TECHNICAL REPORT # 13

Date: December 1972

From: The Crawford Hill VHF Club, W2NFA

Subject: A Kilowatt Power Amplifier for 1296 mc/s

This report will describe the modification of a U.S. military surplus pulse amplifier, designated as a UPX-4, for operation as a CW amplifier at 1296 mc/s, Although only a limited number of these amplifiers are available, this report is issued with the hope that the information can be used as a design guide for construction of a similar amplifier built from stock materials. The last section of this report will be devoted to recommendations on variations of the design which may simplify new construction.

The UPX-4 was originally used in an L-band (900-1100 mc/s) pulsed plate modulated transponder ground station and consists of six 2C39 planar triodes in grounded grid configuration. This amplifier is virtually unusable at 1296 mc/s in its unmodified form. The modifications described will result in a high power amplifier capable of delivering 500 watts CW output at 40 to 50% plate efficiency with a power gain of 10.

The initial modification to be made is to replace each glass sealed 2039 with a ceramic sealed 7289, 3CX100A5 or 2C39B. Glass sealed tubes cannot survive high power fields at these frequencies as the glass will heat up, melt and puncture. The 7289 is plentiful in surplus at prices of about $5 each and are recommended." improved version of this tube is also available at higher cost such as the ML-7855 from Machlett and others. These improved tubes are thermally compensated to minimize changes in interelectrode capacitance with temperature. This fault in the 7289 is noticeable as a change in anode circuit tuning when high power operation is attempted at high anode or grid dissipation levels. The effect is not serious if the tube is operated within CCS ratings. However with suitable precautions and for limited amateur service the 7289 is capable of delivering up to 100 watts output at efficiencies of 40 to 50%.

These last remarks should be kept clearly in mind when considering high power amplifiers for 1296 mc/s as the success of this 6 tube amplifier depends on stressing the tubes somewhat to obtain the stated performance. Experience has indicated that the 7289 is very tolerant and may be operated at much higher ratings than the tube specifications would indicate. In this regard several important guidelines can be developed. (a) Never, never exceed the maximum cathode current rating of 125 mA per tube. (b) Keep the tube well cooled by whatever means is available. For instance, water cooling of the anodes will permit anode dissipation several times greater than the rated air cooled dissipation. (c) Provide a very low loss anode tank and output coupling circuit to minimize mismatch heating of the grid. Poor anode and grid socket fingers, leaky anode byppass capacitor, and faulty soldering at high r-f current points are common causes of poor output efficiency and tube overheating problems.

The remaining physical modifications require the use of some machine tools and a fair knowledge of shop practice, none of which are beyond the capability of a devoted UHF enthusiast.

Limited number of 7289s are available from:
Ed Howell, W4SOD, P.O. Box 73, Folly Beach, South Carolina 29439

UPX-4 Modifications

Anode Circuit

Modification of the anode circuit consists of removing the adjustable tuning capacitor at the center of the cavity and replacing it with a short open-end coaxial stub extension. The entire output link coupling, lines and coax jack should be removed and the output hole bored out to be a snug fit with a piece of 1/2 inch outside diameter copper tube which will be the new output coaxial line. This boring operation may be done by first drilling the hole out with a 1/2 inch diameter drill and then increasing the diameter slightly with a hand expansion reamer to just fit the copper pipe. The output adjustable link coupler will be described in a later section.

Measurements show that at 1296 mc/s there is a current node almost exactly at the center of the cavity. For this reason it is necessary to extend the cavity by means of the coaxial stub. The upper portion of Figure 1 shows the coaxial extension and other modifications. The outer conductor is a short length of copper or brass tube which is soldered securely to the anode tube socket plate. Exercise extreme care when soldering near socket finger stock .as the temper can be removed easily resulting in poor contacts.

A technique which can be used for this soldering operation is to fit the pieces together with solder flux in the joint. Then place the assembly on a "hot" plate raising the temperature to a little less than the melting point of your soft solder. Next apply heat to the top end of the coaxial tube by means of a torch until the solder begins to flow in the joint. Avoid using rosin core solder if possible as the clean up becomes involved. Rosin core residue may be cleaned away with alcohol and a brush while the piece is still hot but the solder solidified. Do this in a well ventilated area as alcohol fumes are harmful. Solid solder may be obtained from plumbing houses along with a suitable flux. A very good flux for brass and copper is WETOIL which is basically a zinc ammonium-stannous chloride solution, similar to muriatic acid

$(HCl + Z_n \rightarrow Z_nC_l + H_2\uparrow).$

This solution is corrosive and MUST be thoroughly washed from all parts of the assemble.

Apply a small quantity of liquid flux with a small soft brush while the solder is in a liquid state. Short brush strokes will produce excellent wetting of the surface and distribution of solder without destroying the brush bristles. Spattering of the corrosive flux will occur and it is advisable to shield clothing and the eyes as well as any other delicate. apparatus within spattering range.

The drawing in Figure 1 is approximately to full scale as a guide in selecting material sizes. No dimensions are very critical and considerable variation can be taken in material sizes. The center post or conductor of the coax extension should be machined from copper if possible and flared at the bottom of the anode cavity as shown. An alternative to soldering this post in the cavity is to very carefully machine the bottom of the flared section so that it mates flush with the cavity wall, then undercut the entire bottom leaving a small chamfered edge. This edge should 'bite' into the cavity wall for a good electrical contact when the piece is secured with three screws through the cavity Wall. Rounding the top of the post is recommended to minimize r-f breakdown as this is an area of high r-f electric field. Alignment of the post in the coax section should be good so that the sliding Teflon dielectric tuner will not bind. Tuning is accomplished by sliding the Teflon rod into and out of the coaxial stub

thus changing the capacitive end loading. A tuning range of ±50 mc/s is easily achieved by this method which is adequate for this amplifier. By making the Teflon rod a snug slide fit to the outer conductor, no locking arrangement need be used. Adjustment will be smooth by turning the rod as it is moved in the axial direction. More elaborate means of adjusting the rod are left to the desire of the builder though not required.

