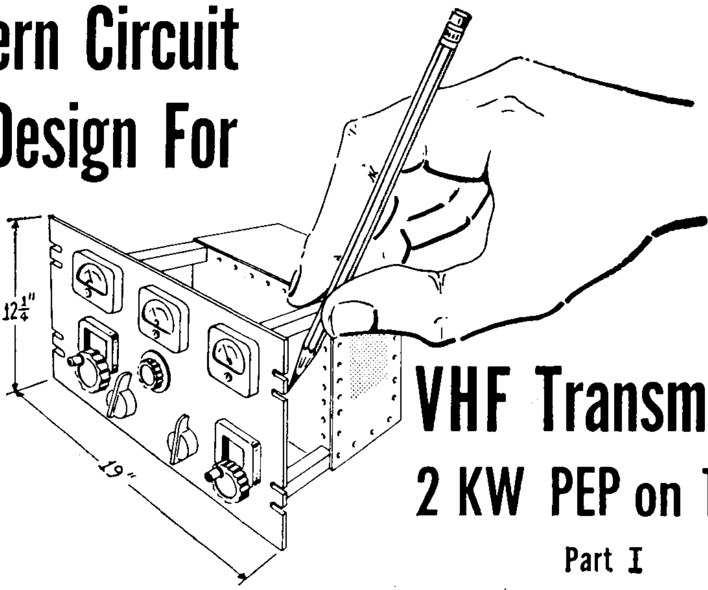
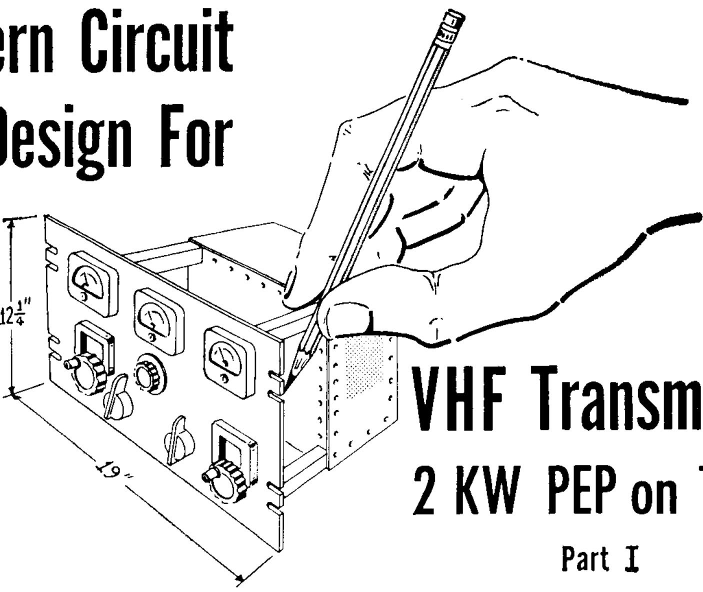
amateur service newsletter
W6SAI

Modern Circuit Design For



VHF Transmitters
2 KW PEP on 144 mc
Part I

Modern Circuit Design For VHF Transmitters



2 KW PEP on 144 mc

Part I

BY H. C. BARBER,* W6GQK; W. I. ORR,† W6SAI; R. RINAUDO,† W6KEV AND R. SUTHERLAND,† W6UOV

Part I describes the design of a two kilowatt p.e.p. amplifier for the serious 2 meter operator. Requiring less than 10 watts of driving power, this efficient amplifier loafs along at the legal amateur power level. Designed for continuous service, a lot of power is packed behind a 12¼-inch relay rack panel. Construction details of this "powerhouse" will be featured in Part II of this two part series.

THE would-be designer of transmitting equipment for the v.h.f. spectrum soon finds that he is operating in a twilight area that falls between microwave techniques and practices associated with the high frequency (h.f.) bands. He realizes, sooner or later, that at some broad, undefined wavelength peculiar things start to happen to h.f. circuitry that otherwise looks deceptively simple on paper. As he progresses from the h.f. int othe v.h.f. region, the attentive amateur soon is aware that bypass capacitors no longer exhibit the normal characteristics they possess at lower frequencies. Short bits of wire assume importance beyond their size. R.f. tends to "leak" through small chassis holes. Components that seemingly are a passive part of normal communications hardware become complex devices that bedevil, and bear little resemblance to the comfortable components that make up h.f. gear.

Viewing the microwave (u.h.f.) region, the amateur finds a new world of waveguides and plumbing. Circuit techniques, equipments, and vocabulary fall into a strange category, and engineering philosophy and hardware of this frequency region are alien to h.f. concepts and techniques.

Between the comfortable world of kilocycles and the alien world of gigacycles are the amateur v.h.f. bands of 144, 220 and 432 mc. What techniques and practices should be used at these frequencies? Are microwave techniques applicable, or is this portion of the v.h.f. spectrum

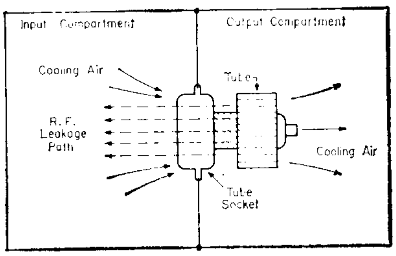


Fig. 1—Socket orfices to permit cooling air to pass across base seals of tube and through anode cooler may also create r.f. leakage path from output to input compartment. Simple "receiving type" sockets have little r.f. attenuation, while most "air-system" sockets afford 20 decibels or so of intra-stage isolation. The new Eimac SK-820 socket and 4CX1000K tube achieve better than 50 decibels of intra-stage isolation below 450 megacycles.

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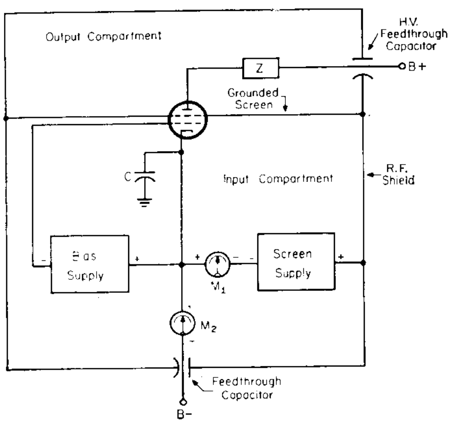


Fig. 2—To achieve maximum isolation between input and output compartments, the screen of the tube may be grounded, with bias and screen supplies placed below d.c. ground potential as shown in this circuit. The screen bypass capacitor is thereby omitted and a cathode bypass capacitor (C) substituted in its place. The B-minus lead is "negative" to the chassis by the amount of the screen voltage. Meter M_1 measures screen current and meter M_2 measures plate current.

merely an extension of the h.f. spectrum, with suitable modifications applied to equipment design and construction?

The answer to both these questions is obscured by realities. The v.h.f. amateur bands can and do use components designed for h.f. service, but these bands fall on the doorstep of the u.h.f. region wherein the components start to assume the size of the radio wave that is being generated. This physical congruence of wave and component calls for techniques and circuitry not normally associated with h.f. equipments.

