8

Power Amplifiers

Contents

Power Tubes at 432 MHz

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To obtain high power (greater than 500-W output) at 432 MHz within a typical amateur budget, still requires the use of vacuum tubes. 432 MHz is in the gray area between VHF and microwave technology. Discrete component circuits will still function at 432 MHz, albeit with limited performance. More important, 432 MHz is short enough in wavelength that microwave-type circuitry such as cavities and striplines are small enough in size to be effectively used. Likewise, 432 MHz is a frequency where old technology glass insulation tubes will still function (at least some of the lower power tubes will) but with very poor performance. Most of the radial design ceramic/metal transmitter triodes and tetrodes will function at 432 MHz; however, only a limited subset of the available models will provide acceptable performance. True microwave tubes, such as planar triodes work very well at 432 MHz but few of these type tubes exist that will run near the maximum amateur power level.

There are several parameters in a power tube's design that determine if it will function properly at 432 MHz:

- The element spacings must be close enough to minimize transit time problems. Transit time effects can result in poor efficiency or worse make the tube literally non functional.
- The grid inductance (or screen) inductance must be low enough that degenerative feedback from the element inductance doesn't kill the gain of the tube.
- Preferably, we want a tube that has a self-neutralizing frequency above 432 MHz so it can be neutralized in conventional methods without requiring tuned grid or screen circuits.
- The interelectrode capacitances must be low enough that the tube can be effectively resonated in efficient and easy to construct input and output circuits.

For high-power operation (500 W or more output) these requirements are only met by external anode tubes with ceramic insulation. With external anode tetrodes many of the common amateur perceptions about tube operation are either incorrect or of little concern with these type tubes. Assuming that the four criteria listed above are met, that is a given tube design functions properly at 432 MHz, let's examine the tube characteristics that determine how much output power can be run.

CATHODE AREA

The primary limiting factor in how much power can be extracted from a tube is how much cathode current can be drawn. Almost all the designs considered in this article have indirectly heated cathodes. That is, they use a solid surface cathode made of an oxide coating, which will freely emit electrons when heated to a minimum temperature. Although some differences in cathode coatings exist, most are similar. This means that the amount of cathode current that can be drawn is proportional to the cathode area. A general rule of thumb is that, under conservative ratings, each centimeter^2 of cathode area will give 125 mA of continuous-duty CW cathode current. More recently, the widespread use of tubes in Class AB1-AB2 and so called Class-B linear service has allowed more liberal cathode current limits of up to 250 mA per cm^2 of cathode area. Older tube designs, such as the 4CX250B have about 2 cm^2 of cathode area. They are rated at 250 mA of continuous-duty plate current. While newer designs such as the 8874, have only slightly more cathode area, they are rated at 350 mA CW plate current and up to 500 mA plate current in intermittent CW and SSB linear service. Some of the larger tubes such as the 8877, 8938, 4CX1000A and the 7213 have about 10 cm^2 of cathode area. These tubes are conservatively rated at 1000 mA of plate current in continuous-carrier service, but they can run 1500 to 2000 mA of cathode current in intermittent service.

GRID INTERCEPTION AND DISSIPATION

Grid interception and dissipation are closely related and not understood very well by most amateurs. Grid interception is the amount of cathode current the grid will grab from the electron stream going from the cathode to the plate. Cathode to grid spacing and alignment along with the plate spacing and physical grid structure size determine how much cathode current will wind up flowing through the grid structure. Older-design tubes such as the 3-1000 (and its ceramic-metal version the 3CX1000A7) have high grid interception, such that their grid current will be 30 to 40% of the plate current. This high grid current means that valuable cathode emission is being lost to the grid and cannot be converted to output power. This high

Table 1
SPECIFICATIONS FOR TRIODE TUBES USABLE AT 432 MHz

	Plate Diss.	Plate V_{MAX}	CCS Plate mA	IVS Plate mA	Grid Diss. (W)	Max Grid mA	Freq Max. Ratings	Filament Volts	Filament Amps	Capacitances (pF) C_{in}	C_{gp}	C_{out}	Anode Dia.
3CX400U7/8961	400	1500	400	500	5	100	1000	6.3	3.0	18.4	.07	6.1	2.10
3CX400A7/8874	400	2200	350	500	5	100	500	6.3	3.0	20.5	.03	6.0	1.63
3CX800A7	800	2250	600	650	4	60	350	13.5	1.5	26.0	.05	6.1	2.50
3CX800U7	800	1800	500	650	4	60	1000	13.5	1.5	23.3	.04	6.2	2.53
Y-730	1000	3000	600	600	1.5	50	1500	5.5	3.2	19.0	.07	6.5	2.79
TH308B	700	2200	600	700	2	70	1000	6.3	5.5	16.0	.13	8.2	2.75
Y-831	1500	3000	600	600	1.5	50	1500	5.7	3.3	21.0	.07	6.9	3.18
Y-846	1500	3000	600	600	1.5	50	1500	5.7	3.3	18.0	.07	7.3	3.18
TH328	750	2200	600	700	2	70	1000	5.5	5.4	19.0	.07	8.2	2.75
TH338	1200	2500	600	700	2	70	1000	6.3	5.5	16.0	.13	8.2	3.20
3CX1500U7/8962	1500	2000	1000	1500	30	200	1000	5.0	11.7	28.0	.04	13.0	3.38
3CX1500A7/8877	1500	4000	1000	1500	25	175	250	5.0	10.5	38.5	.10	10.2	3.38
8938	1500	4000	1000	1500	25	150	500	5.0	10.5	39.0	.14	13.0	3.38

NOTES: 1. All triode tubes are specified for grounded grid, cathode driven operation.
2. Power output levels for all tubes except the 8938 reflect intermittent SSB voice or keyed morse code CW operation.
3. The 8938 is capable of providing 1500 watts output at 432 MHz in continuous duty service.
4. Surplus and used-cost figures are typical and may vary significantly with tube age, condition, warranty terms (if any) and market factors.

grid interception also requires a substantial grid structure that is capable of dissipating the current (ie, power). This large grid structure in turn limits the gain of the tube and can also severely limit the high-frequency capabilities of the tube. If the grid was just made smaller however, the plate current could become uncontrollable.

In the late 1960s a new cathode technology was developed to focus the cathode current between the grid wires. Tubes employing this technology are called focused-cathode or low-grid-interception tubes. By lowering the number of electrons which will be picked up by the grid, the grid can be made smaller, which raises the gain of the tube, makes more cathode current available to be converted to plate output power and when properly designed, both high frequency and linear performance of the tube can be improved. Many long time operators used to tubes with 25-50 W grid dissipations are horrified at new technology tubes, such as the 3CX800A7 with its 4-W grid dissipation. In reality, a properly operating 3CX800A7 will deliver 750-W output power with 25 mA of grid current, whereas a 3-500Z can easily run 150 mA of grid current at that same power level. The only times these low grid dissipations are a problem is if the amplifier is accidentally driven without plate voltage present, or if it is severely mistuned. The danger of harming the tubes can be minimized by the inclusion of proper protection circuits.

PLATE DISSIPATION

Plate dissipation is fairly far down the list of power determining factors for an external anode tube. With glass envelope tubes such as the 3-500Z, the primary means to dissipate plate power is by radiation off the plate. This is readily observed by the red, orange to white color of the plates under modest-to-full power to overload conditions. It doesn't matter how much air is blown by such a tube—there is only so much plate dissipation available. In an external-anode tube, the plate dissipation is directly proportional to how much air is blown through its radiator. In fact, most of the external-anode tube specification sheets will list plate dissipations far greater than their nominally specified value when higher airflows are used. The limiting factor in increasing plate dissipation becomes a combination of the decreasing ability of air to extract heat from the radiator at very high air speeds, and the limitation of the copper anode structure to conduct heat away from the metal-to-ceramic seals at a fast enough rate. In fact, as long as an external-anode tube has reasonable plate efficiency (>40%)

Height	432-MHz Linear Operation Useful Power Out (W)	Drive Power (W)	3rd Order IMD (dB)	New	Cost Surplus	Pullouts
2.50	500	25	-35	$420	$200	$100
2.14	605	35	-35	$330	$200	$100
2.52	750	29	-36	$330	$200	$100
2.85	750	25	-36	$450	$220	$100
3.19	800	12	-40+	$1200	rare	$100
3.20	900	25	-40+	$1200	rare	$100
3.19	1000	29	-40+	$1200	rare	$100
3.19	1000	15	-40+	$1200	rare	$100
3.20	1100	12	-40+	$1200	rare	$100
3.20	1100	32	-40+	$1200	rare	$100
3.40	1500	90	-40	$1800	rare	$150
4.02	1500	150+	-38	$650	$350	$100
3.57	1500+	82	-44	$1800	$600	$200

a large enough blower will make the available cathode emission the limiting factor in power output.

NEUTRALIZATION

Every tube listed in this information must be neutralized for proper operation at 432 MHz. This includes tetrodes when operated in either grid driven or cathode driven operation. It also includes all of the listed triodes when operated in grounded grid mode. Fortunately many of the listed tubes have self neutralizing frequencies close to 432 MHz and can be neutralized with relatively easy grid or screen inductance tuning. More information is given in the 3CX800A7 amplifier construction project.

TUBE CHARACTERISTICS AT 432 MHz

With this background information about power tube operation in mind, the capabilities and operating characteristics of a number of the available power tubes which will operate at 432 MHz will be described. Tube data sheets don't tell the whole story. Some tubes work better than others. The number of tubes that work well at 432 MHz is small. Some will generate their power with much better intermodulation distortion (IMD) products than others. Some are nearly impossible to neutralize, while others offer completely stable operation. Other traits, not usually spelled out on the data sheets, are power drift stability, power gain in real 432-MHz circuits, allowable amateur intermittent voice and keyed CW power levels and last but not least, availability through surplus channels.

Two tables are included in this article. Table 1 lists the operating characteristics of the external anode tubes which will work at 432 MHz. Models that work well at 432 MHz are included along with ones which are usable, but are not good performers. Key parameters to look for when selecting a tube is its efficiency and drive power. The tables start out by listing specification sheet information for the tubes. Parameters such as plate voltage, plate current, screen voltage, interelectrode capacitances etc. are given. This information is what manufacturers' data sheet provides for an amplifier designer. This table tells you what parameters the tube operates within, but not how it will react at 432 MHz. The tables add to this data sheet information by giving actual operating parameters at 432 MHz. For triodes these operating parameters are given for grounded grid, cathode driven linear operation. Power output levels reflect intermittent amateur SSB voice operation or Morse code keyed CW operation. These ratings reflect long term reliable operation in these intermittent modes.

For the tetrodes listed in Table 2, operating specifications are provided for both linear and Class-C operation. Note that some of the tetrodes are not suitable for Class-C operation. The listed power output levels reflect intermittent SSB voice and keyed CW operation under linear specifications. At higher power output levels the tubes will either be not linear or not perform reliably over a period of time. Class-C operation levels are given for keyed CW operation. For continuous-carrier duty (such as FM or ATV) power levels must be reduced to at or below the tube's CCS ratings. More information on intermittent tube operation which is often also called IVS (Intermittent Voice Service) is given by Bill Orr.[3] Tube prices are also included in Tables 1 and 2. The new list prices are typically for Varian Associates, EIMAC brand tubes. The EIMAC tubes are generally considered a premium grade tube. Many of the more common tubes, such as the 4CX250B, are made by several manufacturers, whose list prices may be different. Note that several of the tubes are proprietary models, that is they are made by only one manufacturer. The list prices are not always hard and fast as some distributors and retailers may discount the manufacturers' suggested retail price. Surplus prices are typical street prices for unused tubes that have become available to amateurs. They will typically not carry a manufacturer's warranty. Pull-out prices are for used tubes. Usually they are from broadcast or military transmitters. There are no set prices or availability for surplus and pull-out tubes. The prices given are sort of an average of what I have seen the

Table 2
Specifications For Tetrode Tubes Usable At 432 MHz

Tube Type	Plate Diss.	Plate V_{max}	CCS Plate mA	IVS Plate mA	Grid Diss. (W)	Screen Diss. (W)	Screen V_{max}	Freq Max. Ratings	Heater Volts	Amps	Capacitances (pF) C_{in}	C_{gp}	C_{out}
4CX250B/7203	250	2000	250	275	2	12	400	500	6.0	2.6	15.7	0.01	4.5
4CX250R/7580W	250	2000	250	325	2	12	500	500	6.0	2.6	17.5	0.04	4.8
8930	350	2400	250	325	2	12	500	500	6.0	2.6	17.5	0.03	4.9
4CX300A/8167	300	2500	250	300	2	12	400	500	6.0	2.9	29.0	0.04	4.0
4CX600J/8809	600	3000	600	700	1	15	300	110	6.0	5.4	50.0	0.13	6.3
4CX600B	600	3000	600	700	3	15	300	500	6.0	4.3	45.0	0.15	5.8
7650	600	2500	500	600	3	25	1200	1215	6.3	7.9	37.5	0.11	5.3
4CX1500BC	1500	3000	900	1250	1	12	350	450	6.0	10.0	81.5	0.02	11.8
7213	1500	3000	1000	1250	15	50	1000	1215	5.5	17.1	42.0	0.17	17.1
YL1050	1600	3000	900	1300	10	30	650	400	3.8	20.5	36.0	—	10.0
GS-23B	1600	3500	1000	1500	5	25	600	1000	6.3	5.7	33.0	0.03	11.5
8792	1800	3500	700	1250	10	50	1000	400	5.5	17.3	38 0	0.03	16.0

Notes:
1. Specified parameters are for grid-driven operation.
2. Specified parameters are for cathode-driven operation.
3. Surplus and used-cost figures are typical and may vary significantly with tube age, condition, warrany conditions (if any) and market factors.

various tubes sell for in recent years.

Let's take a look at the inside story of each of the tubes in the tables.

4X150A/7034

These tubes are not recommended for use at 432 MHz. Through 150 MHz the 7034 is as good as a 4CX250B both in power output and linearity. The 7034 also has a 250-W plate dissipation despite its '150 designation. The difference between the 4CX250B and the 4X150A is that the 7034 uses a glass plate-to-screen insulator. This glass heats up easily at 432 MHz and may develop holes or the seals may break. Do not confuse the 7034/4X150A with the original 4X150. The original 4X150 has both glass base and plate insulators. The 7034 has a ceramic base insulator. The original 4X150 will not even run acceptable power levels at 144 MHz.

4CX250B/7203

The 4CX250B has been a standard tube among amateurs for over 30 years. Twenty years ago the "standard" power amplifier design for 432-MHz DX work was the K2RIW parallel kilowatt.[1] The original amplifier used a pair of 4CX250Bs, and was designed to operate at maximum efficiency in Class-C operation (CW or FM, not SSB linear) at 1000 W of input, which was the legal amateur power limit before 1984. Since the power limit was raised to 1500-W output, tales of incredible power output levels from 4CX250B tubes abound, but in reality the 4CX250B is a mediocre tube in linear service. About 600-W PEP linear output, from a pair of tubes, is all you get before IMD performance seriously deteriorates (2000 V on the plate, 550-mA peak plate current for 2 tubes, zero grid current). In true linear service a K2RIW amplifier will run at about 55% efficiency. When run hard in Class-C service, efficiency will reach 70% with power output levels around 900 W.

Some builders of the K2RIW amplifier have reported instability and thermal drift. These problems are most often due to running the amplifier without neutralization. Some builders have neutralized the K2RIW amplifier by feeding back a sample of the grid voltage (by tapping on the center of the grid line between the tubes) back to the plate. Others have successfully tuned the screen inductance. Most builders report that neutralization is easier with the SK620 or SK630 type sockets, which incorporate screen shielding, than with the SK600 or SK610 sockets used in the original amplifier.

Although some operators have run these tubes at even higher power levels, tube life is compromised. Essentially an oxide-coated cathode has a fixed amount of electrons that it will emit over its life. The choice is yours—do you want to stretch the cathode's life over several years, or do you want to use it up in a few months? If you make the decision to stretch the limits of the 4CX250B, you will be best off running the plate voltage higher than specified (up to 2500 volts under load) and keeping the cathode current within reason (less than 300 mA per tube). Also be sure that the screen current is reasonably low (less than 30 mA per tube). To comfortably reach the present amateur 1500-W output power level, some 432-MHz operators have resorted to using power splitters and combiners to run a pair of K2RIW amplifiers simultaneously. Tim Pettis, KL7WE, described how he built hybrid power splitters and combiners to operate a pair of the K2RIW amplifiers.[2] N9AB has used a similar approach to combine a pair of 8874 amplifiers and a pair of 3CX800A7 amplifiers.

Common surplus availability at reasonable prices makes the 4CX250B attractive. The 4CX250 also comes in some newer flavors, the 4CX250BC/8957, which is a premium-quality high-tolerance version and the 4CX250FG/8621, which has a 26.5-V filament. A water-cooled version of the ubiquitous 4CX250, the 4W300B/8249, is also made. There are even conduction cooled models of the '250, the 8560A and

Max. Dia.	Height	Linear Power Out (W)	432 MHz Linear Drive (W)	Typical Linear Eff. (%)	3rd Order IMD (dBc)	Power Out (W)	Class C Drive Power (W)	Eff. (%)	Notes	New	Cost ($US) Surplus	Used
1.64	2.64	300	10	55	-23	450	25	70	(1)	80	50	10
1.64	2.64	425	12	55	-25	550	30	70	(1)	125	60	15
2.08	2.46	425	12	55	-25	550	30	70	(1)	195	80	25
1.64	2.50	325	10	55	-23	500	25	70	(1)	120	40	15
2.08	2.71	750	20	55	-35	n/a	n/a	n/a	(2)	1000	150	35
2.08	2.45	750	23	55	-35	900	30	64	(2)	1200	rare	50
2.06	2.40	680	30	55	-31	960	38	64	(2)	1100	100	30
3.38	5.13	1500	65	50	-40	n/a	n/a	n/a	(2)	1000	rare	rare
3.75	3.34	1500	70	55	-27	1500	100	65	(2)	2500	250	100
3.74	4.33	1500	75	56					(2)	2000	500	150
3.55	4.25	1500	60	56					(2)		250	rare
3.75	3.34	1500	70	55	-37				(2)	2500	300	100

8560AS. Conduction-cooled tubes are not very practical for a high-power 432-MHz amplifier due to the limited available plate dissipation and because of the additional plate-to-ground capacitance of the tube-to-heat sink junction.

4CX250K/8245

A coaxial-base version of the 4CX250B, the 4CX250K will generate the same power output as a 4CX250B. With a properly designed input circuit a 4CX250K can do it at lower drive levels. The pulse rated 4CPX250K/8590, along with the 26.5-V filament (4CX250M/8246) versions are also usable. I have often seen the 26.5-V filament tubes in the 4CX250 family languish on flea-market tables. Filament transformers with 28-V secondaries are readily available, and it is a simple matter to convert an amplifier to 26.5-V filament operation. So, don't pass up the 26.5-V filament tubes when the price is right.

4CX350A/8321

The 4CX350A is a ruggedized, high-linearity version of the 4CX250B. Its spec sheet looks great—full ratings to 110 MHz, 2500 V at 300 mA and better linearity than the '250B. Several amateurs who have tried the 4CX350A, however, have reported poor efficiency and instability. This "poor" operation could be a result of just substituting the '350As for 4CX250Bs without properly adjusting the amplifier for them. The 4CX350A uses a "stretched" cathode giving it more cathode surface area and, hence higher cathode-current capability. This design change requires retuning if not modifications to the amplifier's input and output circuits, due to the substantially higher interelectrode capacitances of the 4CX350A. The different internal construction of the '350A also requires substantially lower grid-bias voltage. This difference in the grid structure gives the 4CX350A its better gain and IMD characteristics. but at the expense of zero grid dissipation. This makes the '350 usable only in linear service. An operator who is primarily interested in SSB operation may want to consider adapting a K2RIW amplifier to these tubes, but an EME operator who is interested in maximum CW power would be better off using 4CX250Rs. One may also wonder what special magic gives the 4CX350 100 W more plate dissipation, since it is physically the same size. The sleight of hand used is to higher specified air flow. Amateurs get very hung up on plate dissipation. On an external-anode tube you should consider the rated dissipation as a nominal value. It is completely dependent upon temperature altitude and air flow. Cathode emission is the more critical element in limiting tube power! As with the 4CX250B, 26.5-V filament versions exist (4CX350F/8322 and 4CX350FJ/8904). The 4CX350FJ also has improved IMD characteristics over the other 4CX350 models.