In the original amplifier, the anode by pass capacitor used 4 pieces of sheet Teflon. In the modification only one need be used as the peak voltages d-c and r-f will be lower than in the pulsed case. The three remaining Teflon sheet pieces should be kept for spares.

The final modification to the anode circuit is in the air plenum. The plenum covers (see Figure 1), which contains the spring loaded tube hold-downs, must have an enlarged center hole to accommodate the coaxial stub and also to provide the air exhaust or intake port. The spring loaded hold-downs should be removed and the holes filled by soldering on thin sheet discs. To replace the hold-downs and provide better distribution of the available air between the tubes, a single thin wall cylinder of insulating material (fiber) is used as shown in Figure 1. The length of this cylinder is carefully cut so that the plenum cover presses down on the cylinder which in turn holds down all the tubes together. The cylinder material cannot be thermoplastic. The cylinder is nominally 2.5 inches in diameter and about 0.8 inches long. If a suitable cylinder cannot be obtained it may be fabricated from flat stock and epoxy cement in the form of a hexagon.

The entire plenum should be sealed except for the intake and exhaust ports. This may be done with plastic electrical tape or other suitable adhesive tape. By sealing the plenum, maximum air flow through the tube cooling fins is achieved. In addition, and most important, the over pressure (or vacuum) in the plenum forces air to pass through the anode finger stock which in turn forces air past the grid finger stock. It is essential that cooling of the anode and grid seats occur as well as to have some air flow through the cathode chamber. This can all be accomplished with a single high velocity blower. At W2NFA a household vacuum cleaner with bag and filter removed is used to exhaust air from the plenum at the side port. Thus all other ports are intakes. The anode plenum provides still another useful function as an r-f shield for any leakage past the bypass capacitor. There is no apparent advantage to applying vacuum or pressure to the plenum.

All solder work must be carefully cleaned of flux residue and excess solder then thoroughly washed in a strong detergent soap, rinsed and dried. This cleaning procedure should be used especially before final assembly of all parts of the amplifier. Too often a small chip of metal will lodge on a vital part, such as the dielectric of a bypass capacitor, causing breakdown or poor seating. In some cases it may be advisable to clean the ceramic grid-anode spacer of the 7289 tube if it is discolored, especially by pencil marks or other conductive materials. Cleaning can be done with a stiff brush and household scouring powder. Do not use a wire brush and thoroughly rinse the tube and carefully dry it before use in the r-f circuit.

Cathode Circuit

This cathode circuit modification is aimed at using as much of the' original amplifier material as possible. An alternate modification, which will be described later, discards the entire cathode assembly. Both modifications are essentially the same electrically and perform equally well. The electrical circuit consists of a single high-Q resonator to which the tube cathodes are magnetically coupled in a non-resonant manner. This arrangement was first suggested by K4QIF and has proven to perform better than others which have been tried.

The lower portion of Figure 1 shows the completed modification in which the cathode casting has been machined. Figure 2 shows the basic modification to the cathode casting which consists of cutting the casting off at the parting line shown. The cut surface should be faced off on a lathe for accuracy. The parting line location is determined by having the effective length of the Teflon loaded cathode coaxial bypass capacitor be an electrical quarter wavelength at 1296 mc/s, which is 1.6 inches for the Teflon dielectric. This dimension dictated the height modification of the cathode chamber. The new cathode chamber wall is made of a piece of 5 inch diameter (1/flinch wall) copper or brass tube, 1.10 inches high which is permanently soldered to the cathode casting and carefully faced off (lapped on a flat surface or turned on a lathe) to be a tight fit with the bottom wall of the anode cavity. Since the cathode chamber wall shape and diameter' are not critical an alternative is a strap of brass or copper which

may be formed into a cylinder or hexagon approximately 5 inches in diameter.

The tapered hole at the center of the casting is filled with a piece of the original tapered coaxial line center conductor which is truncated and soldered inas shown in the lower portion of Figure 1. A short piece of 1.0 inch 0.D. copper tubing is pressed into the central hole of the truncated cone section and soldered in place. This is the cathode resonator and is equipped with finger stock and a sliding copper cylinder which provides capacitive loading and resonance adjustment. A non-metallic plunger handle and guide ring complete the resonator construction. Capacitive loading of the cathode resonator will be large since the resonator is considerably shorter than a quarter wavelength. For this reason small changes in plunger setting will greatly affect the resonant frequency. The builder may wish to consider a vernier arrangement for tuning (either electrical or mechanical).

The original heater-cathode stem assemblies are used as-is but extended further into the cathode chamber than in the original design. The fibre annular ring used to retain the heater-cathode stems is also used in its original role. A minimum of three holes should be drilled and tapped into the casting to provide an anchor for the retaining ring. Assure that registration of the retaining ring and holes in the casting is good before drilling the anchor holes. Six threaded studs were used as anchors in the original design.

Air holes must be drilled through the cathode chamber wall as in the original design. In addition, one 1/2 inch hole must be bored through the casting and chamber wall exactly between two of the tubes for installation of the cathode input line. This will be a non-adjustable assembly as shown by Figure 3.

All of the solder operations can be performed with a single heating if the parts are prepared and fitted before soldering. These parts include the tapered hole plug, resonator piece with finger stock pre-bent and installed, the coaxial input line tube and the cathode chamber wall. After soldering and thoroughly cleaning the assembly of residue flux and excess solder and finally washing in strong detergent, the cathode stems and retaining ring may be installed and the cathode resonator tuning plunger assembled.

Input and Output Coupling Output

Figure 3 shows the details of the output coupling which is by means of a magnetic loop located between any two tubes in the amplifier. The thin wall copper tube (1/2 inch copper water pipe having 0.040 inch wall thickness) and the 3/16 inch diameter inner conductor rod form very nearly a 50 ohm line as discussed in Report #12. The anode cavity wall where the ,original output line was located is carefully bored and reamed to be a snug fit With the line tubing. The new coupling line and loop are inserted through this hole after being assembled. The line section is made approximately one half wavelength long in order to avoid additional mismatch resulting from the line section impedance being different from that of the load. By this selection of line length, the characteristic impedance of the line section may be altered to suit available materials.