One obvious solution to this problem is to reduce the size of the v.h.f. hardware so that the dimension of the radio wave is great compared with that of the components. This is commonly done; but there is a limit to this reduction technique, however, since no one has ever invented a way to shrink the *watt* in a corresponding manner. A limiting factor in the design of v.h.f. gear, therefore, is the ability of small components to radiate or otherwise dissipate the heat generated by the power dissipation of active components.

This natural law of thermodynamics becomes a limiting factor at v.h.f. in the design of a one kilowatt (2 kilowatt p.e.p.) amplifier for linear and c.w. service. To begin with, the number of tubes that will accept this power level at this frequency are but a handful. Tank circuits tend to disappear within the tubes, and the problem of dissipating five hundred watts or so within a shielded enclosure containing small tubes and tiny components poses a difficult mechanical design problem. Even at the relative "low" frequency of 144 mc, the use of "garden-variety" tubes and tank circuits provides a marginal solution.

Special tubes and hardware have been designed to work well at v.h.f., and by the proper combination of tube, hardware and circuitry, a reliable amplifier having the aforementioned power capability may be built that "tunes up just like 20 meters" and is capable of continuous, 24 hour-a-day operation. The design of such an amplifier is covered in this article, with some interesting asides directed to problem areas encountered in the construction of a practical amplifier.

Socket-Tube Intra-Stage Coupling

One source of potential trouble in the v.h.f. amplifier is *intra-stage r.f. coupling* (fig. 1). Passage of r.f. energy between two sealed metal compartments placed side by side is zero, but the introduction of power leads and cables in the compartments permits r.f. leakage; and the placement of a tube between the compartments allows the coupling of energy through the socket

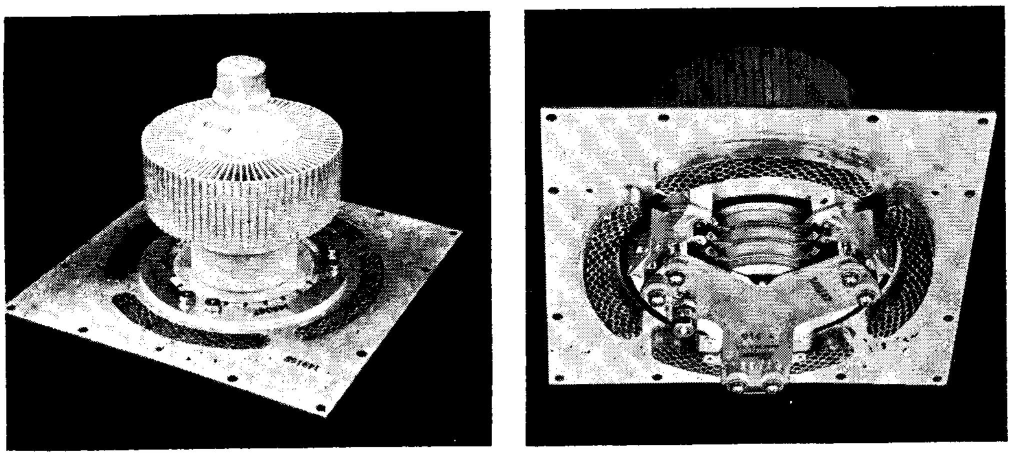


Fig. 3—(Left) Screen terminal of 4CX1000K tetrode is a ring that completely encircles the upper portion of the base structure of the tube. Flexible tabs on matching socket ring insure low impedance ground path from screen element as screen is run at d.c. ground. Cooling air is passed through the socket structure by means of "honeycomb" section of expanded metal (Right) built into socket plate which acts as a waveguide beyond cutoff frequency and provides high degree of attenuation below 450 mc. The socket provides 50 decibels or better intra-stage isolation in the v.h.f. region.

orfices, impairing the erstwhile perfect isolation between the compartments. It is possible to reduce intra-stage coupling via the power leads by proper bypassing and termination of the individual wires. Combining these techniques with the use of a new, improved tube socket and tube base, an intra-stage isolation of —50 decibels or higher may be achieved.

The degree of r.f. coupling between compartments may be determined by injecting a signal into the input compartment at the operating frequency of the gear, and then measuring the residual signal developed in the output compartment. For example, assume each compartment in the illustration has zero r.f. leakage other than the path through the tube and socket. This coupling path has an attenuation of —20 decibels, that is, the signal measured in the output compartment is 20 decibels lower in power than the signal injected in the input compartment. The particular tube in the socket has a power gain of 25 decibels, so it can be seen, without even turning the equipment on, that +5 decibels of positive coupling occurs through the socket-tube path and that the circuit will sustain self-oscillation at the frequency in question.

If the attenuation of the path is increased to greater than —25 decibels, oscillation may still occur under certain conditions of equipment tuning and loading wherein the tube gain may momentarily rise over the nominal figure. Many combinations of tubes and sockets normally used in the v.h.f. region exhibit a high degree of internal coupling since the screening of the tube is not perfect. Also, leads within the tube are long, bypass capacitors are imperfect at the design frequency, and the necessary air path through the socket permits the plate of the tube to "see" the input circuitry.

To provide the proper degree of isolation, the socket-tube intra-stage coupling should provide a degree of attenuation that is at least 20 decibels greater than the circuit gain of the stage, and the internal screening of the tube should be as excellent as the state of the art permits.

The "Grounded" Screen

In order to increase screen isolation at v.h.f. and to insure that the screen is as close to ground potential as possible, it is expedient to ground the screen to the chassis and to supply bias and screen potentials "below ground" as shown in fig. 2. The screen bypass capacitor is thereby eliminated and a cathode bypass capacitor substituted in its place. The screen capacitor usually employed in a tetrode stage is in a critical location in the v.h.f. circuit as it carries almost all of the plate circuit r.f. circulating current and, in addition, introduces regeneration in the circuit if the capacitor exhibits inductive reactance. When this cranky component is removed, the tetrode screen can be physically grounded, and the burden is transferred to the cathode bypass capacitor which carries little circulating current and tends to be a *degenerative* element if it exhibits inductive reactance.

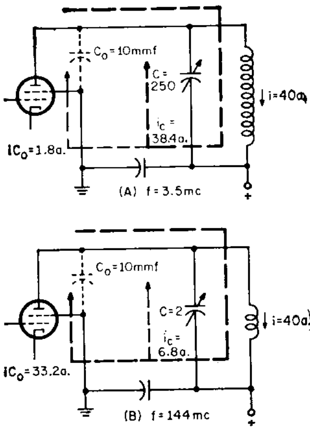


Fig. 4—At v.h.f., the output capacitance of the vacuum tube constitutes a larger proportion of the total tank circuit capacitance than in the h.f. region. Circulating r.f. tank current (*i*) divides through tube capacitance (C_0) and tuning capacitor (C) in proportion to capacitance of each. At 144 mc, current flowing through tube output capacitance (*i*C_0) is almost twenty times as great as at 3.5 mc.