4CX250R/7580W, 8930

These are the best models in the 4CX250 family of tubes and the only ones for which I would spend top dollar. Although the '250R is nominally rated the same as the B models, its better internal construction allows for a manufacturer's specification of 325 mA of peak plate current per tube in linear service. The 4CX250R was originally designed to withstand severe shock and vibration, as in airborne equipment. The 8930 is internally an identical tube to the '250R, but has a larger anode radiator than the 4CX250R. This larger radiator gives a nominal plate dissipation rating of 350 W. The 8930 also has a linear service maximum-plate-voltage rating of 2400 V. In amateur service, even the 4CX250R can be comfortably operated with 2400 V on the plate. The better characteristics of the 4CX250R and 8930 allow them to be comfortably run in a K2RIW-type amplifier in intermittent operation at 432 MHz with a plate voltage of 2400 and a plate current for a pair of tubes of 650 to 700 mA. This will provide over

800 W of linear output power and, when gently run in Class C, 1100-W output—only 1.3 dB below the legal limit. If you can locate the sockets at a reasonable price it will be worth investing in new 8930s or 4CX250Rs. If you have to purchase the sockets at new price you may be better off spending the money on 3CX800A7s.

4CX300A/8167

The 4CX300A/8167 is a fairly early external-anode ceramic-metal tube design that dates back to the late 1950s. It is suitable for either Class-C or AB1 linear operation. These tubes have been successfully used in 432-MHz amplifiers. Power capability is slightly better than the 4CX250Bs, however, reports from some users claim bad thermal drift. Other users have not reported any thermal problems, while obtaining significantly better power output performance than from the 4CX250 family. Since I have never used 4CX300As at 432 MHz, I can't comment about the thermal drift. It may be inherent in the tube design, due to an amplifier problem, or simply a case of the amplifier needing neutralization. From looking at tube prices, it should be obvious that you would not want to sink serious money into 4CX300As, but they are certainly usable if the price is right and you can also locate sockets. The 4CX300As use a twist-lock base, like a mini 4CX1000A. They are not directly interchangeable with the 4CX250 family but they are similar enough in plate characteristics to be adaptable to the same circuits as the 4CX250 circuit designs. The input capacitance is almost twice that of a 4CX250B which will necessitate some extra effort to get a good input circuit functional. A push-pull amplifier design for the 4CX300A appeared many years ago in *QST*.[12] At least one builder has reported success in adapting 4CX300As to the venerable K2RIW parallel design. There is also a high-cathode-current version, the 4CX300Y/8561. The 4CX300Y has significantly higher input capacitance, and may require changes to the input circuit if it is substituted for the 4CX300A. The high-current versions are not as common in surplus channels, have a specified limit of 110 MHz for maximum ratings, and are more suitable for use at 144 MHz than at 432 MHz.

8122, 8122W

The 8122 has a bad reputation for thermal drift, poor reliability and high IMD levels. The 8122 has an 11-pin base like the 8874. Sockets are made from 11-pin sockets in combination with separate screen bypass capacitors. I have not used 8122s at 432 MHz so I don't know if the thermal drift can be eliminated. I don't recommend purchasing 8122s for use on 432 MHz. Even if you have some 8122s lying around, you may want to find an HFer with a National NCL-2000 amplifier or NCX-1000 transceiver, sell him the tubes and buy something else.

3CX400U7/8961

The 3CX400U7 is a coaxial-base version of the 8874, designed for use up to 900 MHz. Varian built a large number of 850-MHz cavities, which Motorola used in cellular phone and paging transmitters. As Motorola replaced them with solid-state units, they sold the old tube units to hams for only $50, a great deal for 200 to 300 W at 902. This great deal came to an end when some enterprising hams were caught buying the cavities for $50 and reselling them at a tremendous profit to competing commercial interests. Now, reportedly, Motorola crushes the cavities when they are taken out of service. I wouldn't recommend purchasing new 3CX400U7s, as the money would be better spent on 3CX800A7s or an 8938. If you find a pair of 3CX400U7s surplus they will make a cool, linear and efficient kW of output power at 432, as long as you don't mind making the coaxial sockets.

3CX400A7/8874

This rugged, reliable triode has been around since 1971. It was designed by Varian Associates as a triode version of the 4CX250 family. Since the 8874 was designed a decade after the '250 family, it incorporates within the same physical size better power output and linearity than its tetrode relatives. The 8874 uses an 11-pin base, and early versions looked just like the 8122. In the mid 1970s Varian made some improvements to the 8875 and incorporated the 4CX250B style ceramic in its plate to grid ring insulator along with a '250 style screen ring for its grid ring. The 8874 is easily adaptable to the K2RIW parallel kilowatt design. A pair of tubes in a K2RIW-type amplifier will give 1100 to 1200 W of intermittent service output power in stable and linear format. I also described a single tube 8874 amplifier[4,5] that delivered 550 to 600 W output. The 8874 now costs new, more than the newer and more powerful 3CX800A7, making the '800 the logical choice for one purchasing new tubes. There is a conduction-cooled model of the 8874, the 8873. The 8873 is not suitable for a high-power 432-MHz amplifier for the same reasons described in the 4CX250B section where the conduction cooled 4CX250B is discussed. Another version of the 8874, the 8875 uses cross tube air flow. The 8875 is not a good choice for a 432-MHz amplifier due to its lower plate dissipation and larger size. In addition they are very difficult to find at surplus prices. The 8874 is used in a few commercial transmitters along with a great number of amateur amplifiers. This has made the 8874 widely available in surplus and pull-out channels, however when purchasing them you will be competing with owners of older ETO Alpha amplifiers. Varian also made some 450-470 MHz cavities that used a single 8874. These units occasionally show up surplus and they can be easily converted to 432 MHz. In summary, the 8874 is highly recommended for use at 432 MHz, although if you are purchasing new tubes you will be better off getting 3CX800A7s.

3CX800A7

This is one of the newer tube designs. Introduced in 1984, it is an improved 8874 featuring very high power gain, for a triode, and a large anode radiator. Testing of a single tube 432-MHz amplifier has reliably given long term CW power levels approaching 600 W. An output of 750 W per tube (1500 for a pair) is easily obtainable in intermittent service. Due to the close grid spacing and precise internal construction, running the 3CX800A7s at high power requires grid overload protection circuits. A compact single tube 3CX800A7 amplifier designed and built by the author appears elsewhere in this book as does an amplifier which uses a pair of the 3CX800A7s. Although the tubes are a bit pricey when purchased new, the sockets are low in cost when compared to tetrodes, the operation is stable, efficient, linear and reliable. If you are purchasing new tubes, the 3CX800A7 is probably the most cost-effective solution to high power on 432 MHz when long tube life and reliable operation is considered. At 1500-W output on 432 MHz, the tubes are somewhat stressed, as they are operating at a frequency 23% higher than specified for maximum ratings. At 432 MHz it is advisable to run only SSB and keyed CW, keeping key down tune up times as short as possible when running full power. Several users of 3CX800A7 at 432 MHz have had tubes go soft after a few years. In examining their operating habits it was found that their amplifiers were not neutralized and they did not take care in keeping cathode current within reason. There is also a pulse rated version the 3CXP800A7. For linear amateur service, the pulse version does not present any major advantages over the standard model.

3CX800U7

This is a coaxial-base version of the 3CX800A7. It features about 10% lower input capacitance and 25% less feedthrough capacitance. Its specified CW ratings are valid through 1000 MHz (although these ratings are reduced from those specified for the 3CX800A7). At 432 MHz in intermittent amateur operation, the 3CX800U7 will be capable of similar power output levels as the 3CX800A7 but in a properly designed circuit it will require less drive power and it may have slightly higher output efficiency. The extra cost of the 3CX800U7 is not warranted over the 3CX800A7 for an amateur 432-MHz amplifier. So far the limited volumes in which 3CX800A7 has been produced makes surplus or pull-out availability unlikely.

3CX600U7

This little-known and hard-to find-tube would be perfect for use at 432 MHz. It was designed as a big brother for the 3CX400U7 for use up to 1000 MHz. At 432-MHz, 1500-W output for a pair would be easily obtainable at high efficiency and low drive levels. Unfortunately, the 3CX600U7 was never produced in significant numbers and is now obsolete.

TH308, TH328, TH338

These tubes are members of a large planar tube design by the French company, Thomson-CSF. Their technology has allowed them to develop some very high-power, high-linearity tubes for the UHF frequency ranges. Conceptually, these tubes are built like a giant 7289/2C39-type tube. The cathode area of these tubes is almost 5 times that of a 7289. The TH308 family was developed primarily for use in linear TV translator service through 1200 MHz. Their three-tone IMD performance is typically better than –52 dBc (at 200-W carrier level). These tubes will generate 300 to 600 W at 1296 MHz in intermittent amateur use. In a properly designed 1296-MHz circular-cavity plate circuit, the tubes will run at 30 to 35% efficiency. Pull outs of the TH308 family of tubes (primarily the TH328) are starting to show up regularly in the US, coming from television translator amplifiers. The internal construction of all three tubes is similar, with the TH328 and TH338 having larger anode radiators. At 432 MHz, these tubes should approach 60% efficiency and will give excellent IMD performance. On the other hand, if you are also a 1296-MHz operator and have a limited tube supply, you may want to save the tubes for that band. At 432 MHz, the TH308 should deliver over 900-W output, while the TH328 and TH338 may provide 1000 to 1100 W. The tubes have very high gain for a triode, close to 20 dB for the '308 and '338 and over 15 dB for the '328. These high-gain designs result in very low grid currents (less than 70 mA) and very low grid dissipations of about 2 W. Because of the low grid dissipation, be very careful in operating the tubes—grid protection circuitry is a must. In addition, these tubes are not the right choice for an operator who likes to push tubes. The high gain of the tubes mean the amplifier must be neutralized. One unique aspect of these tubes is that the anode air radiators sit on a tapered base and are easily removable. This makes them adaptable to water cooling, which is very popular at 1296 MHz.

Y730-YU129, Y831, Y846

These tubes are members of a series of Varian and EIMAC large planar triodes. They are patterned after the Thomson TH308 family and are also primarily intended for use in UHF-TV translator applications. These EIMAC models are rated at higher plate voltages, however they have a smaller cathode area and use a different (and lower dissipation) grid than the Thomson tubes. For amateur use at 432 MHz, the purchase of these tubes new would be hard to justify as their power output would only be slightly higher than a 3CX800A7 but their cost is 2-½ times as much. The YU129 is an IMD grade-out version of the Y730 that is suitable for amateur operation, and has a much lower price tag than the YU129. These tubes do not perform as well as the Thomson models at 1296 MHz (20-25% efficiency at best), making them available for use at 432 MHz. At 432 MHz, efficiencies for the tubes will be around 60%, with available output power in the 800-W range. The limiting factor in output power will be a combination of cathode current and grid dissipation. The low output capacitance of these planar triodes lets them be used in simple stripline circuits as well as in resonant cavities. The relatively large diameter of the anode radiators used on these tubes (2.8 in. for the Y730 & TH308 and 3.2 in. for the Y831, Y846, TH328 & TH338) makes the use of a pair of tubes in a single 432-MHz amplifier a difficult (but not impossible) proposition. Therefore, these tubes are best suited to an operator who desires low drive requirement, excellent linearity and is satisfied with about 800-W output. These tube models are now obsolete and have been replaced by a new series of tubes (described below). The information is included because these older tube series can often be found surplus or as pull-outs and are suitable for 432-MHz operation.

YU328, YU338, YU339

These tubes are a set of improved Varian UHF planar triodes. The YU328 replaces the Y730, the YU338 replaces the Y831 and the YU339 replaces the Y846. The new tubes feature improved internal construction (primarily in the grid) and have significantly better performance characteristics, particularly at higher frequencies. Although these improvements make them a better tube for 432 MHz, operation of the tubes is greatly improved at 1296 MHz, which means those trying to locate surplus of pull-out tubes will face competition from 1296-MHz operators. Any of these tubes will be capable of over 1000 W output at 432 MHz. The new price of these tubes is fairly high and as with any new tube it will take a few years before surplus and pull-outs become readily available.

7650, 8791

RCA stopped marketing their products to hams around 1970, so its tubes aren't very well known by most amateurs. After General Electric acquired RCA it sold off the RCA tube business. These tubes and many other RCA designs are still made by Burle Industries, whose main focus is tubes for VHF and UHF television transmitters. The 7650 has been around since around 1960. It is a mid-size tetrode that has over twice the power-output capability as a single 4CX250B. Over 1000 W output can be obtained running Class C in intermittent keyed CW service, but it is not very linear above 750 W output. A pair of tubes will easily run the 1500-W output limit. The 8791 is an updated version of the 7650 that has drastically improved IMD performance. The 8791 is used as a driver stage in some VHF television amplifiers and pulls can occasionally be located at reasonable prices. The 7650 and 8791 are essentially interchangeable in a stripline amplifier with a little adjustment to the tuning. K2UYH has been running a single tube 7650 amplifier for years (one was documented in the *Lunar Letter*).[19] Recently, DL7APV built a pair of 7650s and reports 1500-W out is very easy to obtain. The 7650 is often available surplus, but is usually passed up because few amateurs know what they are or what to do with them. Be careful when getting broadcast pull-outs as some stations use up the entire life of the tubes before replacing them. You should be sure that several tubes are available before building an amplifier. I have also seen a couple of different single-tube 7650 cavities that looked like they would tune to 432 MHz. The 7650 and 8791 are very good tubes to use at 432 MHz if you can find them at a reasonable price, you don't mind the complexities of tetrode operation and if you are capable of fabricating your own coaxial sockets.

4CX600J/8809-Y584, 4CX600JA/8921, 4CX600JB

These very exotic and very expensive tubes were designed for demanding military airborne applications. The 4CX600 family was essentially Varian's answer to the RCA 7650-8791. The 4CX600J and its large anode brother the 4CX600JA/8921 have found their way into various military amplifiers. They can be made to run very linearly and reliably at 750 W output per tube. The base is physically the same as a 4CX250, however, the electrical pin out is different, requiring modifications to existing sockets or the construction of your own. The anode of the 4CX600J is the same diameter as an 8930 (2-in. nominal) while the 4CX600JA has a larger 2.5-in. diameter anode. The 4CX600JB is an economy version of the '600J that uses a smooth, non-focused cathode. This results in higher drive requirements, but, due to this low gain the 'JB is more suitable for amateur use. The most-common surplus and pull-out version of the 4CX600 family is probably the Y584. The Y584 is similar to the 4CX600J and is used by Rockwell in an airborne transmitter that runs a pair of tubes in the final. Although the specified highest frequency for maximum ratings is 110 MHz, it will work well in intermittent amateur service through 432 MHz. A pair would make a formidable 432-MHz amplifier if you could overcome the inherent design complexities of a very high-gain tetrode at UHF frequencies. The 4CX600J uses a very fine grid structure to obtain its high performance. Because of this, the 4CX600J requires very tightly regulated grid and screen supplies. Its grid dissipation is only 1 W, so only linear operation is permitted and protection circuits are required. In addition, effective neutralization is mandatory for proper operation. Finally, running them cathode driven would be the way to go. At new tube prices there are much better tube choices for use at 432 MHz. I have often seen large quantities of 4CX600J and Y584 pull-outs at bargain prices. The builder with limited financial resources but lots of time and ambition may want to give the tube a try. A single tube 432-MHz cavity was built and described by Varian.[6]

4CX600B, 4CW800B

These are wide-band UHF versions of the 4CX600J. They use an unusual screw-stud base with a bolt-in-place screen ring. Joe Reisert, W1JR, used a 4CW800B (water cooled) tube in a rectangular cavity for many years. He reports 900 W out is obtainable, but he also seems to go through a tube every few years. The design of the cavity was described in an EIMAC application note.[6] Water cooling has become quite common in amateur circles on 1296 MHz, but is rarely used on the lower bands. As with most tubes aimed at the military market there are 26.5-V filament versions, the 4CX600F and 4CW800F. Again, don't invest money in them but if you find them cheap, they're worth considering.

4CX1000A/8168, 4CX1000K/8352

The 4CX1000A is an old external-anode tetrode designed by Varian in the late 1950s. It is known to amateurs primarily because it was used in the Collins 30S-1 HF linear amplifier. The 4CX1000A has also been used in a number of military amplifiers and is often found surplus. These tubes are not recommended for use at 432. Reportedly, K2CBA has made them work, but they will require a bit of effort to get set up properly. The only difference between them is the ring for the screen contact (instead of 3 tabs) on the K. If used in a proper socket, the screen ring can give higher input-to-output isolation (stability) at VHF. When these tubes are used in their standard sockets (SK810, etc) they will have a self-neutralizing frequency below 432 MHz. If you are going to give these tubes a try the best way to get them to work is to run the screen at ground (use a socket without a screen bypass capacitor) and float the cathode. Bypassed screen operation may require tuning the screen to neutralize it. The very high input capacitance in grounded-cathode operation (84 pF) also makes the cathode-driven configuration a must at 432 MHz. This is the procedure used in almost all large commercial and military UHF tetrode amplifiers. The screen at dc ground method of operation was thoroughly described in a 144-MHz grid-driven amplifier.[6,8] You would probably be better off using a 4CX1000A on 144 MHz or 220 MHz, and using something else on 432.

4CX1500B/8660

This is simply a newer, more linear version of the 4CX1000A. The same caveats as with the 4CX1000A apply—

use it on 144! EIMAC prototyped a coaxial-base version, the 4CX1500BC, but this version of the tube is not readily available.

3CX1000A7/8283

This is a ceramic metal version of the long-lived 3-1000Z that uses a 4CX1000A-type twist lock base. A 432-MHz amplifier was described using the 3CX1000A7.[9] It gave substantial power out, but used lots of drive power (it had about 7-dB gain) and had poor efficiency (less than 40%). The only reason why it gave reasonable apparent efficiency was due to all the drive power it required. The 3CX1000A7 is not a good performer at 432 MHz, due to its high grid inductance and a too-wide cathode-to-grid spacing. The tube is better off in an amplifier for 222 MHz or lower. EIMAC now makes another ceramic-metal version of the 3-1000Z, the 3CX1200A7. This tube is designed to use the same socket as the 3-1000Z, and is not suitable for use above 100 MHz. Still another version of the tube is now made, the 3CX1200Z7/YU181. This tube is a 3CX1200A7 that adds a low-inductance grid-contact ring. It is not suitable for use at 432 MHz, but the 3CX1200Z7 should be investigated by serious 144-MHz amplifier builders.

8877/3CX1500A7

The Varian 8877 is an amateur standard through 222 MHz. It is now commonly available in surplus, due to good acceptance in the commercial market. The 8877 is a great tube below 250 MHz, but it's marginal on 432. Due to element spacings which are too wide for 432 MHz, its efficiency is poor (35 to 40%). In addition, its pin socket arrangement makes the cathode inductance high enough that an effective input circuit is hard to design. A combination of both of these effects limits the 8877's power gain to a relatively low 10 dB. If you do run one, use lots of plate voltage (over 3000 V under load) and lots of air. You can get 1500-W out, but only under intermittent operating conditions. W8YIO, K5AZU and K8WW are among the amateurs with experience running the 8877 at 432 MHz. K5AZU described an input circuit for the 8877 at 432 MHz.[10] It has similar plate characteristics to the 8938 and can be used in 8938-type plate circuits. Henry Radio introduced the 3004A 432-MHz amplifier with an 8877, however, they quickly redesigned the model to use the 8938. A pulse version of the 8877, the 3CPX1500A7 is also made. At least one amateur (WB0QMN) reported slightly better results with the pulse version at 432 MHz. If you have 8877s available at a reasonable price and you have lots of drive power, you may want to consider building an 8877 amplifier and hope that you can find an 8938 to replace it with at a later date.