The copper strap comprising the actual coupling loop is carefully soldered into [a] longitudinal slot cut in the copper tube, The slot should be as wide as the strap and about 1/2 to 3/4 inch long. File away excess solder on the outside of the tube until the link assembly will slide into the bored hole in the cavity wall. An alternate and more simple way to solder the strap to the tube is to carefully tin the inside of the tube then fit the copper strap inside the tube and sweat it in place. A locking screw for the output line is required as shown in Figure 3.

This line construction does not provide a captive inner conductor. The builder may wish to use a panel receptacle in place of the cable connector shown in the drawing to provide the captive pin. The coax receptacle should of course be soldered securely to the copper tube. (see Technical Report #12 for details)

The depth of the link into the cavity should be approximately as shown in the drawing. A 'stop' may be provided in the form of a piece of tubing which fits over the line section and located on the outside of the cavity. Its length can be cut so that the line section penetration cannot be deeper than shown. Rotation of the line section changes the orientation of the magnetic loop and thus changes the coupling to the fields inside the cavity. Maximum coupling will occur with the plane of the loop parallel with the axis of the tubes. Experience has indicated that optimum coupling with this link assembly occurs with the plane of the loop at about 45 degrees off axis. This adjustment should be made very carefully with the amplifier under full power (see tune-up procedure).

Input

The input coupling method is also shown by Figure 3 and consists of a semi-permanent tap on the cathode resonator. Details of the line

section with regard to captive pin and impedance are the same as for the output coupling line section. The cathode input line section is soldered permanently into the cathode chamber wall as shown. The actual tap to the resonator is made with a piece of wide finger stock or strip of beryllium copper which is soldered to the center conductor of the coax line but only presses on to the resonator. The position of the tap should turn out to be near the center of the resonator tube length. However, it may be necessary to move the tap point above or below this point for best match from a 50 ohm source impedance (see tune-up procedure).

Final Assembly

The modified cathode casting assembly may now be bolted to the anode cavity lower surface using longer bolts than the originals because of the extended height of the cathode wall. Check to see that the heater-cathode stems are all in good coaxial alignment with the grid rings before drawing up on the bolts. Draw up the bolts to obtain uniform pressure around the periphery of the wall. The remaining parts of the anode cir[c]uit, and plenum may now be assembled along with 6 tubes which have been d-c tested and have nearly balanced anode currents.

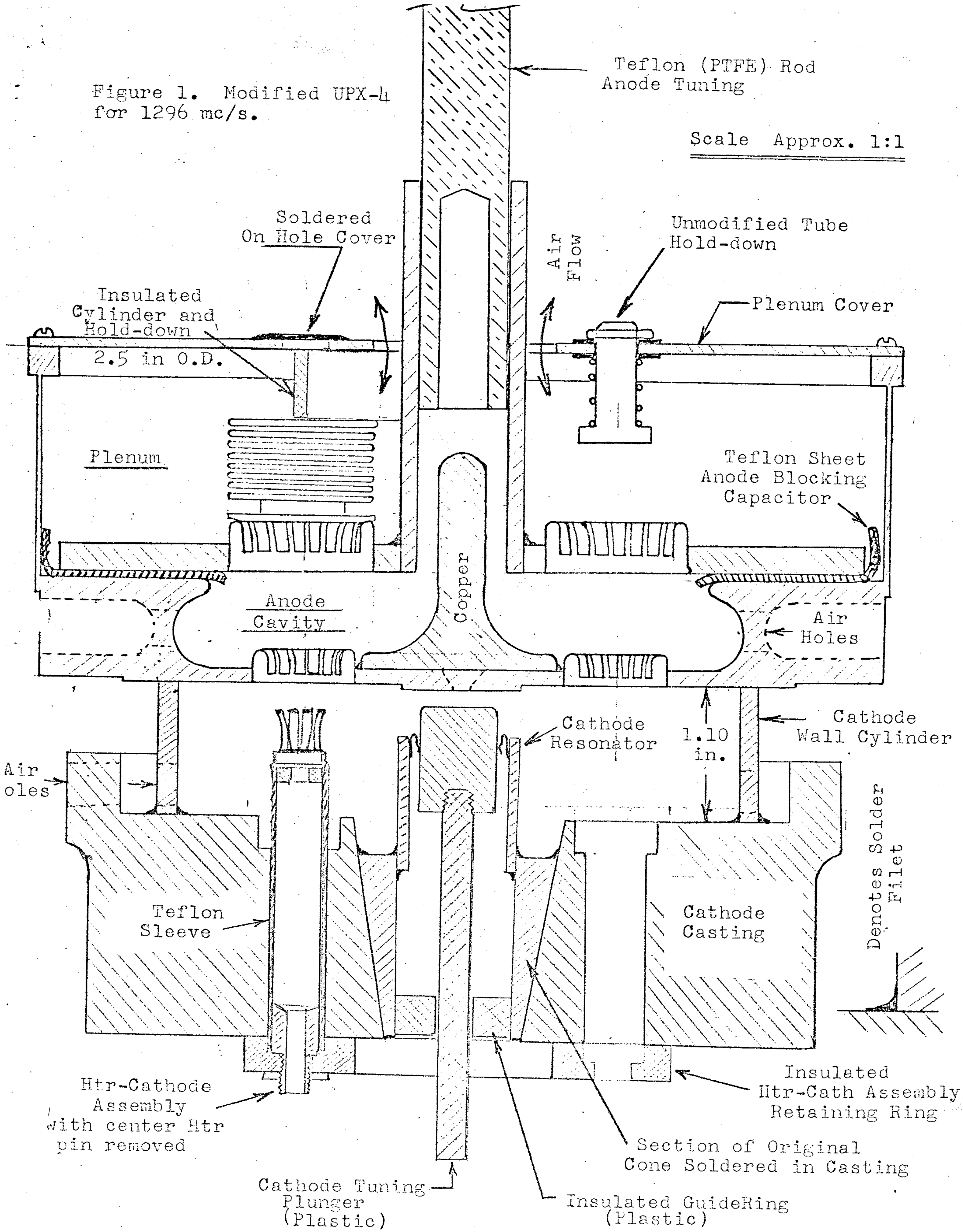
Tube testing may be done directly in the amplifier for socketing convenience. Short term (several seconds) testing without air cooling may be done without damage to the tubes at about 1 kv with 100 ohm cathode resistance. Typically, a useful 7289 will draw anode current of 60 to 100 mA depending on cathode activity. Tubes which draw less than 50 mA are useful tubes but should not be used in this amplifier. Balance between tubes used should be within ±10 mA. Tubes which draw excessive anode current or are erratic may be gassy and should not be used. Save these tubes for dimensional jigs on future projects.