Intra-stage r.f. leakage through the socket may be reduced by modiying the air vents between input and output terminations while allowing cooling air to pass across the base seals and through the tube anode.

A "Grounded Screen" Tube and Socket

Shown in fig. 3 are the new Eimac 4CX1000K tetrode and the companion SK-820 socket. The "K" tube is an improved version of the 4CX1000A having a low impedance screen grid terminal ring that completely encircles the upper portion of the base structure of the tube. The 4CX1000K is designed for improved input-output isolation and the screen terminal ring presses snugly against a circular spring-like grounding plate built into the top portion of the SK-820 socket. The screen is thus completely and securely grounded around its circumference by an extremely low impedance path, reducing r.f. intra-stage leakage through the socket to —50 decibels or better at 450 mc.

Cooling air is passed through the socket assembly by means of "honeycomb" sections of expanded metal built into the socket which act as simple waveguides beyond cutoff frequency, and provide a high degree of attenuation to r.f. currents passing between the grid and plate compartments.

Use of the 4CX1000K in the improved socket permits construction of a high power v.h.f. amplifier having excellent intra-stage isolation and that does not require neutralization. Thus, one of the big "trouble makers" in v.h.f. equipment design has been conquered!

The V.H.F. Plate Tank Circuit

The purpose of the v.h.f. plate tank circuit is twofold: First, it provides an impedance match between the tube and the load; and second, it

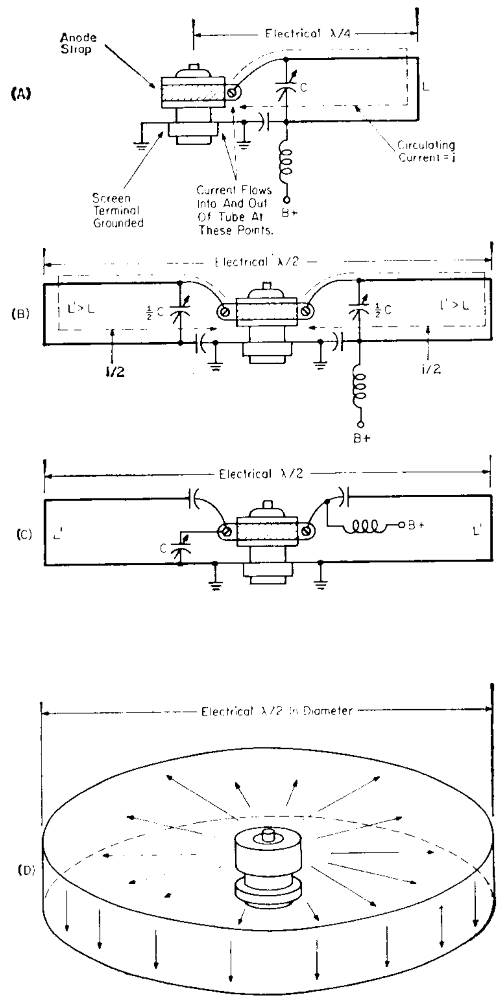


Fig. 5—Simple "quarter-wave" loaded tank (A) may be used as resonant circuit at 144 mc. However the circulating r.f. tank circuit flows into tube at one point and overheating of screen lead and vacuum seal may result from the high concentration of current. Divided tank circuit (B and C) places tube at the high potential point in half-wave line and divides circulating r.f. tank circuit between two sides of the tube. Limiting case is circular cavity (D) with tube placed at center and with circulating r.f. current evenly spread over inner surface of cavity. At 144 mc, the circuit of (C) is an efficient and practical compromise.

attenuates undesired spurious emissions. As the v.h.f. region is approached, the popular h.f. resonant tank composed of a parallel coil and capacitor shrinks in size until it is more practical to employ a different, larger resonant configuration. A capacitance-loaded section of transmission line may be used as a resonant circuit, since v.h.f. short-circuited transmission lines can efficiently replace inductances in tank circuits.[1] Such transmission line circuits exhibit considerably higher impedance at resonance and better Q than can be obtained with "lumped" circuitry. In general, the transmission line tank circuit may be designed for maximum efficiency, for maximum bandwidth, or for mechanical convenience. That is to say, given a reasonable efficiency and line impedance, the physical constants may be "juggled" about to permit a satisfactory circuit to be constructed of the material at hand so that odd sizes of tubing or unusual construction techniques need not be used.

[1]"*Fields and Waves in Modern Radio*", by Ramo and Whinnery, Chap. 10. John Wiley and Sons.

Output Capacitance

In passing, it should be noted that the output capacitance (C_o) of a vacuum tube assumes great importance in the v.h.f. region as compared to the h.f. spectrum since it constitutes a larger percentage of the total tank circuit capacitance (fig. 4). At 3.5 mc, for example, a reasonable value of plate tuning capacitance (C) might be 250 mmf, of which 10 mmf (or 4%) represents the output capacitance (C_o) of the tube. At 144 mc, the total plate tank capacitance may be 12 mmf, and the tube contributes 83% of this capacitance. In a high-Q tank circuit, the circulating r.f. plate current may reach the order of 40 amperes at the kilowatt level and this current divides through the tube output capacitance and tuning capacitor in proportion to the capacitance of each. Thus, in the case of the 3.5 mc amplifier, 4% of the r.f. plate circuit current (1.6 ampere) flows through the output capacitance of the tube, whereas at 144 mc 83% of the current (33.2 amperes) flows through the tube output capacitance! In the case of a tetrode, the circulating current flows through the screen circuit as shown in fig. 4. The screen leads and screen bypass capacitor and a portion of the tank circuit must carry this extraordinarily heavy r.f. current. Elimination of the screen bypass capacitor removes this cranky component from the high current density path; however, the circulating r.f. current flowing through the tube terminals tends to heat the vacuum seals, often to such a temperature that the tube may be damaged. The current cannot be eliminated, but it may be distributed in such fashion as to minimize seal heating consistent with the shortest possible return path from plate to screen. Placing the screen at absolute ground potential, and using a low inductance screen terminal on the tube aids this task.

The Modified Coaxial Tank Circuit

The condition for resonance of a capacitance loaded transmission line is:

$$X_c = Z_o \tan L$$

Where X_c is the reactance of the loading capacitor, Z_o is the impedance of the transmission line, and L is the electrical length of the line in degrees: ($\lambda/4 = 90°$).

In the general v.h.f. situation, the loading capacitance is the output capacitance of the tube, and line parameters (Z_o and L) are adjusted so as to establish circuit resonance with this capacitance.

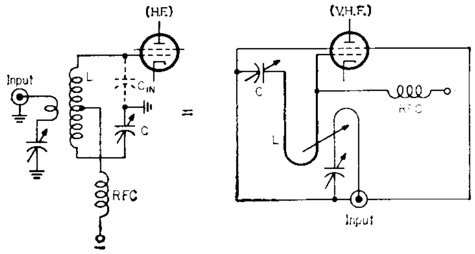


Fig. 6—"Split-stator" h.f. grid tank circuit may be duplicated at v.h.f. by the use of a loaded half-wave line. Input capacitance of tube makes use of quarter-wave line impractical, as the line tends to "disappear inside the tube".