3CX1500U7/8962

This is a higher frequency version of the 8938, designed for use at up to 900 MHz. It will work very well at 432 MHz, its very close internal spacings limit plate voltage to 2000 V. It will be very easy to obtain 1200-W output at 432 MHz with the 8962, and it could be pushed to as high as 1500 W. The 8962 has been discontinued by the manufacturer. The tube is included in this information because I have seen them at flea markets.

7213, 7214

These are a couple more old work horse RCA tubes. Both are tetrodes with 1800 W of plate dissipation and are CCS rated at 3500 volts and 700 mA of plate current. This is the first single tube on the list which will comfortably generate 1500 W of power at 432 MHz. The 7214 is a pulse-rated version of the 7213 and is also usable. Several surplus 7213/7214 cavity designs exist that operate in the 432-MHz range. A number of amateurs have tried to make the 7213 work in λ/2 stripline circuits, but none that I am aware of were ever successful in getting the designs to work properly. The primary problem with their designs appeared to be the use of ineffective screen bypassing. One solution could be to run the screen at dc ground. Screen inductance, capacitance and coupling between the input and output circuits are all critical parameters, which must be managed before the tube will operate successfully at 432 MHz. One military cavity I saw used a tuned screen cavity for neutralization. Another potential problem with using the 7213 in a λ/2 stripline is that the output capacitance of the 7213 is high enough that the first quarter wave of the line almost disappears within the tube. This can cause problems getting the line to work properly and be able to couple power out of it. K2CBA built a 7213 amplifier which uses a λ/2 line arranged in a coaxial form.[11] This design is reported to work very well, although it is physically fairly large. Another arrangement which should work properly is to use a λ/2 stripline that has the tube located in the center. This circuit will require plate blocking capacitors, as either end of the stripline has to be at RF ground. However, this arrangement forces more balanced RF circulating currents. The same is true for the K2CBA design, which is probably key to its success. Another detail in the K2CBA design worth noting was his placement of the screen capacitor plate below the RF deck chassis, on the input side. This arrangement assures much better plate isolation, a critical factor in obtaining amplifier stability. In cathode-driven operation, (the recommended method) power gain will be over 13 dB. The 7213s are commonly available surplus at reasonable prices. The time required to make an amateur design work right will be time well spent. The 4661 is a similar tube to the 7213. It has a different anode radiator and a taller screen to plate insulator

8792/V1

This is a modern, linear version of the 7213. There is also a wide-band, high-gain version, the 8972/V2. What pertains to the 7213 pertains to the 8792, except that they are much harder to find surplus and they will provide a much cleaner SSB signal. They are designed to work cathode driven (as are the 7213, 7214 and most other UHF tetrodes). The 8792 is used in several high band VHF-TV transmitters and in some FM-broadcast transmitters, making local broadcast stations a possible source for these tubes.

YL1050 Family, GS23B

The YL1050 is a relatively common European UHF tetrode. It is part of a series of UHF tetrodes made by Seimens. It will comfortably run 1500 W output in a proper circuit and is used by a fair number of European 432-MHZ-EME operators. Other members of the YL1050 family are the YL1052, YL1055, YL1056, YL1057 and YL1058. All are similar in dimensions and power capability, with the YL1058 having the highest ratings. The YL1050 through YL1057 are capable of working at over 1000 MHz. There is also a Russian-manufactured version, the GS23B. The GS23B is similar in size and capability to the YL1050 but it is not an identical replacement for it. With the opening of world markets, tubes such as the YL1050 and GS23B may become readily available in the United States. At the current exchange rates with the Russian ruble the GS23B may be the best bargain of all. At the Thorn UHF conference in 1992, brand-new GS23Bs were available for under US$200!

GS35B

The GS35B is a Russian VHF triode that is somewhat similar to an 8877. Its internal construction is different enough that it works well at 432 MHz. A few of the Russian and Ukrainian EME operators are using the GS35B and they report a stable 1500-W output is obtainable at 432 MHz. In addition, tube life is excellent at that power level.

TH331 - TH347 Family

The TH331 is part of a Thomson-CSF family of UHF TV tetrodes. Thomson-CSF developed a technology to make the grid structures out of a special type of graphite. These graphite grids solved many of the problems associated with secondary emission and dimensional changes in the grid structure due to heating from the cathode and RF power, while still allowing them to use fine enough wires in the grid. These dimensional changes can lead to poor and unreliable operation. The TH331 is capable of 1500-W output in intermittent amateur service at 432 MHz. The different models in the TH331 family move up in power level such that the TH347 is capable of 5000-W output or more at 432 MHz. There are also some even-larger members of this tube family, the TH563-TH582 which are capable of power levels up to 40,000 W, through most of the UHF TV spectrum! Various tubes in the TH331 family are used by many European 432-MHz operators. They are excellent tubes to use at 432 MHz as long as the builder is capable of handling a large UHF tetrode.

8938

The Varian, EIMAC 8938 is the UHF version of the 8877. Depending upon plate voltage and drive levels, it will run at 52 to 57% efficiency at 432 MHz. A single tube will easily deliver 1500-W output in continuous-duty service, while being stable and linear. The only technical drawback of the 8938 is its relatively low power gain (about 12 dB when stabilized). The chief problem with the 8938 is its cost. The list price for the 8938 is now $1800, and surplus or pull-out availability is very limited. Varian now only makes a handful of 8938s a month, as only two commercial/military transmitters in active service use it. A $\lambda/2$ stripline amplifier I built using the 8938 appears later in this chapter. The 8938 is also quite suitable for operation in a $\lambda/4$ cavity. At one time, Varian built a commercial cavity for the 430-470 MHz range. Although the cavity is no longer made, a few 432-MHz enthusiasts with access to machine shops have kept the design alive by building cavities patterned after the EIMAC design. There is also a water-cooled version of the 8938, the YU-157.

4628

The RCA 4628 is a brute of a tube, designed for UHF-TV transmitter service. It will very easily run 1500-W output. As with most UHF tetrodes it is designed to run in cathode-driven service. Its gain is relatively low, about 11 dB.

CONCLUSION

There are a variety, of tubes which will operate at 432 MHz. All of them have external-anode construction with ceramic insulation. For amateur service, the simplicity and performance of a modern high-gain low-bias triode makes them the preferred choice. If cost were no object, the EIMAC 8938 would be undisputed first choice for a 432-MHz amplifier. When a budget is factored in, a pair of 3CX800A7s is a good choice, if your prefer triodes and are buying new tubes. In addition, the small physical size of the 3CX800A7 allows amplifier designs made from standard 3-in. high aluminum chassis, eliminating the need for special metalwork. The 7213-8792 is my second choice to the 8938 in terms of power capability, but you'll have to live with the additional complexity and critical tuning of a tetrode. The primary advantage of these types of tetrodes is that they are more available surplus at modest prices. The 7650-8791 are also very good tubes if you can find them at the right price. For the budget-conscious, the 4CX250 family, especially the 4CX250R and 8930, will still give respectable performance.

One of the problems in writing an article such as this one, is it lets many more hams in on the secrets of which tubes are most useful. If you come across any of the desirable tubes, please use them or pass them on at your cost to someone who will. This is only a hobby, so don't mess up the works, as others have, trying to make money off companies and individuals nice enough to sell or give away their surplus equipment to amateurs. And finally, please don't hoard tubes and sockets that you will never use. Unused tubes actually do have a shelf life, as their vacuum seals can start to leak, making that gem on the shelf useless. If you're not going to get on the air, please pass them on to another amateur who will put them to good use.

Notes

[1]Knadle, R, "High Efficiency Parallel Kilowatt Amplifier for 432 MHz," *Part 1*: *QST*, Apr 1972, pp 49-55; *Part 2*: *QST*, May 1972, pp 59-62, 79. Construction information also appears in *Radio Amateur's VHF Manual*, third edition, pp 299-304 (Newington: ARRL, 1972).

[2]T. Pettis, "Hy-Brid Hi-Power," *QEX*, Jan 1990, pp 13-14.

[3]W. Orr, "Intermittent Voice Operation of Power Tubes, *Ham Radio*, Jan 1971, pp 24-30.

[4]S. Powlishen, "A Grounded-Grid Kilowatt Amplifier for 432 MHz," *QST*, Oct 1979, pp 11-14. Construction information also appears in *The ARRL Handbook for Radio Amateurs*, for the years 1981 through 1986.

[5]S. Powlishen, K1FO, "Improving the K1FO 8874 432-MHz Amplifier," *QST*, Jul 1987, pp 20-23.

[6]"An EIMAC Family of 4CX600 Tetrodes," *Application Bulletin Number 14*," (San Carlos, CA: EIMAC).

[7]A. Katz, "K2UYH 432-MHz 7650 PA," *The Lunar Letter*, Mar 1983.

[8]H. Barber et al, "Modern Circuit Design for VHF Transmitters, Part 1: *CQ*, Nov 1965, pp 30-36; Part 2: *CQ* Dec 1965, pp 40-45, 92. Reprinted in EIMAC *Amateur Service Newsletter AS-27.*

[9]J. Chambers, W. Orr, "2-kW PEP Amplifier for 432 MHz," *Ham Radio*, Sep 1968, pp 6-12. Also published as *Amateur Service Newsletter AS-25-1* (San Carlos, CA: EIMAC).

[10]P. May, "8877 432-MHz Amplifier Cathode Circuit," *VHF/UHF and Above*, Jun 1986, pp 25.

[11]J. Snyder, "2-KW Amplifier Using the 7213," *432-MHz And Above EME Newsletter*, Jul 1981. The *432-MHz EME Newsletter* is published by Allen Katz, K2UYH. The Snyder amplifier information also appears in a compilation of the 432-EME newsletter technical articles, published by PA3CSG.

A 3CX800A7 Amplifier for 432 MHz

By Steve Powlishen, K1FO

In 1979, I described a 432-MHz power amplifier using a single 8874 tube.[1] The popularity of the amplifier far exceeded my expectations. While stable, linear and efficient, the 8874 amplifier had several drawbacks:

1. Construction required considerable metal fabrication, as the RF enclosure dimensions didn't correspond to a standard chassis size.

2. At 432 MHz, the 8874 requires over 35-W drive for full output—more than current 25-W transceivers can provide.

The introduction of the EIMAC 3CX800A7, essentially an improved 8874, provided the inspiration to build a new and improved amplifier. I wanted higher gain and simplified construction. In addition, this amplifier has TR switching voltages and currents compatible with low-power solid-state transceivers, and tube-protection circuitry.

The IMD performance of this amplifier is almost an order of magnitude better than some 432-MHz exciters! While this point may appear insignificant, operators may have to contend with local signals that are 80 to 100 dB above the noise and only a few kHz away. Any serious 432-MHz operator can attest to near loss-less propagation periods when signals 300 miles away are 80 to 90 dB above the noise. Under such conditions, this amplifier will not aggravate other operators.

While expensive when purchased new, the 3CX800A7 may still be a bargain. When you consider that in intermittent service a properly operated 3CX800A7 still may be cooking long after another operator has gone through several sets of 4CX250-class tubes, the initial price appears more reasonable.

The amplifier described in this article will deliver about 620 W with 25-W drive. At maximum ratings, the 3CX800A7 generates 730 W. Efficiency and maximum power output are better than with the 8874 amplifier.

Construction Details

To minimize metal work, the amplifier uses 4 standard aluminum chassis. The RF plate enclosure is made from a 5- × 13- × 3-in. chassis. The cathode circuit is housed in a 4- × 5- × 2-in. chassis. The RF enclosures are attached to the EIA standard 5¼ in. high, 19-in. rack panel by 2 standard 5- × 7- × 2-in. chassis. Using the smaller chassis in this way makes it unnecessary to fabricate mounting brackets for the RF deck, while also providing space to mount the control circuits. Heavy gauge (0.062-in. or thicker) cover plates are preferred on the RF chassis to assure RF sealing and provide mechanical rigidity.[2]

The construction of this amplifier has the RF deck mounted on its side, relative to the construction of most amplifiers. This mounting method has several advantages. The tuning controls can be positive-actuating lead screws, while still providing front-panel access. Alternately, the fish-line tuning arrangement can be used, as I did. Fish-line actuated controls allow the front-panel knobs to be placed for convenience and esthetics. The mounting arrangement used in this amplifier accommodates a convenient control arrangement while minimizing the length and bends in the fish line. As a result, the plate tuning controls operate smoothly and repeatably. An additional benefit to the mounting method is that tube hot air exhaust exits to the rear of the amplifier. Other equipment can be mounted above or below this amplifier, without leaving cooling space. I built matching 3CX800A7 amplifiers for 50, 144, 222 and 432 MHz. All four amplifiers and their 2200-V power supply can be mounted in a single 28-in. high desktop rack.

I took care to make this amplifier easy to duplicate with readily available parts. Complete metal cutting and drilling drawings are provided for the RF sections. If you accurately follow the drawings and use all parts specified in Table 1, the amplifier should go together and tune up like a commercial kit. I don't discuss the layout of the control circuits as they are not critical, and you may wish to tailor them to your station. Some of the specified parts are priced higher than junk-box substitutes. With some ingenuity you may be able to use cheaper parts, but you do so at your own risk. I'm unable to offer advice about finding and using substitute parts.

Plate Circuit Details

The plate circuit is the now-standard half-wave stripline with the tube located at one end. A "flapper" tuning capacitor is mounted at the other end. The stripline (Fig 1) is larger than

Table 1

Parts List for the Single 3CX800A7 Amplifier

Chassis and Hardware Components

RF deck enclosure: 5x13x3-in. chassis, Bud AC-422 or equiv.
Cathode compartment: 4x5x2-in. chassis, Bud AC-1404 or equiv.
Side chassis (2 req.): 5x7x2-in. chassis, Bud AC-402 or equiv.
Rack panel: 5 1/4x19x1/8-in., Bud SFA-1833 or PA-1103 or equiv.
Tube socket: 11-pin EIA, Eimac SK-1900 or Johnson 124-0311-100.
Grid collet: Eimac 720359 assembly (Eimac 882931 can be used).
Anode collet: Eimac 720829.
Grid collet insulator: Eimac 720518.
Chimney: Eimac SK-1906.
Panel bearings: 1/4-in. diam., Millen 10066 (2 req.).
Reduction drives: Jackson 4511/DAF (2 req.).

Components Referenced On Schematic Diagram

C1—1.5-5 pF miniature air variable (butterfly); Cardwell 160-0205.
C2—1.8-8.7 pF miniature air variable; Cardwell 160-0104.
C3-C5—1000-pF, 300-V feedthrough capacitor; Tusonix 327-005-C5UO-102M.
C6—Plate tuning flapper. See text.
C7—Plate loading flapper. See text.
C8—1000-pF, 4000-V feedthrough capacitor; Tusonix 2498-001-X5UO-102M.
C9-C10—1000 mF, 25-V electrolytic.
C11—0.15 mF, 25-V disk or epoxy.
C12-C19—0.01-mF, 50-V monolytic ceramic; Sprague 1C105Z5U103M050B.
D1—5.6-V, 10-W Zener, mounted on RCA SK122/5178A heatsink.
D2—10-A, 400-PIV.
D3-D4—2.5-A, 1000-PIV; R170 or equiv.
D6-D14—1-A, 1000-PIV; 1N4007 or equiv.
F1—2-A, AGC or 3AG fast-blow.
F2—3/4-A, AGC or 3AG fast-blow.
I1—120-V neon, amber; GC Electronics 38-282.
I2—120-V neon, red; GC Electronics 38-280.
J1—Chassis-mount BNC female, UG-1094/U.
J2—Chassis-mount N female, UG-58A/U.
J3—Chassis-mount MHV female, UG-931/U.
J4—6-pin male chassis mount; Cinch P306AB.
J5—6-pin miniature chassis connector; Waldom Molex 03-06-1061.
J6-J8—Phono connector; Switchcraft 3501FR.
K1—180-sec. thermal time-delay relay, 115-V heater, SPST-NO; Amperite 115NO180B.
K2—Control relay, DPDT, 24-V dc coil; Potter and Brumfield R10-E1-X2-V700.
K3—Control relay, 4PDT, 24-V dc coil; Potter and Brumfield R10-E1-X4-V700.
K4—Coaxial relay, SPST, BNC connectors, 28-V dc coil.
K5—Coaxial relay, SPST, high-power, N connectors, 28-V dc coil.
L1—2 turns no. 16 copper, 1/4-in. diam., 3/4-in. long.
L2—Brass strip 1/4-in. wide × 1/-3/16-in. long.
M1—Dc milliammeter, 600 or 1000 mA fullscale.
M2—0-1 milliammeter with shunt resistors to give full-scale deflections of 60 mA (grid current); 3 kV (high voltage); 30 V ac (filament voltage).
MOT1—54 cfm blower; Dayton 4C012 or equiv.
Q1-Q2—2N2222A, 2N3903 or equiv.
Q3—2N3053 or equiv.
Q4—2N4037 or equiv.
Q5—2N2904, 2N3905 or equiv.
R1—200-Ω, 25-W wirewound.
R2—1000-Ω, 12-W wirewound.
R3—10-kΩ, 25-W wirewound.
R4—1-Ω, 1-W, 1%.
R5-R10—499-kΩ, 1/2-W, 1% metal-film, type RN-60 preferred.
R11—820-Ω, 1/2-W, metal film. Select value to calibrate HV meter.
R12—1.5-kΩ, 1/2-W metal film. Select value to adjust HV relay trip point.
R13—9-Ω, 1/2-W metal film. Select value to calibrate grid meter.
R14—10-Ω, 2-W, metal film
R15—10-kΩ, 1/4-W miniature trimmer.
R16—1200-Ω, 2-W. Select value to set K1 time delay.
R17—50-Ω, 12- or 25-W adjustable slider wirewound.
R18—1-Ω, 5-W wirewound.
R19—12-kΩ, 1/2-W, film.
R20—2-kΩ, 1/4-W, miniature trimmer.
R21, R22, R25, R27—2.7-k, 1/2 W.
R23, R28—10-kΩ, 1/4 W.
R24—4.7-kΩ, 1/4 W.
R26—2.2-kΩ, 1/4 W.
R29—330 Ω, 1/4 W.
R30—500-Ω, 25-W wirewound.
RFC1—8 turns, no. 18 enameled, 1/4-in. diam., closewound.
RFC2, RFC3—8 turns, no. 16 enameled, 1/4-in. diam., closewound.
RFC4, RFC5—7 turns, no. 18, 3/4-in long, 1/4-in. diam.
S1—DPST toggle.
S2—SPST toggle.
S3—2-pole, 4-position rotary.
S4—SPDT miniature toggle.
T1—Filament transformer: 14-V, 2-A secondary, 120-V primary; Stancor P8556 or equiv.
T2—Control transformer: 10-V, 2-A secondary, 120-V primary; Stancor P8653 or equiv.
W1—Plate stripline.
W2—Cathode stripline.

the one used in the 8874 amplifier, both to fill the larger plate compartment and to accommodate the larger (2.5-in.) diameter of the 3CX800A7 anode radiator. The larger stripline allows for better placement of the tuning controls. The preferred material for the stripline is 1/16-in. brass, which is silver plated after the collet is soldered in place. Copper is also suitable, but

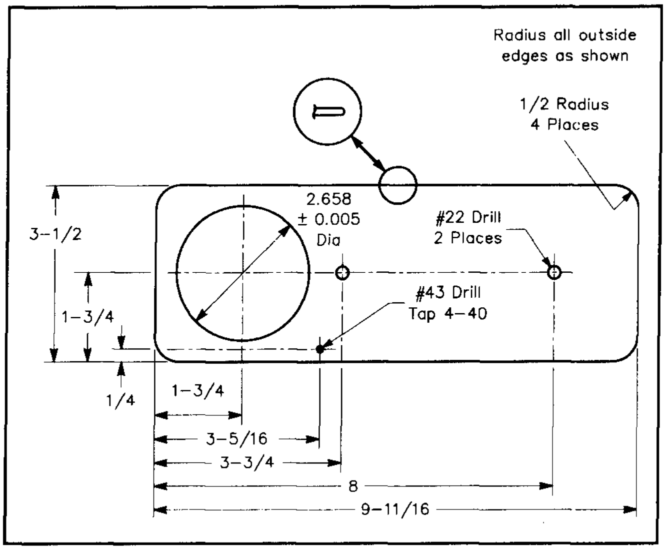


Fig 1—Plate line of the single 3CX800A7 amplifier. Except as noted on the drawing, dimensions are ± 1/32 in. Material is 1/16-in. copper or brass. Anode hole is sized for the EIMAC 720829 collet. Dull-finish (nickle-less) silver plating is recommended after the collet is soldered in place.