A suggested control and metering wiring diagram is shown by Figure 4. Only one meter is used which requires a 'home brew' shunt to increase the meter range from 200 mA to 1000 mA full scale. Each heater may be energized from separate transformers if one with six 6.3v/1A windings is not available. The 250 ohm 2 watt adjustable cathode bias resistors are composition resistance potentiometers whose shafts should be easily accessible for trimming bias on individual tubes. These pots have been used and found adequate even though their dissipation rating may be slightly exceeded. Mount them on an aluminum panel for a heat sink.

A high voltage supply capable of delivering 600 mA at 1600 volts is recommended although any supply voltage in the range 1500 to 2000 volts will suffice. The higher voltage may be more desirable since reduced anode current can be used.

A non-inductive resistor of approximately 50 ohms and 20 watts dissipation should be mounted next to the anode voltage terminal on the amplifier and in series with the supply lead. The purpose of this resistor is to suppress parasitic oscillations as described in the remarks section.

Figure 1. Modified UPX-4
for 1296 mc/s.



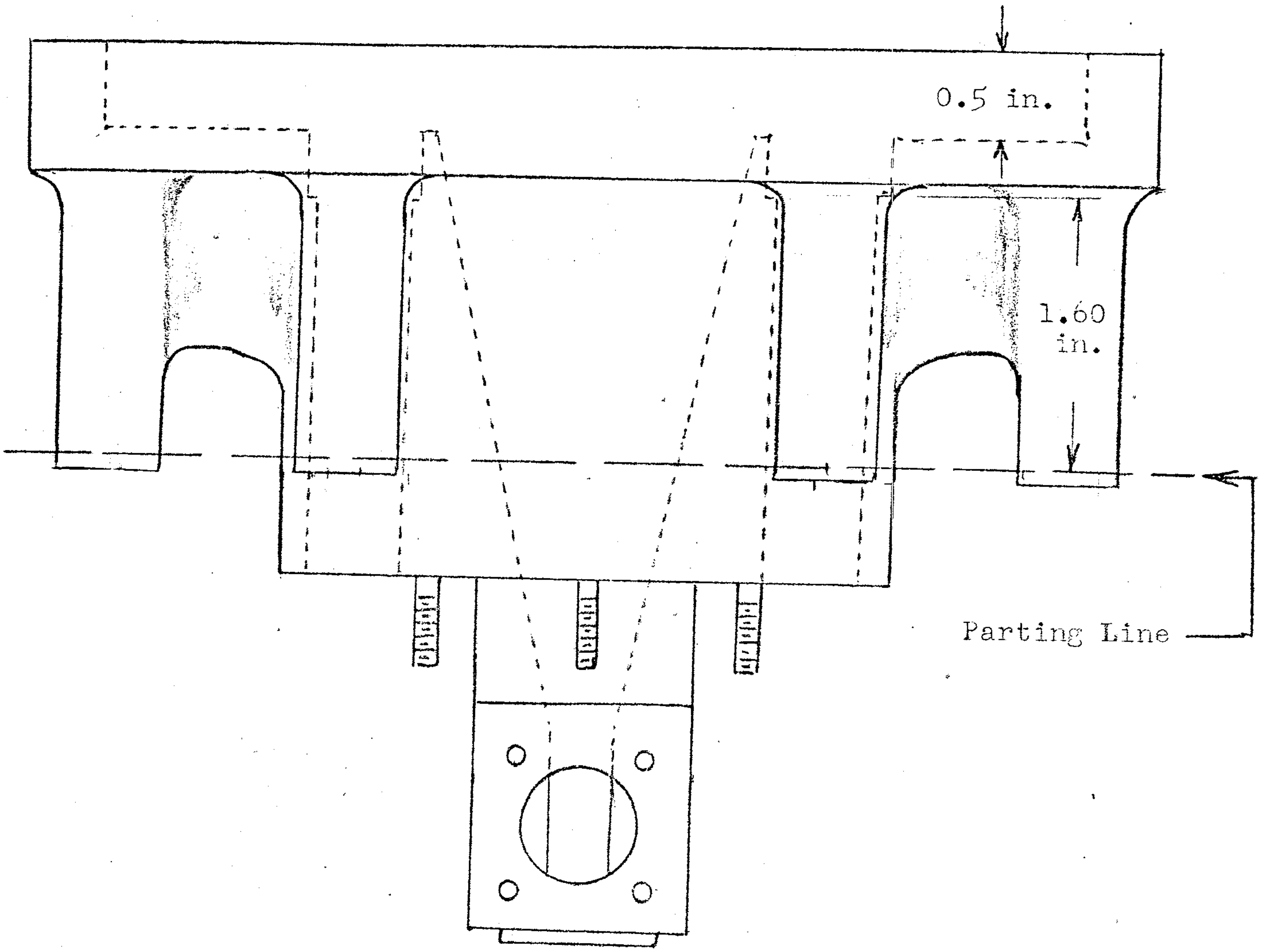


Figure 2. Unmodified cathode casting stripped showing parting line and important dimensions.

Figure 3
Input-Output coupling methods for the modified UPX-4 1296 mc/s Power Amplifier. The coaxial lines may be located between any pair of tubes in the amplifier. Locating the input and output lines on diametrically opposite sides of the amplifier may be desirable for convenience and minimum external feedback.

The line sections are made about one half wavelength long so that if the characteristic impedance of the line section is in error by a moderate amount its effect will not introduce additional mismatch.