A simple "quarter-wave" loaded line may be used as a resonant tank circuit (fig. 5A) but the circulating r.f. tank current flows through the tube via one small area and overheating of the screen terminal and vacuum seal in this particular area may result. It is possible, however, to achieve the same resonant frequency with one-half the tuning capacitance and a somewhat longer transmission line section (L') as shown in fig. 5B. Combining two of these circuits (fig. 5C) permits the use of the longer line (an electrical half-wavelength long) with the tube placed at the center. Circulating r.f. plate currents now flow through both sides of the tube, providing somewhat better current distribution than before. The longer line is easier to extract energy from because of its greater length, and it is less critical of construction. In addition, the physical mass of metal in the long line can dissipate heat more readily than can the smaller mass of the shorter quarter-wave line. The limiting design, of course, is when the tank circuit completely surrounds the tube in the form of a cavity (fig. 5D), wherein r.f. plate current is equally divided around the circumference of the tube. Such an approach is necessary in the upper regions of the v.h.f. spectrum, but at 2 meters, the simple half-wavelength line discussed here works well, and is simpler and cheaper to construct than the cavity configuration.

An optimum value of line impedance exists, which is a function of the dimensions of the resonant line. In the design of 5C the line is made in coaxial fashion, composed of a circular center conductor (made of a section of readily obtainable copper water pipe) and the outer walls of the shielded plate circuit enclosure. The impedance of a line of these rough dimensions is approximately 60 ohms, and the enclosure dimensions and spacing of the line are chosen to provide minimum surface area of the elements consistent with maximum volume, thus reducing the surface "skin resistance" of the elements.

The V.H.F. Grid Input Circuit

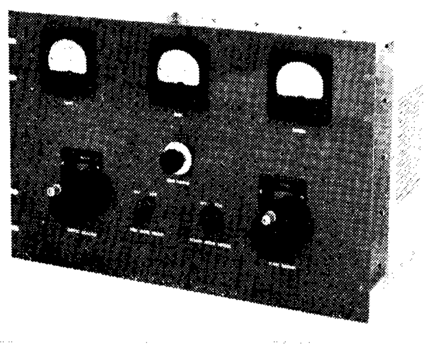
It is possible to use a quarter-wave line for the input circuit in the lower portion of the v.h.f. spectrum. However, the law of diminishing returns is at work: since the tube input capacitance does not shrink as the operating frequency is raised, the line must necessarily be drastically reduced in length to maintain resonance. Broad, low resistance circuits and wide contact areas are very fine for heat radiation but, by their very area, they add residual capacitance to any circuit built around them. Input capacitance of tubes designed for the v.h.f. region tends to run into a respectable figure, and some of the better tubes have input capacitances in the range of 50 to 100 mmf. The input capacitance is the sum of the grid-cathode, grid-screen, and grid-plate capacitances. Considerable ingenuity is demanded of the v.h.f. engineer to construct a high impedance tank resonated by such a value of capacitive loading, but it can be done, even though the quarter-wave tank tends to disappear within the tube!

An effective solution to this problem is to add a capacitance-shortened quarter wave line to lengthen the tank assembly to an electrical half wavelength (fig. 6). A form of "split stator" resonant circuit is achieved, and the driving signal may be easily coupled to the added tank section, as shown in the illustration. Low inductance leads are required, and the tank circuit may advantageously be made of wide copper strap, with multiple strap connections to the grid terminals of the tube to insure proper division of circulating current. A simple series tuned inductive loop can be used to efficiently couple the driving signal into the grid circuit of the v.h.f. amplifier. At best, grid drive is hard and expensive to obtain at v.h.f. and it is poor engineering practice to waste it!

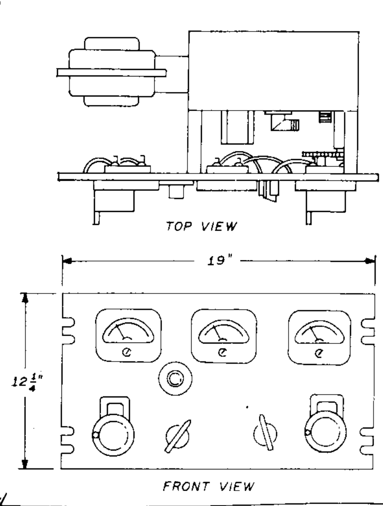
A Practical V.H.F. Amplifier

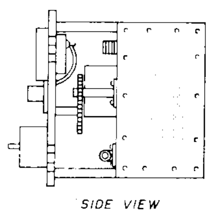
A high power 144 mc amplifier making use of these design techniques and featuring the 4CX1000K and SK-820 socket will be described in the second part of this article.

[*To be continued*]



The next part will deal with the construction of the above amplifier. This is a front view of a compact two kw p.e.p. linear amplifier suitable for s.s.b., a.m., f.m., or c.w. It requires less than ten watts of drive to reach the maximum legal power.





Modern Circuit Design for VHF Transmitters

2 KW PEP on 144 mc

Part II

BY H. C. BARBER,* W6GQK; W. I. ORR,† W6SAI; R. RINAUDO,† W6KEV AND R. SUTHERLAND,† W6UOV.

Part II of this article describes the construction of a 2 kw p.e.p. linear amplifier that loafs along at the legal amateur power level and requires less than ten watts of drive.

The serious v.h.f. operator has a need for high power transmitting equipment if he is interested in Oscar IV, meteor scatter, moon bounce or other exotic forms of long-distance v.h.f. communication. In addition, if he contemplates s.s.b. operation, he may be desirous of running the "two kilowatt p.e.p." limit.[2] Equipment capable of achieving this power level on a reliable basis is scarce in the world of hamdom, although such gear is fairly commonplace in the commercial fields. Many instances exist where commercial gear has been patterned after equipment designed for radio amateur use, so perhaps there is justification for purely amateur gear designed around a proven item of commercial equipment.

This article describes a unique 144 mc high-power linear amplifier, patterned after a 5 kilowatt amplifier that has proven itself in space communication work in the v.h.f. spectrum. Scaled down to amateur size and power level, and making use of the new Eimac 4CX1000K v.h.f. tetrode, this compact continuous service kilowatt unit combines high power gain, stability and good linearity in a small package. This amplifier design, moreover, may be further scaled down for use at a lower power level, employing a single tube of the 4CX250B family. Requiring no neutralization, and straightforward in adjustment and tune-up, this linear amplifier is an interesting example of up-to-date v.h.f. design techniques. Even though many amateurs may not care to duplicate this unit in its entirety, many of the unique circuits and layout may be well adapted to other v.h.f. equipments.

The previous article[3] discussed some of the problems overcome in the design of a high power v.h.f. linear amplifier and the techniques that were employed to solve these problems. This article describes the construction of a 144 mc linear amplifier employing these previously discussed techniques and which is capable of continuous operation at a maximum power level of 2700 watts (p.e.p.). This margin allows a reasonable safety factor at the maximum amateur power input limit and insures that the equipment will not blow up at a crucial moment when an existing DX record is about to be shattered.