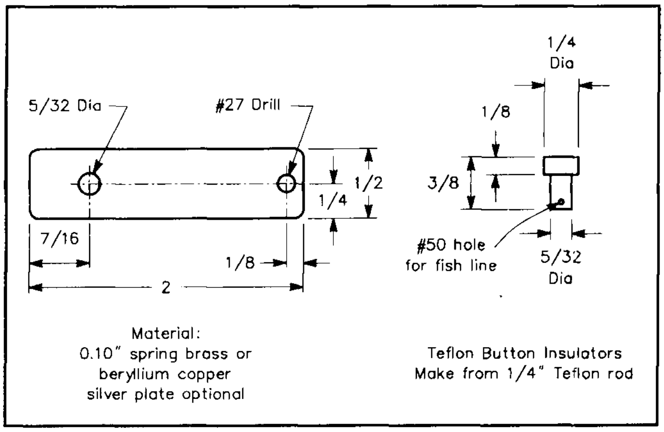


Fig 3—Plate loading capacitor C7 is made from 0.010-in. spring brass or beryllium copper. The button insulator is made of 1/4-in. Teflon rod.

harder to machine. If you have your line professionally plated, specify a "dull" finish; that is, without nickel content. A plater experienced in RF work will know what you mean. He will copper flash the line before plating it. Specify a minimum silver thickness of 0.001 in. In 1986, the cost to silver plate all parts (W1, W2, L2, C6 and C7) was $63, of which $60 was for setup and only $3 was for material. For minimal additional cost, you and other hams can collect a wide assortment of RF parts and have them all plated at once.

Silver plating is *not* necessary for proper operation. The difference in efficiency between a clean, polished but unplated stripline and a silver-plated line was nearly impossible to measure. Experience with the 8874 432-MHz amplifier has shown that an unplated line begins to tarnish after a few years. When the oxidation is heavy enough, the amplifier tuning drifts as it heats up. Polishing the stripline returns the amplifier to

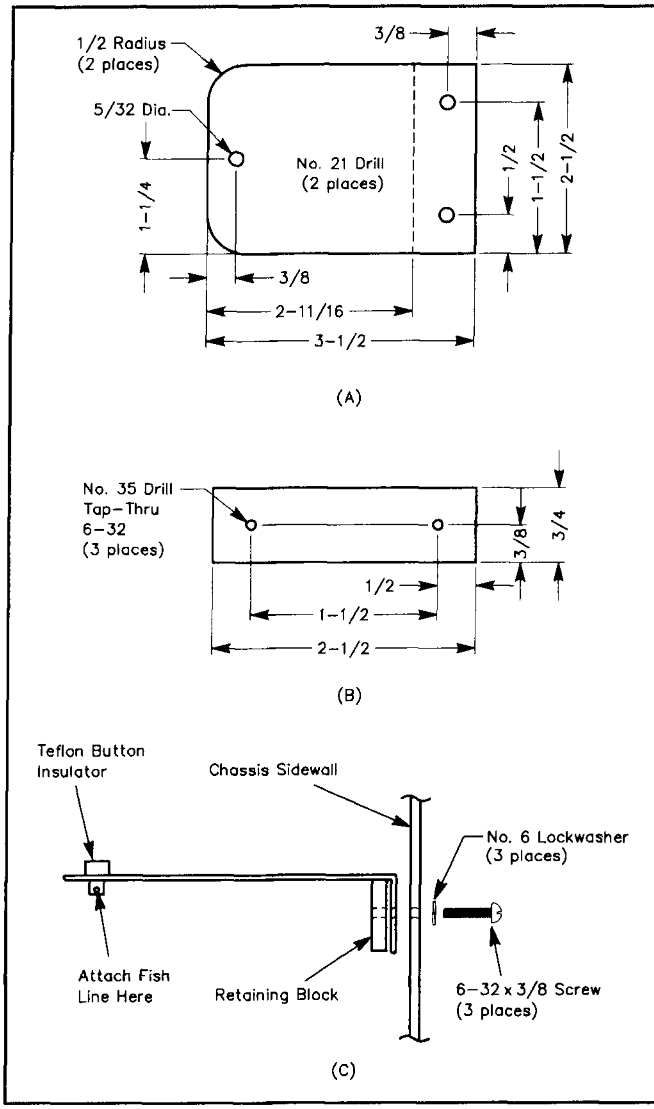


Fig 2—Plate tuning capacitor C6 (A); retaining block (B); mounting of the capacitor and retaining block (C). The capacitor is made from 0.010-in. hard brass or beryllium copper. Silver plating is optional. The mounting block is made from 1/8-in. aluminum.

like-new operation with no thermal drift.

The plate line is held in place with two 1½ in. high × ⅜-in. diameter ceramic standoff insulators. Homemade Teflon insulators are even better. They can be made ⅜ or ½ in. diameter. Tap the ends for 6-32 screws. Use brass screws to hold the stripline in place. Steel (and especially stainless steel) can cause unwanted tuning effects. Also use a brass screw to attach the plate RF choke (RFC4). The screws used to attach the standoff insulators to the chassis bottom can be steel. The hole in the plate line for the anode is sized for an EIMAC 720089 collet. Finger stock may be used if you prefer. If you use finger stock significantly larger than the EIMAC collet, the position of the plate-tuning capacitor will be different. Try to obtain finger stock with contacts that are rolled over 180°, sized about ⅛ to 3/16 in. high, with the fingers rolled over about ⅛ in. Be careful to size the anode hold in the plate line correctly.

The tuning and loading capacitors are made from 0.010-in. thick brass shim stock. This material has a spring temper

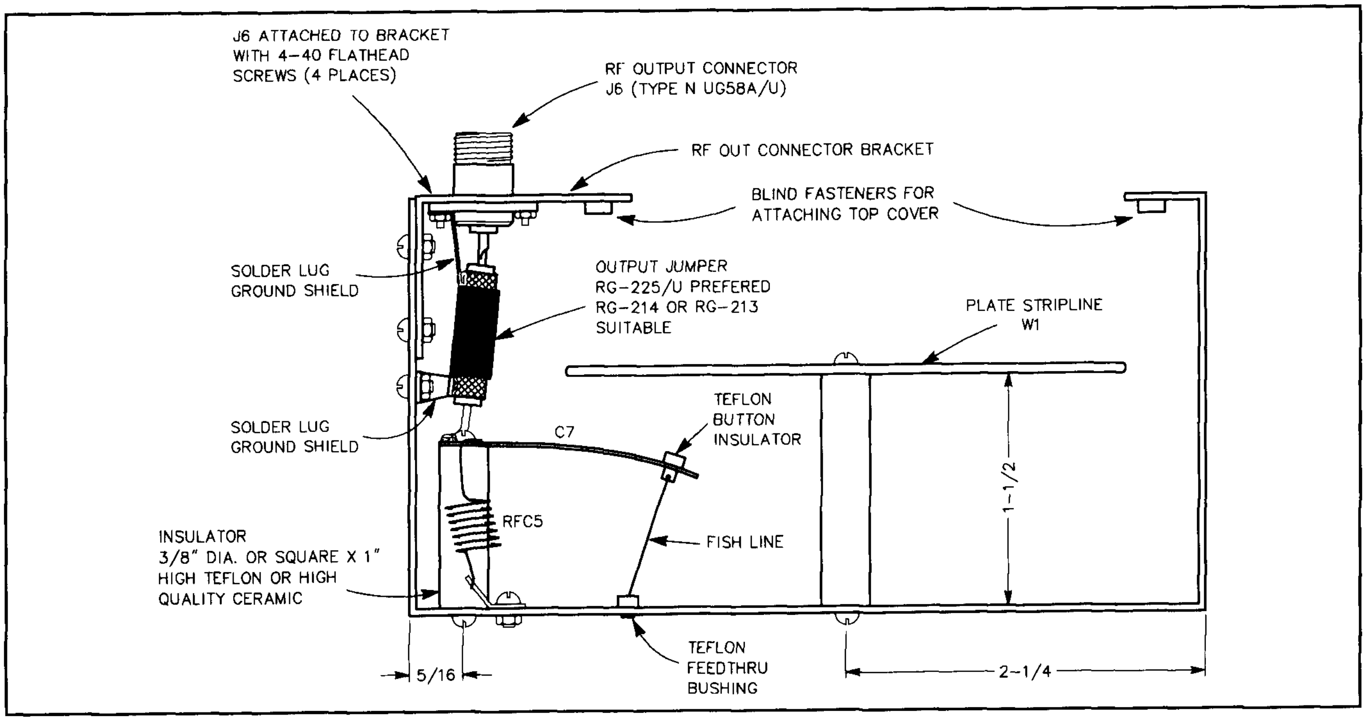


Fig 4—RF output compartment details. The plate line is not centered in the enclosure. See Fig 5 for construction details of the RF output jumper.

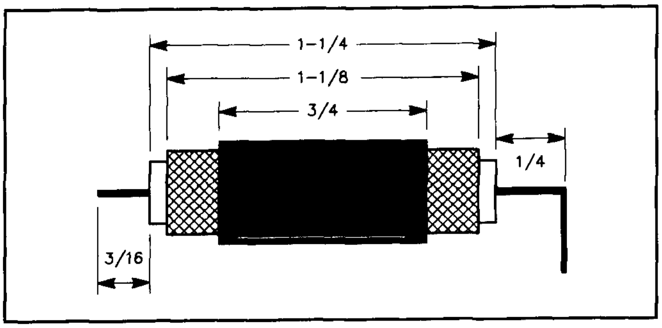


Fig 5—RF output jumper details. RG-225 Teflon-dielectric cable is preferred, but RG-214 or RG-213 cable may be used. Alternately semi rigid solid copper sheathed cable such as UT-141 or UT-250 may be used.

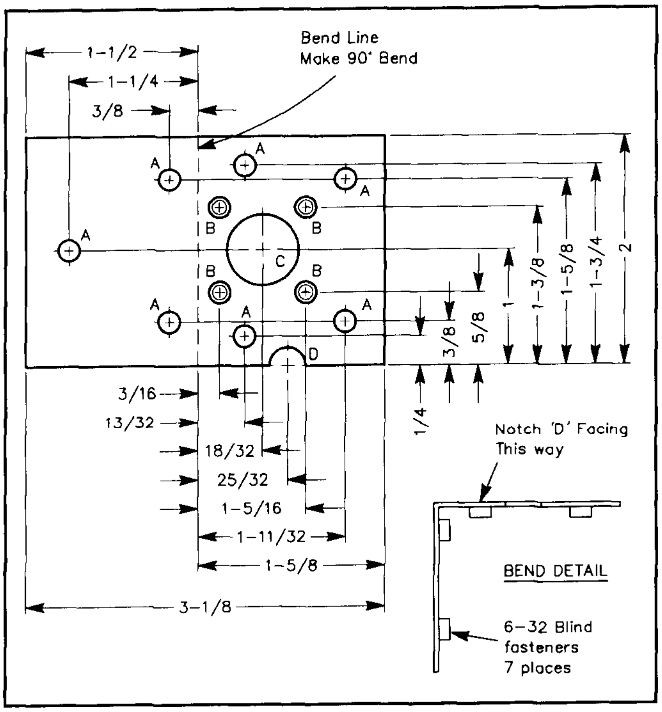


Fig 6—RF-output connector bracket is made from 0.062.-in. aluminum. Holes marked A are 3/16-in. diam., for 6-32 blind fasteners. Asterisks (*) indicate holes that should be located using the top cover as a template when the bracket is mounted. Holes marked B are No. 30, countersunk for flush mount with 4-40 screws. The connector mounting holes may also need to be countersunk. Hole C is 5/8 in. diam. Hole D is a 5/16-in. diam. notch to clear the blower mounting plate.

and works well. You can also use beryllium copper. Don't use material thicker than 0.010 in. Thicker stock is more likely to take a set and not spring back to its original position. In addition, thicker material may place too great a load on the fish line and tuning controls. The strain may stretch the fish line or move the tuning control positions, affecting tuning.

The plate flapper (Fig 2) is held in place by an aluminum block ¾-in. wide × 2½ in. long × ⅛-in. thick. Tap the holes for 6-32 thread, for easy installation and removal. The loading flapper (Fig 3) is mounted on a 1-in. tall, ⅜-in. dia. Teflon or ceramic insulator. Both flappers use small Teflon button insulators to secure the fish line. These homemade insulators serve the dual purpose of providing an attachment point for the fish line and preventing the flappers from accidentally contacting the plate stripline.

The preferred fish line is braided Dacron fly line. I used Specialist 18-lb Fly Line Backing, made by Berkley. Be sure

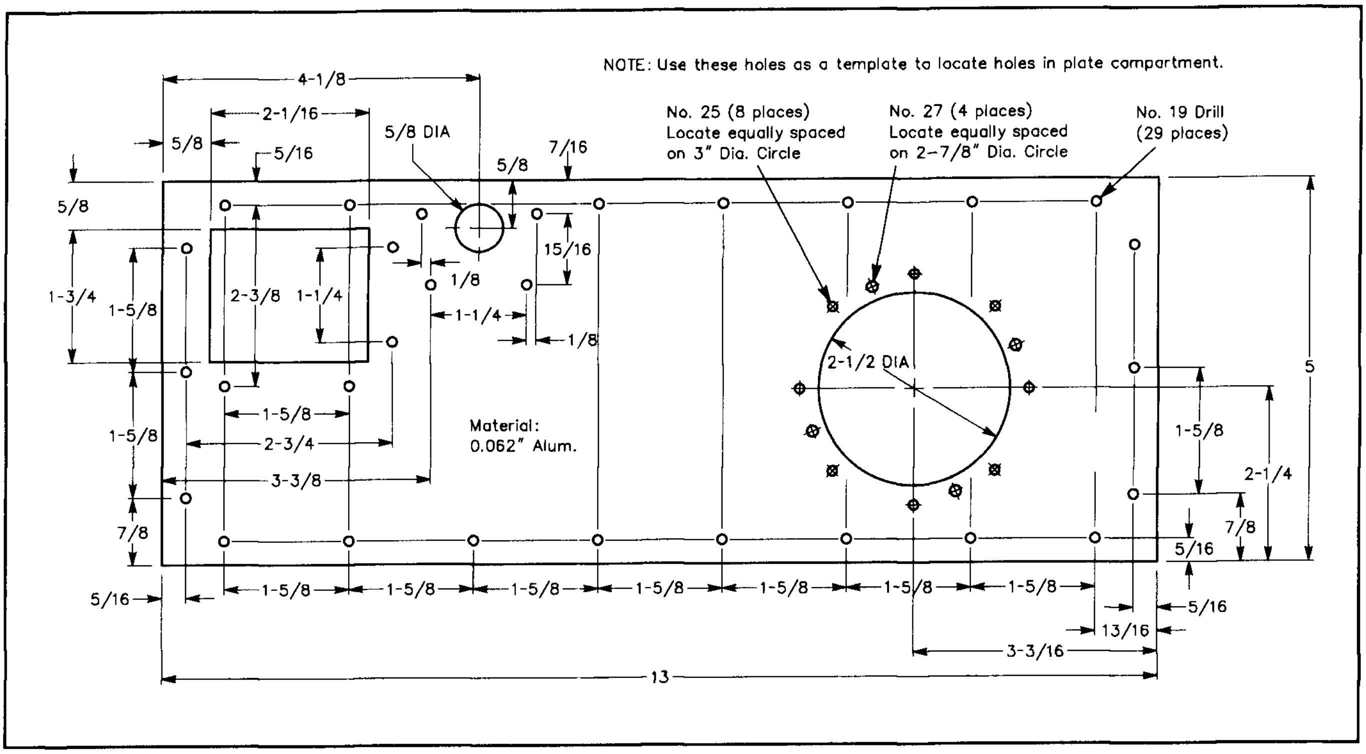


Fig 7—Top cover of the amplifier is made from 0.062-in. aluminum. Use the cover as a template to mark holes in the chassis.

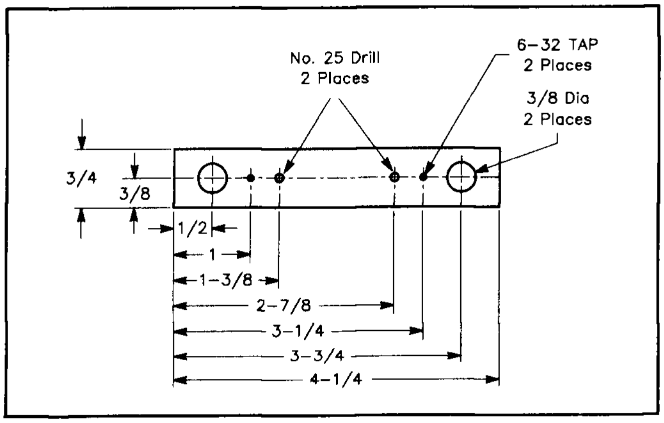


Fig 8—Plate tuning control bracket is made from 0.062-in. aluminum.

all edges on the flappers are smooth and free from burrs. Also make sure the flappers are mounted parallel to the stripline. These precautions assure RF or dc doesn't arc from the plate line to the flappers.

A small piece of RG-225 coax connects the loading capacitor to the RF-output Type-N connector (J2). Fig 4 details assembly of the loading capacitor (C7) and Fig 5 gives dimensions for the coax jumper. RG-225 is similar to RG-214, but uses Teflon dielectric and jacket, along with double silver-plated shields. You can also use RG-213 or RG-214 if you're careful not to melt the dielectric while soldering it in place. Both ends of the shield are grounded through solder lugs. Be sure that the jumper is mounted close to the chassis wall and away from the stripline. The output connector is mounted on a small bracket to allow for rear-panel RF-output connection, while not requiring any disassembly when the plate-compartment cover is removed. Fig 6 gives the layout of the output connector bracket.

Be very careful when notching the plate chassis for the RF- output-connector bracket. Once the lip is cut out it is very easy to bend the chassis if the bracket is not secured in place. The top cover (Fig 7) should be drilled first. Then you can use it as a template to locate the holes in the chassis that will hold the top cover in place. Next, install the blind fasteners (PEM nuts). Once the fasteners are in place, you can notch the chassis for the output-connector bracket. Cut the bracket to size and bend it 90°, as shown in Fig 6. Drill the 3 holes for the bracket mounting screws and install the bracket. Now use the top cover again as a template to locate the output-connector hole and the 4 top-cover mounting holes. You can use the UG-58 output connector as a template to locate its mounting holes.