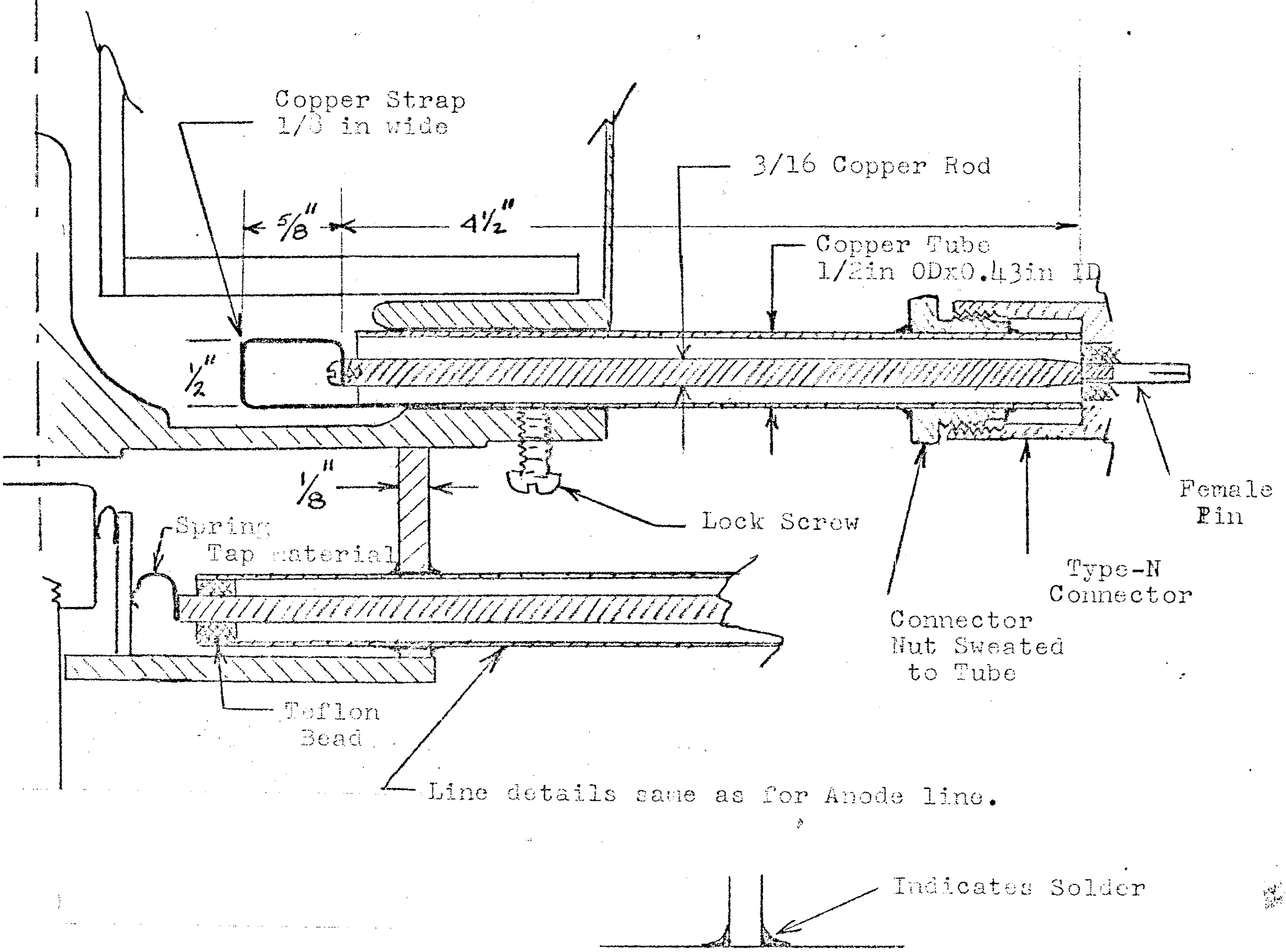
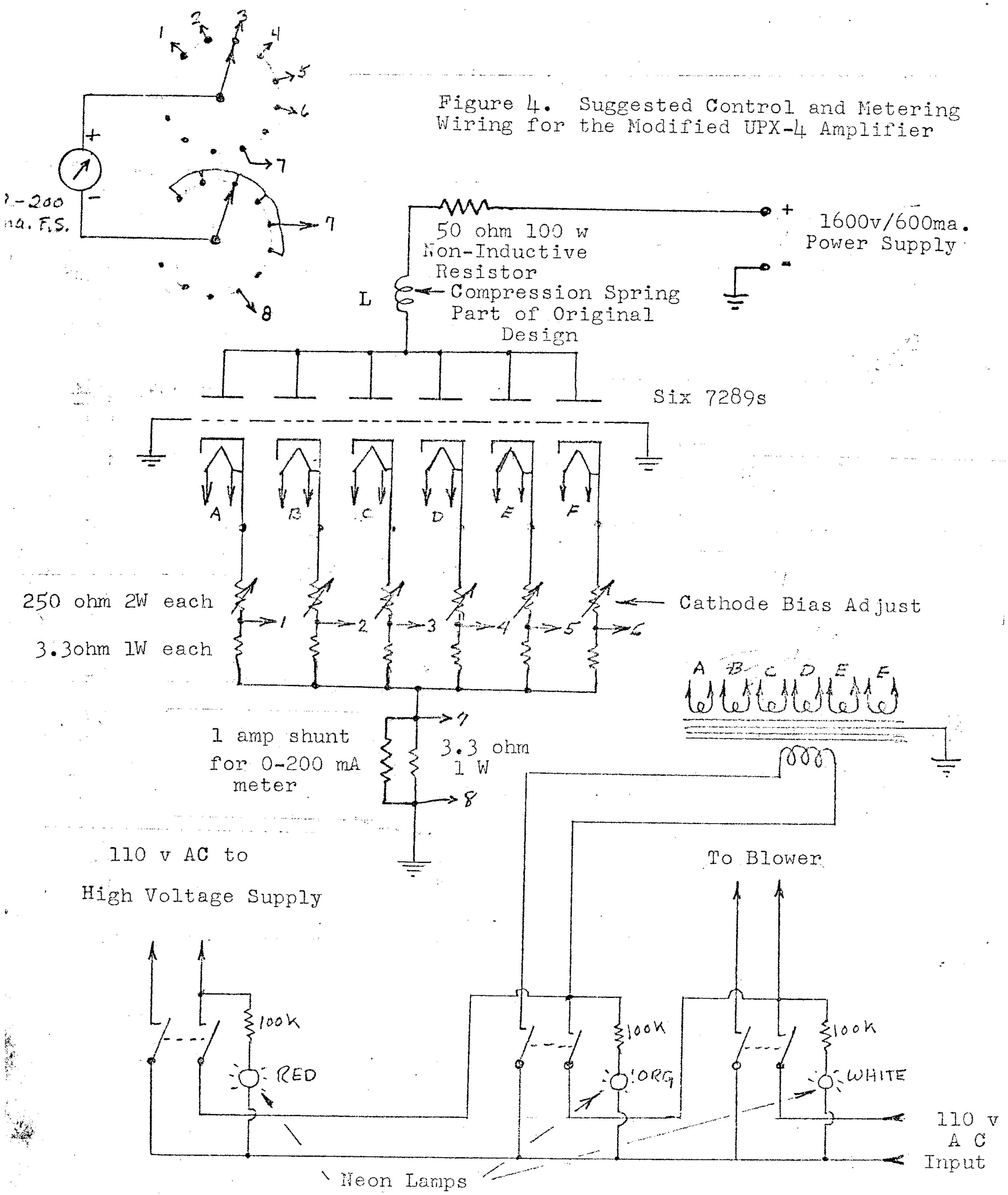


