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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 unuseable 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 2C39 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. An improved version of this tube is also available at higher cost such as the ML-7355 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 bypass 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 VHF enthusiast.

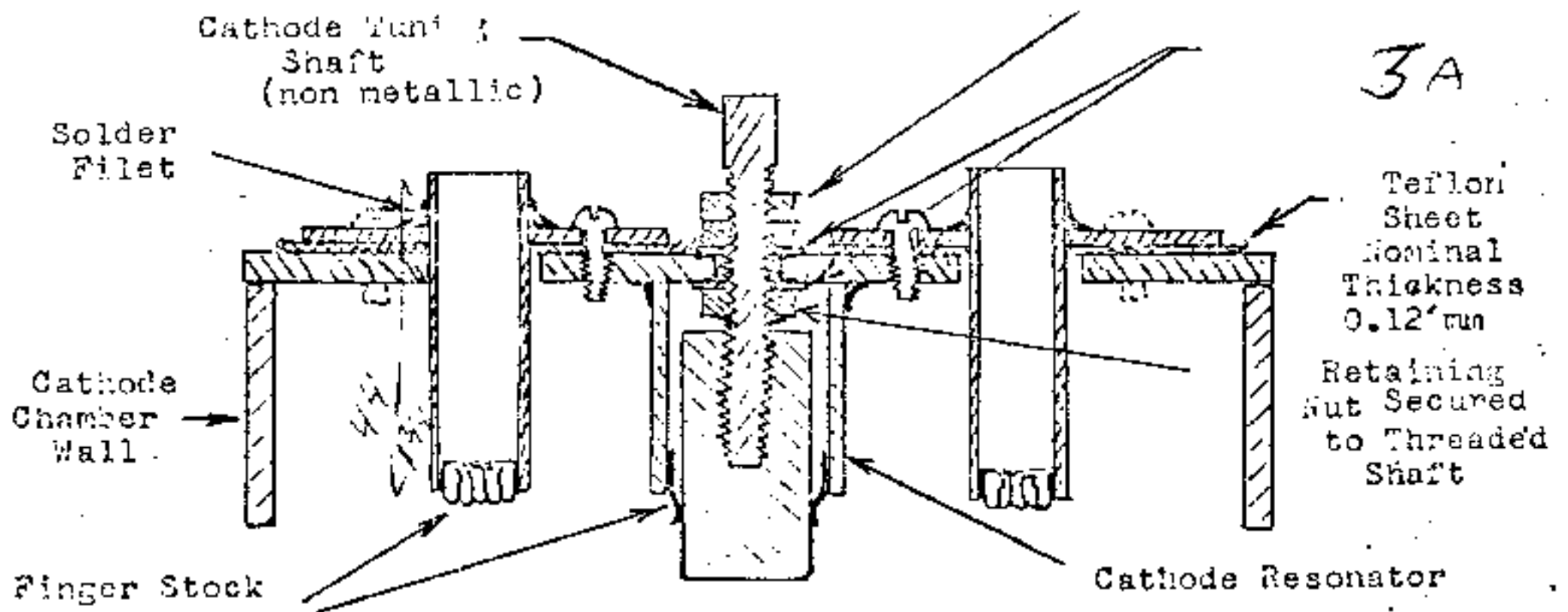
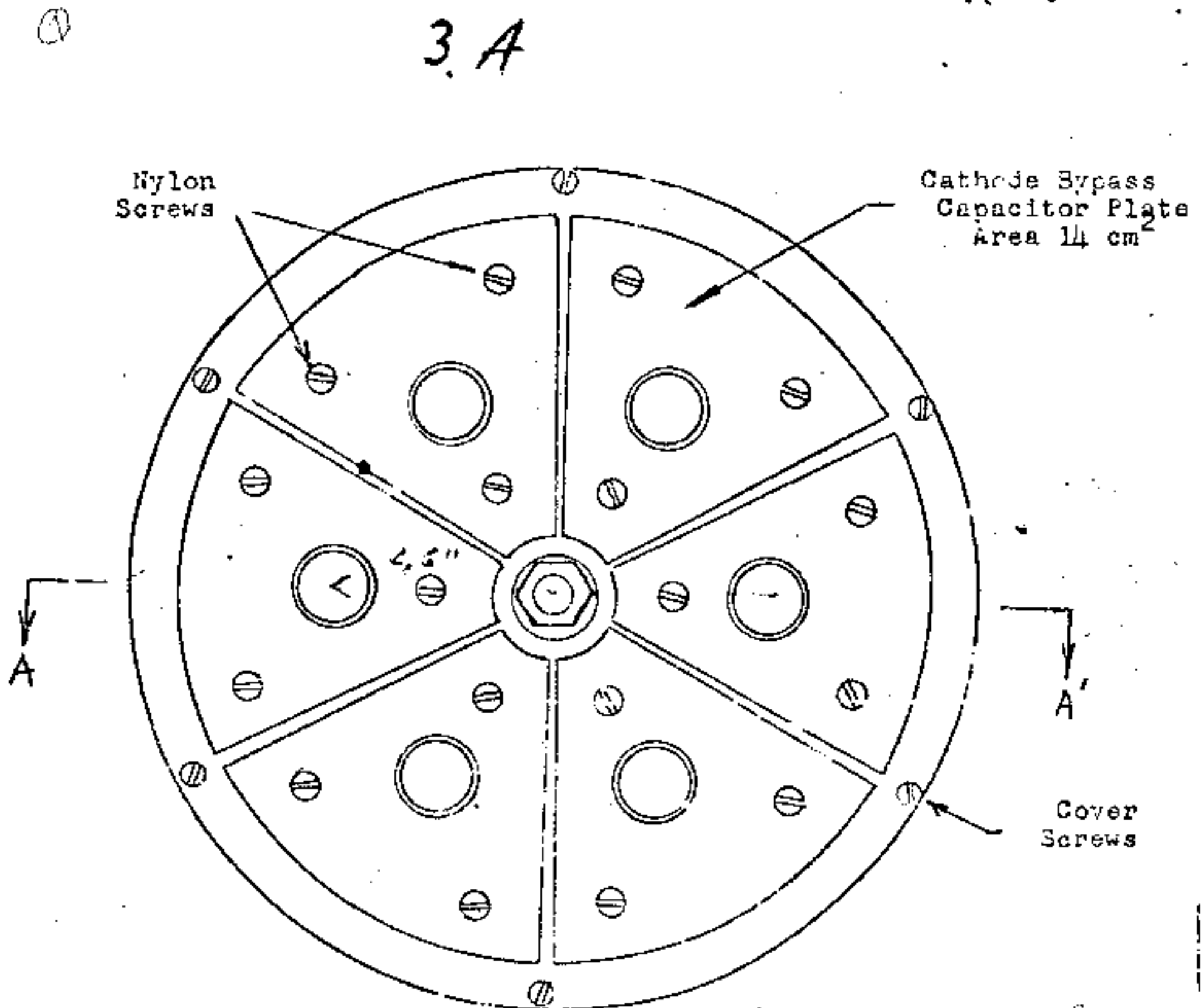