The plate tuning and loading fish lines are brought through the chassis through small homemade Teflon bushings. The lines run over small pieces of ¼-in. Teflon rod, giving nearly friction-less 90° transition of the tuning controls. Brass shafts, which run through panel bearings that are mounted on a support bracket (Fig 8), control the tuning lines. This bracket is supported by standard 1¼ in. long steel standoffs. To impart a slow, smooth feel to the plate tuning and loading controls, 6:1 ball-reduction drives are used. The drives I used are Jackson Bros. 4511/DAF, and is available from Radiokit or Surplus Sales of Nebraska.[3] The ball drives are

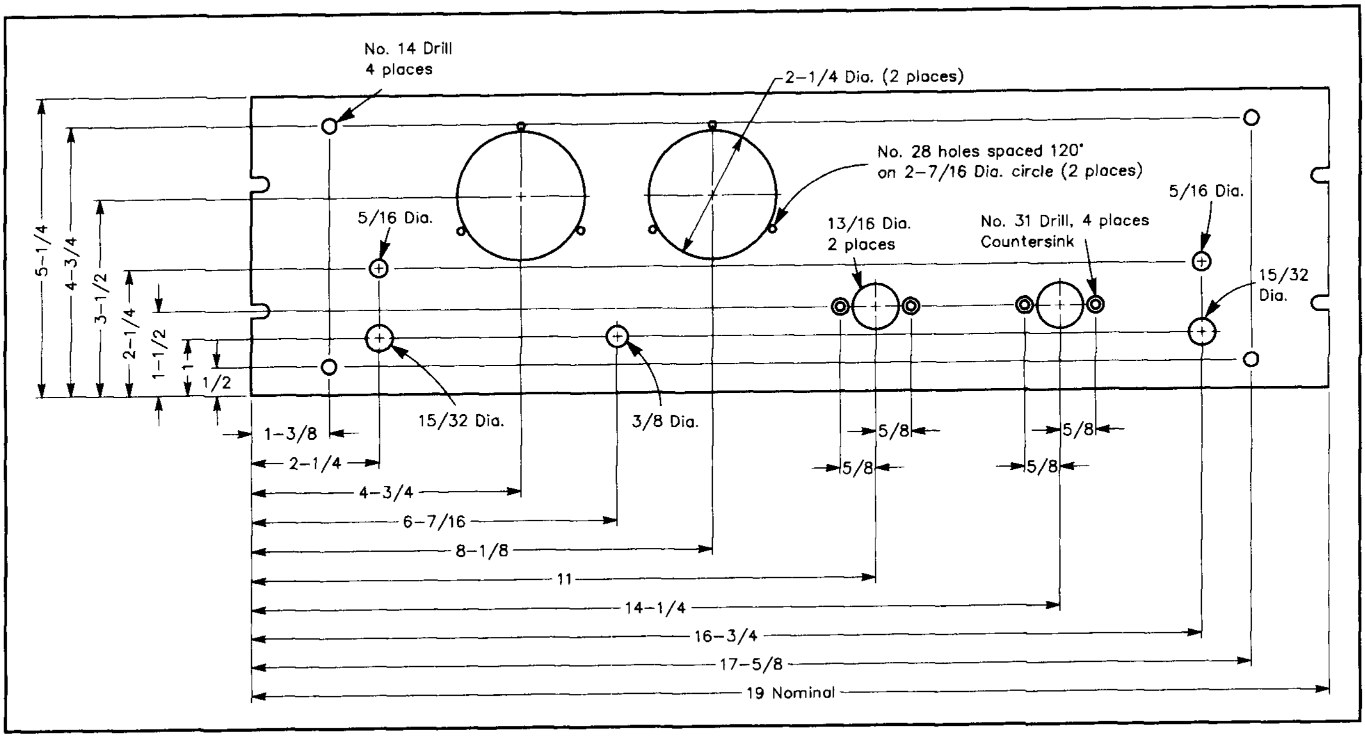


Fig 9—Front-panel layout. The panel is made from a standard 5-1/4 in. aluminum EIA rack panel.

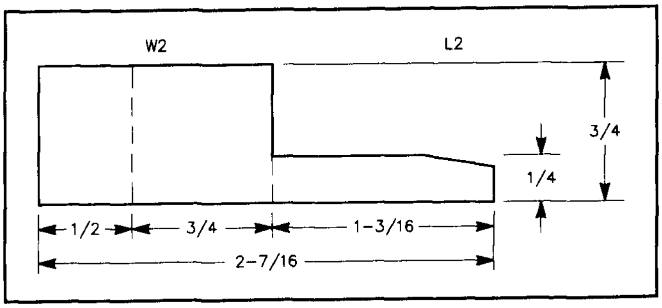


Fig 10—Cathode stripline is made from 0.015-in. brass. Silver plating is optional.

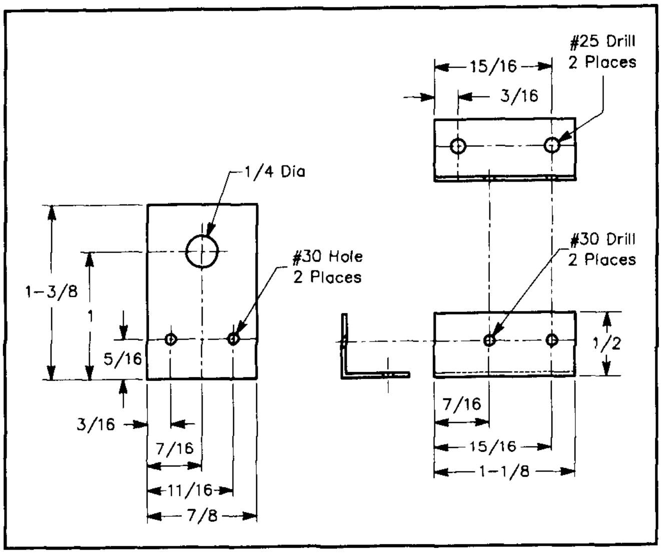


Fig 11—C1 mounting bracket is made from 0.062 X 1/2-in. aluminum angle or 0.062-in. aluminum sheet. The mounting insulator is made from 1/16-in. G10 circuit-board material from which the copper has been removed.

mounted to the front panel with 4-40 flat-head screws. Fig 9 shows the front rack-panel hole sizes and locations for the ball drives and other holes. Use 4-40 nuts to secure the screws, so they act as mounting studs for the ball drives. The nuts also serve as spacers to position the ball drives nearly flush with the front panel. Homemade pointers attached to the ball drives serve as control position indicators.

The specified high-voltage feedthrough capacitor may be hard to find. It may be available from Microwave Components of Michigan.[4] You can also construct a bypass capacitor from 1/16-in. thick brass plates and 0.005-in. Teflon or Kapton sheets. A two-plate capacitor with one plate inside the RF enclosure and another plate on the outside is recommended. Plates sized approximately 2½ × 3¼ in. are suitable. The plates should be flat, polished so they are smooth and free from any burrs, and have rounded edges. If you use Teflon, spread silicone grease on the Teflon to fill in any imperfections. You don't have to coat Kapton, as it doesn't have the porosity or cold-flow characteristics of Teflon.[5]

Cathode Circuit Assembly

The cathode circuit consists of a quasi-half-wave line, similar to that used in the original 8874 amplifier. Changes have been made, due to the higher input capacitance of the 3CX800A7 and to make the circuit more repeatable when duplicated. Fig 10 gives the layout of W2 and L2. Most of the first quarter wave of the half-wave input line is actually inside the tube and socket. W2 forms the rest of the first quarter wave and part of the second quarter wave. L2 completes the second

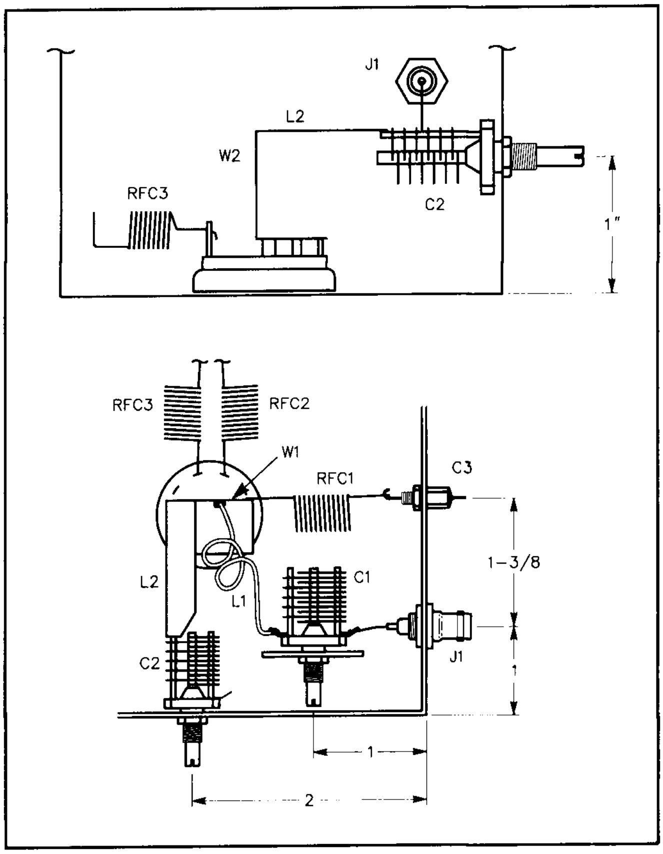


Fig 12—Side and bottom views of the cathode circuit.

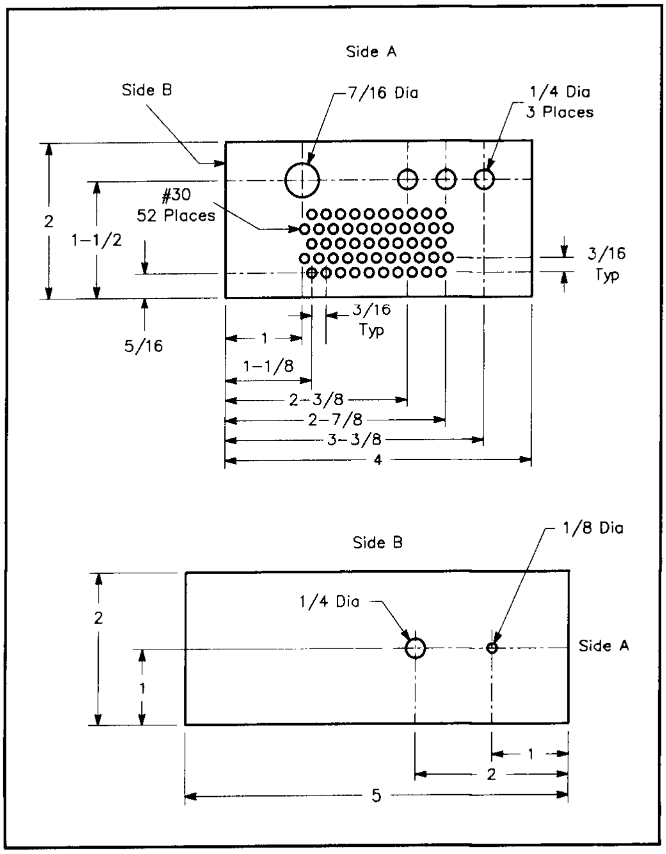


Fig 13—Cathode compartment details. The compartment is made from a 5 X 4 X 2-in. chassis.

half of the line. C2 is simply used to tune the line to resonance. L1 is a series inductance to match the 50-Ω input impedance to the input impedance of the tube. L2 has slightly too much inductance so the series capacitor C1 is used to adjust the total reactance for a proper match. Note that the rotor of C1 must be insulated from ground. A small piece of G-10 epoxy PC board material serves as a mounting insulator. The circuit board is held in place by a small aluminum bracket (Fig 11).

To assemble the cathode circuit, first remove the unused grid pins (4, 7, 11) from the tube socket. Next bend the 6 cathode pins (1, 2, 3, 8, 9, 10) in toward the center of the socket, forming a 90° angle. The bend is made just above the dimple that keeps the pins in place in the socket. The socket is then mounted in place on the grid collet. Note how the 2 filament pins point to the top of the amplifier and the 6 cathode pins point toward the bottom. Mount the rest of the cathode components, C1, C2 and J1. If the layout has been followed, when W2 is soldered to the 6 cathode pins, L2 should line up right on the stator wires of C2. Fig 12 gives 2 views of the cathode-circuit layout. Fig 13 covers the hole-drilling patterns in the cathode compartment. If you follow the layout, the input circuit should tune up easily and you'll obtain an input SWR less than 1.2:1.

Tube Socket Mounting

The recommended EIMAC 720359 grid-collet assembly simplifies construction. It consists of an EIMAC 882931 collet that has been soldered to a 1/16 in.-thick brass mounting ring. The mounting ring has three 4-40 studs that are positioned to match the mounting holes of the 11-pin tube socket. An alternate method of construction is to use the 882931 collet and attach it to a homemade mounting ring. Although the 720359 collet assembly is more expensive, it will save you considerable construction time.

To cut the hole for the tube socket, first punch a 1¼ in. diameter hole in the chassis bottom, located as shown in Fig 14. Next use the tube socket to locate 3 no. 28 holes, orienting the socket per the hole layout in Fig 14. Put the EIMAC 720359 collet in place and use it as a template to drill its 4 mounting holes in the chassis with a no. 27. Remove the collet and socket. Next, drill out the 3 #27 holes with a 9/32-in. drill. Then file out the holes until they form one hole that matches the shape shown in Fig 14. The socket should be able to pass through the hole. Drill a series of 6 no. 43 holes in the collet, matching the pattern shown in Fig 22. Again use the collet as a template to drill 6 no. 42 holes in the chassis. These holes are for bleeding air into the cathode compartment for cooling the tube base. The tube socket may then be mounted to the collet, using 4-40 nuts and lock washers. The collet is then mounted to the chassis with 4 6-32 screws. With everything properly assembled the tube socket will mount flush with the collet.

Additional air is let into the cathode compartment through a series of cooling holes. A metal plate (Fig 15) is used to make an RF filter to prevent leakage from the plate compartment into the cathode compartment. The cathode box is perforated on the side away from the cooling holes. In this way, the air passing into the cathode box is forced across the tube base, to maximize its cooling effect.

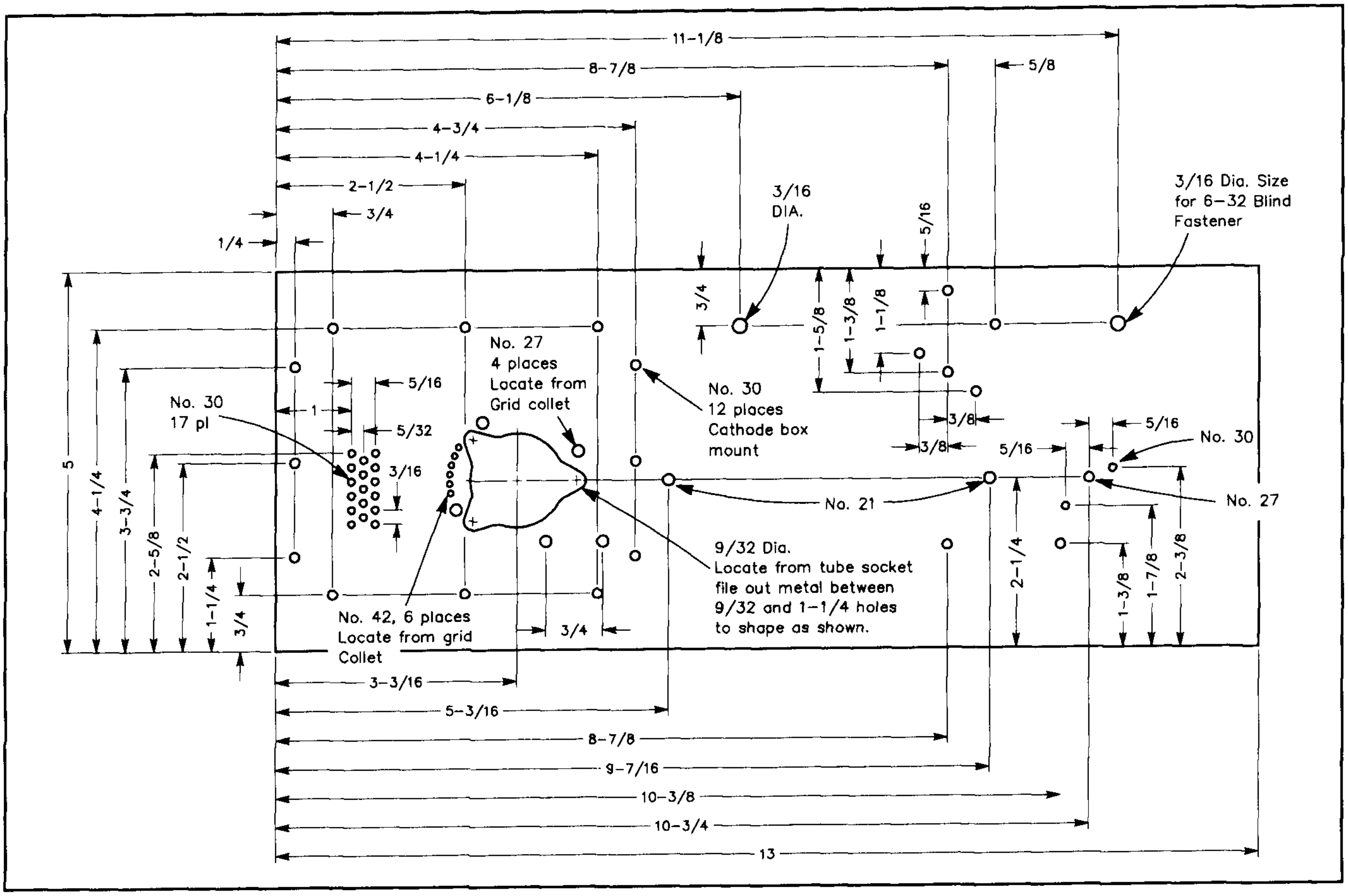


Fig 14—Bottom cover of the plate RF enclosure is made from 0.062-in. aluminum.

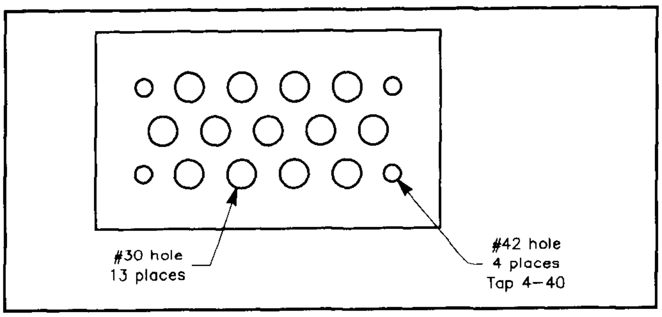


Fig 15—Cathode air vent waveguide is made from 3/16-1/4 in. aluminum.

Cooling Considerations

The air inlet and outlet are RF shielded by means of aluminum cooling screen, sandwiched between the RF deck top cover and ¼-in.-thick retaining plates. Matching hole patterns are cut in the top cover and the retaining plates. For best alignment, use the top cover as a template for drilling the plates. Although these plates may look complicated to make, they were fabricated with hand tools. The large air inlet and outlet holes were first scribed. Then, a series of small holes was drilled along the inside of the marks. The holes are then drilled out with a larger drill so the hole slug can be knocked out. The holes are then simply filed to shape. Fig 16 gives the inlet plate layout and Fig 17 shows details of the outlet plate.

The air-outlet plate is mounted on the inside of the chassis

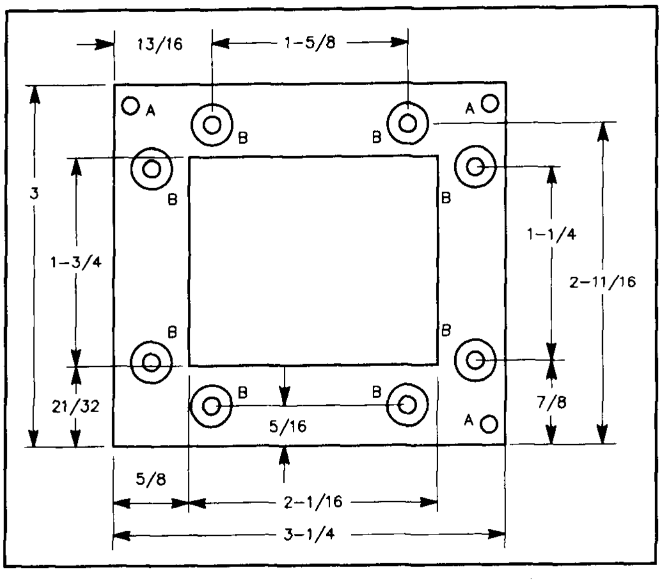


Fig 16—Air inlet retaining plate is made from 3/16-1/4 in. aluminum. Hard alloys, such as 6061-T6 or 2024-T6 are preferred. Holes marked A are No. 7, tapped 1/4-20. Use the blower itself as a template to locate the holes. Holes marked B are No. 25, countersunk for 6-32 flathead screws. Use the top cover to locate these holes.

sandwiching the screen between it and the cover plate. The plate also serves to space the chimney down to the plate line. The EIMAC SK-1906 chimney is held in place with 4, ½-in.-

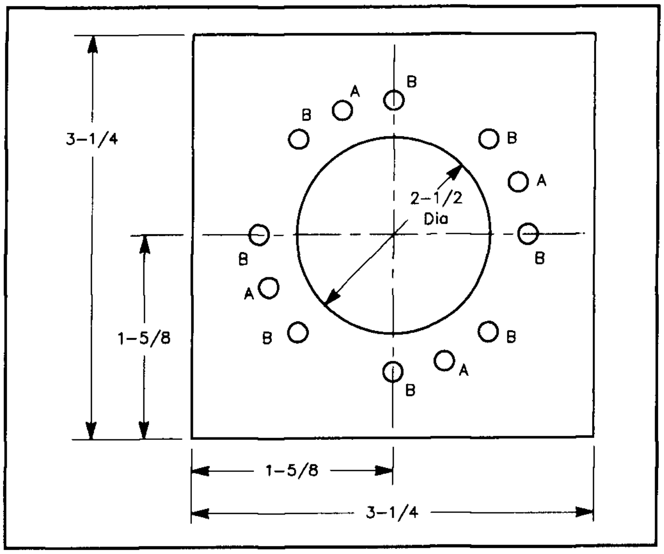


Fig 17—Air outlet retaining plate is made of 1/4-5/16 in. aluminum. Hard alloys, such as 6061-T6 or 2024-T6 are preferred. Holes marked A are No. 27. Locate the 4 holes equally spaced on a 2-7/8 in. diam. circle. Holes marked B are No. 35, tapped 6-32. Locate the holes equally spaced on a 3-in. diam. circle.