Figure 4. Suggested Control and Metering Wiring for the Modified UPX-4 Amplifier



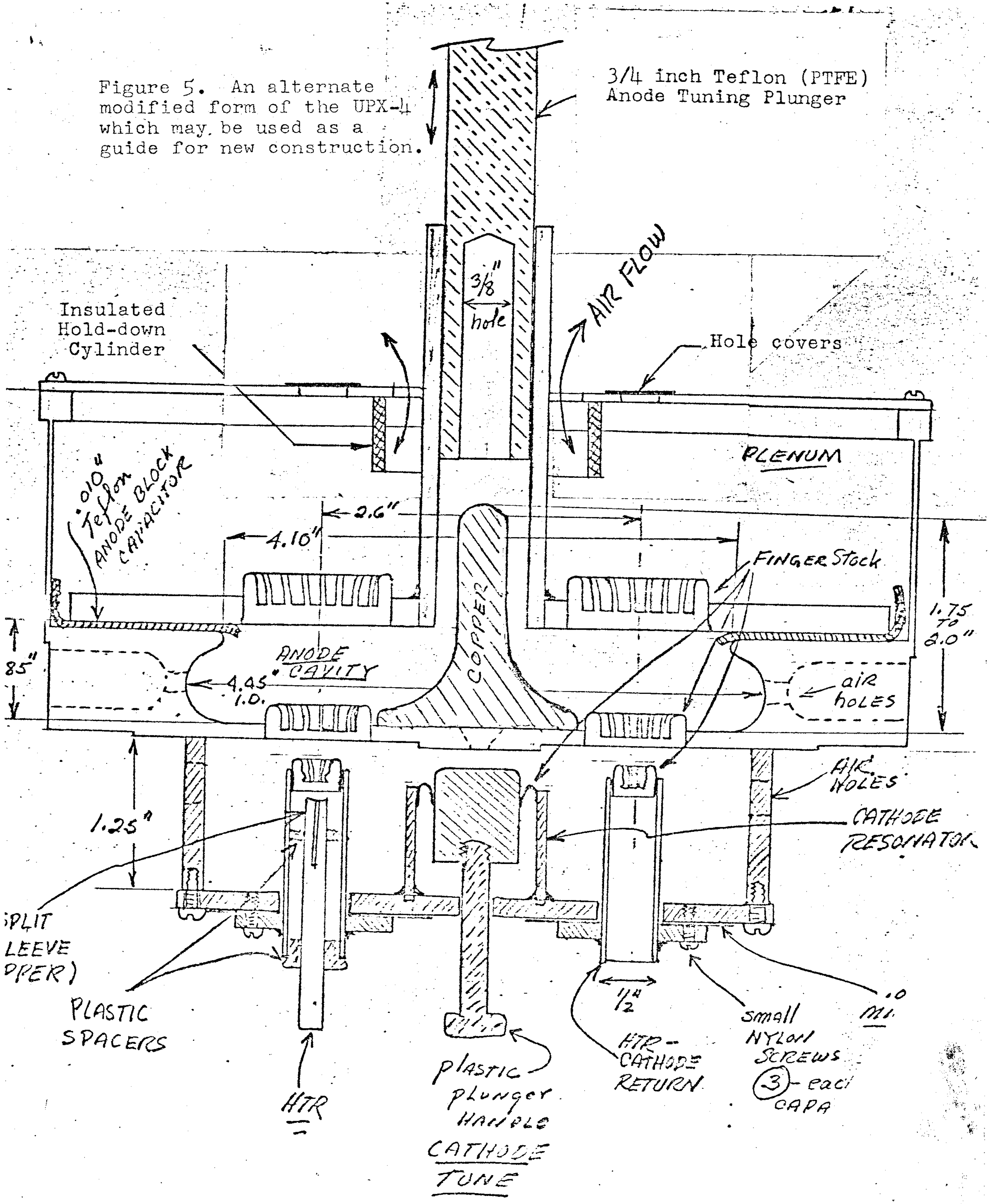


Figure 5. An alternate modified form of the UPX-4 which may be used as a guide for new construction.