The 4CX1000K amplifier employs a half-wave linear plate tank circuit and the grounded screen

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[2]The F.C.C. definition of the so-called "two kilowatt p.e.p." limit is: "The maximum d.c. plate power input to the radio frequency tube or tubes supplying power to the antenna system of a single-sideband suppressed-carrier transmitter, as indicated by the usual plate voltmeter and plate milliammeter, shall be considered as the "input power" . . . provided the plate meters utilized have a time constant not in excess of approximately 0.25 second, and the linearity of the transmitter has been adjusted to prevent the generation of excessive sidebands. The "input power" shall not exceed one kilowatt on peaks as indicated by the plate meter readings."

[3]Barber et al., "2 KW PEP on 144 mc," *CQ*, Nov. 1965 page 30.

configuration discussed in the previous article. Overall amplifier efficiency in the Class AB-1 linear mode is unusually high for these frequencies, being of the order of 60 percent or better at a plate potential of 2500 volts. As the practical limit of plate efficiency of a Class AB-1 linear amplifier is no more than 68 percent, it can be seen that tank circuit losses of this unusual design consume only about 8 percent of the output power. Most garden variety v.h.f. tank circuits exhibit losses ranging from 20 to 50 percent.

At a plate potential of 3000 volts the power gain of this linear amplifier is over 22 decibels at the maximum power level, and the peak driving signal power is only 9.5 watts. At a two kilowatt p.e.p. level (3000 volts at 666 ma) the peak driving power is about 6.3 watts. For c.w. or f.m. service at one kilowatt input, the amplifier is capable of 625 watts power output with a driving power of 5.2 watts, and as an a.m. linear amplifier at the one kilowatt input level, a fully modulated 250 watts output may be obtained with only 1.25 watts of drive power.

Thus, in these classes of service, this compact "black box" is capable of better than 22 decibels power gain up to the maximum power level of 2700 p.e.p. on a continuous, 24 hour basis. Cost of all components is less than five hundred dollars, including the tube and socket, so on a watts-per-dollar basis, it is difficult to surpass the high power economy of this modern v.h.f. amplifier package.

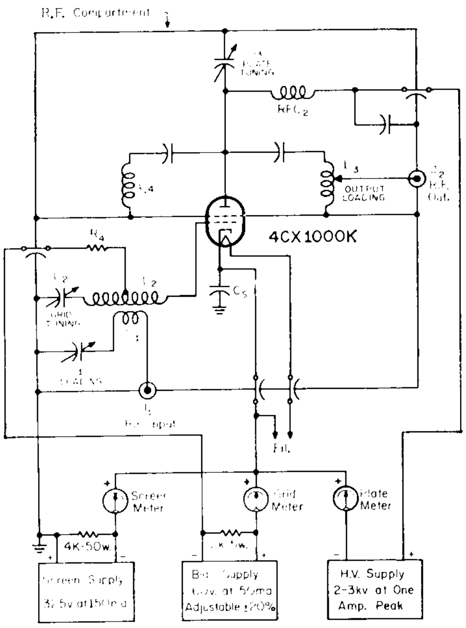

Fig. 7—Simplified schematic of 4CX1000K amplifier. The screen circuit of this v.h.f. amplifier is operated at d.c. and r.f. ground potential with bias and screen supplies placed "below chassis ground". The cathode capacitor (C_5) is an integral part of the Eimac SK-820 socket. Grid circuit components are placed in "r.f. tight" compartment and the special v.h.f. socket prevents intra-stage r.f. currents to flow between plate and grid circuits. The plate tank circuit (L_3, L_4) is a half-wave line with the 4CX1000K placed at the center. All power leads entering the compartments are suitably bypassed to keep the r.f. where it belongs.

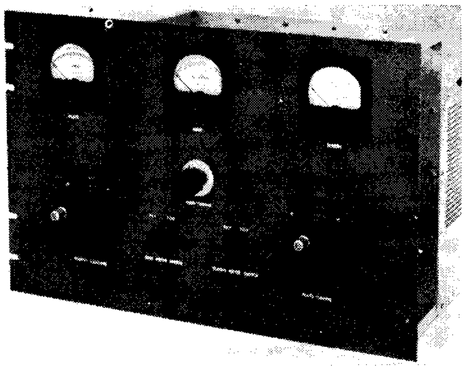

Fig. 8—Front view of a compact two kilowatt p.e.p. linear amplifier for the v.h.f. man. This high power 144 mc linear is suitable for s.s.b., a.m., f.m. or c.w. operation, requiring less than 10 watts drive power to reach the maximum legal amateur power level. The amplifier is mounted behind a standard 12¼" relay rack panel. Across the top of the panel (l. to r.) are the plate, grid and screen milliameters, with the grid tuning capacitor (C_2) centered below. At lower left and right are the counter dials for the OUTPUT LOADING control and PLATE TUNING (C_3). Between the counter dials are the grid and screen meter reversing switches. The amplifier enclosure is spaced behind the panel by sections of rectangular aluminum rod and the 4CX1000K mounts in a horizontal position within the enclosure. At the right end of the enclosure are the ventilation holes above the anode of the tube.

Circuit Features

A simplified circuit diagram is shown in fig. 7. The 4CX1000K power tetrode is operated with the screen at d.c. and r.f. ground potential, with the positive terminal of the screen supply grounded and the screen and bias supplies placed "below chassis ground." This is done to eliminate the screen r.f. bypass capacitor in order to achieve maximum intra-stage isolation. Because of the excellent isolation between input and output circuits, neutralization is neither desired nor required.

The plate circuit is composed of a half-wave, shunt-fed, inductor (L_3, L_4) with the tube positioned at the center of the line. The r.f. output loading tap is placed on one segment of the line. Resonance is established at the operating frequency by plate tuning capacitor C_3, which is a simple two plate assembly with one plate mounted to the anode cooler of the tube.

Two ceramic transmitting capacitors in parallel are used as blocking capacitors for each segment of the plate line inductors. So-called "TV-type" ceramic capacitors should *not* be used, as the circulating tank current is of the order of 40 amperes at maximum power level, and a large portion of this r.f. current flows through the blocking capacitors. The TV capacitors are not rated for such severe operating conditions.

The loaded Q of the plate tank circuit is determined almost entirely by the ratio of plate load impedance to reactance of the output capacitance of the tube. This capacitance is a fixed value and the load impedance is determined by the operating conditions imposed by the tube. Loaded Q therefore is relatively inflexible, although higher than normally encountered at lower frequencies. Even so, good tank circuit efficiency can be readily obtained if the unloaded Q is sufficiently high. It is in this case, being approximately 1000. Unloaded circuit Q of this magnitude is difficult to achieve at lower frequencies as the unloaded Q of good coils usually falls below 400. The loaded Q in this instance must be of the order of 10 to 20 to achieve a reasonable degree of tank circuit efficiency.[4] One disadvantage of high tank circuit Q (usually demanded by high-C v.h.f. tubes) is that a corresponding high value of r.f. circulating current flows. (Restricted bandwidth could also be a disadvantage in some applications). Wide leads having low r.f. resistance are required to carry this current. Ordinary lead solder is *out* as its r.f. resistance is too high, and high temperature silver solder is used for connections in v.h.f. tank circuits operating at power levels in excess of a few hundred watts. Alternatively, the joints may be physically bolted together with brass bolts, provided the r.f. current does not pass through the body of the bolt.