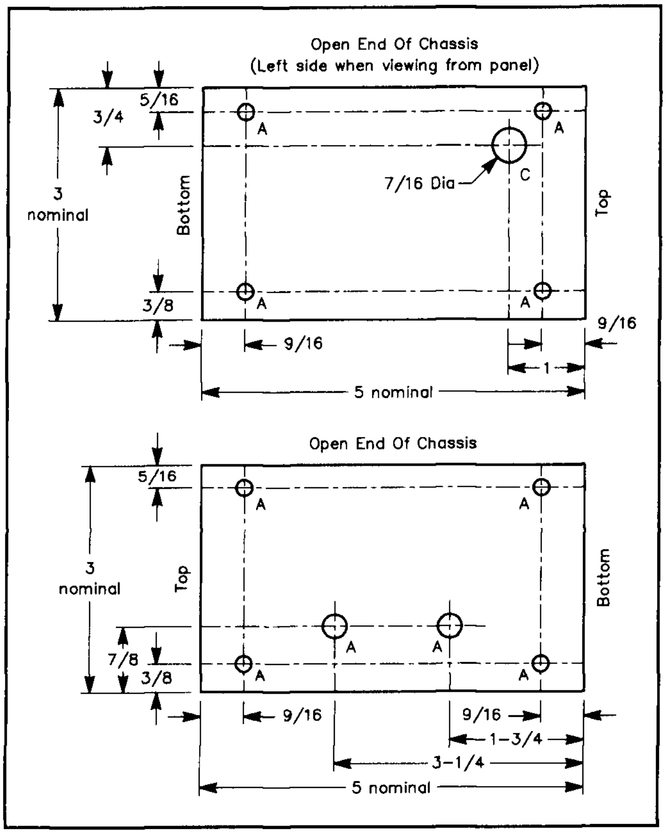


Fig 18—RF deck. At top, tube end; at bottom, flapper end. Holes marked A are chassis mounting holes, No. 23.

long 4-40 screws, which pass through the cover plate and retaining plate. The threaded metal inserts in the chimney should be removed from the plate line side of the chimney. Alternately, you can use a homemade Teflon chimney. The air-inlet

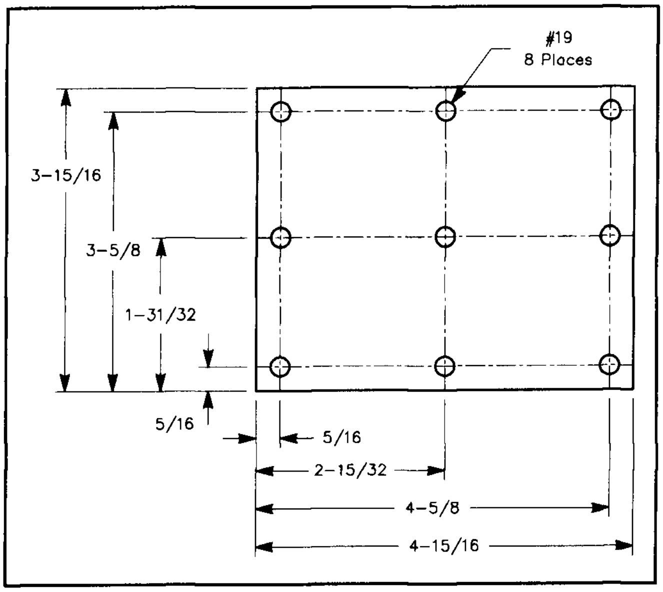


Fig 19—Cathode compartment cover plate is made from 0.062-in. aluminum. Use the finished cover as a template to locate holes in the cathode compartment.

plate and screen are mounted on the outside of the top cover. Tap three ¼-20 blower-mounting holes in the plate. Note that 4 of the inlet plate hold-down screws also secure the top cover. Since the blower covers all 8 of the mounting screws, their holes are countersunk and flat head screws are used. The blower must be removed to take the plate compartment top cover off.

To ensure that adequate RF shielding is maintained, the air inlet retaining plate and the top cover must be fastened tightly. The 5- × 13- × 3-in. chassis is made from 0.040-in.-thick soft aluminum. Sheet-metal screws will easily strip out the thin aluminum after being removed and replaced several times; it's essential to use blind fasteners (PEM nuts or Rivnuts). They are readily available from Small Parts Inc. I used 6-32 fasteners. When installing the fasteners, be very careful not to distort the chassis lip. It is easy to make ripples in the metal, which will cause RF leakage.

The amplifier operates quietly with the specified blower, in combination with effective shock mounting. A ⅛-in.-thick gasket made from high-density foam rubber is placed between the blower and its mounting plate. The blower is attached with three ¼-20 nylon screws, ½-in. long. Rubber grommets are placed on the screws before they are installed. This arrangement assures that there are no solid mechanical contacts to transmit blower noise and vibration.

Metal Finishing

The professional finish on the amplifier is gold-irridite applied by a plating company. Irridite provides a hard and conductive finish. Don't confuse irridite, which is sometimes known as chromate finish, with anodizing. Anodize is not a conductive finish and may contribute to RF leakage and improper operation of the amplifier. All aluminum was wet sanded with 320-grit wet-sanding paper. Sand in one direction in a straight motion. You are sanding the aluminum to remove

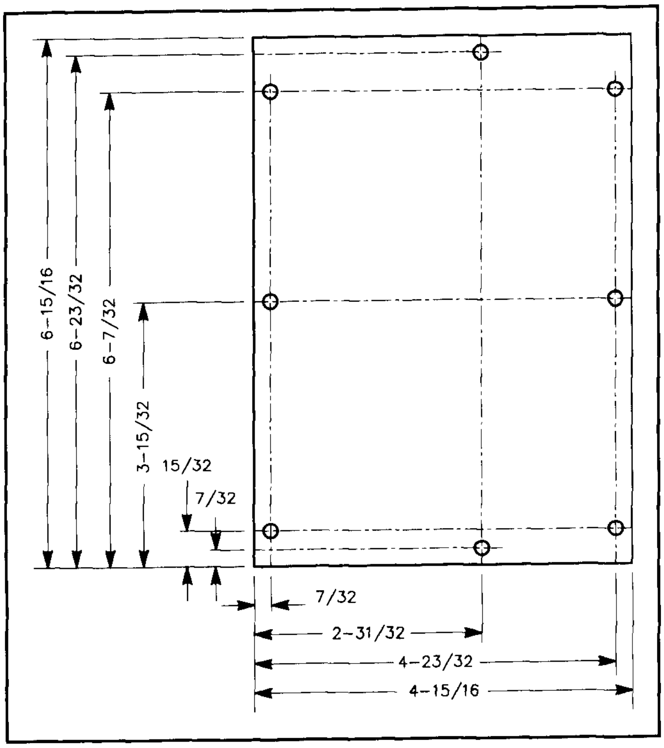


Fig 20—Side-chassis cover plates (2 required). Holes are No. 19. Use cover plates as templates to drill side chassis.

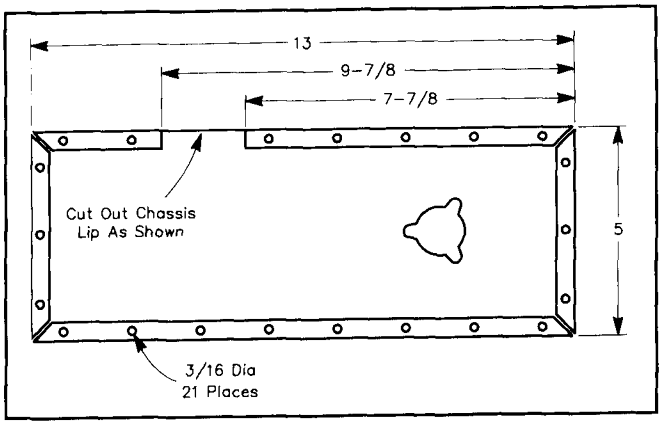


Fig 21—RF plate enclosure. Install blind fasteners in the 21 3/16-diam. holes.

scratches and burrs made during construction. At the plater's specify a deep etch, which will remove any remaining scratches, unless they are very deep. While you can apply irridite at home, I don't recommend you try, though. The aluminum must be absolutely free of contaminants, and the chemicals necessary to ensure it is are not readily available and are dangerous to use. I paid only $32 to have all the amplifier parts irridite plated, in 1986.

The drill work done to make the various air-vent holes (cathode compartment and side chassis) may look as if it was done by magic, to achieve their near-perfect patterns. In truth, these vent holes are simple to create. A piece of standard perforated steel was used as a drilling template, so the many holes do not even have to be marked! After drilling, the burrs are sanded smooth to create the clean, sharp holes. Figs 18 to 21 give additional metalwork drilling and cutting information.

Protection Circuits

The specified filament warm-up time for the 3CX800A7 is 3 minutes. Follow this specification to obtain maximum tube life. As the cathode is heated, the areas directly in front of the filament wires get hot first, and become the first areas to emit cathode current. If you operate the amplifier in this condition, the cathode hot spots will emit all the cathode current, and may vaporize.

An Amperite thermal time-delay relay is used to prevent operation of the amplifier for 3 minutes. A solid-state timing circuit was considered, but the thermal time-delay was chosen because it is simple and heats just like the tube filament. There's no need to wait another three minutes if filament power is only interrupted momentarily. Brief interruptions may be caused by power failures or HV arcing. This kind of flexibility is hard to design into a solid-state circuit.

A 120-second time-delay relay was used because it is the longest delay available in the 9-pin miniature size. I extended its turn-on time to 180 seconds by placing a resistor in series with the heater element. Even if you obtain a 180-second unit, you should check the turn-on time. Most units are specified for use on a nominal 115-V ac circuit. With US line voltage now typically 118 to 120 V, some timers will warm up 15 to 20% faster than the specified time. If necessary, use a series resistor to adjust the warm-up time. Since I built this amplifier, the Amperite 115NO120T (9-pin) and 115NO180 (octal) have become hard to get and very expensive. An inexpensive sealed-plastic-case model (115NO180B) can be used instead.

A small but significant point is the use of a 14-V transformer for the filament. Since the filament voltage is backed off to 13.0 V for operation, you may be tempted to use a commonly available oversized 12.6-V transformer. Doing so will be detrimental to the life of the tube. A well-cared-for tube used in intermittent service may first fail with an open filament. A cold filament has very low resistance (1.5 Ω for the 3CX800A7). Unless some protection is used, the turn-on surge may be as high as 10 A. By using a higher-voltage transformer and series resistors, automatic surge limiting is easily achieved. I used a 1-Ω resistor in series with the secondary of the transformer. A 50-Ω, 12-W variable resistor is used in the primary circuit to set operating filament voltage.. This combination limits turn-on surge to just over 2 A.

To achieve high gain and efficiency, the 3CX800A7 uses a grid structure constructed of small wires. This construction limits grid dissipation to 4 W. It is common practice for HF amplifier designers to include a circuit to sense excessive grid current. Such sensing circuits are not always useful at UHF, as transit-time effects may cause negative grid currents vastly different from real grid absorption and secondary emission. In testing the 3CX800A7 at 432 MHz, the grid current was found to behave predictably, that is positive current which corresponded directly to drive levels was observed. Because of this desirable behavior, a grid-current-sensing circuit was included in this amplifier. R14, in combination with grid shunt R4 develops a voltage sufficient to switch on the grid-trip relay K3, through switching transistor Q2. Contacts on K3 lock in the over-current relay and turn off the OPERATE pilot lamp. No reset switch is used. The circuit is reset by setting STANDBY/OPERATE switch (S2) to STANDBY, then back to OPERATE.

An additional protection circuit senses high voltage. It consists of Q1, which senses the presence of high voltage through the HV metering circuit. Q1 allows the T/R relays to switch on transmit. This circuit prevents the amplifier from keying should plate voltage not be present. While just the grid-trip circuit may seem adequate, the absence of plate voltage will cause the tube to draw excessive grid current when drive is applied. The HV sensing circuit protects against such an occurrence.

Many high-performance 432-MHz stations use a single T/R relay at the array, in combination with an antenna-mounted receive preamplifier. In these stations, in-out RF relays are not used at the amplifier. This could cause a problem if the amplifier ac fuses blow. Since the grid-trip circuit requires that power be present to operate, ac-power loss to the amplifier but not the exciter can result in damage to the tube, unless a driver-to-amplifier interlock is provided. The HV-sensing circuit will protect the tube. Simply unshorting the cathode-bias resistor (R3) will provide sufficient protection for the tube from drive power, but it is better to remove all drive power when plate voltage isn't present.

Another feature of the switching circuitry is provided by S4. This switch, located on the rear panel, allows the operator to determine whether the RF relays actuate every time he transmits, or lock in when the amplifier is switched from standby to operate. This feature can be used if the station includes a tower-mounted preamp with a separate feed line. It eliminates the noise generated by switching the relays in the shack. If an in-out tower preamp is used (with a single transmission line) or a transceiver without an external preamp, this locking feature is not usable. Note though, even if the RF relays are locked in, either an excessive grid-current trip or loss of plate voltage will still drop out the RF relays.

Metering Circuits

The metering circuit has one anomaly: The resistor string is used both for the high-voltage meter and for the high-voltage sensing circuit. Since the HV sensing circuit is referenced to ground, the current from the circuit will return to the HV supply B– lead through the grid-meter shunt. The grid meter will read this current. At idle conditions, the grid-current meter will read negative by about 0.8 mA. If you find this to be a problem, use separate resistor strings for the HV meter and HV sensing. The HV meter would then be connected to the B– line, not to ground.

Note also that the HV meter also reads plate voltage relative to ground. Since the actual power input is determined by plate-to-cathode voltage, the bias voltage must be subtracted to obtain the true plate voltage and power input. As the bias voltage on the 3CX800A7 is only 5.6 V, so the correction is only 0.2%. To obtain a true plate-to-cathode voltage reading, you must reference the HV meter circuit to the tube side of the Zener bias diode. This would again require separate HV meter and sensing resistor strings. Arranging the meter circuit in this way also causes the plate meter to indicate the metering string resistor current.

Many operators will want to build 3X800A7 amplifiers for other bands, and share a common HV supply. This would place the grid shunts in parallel. Grid-current meters on the unused amplifiers will indicate a portion of the operating amplifier's plate and grid currents, uncalibrating all the metering circuits. There are two methods to reduce this problem. One is to place a resistor in series with the grid-sensing resistor (R21). Alternately, you can install a resistor in series with the B– line. T/R relay K2 would short out these resistors on transmit. Use the lowest-value resistors which eliminate the problem. This value depends on the number of amplifiers connected to the same power supply, but a value of 500 Ω is typical. A word of warning: These resistors increase the possibility of damage to the metering circuits when a HV arc occurs. Also note that the 11-Ω effective grid-shunt value (due to the grid over-current sensing circuit) causes a portion of the grid current to flow through the B– safety resistors (R1 on the amplifier and any similar resistors at the HV power supply). R13 can be adjusted to make the grid meter read the correct value when connected to the power supply.

Keying Circuits

A transistorized relay-switching scheme is used. The circuit can be switched by either grounding J6 or by supplying +12 V to J8. Current sinking or supplying capability is only 15 mA, which should be compatible with current 432-MHz exciters. If you are using conventional switching circuits, make sure your relays will reliably contact at only 15 mA of current. As described in the protection-circuit section, a loss of high voltage will prevent the relays from switching, or drop them if they have already switched.

The coaxial relays you use should have dc coils. Dc coils switch faster, have less contact bounce and run cooler than ac types. The coils don't have to be 28 V, as are most available military surplus relays. Several types of suitable coax relays with 12-V coils are available. The switching circuitry can be made to work with 12-V coils but you'll have to change T2. If you have relays with 120-V ac coils, don't despair. Many 120-V ac relays work better on 12 to 28 V dc, so try them on a dc supply.

Amplifier in-out switching relays don't need high isolation. If you use separate input and output relays, the input relay can be a low-power type.

Power Supply Considerations

The high performance of the 3CX800A7 at VHF and UHF is partially a result of the close internal spacings of the tube elements. These close spacings increase the possibility of a plate-to-grid arc over. To protect the tube, power supply, metering circuits and the operator, a 50-Ω 50-W resistor is connected in series with the HV power lead. This resistor substantially reduces the energy dissipated in the tube during an arc over, yet only reduces the full-load plate voltage by 30 V. EIMAC specifies that idle plate voltage should not exceed 2500 V.

I built a modern capacitor-input power supply, which uses a solid-state bridge rectifier in combination with a low-resistance plate transformer. My supply uses a Peter Dahl Hypersil transformer (1800 V at 700 mA, CCS). The electrolytic-capacitor string has a total capacitance of 22 µF. An oil-filled capacitor is preferred. Adequate regulation and ripple filtering can be obtained with less than 25 µF of filter capacitance. No-load voltage is approximately 2510 V. At 600 mA, the plate voltage is 2250 V. Out of the 259-V drop, over 100 V is due to line-voltage sag and the protection resistor. In no case should you use more than 50 µF of filter capacitance. Higher values will not significantly improve regulation, but will greatly increase the possibility of damage during an arc over.

Avoid choke-input filters. I have seen many improperly designed amateur supplies that were made from surplus components haphazardly cobbled together. These supplies can have bad transient-voltage-spike problems, induced from the chokes. These transients will blow rectifier diodes and cause tube arcs. They can also severely reduce the IMD performance of the amplifier. Finally, be sure to use MOV transient suppressors on the ac-input leads.

I highly recommend MHV-type HV connectors. The most dangerous condition to the operator is when high voltage is present and the power-supply-to-amplifier ground connection open. If this happens and you touch the amplifier and power supply (or any other grounded object if the power supply was grounded), you become the ground return. MHV connectors prevent this possibility as the shield makes contact along with the center conductor. RG-59 cable can comfortably handle the 2500-V power that this amplifier uses.

Amplifier Stabilization

Many amateurs mistakenly believe that neutralization of a grounded-grid amplifier is not required. Although operation of this amplifier is possible without neutralization, the simple neutralization procedure used provides for improved tuning, more stable operation and greater apparent efficiency. In addition, tube life may be increased due to the elimination of unwanted higher frequency circulating currents. The amplifier was neutralized by adjusting the grid inductance until the plate current dip matched the maximum output point. The amplifier operates so well that it can be tuned up without a power-output indicator. By dipping the plate current and adjusting the loading for proper grid current one can obtain output power that will be within a few watts of tuning it up for maximum output on a directional wattmeter!

Since the 3CX800A7 is operating below its self-neutralized frequency, neutralization is easily accomplished by breaking off grid collet fingers. The so-called self-neutralizing frequency of a tube is simply the frequency at which the combination of tube and socket have the right combination of feedback capacitance and inductance as to create the maximum input-to-output isolation. It should be noted that not all tube and socket combinations have any frequency where their isolation will be acceptable.