Figure 6. Cathode bypass capacitor details. Also a method of vernier tuning of the cathode resonator.



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

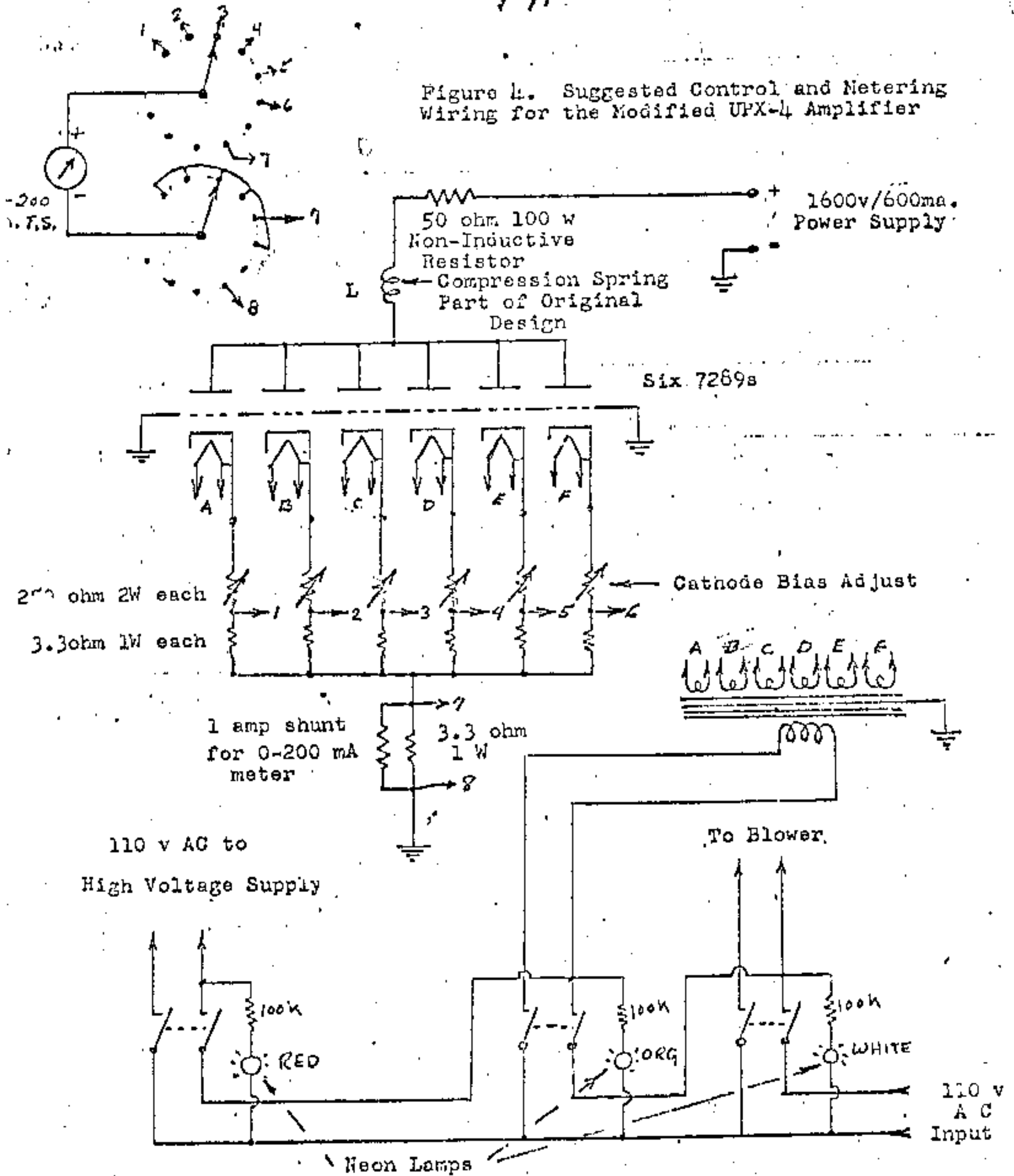
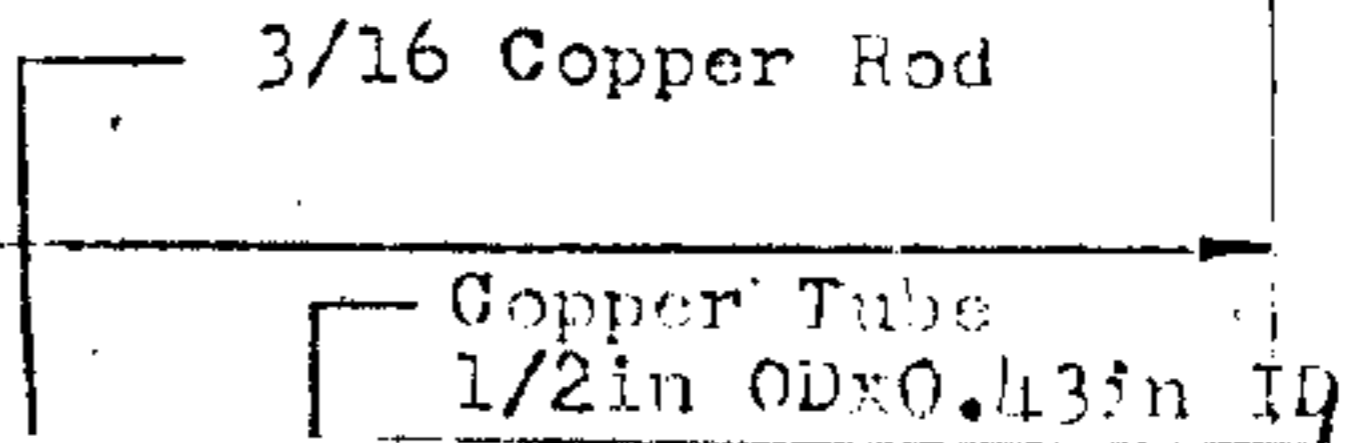
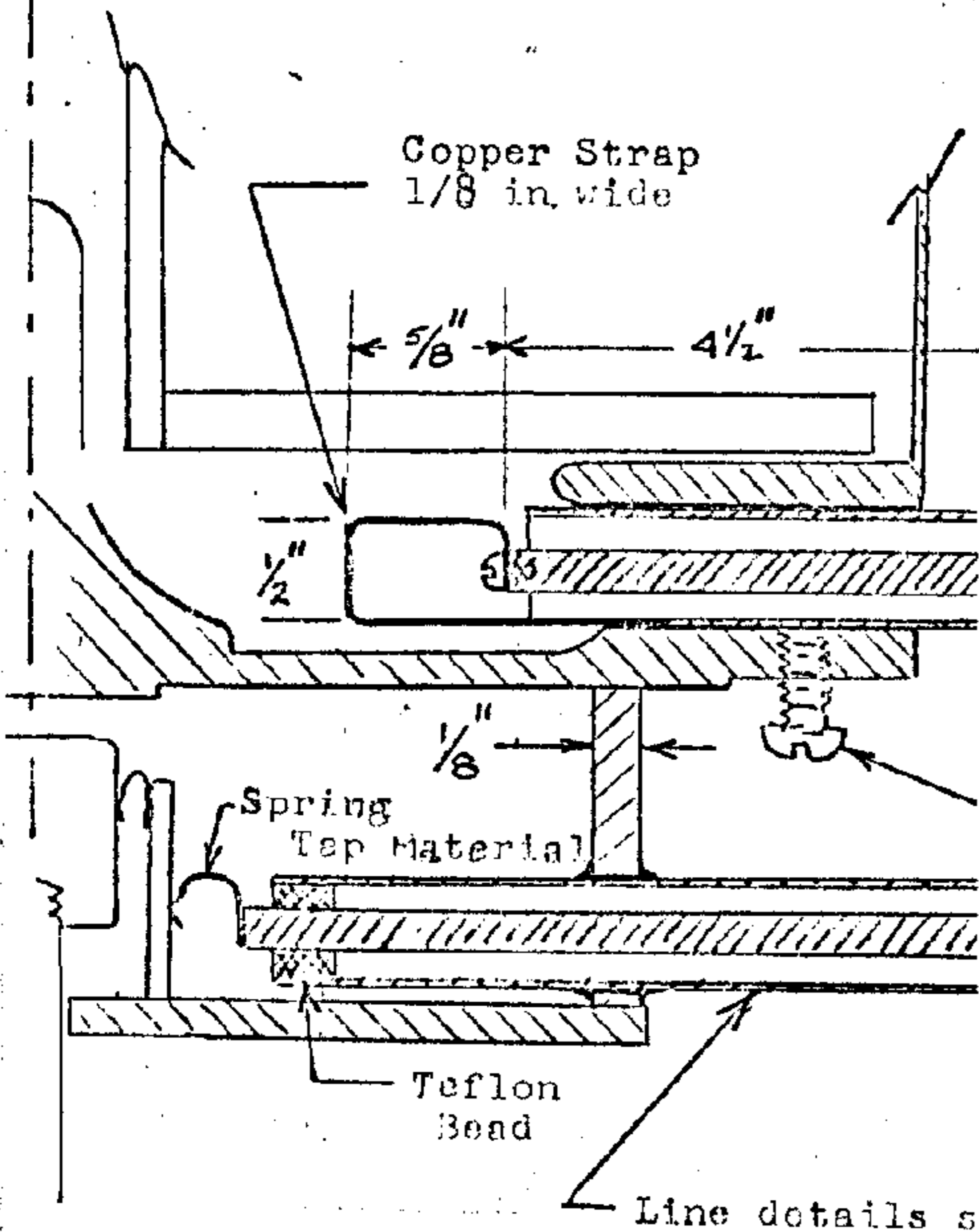