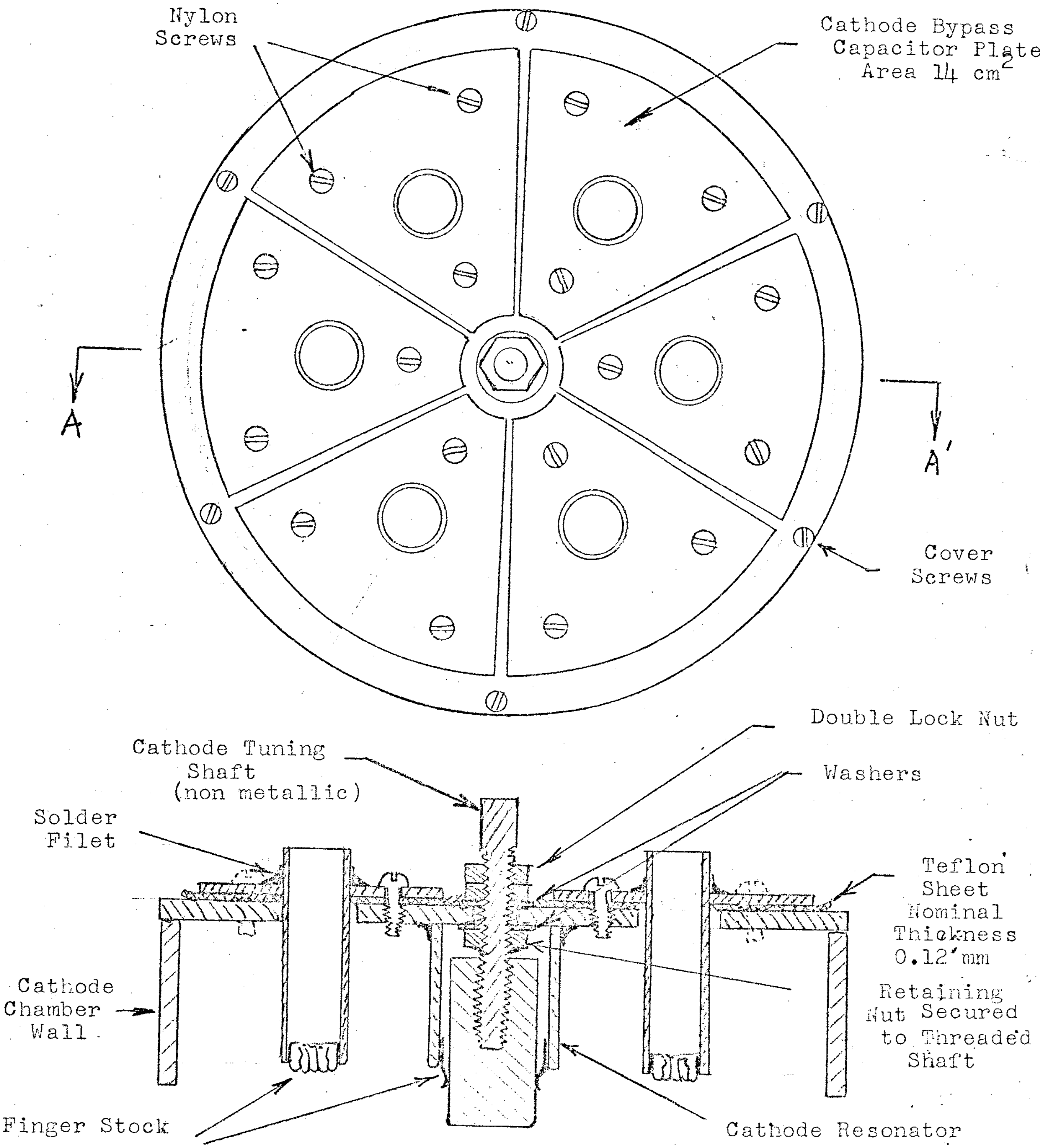


Figure 6. Cathode bypass capacitor details. Also a method of vernier tuning of the cathode resonator.

Tune-Up Procedure

Initial tune-up of this amplifier, as with any high power amplifier, should be done very carefully and with caution. Hazardous voltages and r-f field levels are involved. The high voltage supply should be initially equipped with a variable autotransformer at its input in order to slowly increase the anode voltage while checking for faults in wiring, Teflon sheet errors or breakdown and tube balance. The high voltage supply should be fused at both input and output if possible.

With the bias resistors set at approximately mid range, the supply voltage may be increased to about 1000 volts while noting and trimming the bias for nearly equal anode current to each tube. It is highly advisable while making these initial d-c tests to have a suitable r-f termination at both input and output with the output coupler set for maximum coupling. This precaution is to minimize the possibility of the amplifier oscillating on frequency due to unfortunate tuning of the circuits.

If no erratic behavior of the anode currents is noted and the tubes are reasonably balanced (±10 mA), full anode voltage may be applied and tube bias readjusted so that the static idling current per tube is about 50 mA. Of course the full air cooling system should be in operation during all power tests.

It will now be necessary to include the output double slug tuner (seeTechnical Report #12) as a permanent part of the output coupler assembly. A good matched load capable of dissipating several hundred watts must be available as well as some means of indicating output power. A simple detector probe, weakly coupled to the termination, will indicate when maximum output occurs but will not give an absolute indication of output power. The method described in Tech Report #7 may be used for absolute power determination once the amplifier is properly tuned for maximum efficiency.

Next connect a suitable driver with adjustable output up to about 50 watts maximum to the input port. With output load and indicating device attached, apply input power of about 10 watts and carefully tune the cathode resonator for maximum increase in cathode current. Without high voltage, the metering reads grid current while with high voltage, the meter reads anode plus grid current which is cathode current.

Once the cathode resonator is tuned, anode voltage May be applied and the drive level adjusted so that maximum current per tube does not exceed about 100 mA. Now, quickly tune the anode cavity for resonance as indicated by maximum output. The link coupling should be set at about 45 degrees or less to the tube axis initially. The remaining procedure consists of readjusting input and output tuning, as well as coupling, in incremental amounts for maximum output while maintaining cathode current less than 100 mA per tube. Reduce the drive if more current occurs and observe carefully for erratic behavior indicating oscillations. When the amplifier circuits have been reasonably optimized, the output double slug: tuner may be adjusted for maximum output while readjusting the link position (rotation) and anode cavity tuning.

It will be observed that maximum output and minimum cathode current do not coincide. It will also be observed that tuning the anode cavity slightly higher in frequency than where maximum output occurs will significantly reduce the anode current with little sacrifice in output. This tuning procudure will result in maximum anode circuit efficiency.

