in this box. A Millen high-voltage chassis connector is included, to mate with the power-supply output cable.

Most readers will notice that there is another metal sheet on the chassis in the plate-compartment enclosure. This is quite evident when inspecting the input-circuit area. This sheet was used as a portable base in development of the amplifier, and was simply transferred to the final constructional layout. This sheet is not necessary for successful duplication of the amplifier.

The enclosure top cover is made of perforated aluminum sheet of moderate rigidity. If the cover sheet is flexed when the amplifier is in operation, a decrease in power output will result. However, if the cover is left alone, no problems are encountered.

The front panel of the amplifier, 10-1/2 inches high, is supported by four metal spacers extending forward two inches from the top edge of the plate-line enclosure and the bottom edge of the chassis. This spacing provides ample clearance for meters and switches behind the panel. The metal spacers are not designed to support the weight of the amplifier. A special mounting plate is installed in the cabinet for this purpose.

Support Electronics

The grid- and cathode-metering circuits employed are conventional for cathode-driven amplifiers. The multimeter, a basic 0-1 mA movement, is switched to appropriate monitoring points.

An rf-output monitor is a virtual necessity in vhf amplifiers to assure maximum power transfer to the load while tuning. Most capacitive-probe output coupling schemes presented to date do not lend themselves to built-in relative-output monitoring circuits. In this amplifier, one of these built-in circuits is achieved quite handily. The circuit consists of a 10:1 resistive voltage divider, diode rectifier, filter and adjustable indicating instrument. Two 7500-ohm, 2-watt carbon resistors are located in the plate compartment, connected between the type N rf-output connector and a BNC connector. A small wire was soldered to the center pin of the BNC connector, inside a Minibox, with the 1500-ohm, 1-watt composition resistor and the rectifier diode joined at this point. Relative output voltage is fed, via feedthrough capacitors, to the level-setting potentiometer and multimeter switch.

A calibrated string of 2-watt composition resistors, totaling 5 megohms, was installed to facilitate "on-the-spot" determination of power input, and to attest to the presence or absence of high voltage in the plate tank circuit. A full-scale range of 5000 volts is obtained with the 0-1 mA meter. If desired, the builder may use ten 500-K-Ω, 2-watt, 1-percent resistors for the string and reasonable accuracy will be obtained. Of course this monitor feature may be eliminated if other means are used to measure and monitor plate voltage.

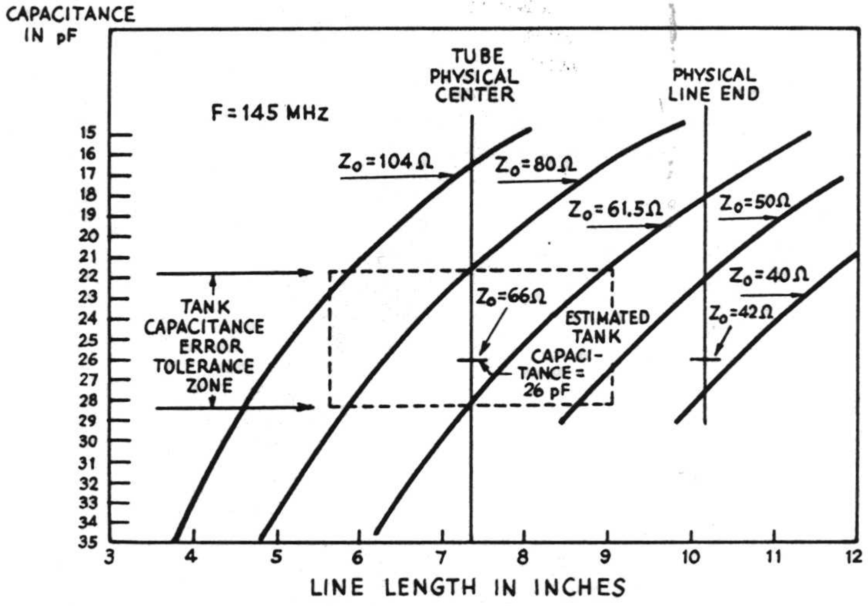
Rather than tie up a portable VSWR indicator, I decided to build an inexpensive reflectometer and install it permanently in the rf-input line to the amplifier. The reflectometer was designed using air strip-line techniques similar to those employed for the plate circuit. One position of the multimeter serves as an indicator, with meter sensitivity set by a potentiometer in the reflectometer. This potentiometer could be brought to the front panel if desired and placed to the left of the multimeter switch. The reflectometer strip-line center conductor (L1) is made of double-sided copper-clad G-10 fiberglass pc board, 1/16-inch thick, 1-1/4-inch wide and 4-7/16-inches long. Line length is not critical and will depend on the type of input and output connector used in construction of the unit. Line width and thickness should not change, as this will change the line impedance. Other material, such as brass or copper can be used for the center conductor. Notches are cut in the center of each end of the line, of sufficient width and depth to fit tightly on the center pin of a BNC (or N, or UHF) coaxial connector. This line is then soldered between the center pins of the connectors. Be sure to solder both sides of the double-sided pc board to each center pin. These centerpins serve as the physical support for the line. The stripline is spaced equidistant between two ground planes. Wall-to-wall spacing of these planes is 1-1/16 inch in this unit. The enclosure side cover serves as one of the ground planes, while a second plane, 2 inches high, extending the full length of the box, is set up inside. The voltage sampling loop, terminating resistor, diode and bypass components are mounted on the internal plane. A small hole, about 1/4-inch in diameter, was cut in the inner plane at each end of the voltage sampling loop, to pass the diode and loop-terminating-resistor leads. Small ceramic or Teflon standoff insulators were used to support the sampling loop (L2). This loop consists of 4-1/4 inches of No. 18 solid wire run on a straight line parallel to, and spaced 1/8-inch from, the stripline center conductor. With five watts applied, this length and spacing results in an instrument sensitivity on the order of 20 dB, or a capability of sensing a VSWR as low as about 1.2:1. For this application, 20-dB sensitivity was considered adequate. Power levels up to about 70 watts have been run through this reflectometer with no problems. It has not been tested at higher power levels. The unit is self contained, with the exception of the meter, in a small aluminum Minibox (Bud CU-2106A). If this box is used, be sure to remove the paint from around the edge of the side of the cover serving as one of the strip line ground planes; better electrical contact will result. A plain aluminum box of similar dimensions is a better choice.