The coaxial output receptacle, J_2, is a *Type N* fitting, with the flexible strap jumper from the moveable tap on inductor L_3 bolted to the center pin of the fitting. Appreciable current flows through the jumper and a soldered joint at the receptacle has sufficient r.f. resistance at 144 mc to run hot enough to melt the solder at full amplifier input. The older SO-239 style coaxial receptacle is *not* recommended at this point, as the matching PL-259 coaxial plug does not make adequate contact to the shield of the coaxial line, which is only soldered at four points within the plug.

The resonant grid circuit is a half-wave line (L_2), capacitance loaded at one end by grid tuning capacitor C_2 and at the opposite end by the input capacitance of the 4CX1000K. Bias is applied to the tube through the grid line, via isolating resistor R_4 placed at the minimum r.f. voltage point of the circuit. Use of a v.h.f. choke at this point instead of the isolating resistor resulted in a violent 10 mc parasitic oscillation which is entirely absent when the resistor is employed.

The point of minimum r.f. voltage is at the electrical center of the half-wave grid line which happens to fall very close to the socket terminals. The input capacitance of the 4CX1000K is approximately 80 mmf and a simple parallel resonant tank tends to "disappear within the tube" at 144 mc. A half-wave line made up of the tube capacitance and lead inductance permits sufficient tank circuit external to the tube to efficiently couple excitation to the tube. To satisfy this requirement, the grid line is made of copper strap and has an unloaded Q of about 300. Loaded Q is close to this figure as the grid circuit is swamped only by the circuit losses and input conductance of the 4CX1000K. Grid driving power is theoretically zero. In practice a few watts are required to develop the proper voltage at the grid of the tube because of the circuit losses.

Because of the high value of circuit Q and the appreciable capacitance of tuning capacitance C_2, grid circuit tuning is quite sharp and resonance must be reestablished for frequency excursions of more than a few hundred kilocycles.

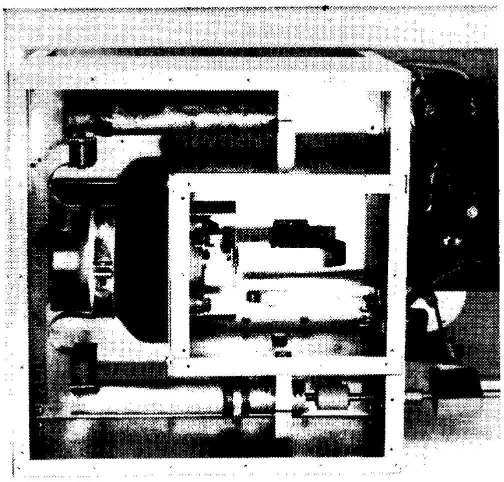

Fig. 9—Interior view of the amplifier enclosure with the rear plate removed. The enclosure normally mounted on its side, is shown in a vertical position. The 4CX1000K, air chimney, and special socket are placed atop the center of the grid compartment, with cooling air passing into the "bottom" of the compartment. The three grid terminals of the 4CX1000K socket are strapped together and the junction is bolted to the U-shaped grid inductor (L_2). The opposite end of L_2 terminates at the GRID TUNING capacitor, C_2, mounted to the front wall of the compartment. Below the grid assembly at one side is the input link (L_1) with LOADING CAPACITOR, C_1, mounted to the wall of the compartment. Mounting brackets for the two plate inductors are affixed to the outer side walls of the compartment. The squirrel-cage blower is mounted with a piece of screening across its mouth to restrict r.f. leakage through the vent opening. At the side of the blower is the right-angle drive and flexible shaft for the OUTPUT LOADING adjustment, visible on one anode inductor. The moveable tap is driven via a threaded rotary shaft integral to the plate line.[5]

Metering and Power Circuits

Separate d.c. milliammeters are used to mon-

[4]Tank circuit efficiency is defined as:

$$\text{Eff} = 100\frac{Q_u - Q_l}{Q_u}$$

Where Q_u is the unloaded Q, and Q_l is the loaded Q.

[5]A set of blueprints is available at a cost of one dollar which covers, in detail, the various plate circuit components. Write: Amateur Service Dept., Eitel-McCullough, Inc., San Carlos, Calif.

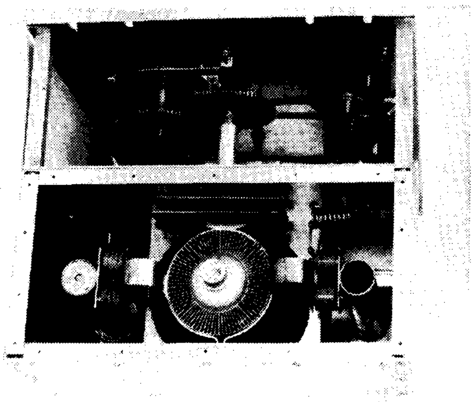

Fig. 10—View into top of plate circuit compartment with the perforated top removed. The PLATE TUNING capacitor (C_3) is immediately in front of the 4CX1000K, driven from the panel-mounted counter dial by two surplus gears. The moveable plate of the capacitor is grounded to the wall of the enclosure by a two-inch wide strap of flashing copper which flexes as the capacitor plate moves closer to the fixed anode plate. The dual plate blocking capacitors are mounted to the sides of the anode strap of the 4CX1000K, and visible at the right is the simple air-wound plate r.f. choke. The bearing of the rotary drive shaft for the OUTPUT LOADING tap is visible at the top of the left plate circuit inductor.

itor grid, screen and plate currents. Normal grid current of the 4CX1000K tetrode is zero in Class AB-1 service; however, small values of current flow during the tune-up process, and grid current excursions up to plus or minus 5 milliamperes may occur. In like fashion, screen current can be either positive or negative in value up to approximately 40 milliamperes or so. Negative current excursions are common in the grid and screen circuits of high gain tetrodes operating in the Class AB-1 mode. To accommodate positive and negative excursions of screen and grid current, zero center meters may be used or a polarity reversing switch can be employed with less expensive positive reading meters. The latter technique is used in this amplifier. Screen and grid metering are accomplished across shunt safety resistors, and rotary meter switches are used in lieu of toggle switches to insure low contact resistance. The safety resistors are placed across the switch arms rather than across the meters so that the circuits are not interrupted during the switching action.