If possible, a check should be made of the input line SWR. In general if the line between driver and input to the UPX-4 is short (under one meter) and low loss, any reasonable mismatch at the UPX-4 input can be compensated at the driver output tuning. Some effort should be made to readjust the input tap if the input SWR is greater than 4:1. If drive power is at a premium perhaps the use of a tuner similar to the output slug tuner may also be used at the input.

Alternate Designs

The efficient use of multi-tube parallel operation of planar triodes `at UHF in a properly designed circuit has been well established." The UPX-4 represents a good working design and can be duplicated or used as a guide with variations to suit available materials.

A variation of the input circuit is shown by the lower portion of Figure 5. In this variation, the major difference in design is in the cathode bypass capacitors which are shown in more detail by Figure 6. These are non-resonant capacitors and, because of the larger surface area, capacitance greater than 100 pf can be obtained with reasonable dielectric thickness.

The anode cavity may also be altered by enlarging its diameter and placing the tube centers on a larger diameter circle. In this way the coax stub extension necessary in the UPX-4 modification may be absorbed into the annular cavity resulting in a simple 3 /4 mode radial waveguide type cavity with capacitive center loading. The walls of the anode cavity need not be made from a single large casting as was done in the UPX-4 but may be made from a cylindrical copper section of appropriate height. The anode cavity height is largely determined by the spacing of the anode-grid connections. Increasing the anode cavity inside diameter to 5 inches, similar to the cathode chamber, and placing the tube centers on a 3.5 inch circle should result in a resonance at 1296 mc/s with little or no stub extension at the center of the cavity. The experimenter should be prepared to make two designs when trying new circuits at UHF, one as an exploratory model to determine exact dimensions and a final design which can be powered.

Figure 6 details a simple method of mechanical vernier for tuning the cathode resonator.

There is little doubt that the number of tubes operated in parallel in this type circuit can be from 5 up to perhaps 10 if higher output power is allowed. In changing the number of tubes the experimenter should be prepared to do more exploratory work as the possibility of extraneous resonances existing in the larger cavities increases.

In general new designs should incorporate relatively thick wall material for resonator cavities for physical stability under thermal and mechanical stress.

"Annular Circuits for High-Power Multipe Tube, Radio-Frequency Generators at Very-High Frequencies and Ultra-High Frequencies", D. H. Preist, Proceedings of the IRE, May 1950, pages 515-520.

Remarks

WARNING High power radio frequency fields, especially in the UHF region of the spectrum, ARE harmful to health!

The amplifier described in this report is capable of delivering as much r-f energy as most microwave cooking ovens and should be treated with equal or more respect. Damage to human tissue occurs as a direct result of heating. As with microwave cooking, heating occurs throughout the tissue mass and is not confined to the surface as in radiant cooking. The eyes are especially vulnerable since their ability to dissipate internal heat is very poor. If you can 'feel' the effect of r-f heating with your fingers, the level is already far in excess of acceptable levels.

In testing high power r-f amplifiers, take care to see that the r-f fields are confined to circuits, lines and loads. Use shielding where leakage cannot be avoided. A special precaution is indicated in testing with antennas and ultimate use of antennas with high r-f power. Never, never allow your body to come near the mouth of a horn radiator or feed antenna. Linear antennas (dipoles, ground plane verticals, loops and small yagis) are especially dangerous since the radiation is not confined to a small angular sector.

A generally acceptable r-f energy density level is 1 milliwatt per square centimeter. Energy density level estimates can be made knowing the power delivered to an antenna, its absolute gain in the direction of concern and the distance from antenna to the point of concern.

$$P_{mw/cm^2} = \left(\frac{P_o}{4\pi}\right) \cdot \left(G_p \right) \cdot \left(\frac{1 \text{ cm}}{R \text{ cm}}\right)^2$$

As an example suppose that you have a dual mode feed of the type described in Technical Report #5 or #9 which has an on-axis absolute gain of about 10 and you can deliver 450 watts of r-f power into this feed. The radiation density at a distance of 3 meters directly in front of the feed horn is:

$$P(mw/cm^2) = \frac{450{,}000 \text{ mw} \times 10}{4\pi \times (300\text{cm})^2} = 4 \text{ milliwatts/cm}^2$$

This is a relatively high level by acceptable standards and a dangerous level for exposure periods of more than a few seconds. Remember that heating effects are generally polarization insensitive in the human body.

Of particular concern with a high power amplifier of this type (grounded grid) is that although the r-f circuits are adequately contained in this design at UHF, it is not true at much lower frequencies. Parasitic oscillations can occur at any frequency where the anode and cathode are subject to certain impedances which are a function of stray external lead lengths (inductance) and stray as well as circuit capacitances. These oscillations are usually indicated by erratic behavior and presence of r-f outside of the UHF enclosures. In order to minimize the possibility of the amplifier becoming a high power oscillator at frequencies far removed from 1296 mc/s, a resistive load is provided in the anode power supply line. Approximately 50 ohms of non-inductive resistance which will dissipate about 20 watts can be used with a slight reduction in anode supply voltage. This resistor also serves a dual purpose in limiting the maximum peak current to the tubes in the event of internal flashover. This is protection which the tube manufacturers recommend.

If a single non-inductive resistor cannot be obtained, a network of smaller resistors is acceptable. These resistors may be insulated from and mounted on the plenum cover plate. The absolute value of resistance is not critical provided that it can dissipate the resulting I^2R heat. Further decoupling, and parasitic suppression maybe required in specific circumstances.

Oscillations at or near 1296 mc/s can also occur with improper loading and or tuning. A grounded grid amplifier is only conditionally stable.

WARNING

In this modification, no mounting, packaging or enclosing structure are indicated. As the d-c power requirements for this amplifier are lethal special consideration should be given to a suitable protective shield around the anode circuit. Note particularly that the coaxial extension stub operates with the outer conductor at full anode d-c voltage. Since the anode tuning control is located at the end of this stub, it is highly advisable to enclose the upper plenum with a suitable shield to prevent accidental bodily contact with the high voltage. The high voltage lead from the power supply may conveniently be made from a piece of RG/8 coaxial cable whose outer shield should be used for the ground return to the power Supply.