Figure 3

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.



Modifications to the UPX-4 1-3GHz pa.

A number of UPX-4 type six-valve amplifiers (either homebuilt or ex-OZ9CR) are known to be operational in the UK. A number of users of this amplifier have reported difficulty in achieving the power output of which the amplifier is capable. The main reason for this seems to be that the output link as originally specified is not optimum. The use of a slug tuner (see *Microwaves* June 1981) can help considerably, but a better solution is to use a modified output loop. G3YGF and G4CNV have developed a new output loop so that the amplifier can deliver full power, into a well-matched load, without needing a slug tuner. Details of their modified loop are given in Fig 2(a). When optimizing the penetration and angle of the loop for optimum power output, it will be found that there are two possible penetrations for best performance, one with the loop barely into the cavity, the other with the loop well into the cavity. To prevent possible flash-over problems the position with the loop only just into the cavity is preferable.

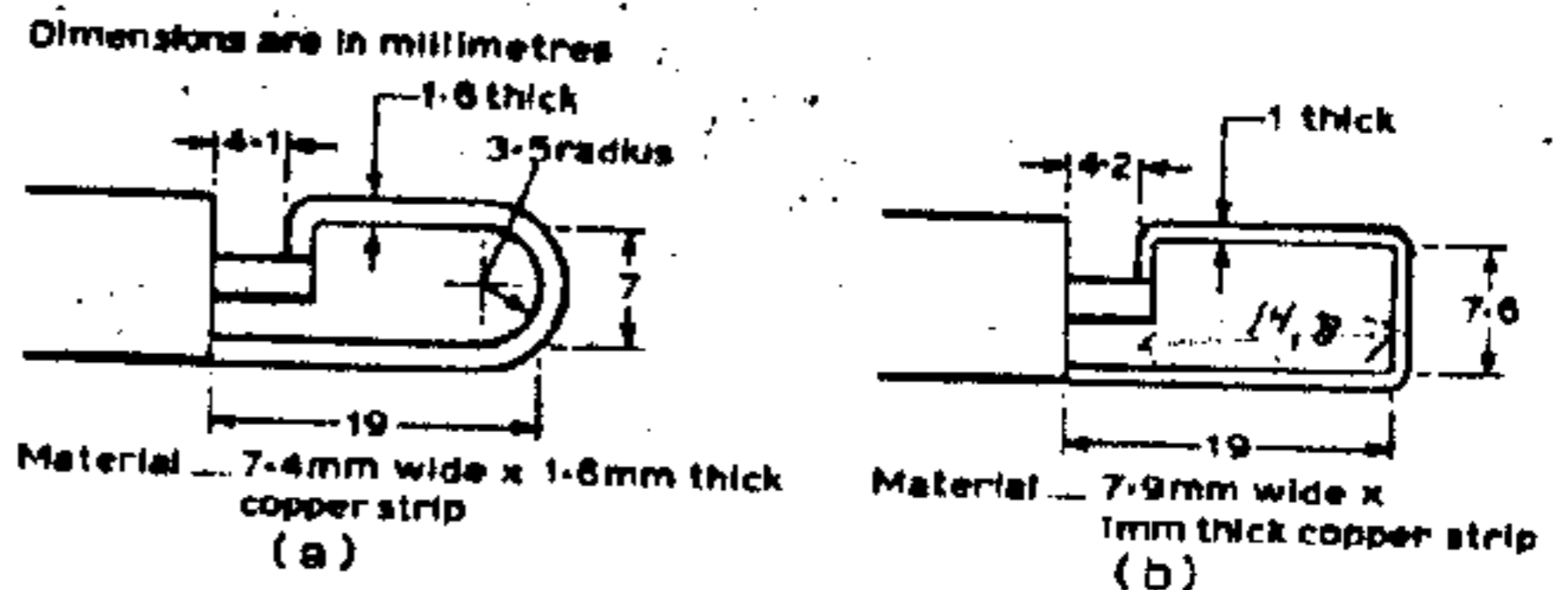


Fig 2. (a) modified output loop for UPX-4 amplifier. (b) modified input coupling

G3YGF and G4CNV also found that it was possible to increase the gain of the amplifier by changing the input coupling to a loop, details of which are given in Fig 2(b). The angle and penetration of the loop are adjusted for maximum drive, but care should be taken to avoid instability which can result if the loop is too far out (ie the coupling is too light). After these modifications, and with an on-load anode voltage of 1.5kV, it was found possible to achieve 13dB gain (at 25W drive).

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 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.

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 may be required in specific circumstances.

oscillations at or near 1296 MHz can also occur with improper loading and or tuning. A grounded grid amplifier is only conditionable stable.

A non-inductive resistor can be made by using 30 resistors each of 1500 ohm and 2 watt connected in parallel. Two round discs of brass plate with 30 holes drilled and the resistors soldered in between the plates makes a neat arrangement.

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 ground return to the power supply.

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 (see Technical 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 procedure will result in maximum anode circuit efficiency.

Remarks