Amplifier Cooling

The 4CX1000K tetrode installed in the SK-820 Air System socket requires an air blast of 25 cubic feet per minute for operation at maximum plate dissipation with inlet air temperatures up to 40 degrees Centigrade. This corresponds to a pressure difference of 0.2 inch of water column. A Dayton #1C-180 blower or Ripley #8472 blower will provide adequate cooling at this level of back pressure. The mouth of the blower is mounted to the under-chassis area as shown in the photograph and r.f. leakage through the blower air vent is prevented by covering the blower opening with a piece of screening. Cooling air passes from the blower into the grid compartment, through the honeycomb vents in the SK-820 air socket, and is conducted to the tube anode by means of a phenolic hood (Eimac SK-806) that slips over the top of the socket assembly. The air is exhausted from the plate circuit compartment through a perforated area in the enclosure located above the tube. The blower is energized as soon as filament voltage is applied to the tube.

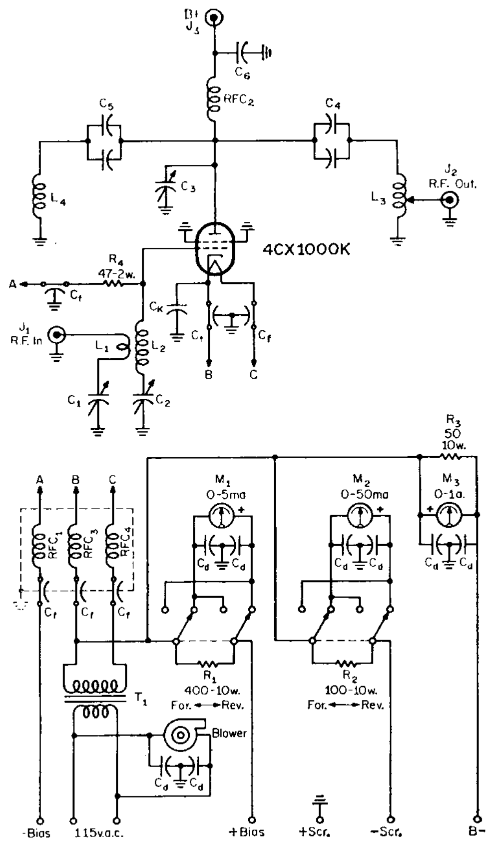

Fig. 11—Circuit of the 2 kw p.e.p. linear amplifier.

C_1—20 mmf, Hammarlund HF-20 or equiv.

C_2—15 mmf, Hammarlund HF-15X or equiv.

C_3—Approx. 3.5 mmf Plate size 2¼" × 4", spaced about ⅜". See text.

C_4—C_5: Each two 100 mmf, 5kv in parallel. Centralab 850S-100 or equiv.

C_6—1000 mmf, 5kv. Centralab 858S-1000 or equiv.

C_d—1000 mmf disc ceramic, 1.6 kv.

C_f—1500 mmf ceramic feedthru. Erie 327-X5U-152M or equiv.

BL_1—25 cubic feet/min. at 0.2" pressure. Dayton #1C-180 or equiv.

RFC_1—1.8 microhenries, Ohmite Z-144 or equiv.

RFC_2, RFC_3, RFC_4—9 t. #12, ½" dia., 1¼" long.

T_1—6.0 volts at 13 amperes. Stancor P-6463 or equiv.

J_1—Receptacle, BNC (UG-1094/U).

J_2—Receptacle, right angle, type N (UG-997A/U).

J_3—High voltage receptacle, Millen 37001 or equiv.

S_1, S_2—D.p.d.t. rotary switch, Centralab 1464 or equiv.

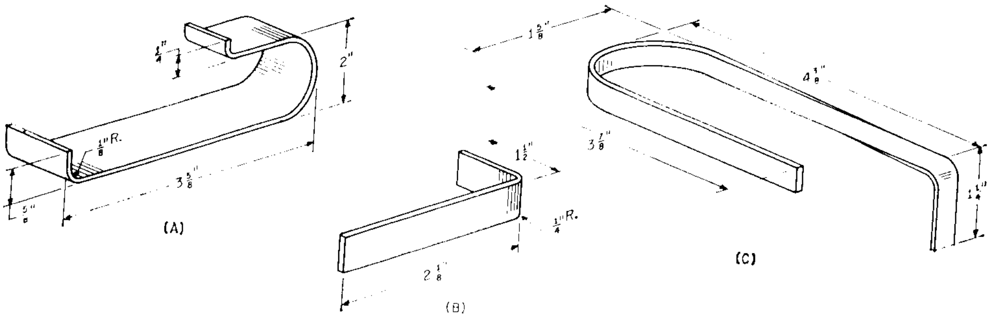

Fig. 12—Structural details for the grid circuit components. (A)—L_2, ⅝" strap, 0.032 material formed to dimensions shown. (B)—Grid connecting strap ⅝" wide, 0.064 material, 3 required. (C)—Input link, L_1, ¼" strap, 0.032 material.

Amplifier Enclosure

The amplifier mounts behind a standard 12¼" relay rack panel, with the 4CX1000K placed in a horizontal position behind the panel (fig. 9). The r.f. enclosure measures 12 inches square and is 6 inches deep. This aluminum enclosure is spaced 4½ inches behind the panel, and in this panel space are located the various meter switches, the meters and counter dials, the filament transformer and a small aluminum box containing the filament and grid isolation networks. The SK-820 air socket is mounted atop the grid compartment box which measures 6 inches wide, 7 inches high and 6 inches deep. The front and back panels of the amplifier enclosure also form the panels of the grid compartment box. As the enclosures are not standard size items, they were made up of 0.062 inches aluminum sheet, formed into simple panels.

Plate Circuit Assembly

The half-wave plate inductor is made up of two 7½ inch lengths of 1⅛ inch outside diameter copper water pipe (fig. 9). The pipes are clamped to the outer walls of the grid compartment box by means of heavy dural blocks, as shown in the photographs. A special sliding fitting is required on one plate line to allow adjustment of antenna coupling. This fitting consists of a copper ring which slides over the pipe and makes contact to the pipe by virtue of a circular section of flexible "finger stock" which is soldered to the inner circumference of the ring. The ring is driven along the length of the pipe by means of a threaded brass rod internal to the pipe, which is controlled from the front panel through an insulated coupling, a right-angle gear drive and a length of flexible shaft.[5]

The anode collar assembly is shown in fig. 13. It is made up of a circle of ¾-inch wide copper strap to which "ears" have been silver soldered. The ears form mounting brackets for the twin plate blocking capacitors. The stator plate of the variable tuning capacitor (C_3) is also silver soldered to this assembly.

The moveable plate of the tuning capacitor is panel driven by means of a simple bearing that translates rotary motion into thrust (fig. 10). The capacitor plate is prevented from turning by a wide ground strap as shown in fig. 10. To preserve panel symmetry, the capacitor is driven off-center from the counter dial by a set of surplus gears.

Grid Circuit Assembly

Three grid terminals are provided on the SK-820 socket and these are connected in parallel by ½ inch wide lengths of ⅝ inch wide copper strap silver soldered to the projecting socket terminals. The junction of the three straps is bolted to the grid inductor (L_2), which consists of a single length of copper strap bent into a hairpin which terminates at the stator lugs of the grid tuning capacitor, C_{12}. The composition isolating resistor R_1 is attached to the junction of the straps which is close to the point of minimum r.f. voltage in the grid circuit.