By breaking off some of the grid-collet fingers, the effective grid inductance is raised and the maximum reverse isolation point is lowered to 432 MHz. Fig 22 shows the proper pattern for breaking off the grid-collet fingers. Tube characteristics appear to be close enough among different 3CX800A7 tubes such that neutralization for a specific tube is not required. If you want to be safe, however, break off every other finger on the grid collet. There will be 18 remaining fingers. Tape over 6 of them with Kapton tape, spacing the taped fingers equally around the tube. These taped fingers will then allow future tuning adjustments without replacing the grid collet.

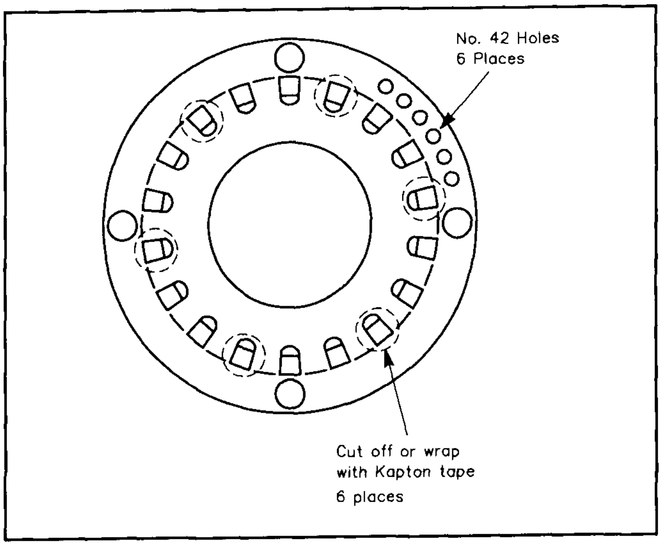


Fig 22—Grid collet modification. The EIMAC 720359 collet is supplied with 36 fingers. Break off every other finger. Wrap 6 of the remaining fingers (as shown) with Kapton tape or break them off. Removing the fingers adjusts grid-circuit capacitance and helps neutralize the amplifier.

An even more scientific approach to neutralization is to look at the reverse isolation of the amplifier. This is done by connecting the output of a signal generator or network analyzer to RF-output connector and measuring the fed-through power with a power meter, spectrum analyzer or network analyzer. Ideally, this test is performed after tuning up the amplifier with all voltages in place. If isolators are not available, there is a danger that the amplifier can oscillate during the test procedure and put out enough power to destroy your signal generator.

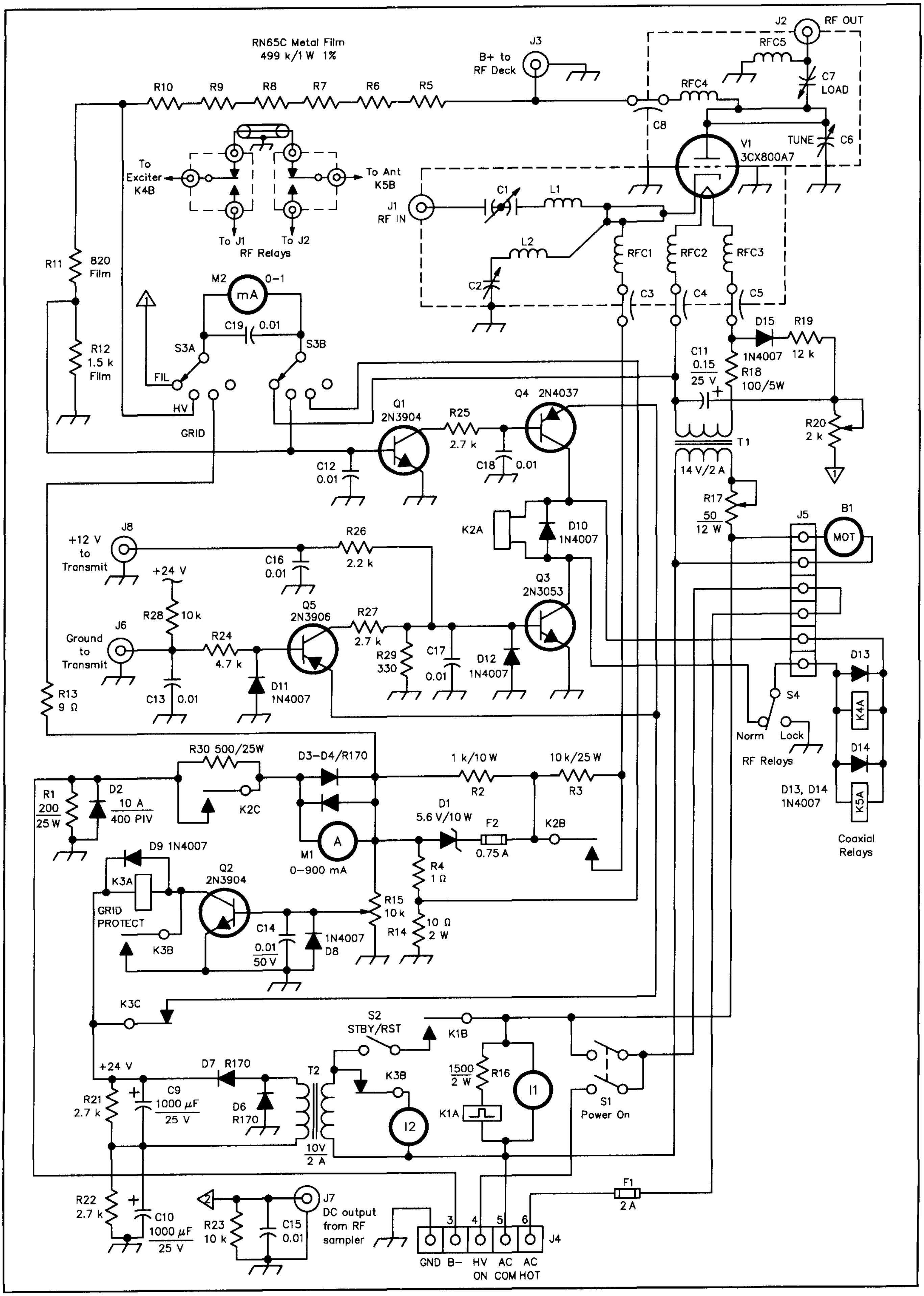
The reverse isolation of the amplifier should be a minimum of 20 dB greater than its power gain. Since the 3CX800A7 amplifier has a gain of 14.2 dB, you should see over 34-dB reverse isolation when it is neutralized. This amplifier had less than 20-dB reverse isolation before neutralization and over 30 dB after the collet was modified.

After neutralization, power drift became almost nonexistent. Power output will slowly rise by only 20 to 30 W from a cold start to full operating temperature. This represents a less than 0.2 dB of power drift, certainly an acceptable amount.

Initial Tuning Adjustments

Tune up of the amplifier is quite straight forward. If the dimensions and layout of the amplifier have been closely followed, the following initial settings will place the amplifier very close to optimum tuning at 432 MHz and full power output.

C1: Plates approximately 50% meshed


RN65C Metal Film
499 k/1 W 1%
R10
R9
R8
R7
R6
R5
J3
B+ to
RF Deck
J2
RF OUT
RFC5
RFC4
C7
LOAD
C8
TUNE
C6
V1
3CX800A7
To
Exciter
K4B
To Ant
K5B
To J1
To J2
RF Relays
J1
RF IN
C1
L1
L2
C2
RFC1
RFC2
RFC3
C3
C4
C5
R11
820
Film
R12
1.5 k
Film
M2
mA
0–1
C19
0.01
S3A
S3B
FIL
HV
GRID
D15
R19
C11
0.15
25 V
1N4007
12 k
R18
100/5W
Q1
2N3904
Q4
2N4037
R25
2.7 k
C12
0.01
C18
0.01
R20
2 k
T1
14 V/2 A
R17
50
12 W
K2A
D10
1N4007
J5
B1
MOT
J8
+12 V
to
Transmit
R26
2.2 k
C16
0.01
+24 V
Q3
2N3053
R28
10 k
Q5
2N3906
R27
2.7 k
J6
Ground
to
Transmit
R24
4.7 k
R29
330
C17
0.01
D12
1N4007
D11
1N4007
C13
0.01
R13
9 Ω
S4
Norm
Lock
RF Relays
D13
K4A
D14
K5A
D13, D14
1N4007
Coaxial
Relays
R30 500/25W
D3–D4/R170
1 k/10 W
R2
10 k/25 W
R3
R1
200
25 W
D2
10 A
400 PIV
K2C
D1
5.6 V/10 W
F2
0.75 A
K2B
M1
A
0–900 mA
R4
1 Ω
D9 1N4007
Q2
2N3904
K3A
GRID
PROTECT
K3B
C14
0.01
50 V
1N4007
D8
R15
10 k
R14
10 Ω
2 W
K3C
S2
STBY/RST
K1B
+24 V
D7
R170
T2
K3B
R21
2.7 k
C9
1000 µF
25 V
D6
R170
I2
1500
2 W
R16
K1A
I1
S1
Power On
10V
2 A
R22
2.7 k
C10
1000 µF
25 V
J7
DC output
from RF
sampler
R23
10 k
C15
0.01
F1
2 A
3
4
5
6
J4
GND
B–
HV
ON
AC
COM
AC
HOT

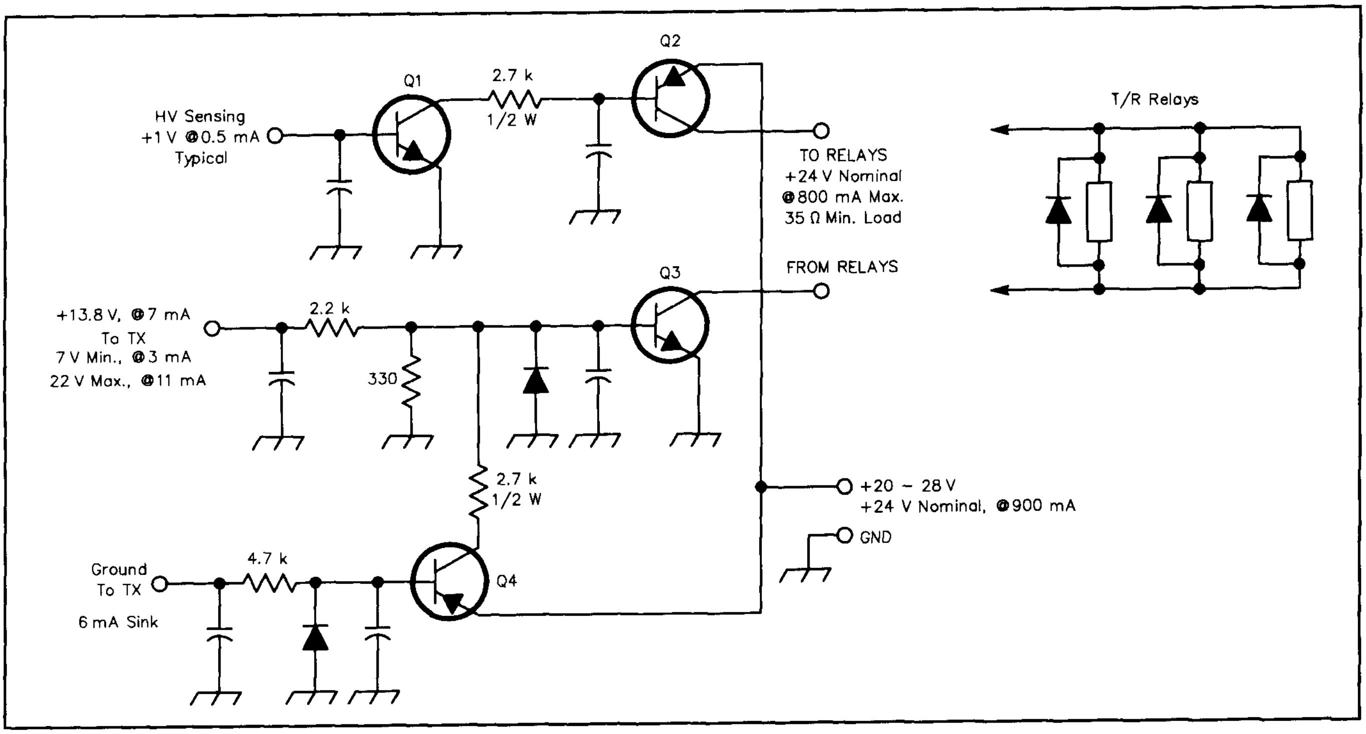


Fig 24—TR switching circuits for use with 24-Vdc relays. These components are mounted on the PC board shown in Fig 25.

←

Fig 23—Schematic diagram of the amplifier. Control circuits protect the tube and amplifier from potentially catastrophic events, such as overdrive, loss of high voltage or loss of heater voltage.

C2: Plates approximately 25% meshed
C6: Fixed end of flapper 1¼ in. above bottom of chassis
Moving end of flapper ¾ in. above bottom of chassis
C7: Fixed end of flapper 1 in. above bottom of chassis
Moving end of flapper ⅞ in. above bottom of chassis

After all wiring has been checked, set R17 (filament adjust) to maximum resistance. Attach an accurate RMS voltmeter to the filament feed-through capacitors. After the filament has warmed up for 3 minutes, adjust R17 until the filament voltage is 13.0 V. Next, adjust R29 such that the filament meter indicates 13.0 V. If the meter cannot be calibrated, change R19.

Apply high voltage and verify the tube draws proper idling current when J6 is shorted to ground (approximately 55 mA at 2400 V). Remove high voltage. Short out cathode resistor R3. Apply a very small amount of drive, increasing drive until the grid current reads 60 mA. Adjust R15 so the grid overcurrent trips at 60 mA. If you are unable to obtain 60 mA of grid current, adjust the cathode tuning controls (C1 and C2) for maximum grid current. After adjusting the grid-trip, reduce drive power and peak C1 and C2 for maximum grid current, being sure not to exceed 60 mA.

Remove the shorting jumper from R3 and turn the high voltage back on. Apply drive power so the plate meter reads 200 to 300 mA. Start adjusting C6 and C7 (plate tuning and loading) maximum power output. As the power output comes up you can increase drive until you are operating at the desired power level. If the amplifier cannot be driven to full power, C1 and C2 may need to be adjusted.

Final adjustments to the cathode circuit must be made at full power. With an in-line power meter connected as close to J1 as possible, alternately adjust C1 and C2 for minimum SWR. You may find that there are combinations of the cathode capacitors that allow the amplifier to be driven but the input SWR is poor. There will be a unique combination of the capacitors that will adjust the amplifier such that the lowest input SWR (less than 1.2:1) corresponds to maximum plate current (lowest drive-power requirement). To obtain this condition will require alternately adjusting C1 and C2 several times. If you cannot obtain a good input SWR, check to see if C1, C2 or both are at minimum or maximum capacitance. If C1 is at minimum capacitance, shorten L1. Lengthen L1 if C1 is at maximum capacitance. If C2 is at minimum or maximum capacitance, it is most likely because you didn't follow the cathode-circuit layout. Using a Bird 43 wattmeter with a 50D element (50 W, 200 to 500 MHz), I can completely null out the reflected power, so that with 30-W drive the wattmeter indicates no reflected power. (This only indicates that reflected power is lower than the directivity of the element, not that I have obtained a perfect match.)

With the input circuit properly adjusted, final adjustments to the plate tuning and loading controls may be made. There will be many settings of C6 and C7 that will deliver lots of power output. There will be a unique combination that will deliver that power output at maximum efficiency. Grid current is an excellent indicator of proper tuning. At full power output the grid current will range from 15 to 30 mA (varies from tube to tube). If the amplifier is properly tuned, grid current should increase as you increase drive. The plate-current dip should

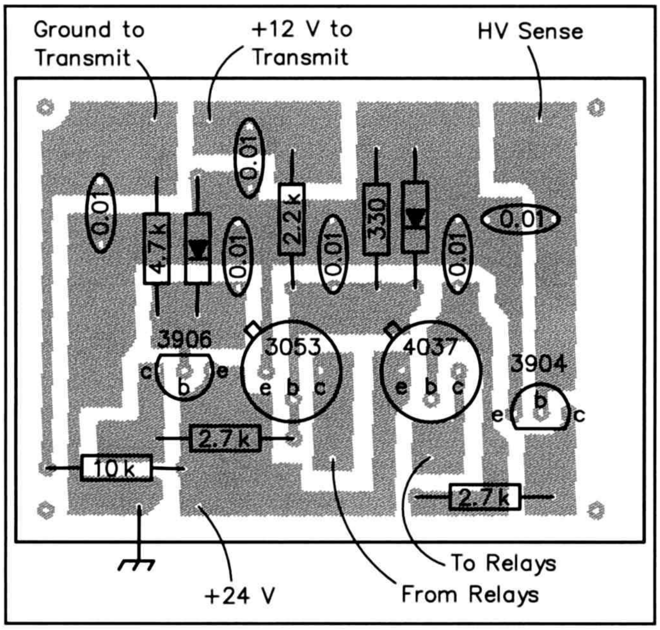


Fig 25—TR switching PC board, component side. While board layout is not especially critical, the board itself must be 1.75 X 3.25 in. or smaller in size.

Table 2
Full Power CW Operating Conditions
Keyed CW and SSB PEP Operation

Plate voltage, full load:	2250 V
Plate current:	600 mA
Dc Input power:	1350 W
RF Output power:	730 W
Apparent efficiency:	54%
Power gain:	14.2 dB
Grid current:	26 mA (will vary from tube to tube)
Drive power:	28.5 W
Input VSWR:	1.16:1
Filament voltage:	13.0 V
Idling current:	55 mA (@ 2400 V; will vary tube to tube)
Bias voltage:	5.6 V

Note: These conditions are for SSB and keyed CW service. Key-down time not to exceed 1 minute. For maximum continuous duty ratings, see text.

also match very closely (within 20 W) of maximum power output. There should also be minimum thermal drift. After letting the fish lines stretch for a few days, power should drift less than 30 W from a cold start.

Amplifier Operation

Efficiency of the amplifier is about 54%. If you are measuring higher efficiency you either have an inaccurate power meter or your high voltage and plate meters aren't calibrated. Use a Bird 1000D element with the Bird 43 wattmeter; 1000E elements typically read about 10% high at 432 MHz. An antenna or dummy load with a high SWR can cause inaccurate power meter readings. This can be verified by placing ¼-wave-length coax sections in series with your feed line, and checking to see if the SWR or indicated power change. Power measurements were made with a directional coupler in combination with a microwave power meter. The directional coupler was measured on a network analyzer to verify the amount of coupling it has at 432 MHz. If your efficiency is below 50%, you may have any of the previously mentioned measurement accuracy problems, a bad tube or just a mistuned amplifier.

At full rated output (about 730 W) the 1-dB bandwidth of the amplifier is 1.3 MHz. The 3-dB bandwidth is 3.9 MHz. The amplifier was designed to operate between 430 and 440 MHz. With the specified plate line and tuning capacitor sizes, the amplifier will operate efficiently at output levels from 300 to 730 W over that frequency range. If operation is desired at higher or lower frequencies, you'll have to adjust the length of W2 or C6.

Maximum CCS ratings of the 3CX800A7 are 2250 V at 600 mA. The specified highest frequency for maximum ratings is 350 MHz. No problems have been experienced running the tube at those ratings in keyed CW and SSB service at 432 MHz. I recommend, however, limiting CW key-down tuneup time to under 1 minute. If the amplifier is to be used in continuous-duty service, such as FM repeater or ATV, limit maximum plate current to 500 mA and reduce full-load plate voltage to 2000 V or less. In continuous service the filament voltage should be reduced to 12.2 V during transmit. A switching circuit should be added to raise the filament voltage to 13.5 V during warmup and standby periods. Maximum CCS output will be 500 W at a drive level of 22 W and 50% efficiency (2000 V at 500 mA). Continuous-duty service at elevations above 2000 feet may also require a larger-capacity blower. When shutting off the amplifier, be sure to let the tube completely cool down. The amplifier should be left powered up (blower running) for at least 5 minutes after the last transmission. The cathode compartment can still be warm after the anode air exhaust is blowing cool air.