A special comment should be made regarding determination of anode current and voltage for computing total d-c input power. In a grounded grid amplifier with cathode bias, the anode voltage is NOT the supply voltage nor is the cathode current the anode current. The anode voltage is the supply voltage minus the measured cathode voltage at a given cathode current. Likewise the anode current is the cathode current minus the grid current in the r-f drive case. It is advisable therefore to measure anode current and voltage directly at the tube terminals with separate meters and with proper precautions for safety. The anode voltage is measured with a voltmeter connected directly from anode-to-cathode and the anode current should be measured with the meter directly in the anode supply line. Only from these direct readings should total anode input d-c power be computed.

One further comment should be made regarding absolute accuracy. Some of the r-f power generated in the anode circuit of the amplifier may be dissipated in the anode circuit, cavity walls, joints, etc., and will not appear as heat at the anodes of the tubes. This will result in slightly optimistic determination of useful output power. Note that the true output power is determined by this method but it can not all be recovered at the output port. In general, the amplifier with poor efficiency will produce the greater error of this type.

As an example of the magnitude of this type error, data taken on an amplifier at 1296 mc/s with poor total efficiency indicated an output power of 29 watts for 100 watts d-c input power while the true output power measured directly at the output port was 25 watts. The 14% (0.7 db) error can in part be accounted for by the d-c meter inaccuracies but is believed to be largely due to circuit losses in the anode cavity. The saturated exhaust temperature for this particular case was 124°F.

If other devices are used to measure temperature, such as a thermistor, it is advisable to determine the effects of stray r-f fields on the operation of such devices. Indeed, a mercury column thermometer may be effected if its column length is near half wave resonance at 1296 mc/s. It may be advisable to use alcohol thermometers in cases where stray r-f leakage is occurring.

The accuracy of your d-c meters to measure both anode current and voltage should be ascertained if absolute output power determination is desired. It is interesting to note however, that even with inaccurate meters, the plate efficiency may be determined with high accuracy.

While power determination at 1296 mc/s has been stressed in this report, it should be obvious that the heat equivalence method can be applied at any frequency.

Contributions by W2CQH and WA2VTR are acknowledged.