The input coupling loop (L_1) is about an inch away from the grid inductor and consists of a section of ¼ inch copper strap formed in a hairpin and connected between the input coaxial receptable (J_1) and the loading capacitor, C_1. Aside from the isolating resistor and the two tuned circuits, no other components are mounted within the grid circuit enclosure. Filament and bias leads exit via feedthrough capacitors into a small aluminum box which houses simple r.f. decoupling networks. With a stage gain of over 20 decibels, it is important that no

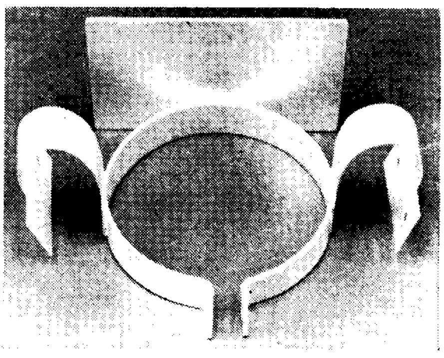

Fig. 13—Anode collar assembly. The anode assembly of the 4CX1000K is made of copper, silver soldered and silver plated. The circular strap encircles the anode cooler of the 4CX1000K and supports one plate of tuning capacitor C_3 and two "ears" which attach to the dual plate blocking capacitors. The capacitor plate measures 2¼" × 4".

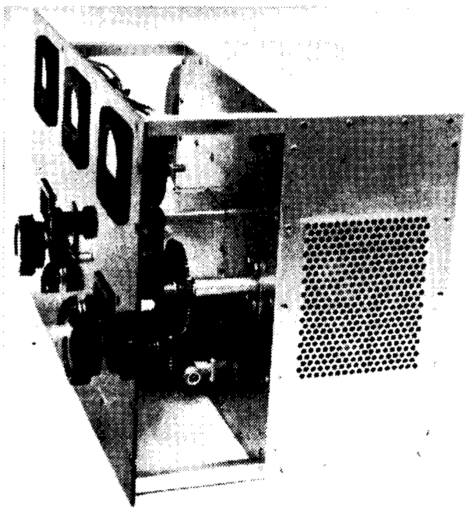

Fig. 14—Oblique view of the v.h.f. amplifier. The r.f. input fitting (J_1), plate circuit gears, and compartment for the power lead filters may be seen in this view. The B plus high voltage connector is located at the top of the enclosure. All meter leads are run in shielded wire, with the shields grounded at each end of the lead and the inner conductor bypassed to the shield with small disc ceramic capacitors at the meter terminals. The end of the plate compartment is perforated to allow exit of cooling air.

r.f. energy be permitted to leak into the grid enclosure. The air inlet at the base of the grid enclosure is covered with screening to reduce r.f. coupling through this opening. In addition, all power leads external to the enclosure are run in shielded braid which is grounded and bypassed at both ends of the lead.

Metering Circuits

Screen, grid and plate circuits are monitored separately by three panel meters. It is useful to observe the ratio of these currents during the tuning process and proper loading can readily be achieved when the operator has sufficient information to adjust the ratio of grid drive to plate impedance. Polarity reversing switches are incorporated in the grid and screen circuits in order to note negative currents often encountered when tetrodes are operated in the v.h.f. region. Meter circuits are returned to a common cathode point, as shown in fig. 7. The complete metering circuitry is shown in the general schematic, fig. 11.

Plate current is measured in the cathode return circuit to the high voltage power supply. It is necessary, therefore, that the negative terminal of the supply be isolated from ground. Both terminals of the bias supply are isolated from ground as is the negative terminal of the screen supply. The bias supply, in addition, is "hot" to ground.

Power Supplies

As is common with all power tetrodes the screen power supply of the 4CX1000K should be well regulated and the supply "bled" to 70 milliamperes or so. Dangerously high plate currents may flow if the screen power supply exhibits a rising voltage characteristic with negative values of screen current.

Voltage stabilization may be accomplished in several ways: a suitable bleeder resistor may be connected across the screen supply or an electronically regulated supply may be used. It is essential to use a bleeder if a *series* regulated supply is used, as such a supply exhibits a high input impedance to negative current. A well regulated, choke input supply capable of 150 milliamperes current capacity and bled to 70 ma is probably the best compromise solution.

The rated heater voltage for the 4CX1000K is 6.0 volts (*not* 6.3 volts). Tolerance is plus or minus 5%, but for longest tube life, the voltage should be held between 5.8 and 6.0 volts. The cathode and one side of the heater are internally connected. Heater voltage and blower should be turned on for three minutes before other operating voltages are applied.

Amplifier Tuning and Adjustment

For initial adjustment, a kilowatt dummy load is connected to the amplifier; bias voltage is applied first and set to approximately —60 volts.

Mode (Class)	Plate Volts	Plate Current (ma)	Plate Input (watts)	Peak Drive Pwr-watts	Power Output (watts)	Max. Grid Current	Max. Screen Current	Grid Bias* (Approx)
AB^1 (s.s.b.)	2000	883	1766	4.5	915	0	20	—53
AB^1 (s.s.b.)	2500	800	2000	4.4	1165	0	21	—55
AB^1 (s.s.b.)	3000	666	2000	6.3	1200	0	18	—56
AB^1 (a.m.)	2500	400	1000	1.2	250	—0.3	—29	—57
B (c.w.)	2500	400	1000	5.2	625	—2.5	21	—80

*Adjust bias for: Resting plate current of 250 ma for Class AB^1.
—Resting plate current of 1 ma for Class B.
—Resting plate current of 200 ma for a.m. linear service.

Fig. 15—Amplifier operating characteristics for the 4CX1000K.

2 KW on 2

Screen and plate potentials are applied *simultaneously* and the grid bias is adjusted for a resting plate current of 250 milliamperes. A small amount of r.f. drive is applied to the amplifier and the grid and plate circuits brought to resonance. The link loading capacitor C_1 is adjusted for lowest s.w.r. on the coaxial line from the driver. Driving power is slowly increased, while dipping and loading the plate tank circuit. Plate loading and grid drive are juggled until the desired parameters outlined in the "Amplifier Operating Characteristics" (fig. 15) are achieved. Grid and screen currents are sensitive indicators of amplifier operation,[6] and these, together with some form of r.f. output meter, will permit the operator to quickly adjust the amplifier for optimum operating parameters. For best linearity, the amplifier should be slightly overcoupled to the antenna so that the r.f. power output drops about two percent from maximum value at the point of proper loading. Under the two kilowatt p.e.p. rating, the amplifier will deliver 1200 watts to the antenna circuit, with a power gain of over 22 decibels. Intermodulation distortion products are low and the signal, when driven by a clean s.s.b. exciter is a pleasure to to listen to. Neutralization, of course, is not required and the amplifier tunes up "just like on the d.c. bands." ■

[6]Meacham, D., "Understanding Tetrode Screen Current," *QST*, July 1961, p. 26.