To facilitate amplifier testing, as much of the support electronics as possible was kept above the chassis, outside the pressurized compartment. A 24-volt supply is built in, to power a VOX-controlled relay and a small coaxial relay used in the input line. A standard Dow Key relay with a high isolation receiver port is used to transfer the antenna. It is keyed by a spare set of contacts on the VOX-controlled relay. Troubles were encountered with the Dow Key relay until a sequential relay-keying system was set up to avoid "hot switching" during fast-break-in cw operation. Now everything transfers smoothly – without fireworks.

Cooling Requirements

The manufacturer specifies 38 ft^3/min of air at a back pressure of 0.60 inches of water for the full 1500-watt dissipation rating at 30 MHz. This air flow rating should be increased for operation at 144 MHz. Representative conditions would be 30 ft^3/min at a back pressure of 0.34 inches of water for 1000 watts dissipation and 55 ft^3/min. at a back pressure of 0.88 inches of water for 1500 watts anode dissipation. Don't skimp on the blower for this one. The blower employed in the amplifier is designed for mounting in any plane. Air is pulled upward through a screened hole cut in the bottom plate, pressurizing the entire under-chassis area. If the blower is mounted as shown, be certain to allow a free space under the amplifier when it is mounted in the rack or cabinet, to accommodate unrestricted air input. Cooling air is thus forced through the tube socket hole and anode cooler, venting through the perforated top cover. The blower motor itself requires draft cooling, which is provided by air passing through four 5/8-inch holes in the chassis base, directly below the blower motor, and in line with the air-passage holes in the motor frame. Similar cooling is provided with the blower in its normal housing. The holes in the chassis base are hidden from view by the blower wheel. The blower motor frame is grounded to the chassis base with a short length of flexible braid. A slight turbulence is apparent with the blower mounted in this manner, but it does not greatly reduce blower effectiveness. Perhaps some appropriately placed baffles would reduce this turbulence.

Fig. 6 — Graph used by the author as an aid to finding plate line length and the position of the tube. Curves are for shorted quarter-wave lines of the five listed impedances.



Testing and Operation

The amplifier is unconditionally stable, with no parasitics. To verify this, a zero bias check for stability was made. This involved shorting out the Zener diode in the cathode return lead, reducing bias to essentially zero volts. Plate voltage was applied, allowing the tube to dissipate about 885 watts. The input and output circuits were then tuned through their ranges with no loads attached. There was no sign of output on the relative output meter and no change in the plate and grid currents. As with most cathode-driven amplifiers, there is a slight interaction between grid and plate currents during normal tune-up under rf-applied conditions. This should not be misconstrued as amplifier instability.

Tolerances of the Zener diode used in the cathode return line will result in values of bias voltage and idling plate currents other than those listed in Table I. The 1N3311, a 20-percent tolerance unit, is rated at 12 volts nominal but actually operates at 10 volts in this amplifier (within the 20-percent tolerance).

All testing and actual operation of this amplifier was conducted with a Raytrack high-voltage power supply used in conjunction with the authors 6-meter amplifier. The power supply control and output cable harness was moved from one amplifier to the other, depending on the desired frequency of operation.

Drive requirements were measured for plate power-input levels of 1000 and 1600 watts with a Bird model 43 Thru Line Wattmeter and a plug of known accuracy. Output power was measured simultaneously with drive requirements at the 1000 and 1600 watt plate power input levels. A second Bird model 43 with a 1000-watt plug was used to measure amplifier output into a Bird 1000-watt Termaline load. A 2500-watt plug would be necessary to determine output power at the 2-kW input level, so I stopped at the 1000-watt output point and worked backwards to calculate apparent stage gain and efficiency.

Efficiency measurements also were made employing the "tube air-stream heat-differential" method. Several runs were made at 885 watts static dc and normal rf input. Apparent efficiencies of 62 to 67 percent were noted. These values were about 5-percent higher than the actual power output values given in Table I. Both efficiency measurement schemes serve to confirm that the amplifier is operating at the upper limit of the theoretical 50-60-percent efficiency range for typical Class AB2 amplifiers.

To commence routine operation, the variable capacitor in the input circuit should be set at the point where lowest input VSWR was obtained during the "cold tube" initial tube-up. The ability of the plate tank to resonate at 144-145 MHz with the top cover in place should be verified with a grid-dip meter, via a one-turn link attached to the rf output connector. Top and bottom covers are then secured. **As with all cathode driven amplifiers, excitation should never be applied when the tube heater is activated and plate voltage is removed.** Next, turn on the tube heater and blower simultaneously, allowing 90 seconds for warm-up. Plate potential between 2400-3000 volts then may be applied and its presence verified on the multimeter. The power supply should be able to deliver 800 mA or so. With the VOX relay actuated, resting current should be indicated on the cathode meter. A small amount of drive is applied and the plate tank circuit tuned for an indication of maximum relative power output. The cathode circuit can now be resonated, tuning for minimum reflected power on the reflectometer, and not for maximum drive power transfer. Tuning and loading of the plate-tank circuit follows the standard sequence for any cathode driven amplifier. Resonance is accompanied by a moderate dip in plate/cathode current, a rise in grid current and a considerable increase in relative power output. Plate-current dip is not absolutely coincident with maximum power output but it is very close. Tuning and output-loading adjustments should be for maximum efficiency and output as indicated on the output meter. Final adjustment for lowest VSWR at amplifier input should be done when the desired plate input-power level has been reached.

Table I

Performance Data

Power input, watts	1000	1600
Plate voltage	2600	2450
Plate current (single tone)	385 mA	660 mA
Plate current (idling)	50 mA	50 mA
Grid bias	-10 V	-10 V
Grid current (single tone)	35 mA	54 mA
Drive power, watts	18	41
Efficiency (apparent)	59.5 %	61.8 %
Power gain (apparent)	15.2 dB	13.9 dB
Power output, watts	595	1000

Acknowledgements

I would like to express my gratitude to my colleagues at MIT Lincoln Laboratory for their assistance in this project. Special thanks go to Ted Simmington, W1JOT; Lew Collins, K4GGI and Leo Wilber, W1MV, for their excellent comments on the construction portion of this article, and to Mr. Eino O. Gronroos, for his objective review of the technical manuscript.

References

5) Cool Amp Silver Plating Powder, part No. 1233-500, available from The Cool Amp Co., 8603 S. W. 17th Ave., Portland, OR 97219.

6) Tube socket grid clips, part No. 149-842, and Teflon chimney, part No. SK-2216, available from Eimac Division of Varian, 301 Industrial Way, San Carlos, CA 94070.

7) *The Radio Amateur's VHF Manual*, 2nd Edition, p. 288. (This Edition was erroneously labeled as the 11th at the time of printing.)

The Art of Dipping

(Continued from page 18)

These twenty reasons are not all the possibilities, but seem to be among the most important, and illustrate why a dipper is a handy thing to have around the ham workshop.