Note that in addition to the grid dissipation value of 4 W, the maximum grid current is 60 mA. Under linear service the grid dissipation will be far under the rated value (less than 0.5 W). The grid-current restriction therefore becomes a matter of a total limit of cathode current, which is normally 600 mA of plate current and 60 mA of grid current. At 432 MHz, transit time effects, secondary emission by the grid and back bombardment of the cathode start to occur. The amplifier can be loaded so that negative grid current will be indicated. These conditions require that you be even more careful about grid and cathode current. In general, the amplifier should never be operated with an indicated grid current over 40 mA. An indication of these back-heating effects is grid-current drift. If you are seeing the grid current drift upward at a constant drive and plate-current level, you are running the amplifier too hard (or you may have a bad connector or cable in the system).

You should also be very careful not to overdrive the amplifier. Cathode-driven triodes such as the 3CX800A7 will not exhibit the gain-compression phenomena shown by solid-state amplifiers. That is, the power gain of the tube is just as high at full power as it is at low power. The station should have an exciter that has stable output power. In addition, make provisions to limit the available drive power to 35 W or less.

Table 2 gives full power operating conditions. For SSB operation the conditions represent the PEP point. There is little

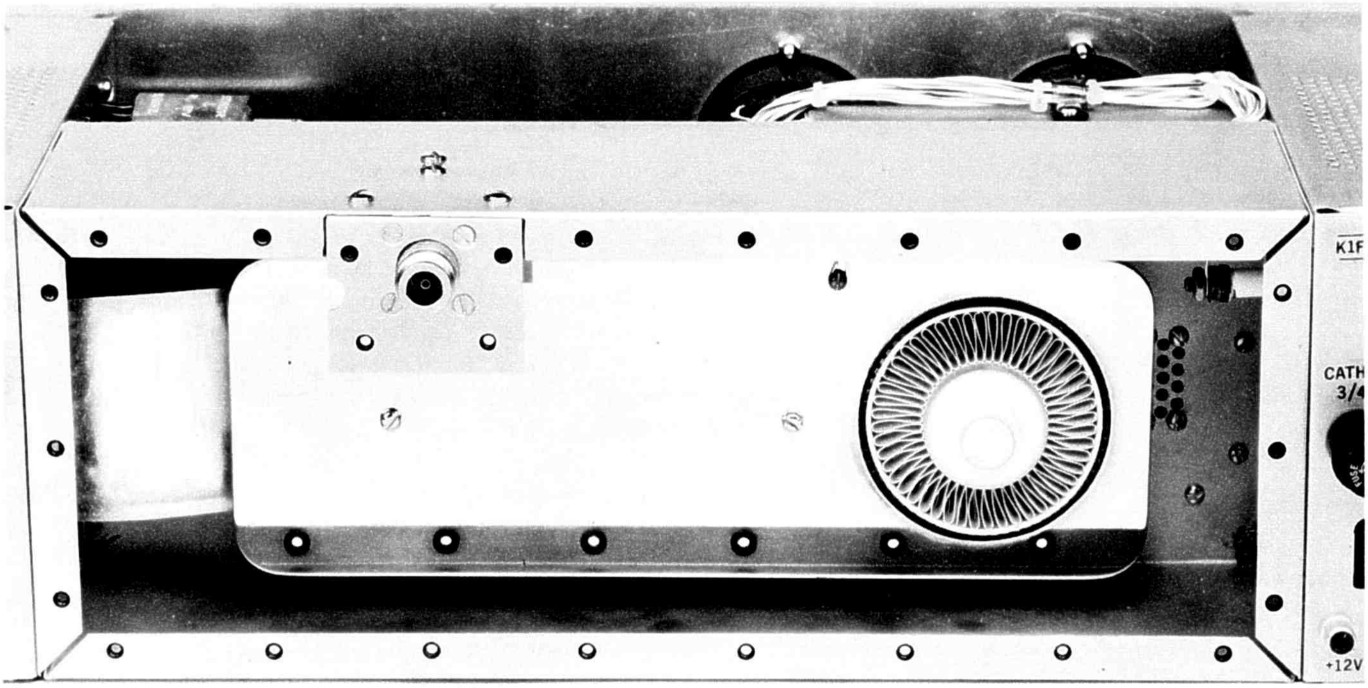
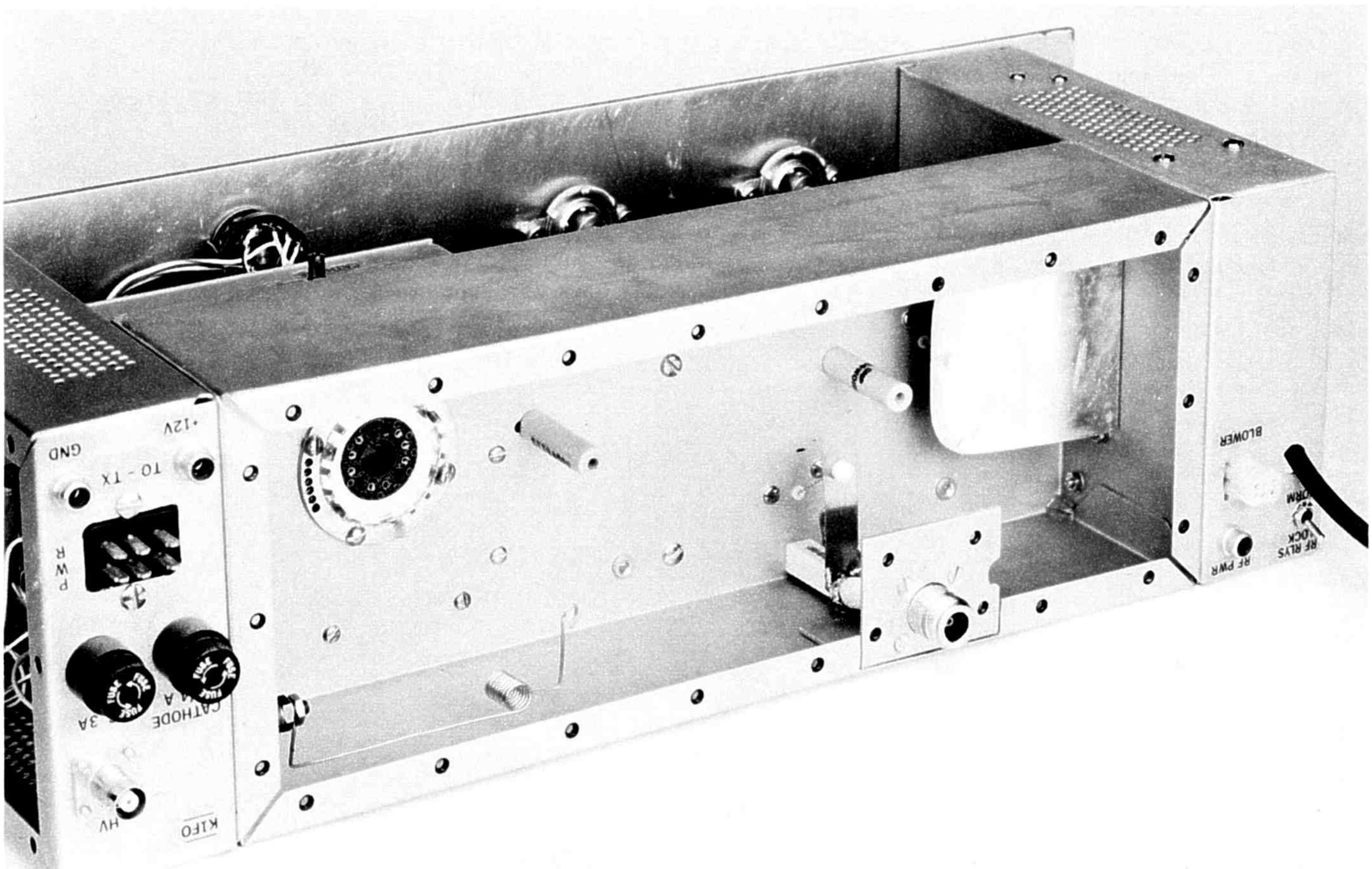
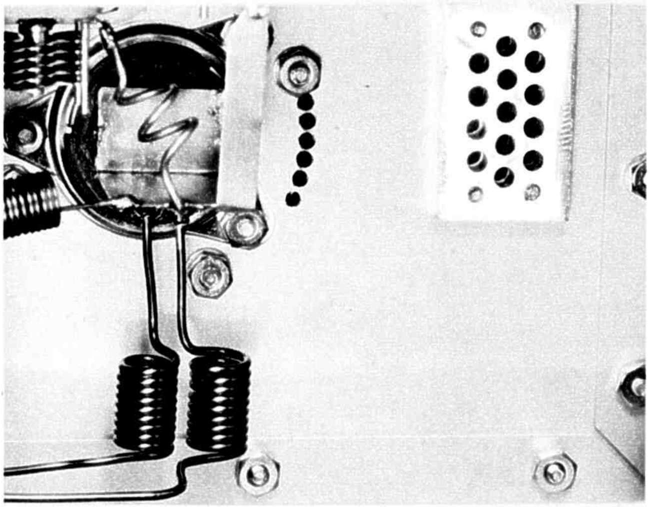


Plate compartment of the single 3CX800 amplifier. Plate tuning capacitor is shown to the left. The RF-output connector is at top.



This inverted view of the plate compartment shows the output loading capacitor, which is adjusted by means of a non-conducting cord fastened to its lower edge.



Interior of the cathode compartment. The filament RF chokes are at bottom.

sense in investing in a tube of this quality if you are going to overdrive or mistune the amplifier. During proper SSB operation, without speech processing, indicated plate current on *voice peaks* should be less than 250 mA. Power output as indicated on a slow-responding average-power meter (such as the Bird 43) should be less than 200 W on peaks. If an effective RF peak clipper is used (10 dB of compression and clipping), indicated plate current on voice peaks can approach 400 mA. Average-power watt meters may indicate up to 325 W on peaks. While driving the amplifier harder may give you the satisfaction of seeing higher meter readings, the additional power will be transmitted primarily as distortion products, and won't make your on-frequency signal any stronger.

Pay attention to the cable, connectors and relays you use. All high-power connections should use Type-N connectors. Assemble each connector properly so the shield has good contact and the center pin is aligned and at the proper depth. This much power at 432 MHz will destroy poorly assembled connectors. Use ½-in. or larger Hardline for the antenna feed line. For flexible jumpers, use RG-225 coax.

Using An 8874

This amplifier will also work with an 8874 tube. To use an 8874, set the filament voltage to 6.0 V RMS. Substitute a 6.3-V, 3-A transformer for T1 and eliminate R18. Make the hole in the plate line (W1) 1.75-in. diameter. An EIMAC 008294 collet makes for a simple connection between the plate line and the 8874 anode radiator. Make the air-outlet hole 1⅝ in. diameter, You'll have to make a chimney (sheet Teflon). In the input circuit, L1 and L2 may need to be made longer. Neutralization of an 8874 is slightly different.

The maximum ratings of an 8874 are 2200 V at 500 mA, in intermittent amateur service (keyed CW and SSB). Peak power output will be 570 W. Drive power for that output level will be 35 to 38 W. In continuous duty, limit the 8874 plate current to 350 mA.

Conclusion

This amplifier is easy to build and requires minimal special metal fabrication. Performance is excellent. The investment in parts and careful assembly time will pay off with years of trouble-free operation.

Notes

[1]The 8874 432-MHz amplifier appears in ARRL *Handbook* editions from 1981 through 1986.

[2]Aluminum sheet cut to size is available from Chassis Kit. Charles Byers, K3IWK, 5120, Harmony Grove Road, Dover, PA 17315. Tel 717-292-4901.

[3]Surplus Sales of Nebraska, 1315 Jones St., Omaha, NE 68102. Tel. 402-346-4750.

[4]Microwave Components of Michigan, P.O. Box 1697, Taylor MI 48180. Tel 313-753-4581.

[5]S. Powlishen, "Improving the K1FO 8874 432-MHz Amplifier," *QST,* Jun 1987, pp 20-23.

A Parallel 3CX800A7 Amplifier for 432 MHz

By Steve Powlishen, K1FO

Many 432-MHz DXers, especially those contemplating EME operation, desire to run the US 1500-W output-power limit. This amplifier, which uses a pair of Varian 3CX800A7 ceramic-metal triodes, is capable of reaching that power level in intermittent amateur service (SSB voice and keyed CW). Its design is very similar to the single-tube 3CX800A7 amplifier previously described. The plate circuit is a half-wave stripline with the tubes located at one end of the line. The metering and control circuits are identical to those used in the single-tube amplifier, except that meter calibrations and filament power are set for two tubes instead of one.

Selecting a Design

An amplifier design process involves a number of factors. A pair of 3CX800A7s were chosen for the following reasons:

- They can reach the 1500-W power level.
- They have the simplicity and stability of triode operation. (ie simple zener diode bias and no screen supplies or grid and screen bypassing is needed).
- They have relatively low drive requirements as their gain is very high for a grounded grid triode.
- They have very good IMD performance, making them an excellent choice for SSB voice operation.
- They are small enough to allow an amplifier to be built using standard commercial aluminum chassis.
- Their price point is within most amateur budgets
- They are a modern tube design, readily available today and for the foreseeable future.
- Their acceptance in commercial amplifiers have made them available at reduced cost via pull-out and surplus units.

Few items in our world are perfect and the 3CX800A7 is no exception. Some of the problems encountered in using the 3CX800A7 at 432 MHz are:

- Their anode radiator is large enough in diameter such that making an amplifier with a pair of tubes presents some design challenges.
- Their frequency for maximum ratings is 350 MHz.
- Their efficiency of the 3CX800A7 at 432 MHz is lower than desired.
- 1500-W output power operation at 432 MHz is strictly intermittent if long tube life is to be expected.
- While the price of a pair of tubes is not totally exorbitant, they are priced high enough that they are certainly not disposable items.

When all the pros and cons of the 3CX800A7 are considered and compared to the pros and cons of other tubes that are usable at 432 MHz, however, the 3CX800A7 becomes a good choice for a 432-MHz amplifier.

With the tube model selected, the next task is to design input and output circuits that will deliver, with minimum losses, the RF power that 3CX800A7s are capable of generating. The first design considered was to operate the tubes in parallel with a half-wave stripline, with the tubes located at one end of the line. This is the same arrangement that K2RIW used with 4CX250B tubes. Schematically this type of circuit is shown in Fig 1. The primary advantage of the parallel half-wave circuit is, it is the simplest circuit for an amateur to build. There are no critical or hard-to fabricate blocking capacitors, nor are there any complicated sliding contact surfaces. The primary disadvantage of the half-wave plate line is that circulating currents are not evenly distributed around the tubes seals. This could potentially shorten tube life.

The second disadvantage is that the large diameter of the

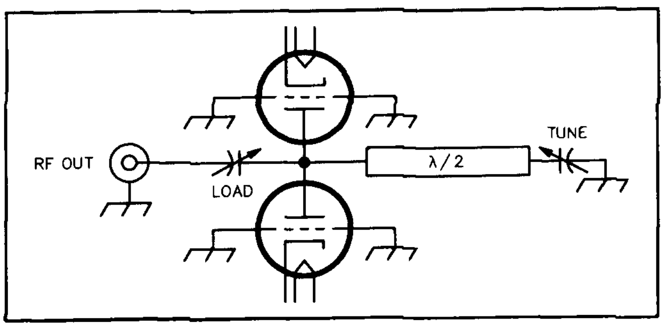


Fig 1—Schematic of a half-wave stripline amplifier using parallel triodes. While easy to build, the large diameter of the 3CX800A7 tubes results in a plate line that is wider than optimal. See text.

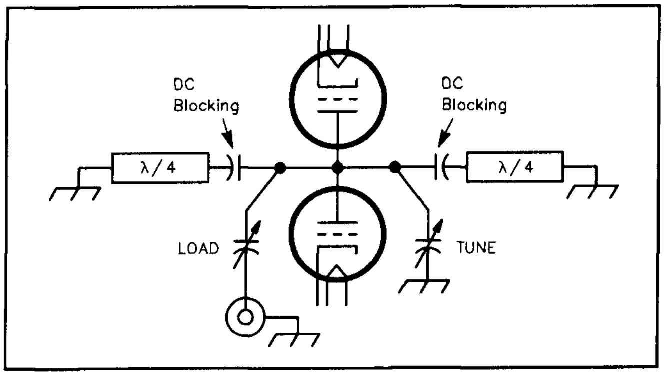


Fig 2—Schematic of a half-wave stripline amplifier in which the tubes are mounted at the center of the line. This circuit has all of the disadvantages of the circuit shown in Fig 1, and is more difficult to build.

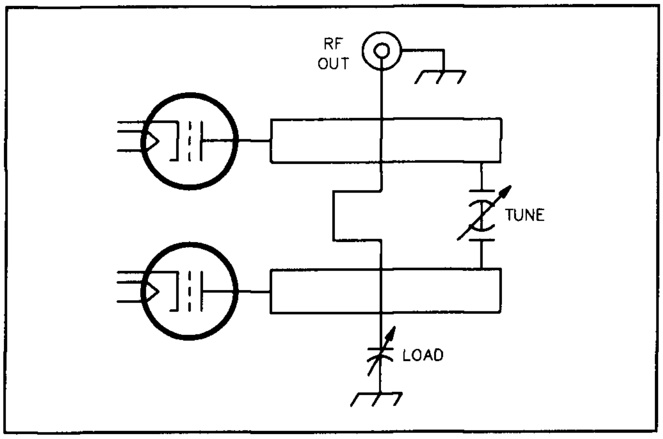


Fig 3—Schematic of a push-pull amplifier. This circuit is also difficult to construct. Balanced loading of the tubes is more difficult to obtain than with an amplifier using parallel tubes.

3CX800A7 anode radiator requires a plate line that is very wide, which yields a plate-line impedance considerably lower than desired. Theoretically, a cavity or stripline resonator will have its best loss and bandwidth characteristics when it has a characteristic impedance of around 75 Ω. An additional design problem with the 3CX800A7 in a parallel stripline design is the large diameter of the tubes necessitates using a relatively wide spacing between them. The wider the tube spacing the more difficult it can be to keep the tubes operating in parallel mode (ie, push-pull resonances must be placed far from the operating frequency for best operation).

Other designs were considered. A λ/2 stripline with the tubes located in the center of the line was a possibility. This arrangement would improve the circulating current problem by distributing the current paths to two sides of the tubes. However, all of the other previously covered stripline design problems would remain, that is lower than optimum line impedance and potential push-pull modes. In addition, locating the tubes in the center of a half wave line makes the inclusion of a critical plate-blocking capacitor necessary. This blocking capacitor adds another potential failure point and makes construction more complicated. The extra complexity of this circuit type can be seen in Fig 2. Moreover, designing and building plate tuning and loading capacitors which would both not disturb the symmetrical current benefits of this type of plate circuit and couple equal power from both tubes is a difficult task.

Although not often used today in amateur amplifiers, the push-pull amplifier was very popular until a few years ago. When designed properly the push-pull design offers some significant benefits. The primary advantage is that tube output capacitances appear in series instead of adding together, as in a parallel design. This effectively raises the output capacitive reactance of the tubes, giving the designer more flexibility in designing the plate resonator. Another advantage of a push-pull UHF amplifier is that, since the tube anodes are not connected together, low-loss plate lines near the optimum 75-Ω impedance are relatively easy to incorporate.

In addition, the push-pull arrangement could be made in a fashion similar to the old "plumber's-delight" 144-MHz amplifiers. This type of design can have better current distribution than a stripline. A proper push-pull design would also be less sensitive to the spacing between the tubes as parallel responses near 432 MHz would not be likely. A push-pull schematic representation is in Fig 3. The down side of the push-pull design is that the plate circuit fabrication is more complex than a K2RIW-style amplifier since standard commercial chassis could not be used. At 432 MHz it becomes very difficult to obtain balanced loading from the two tubes which creates another design problem and potential adjustment headache. Still another problem area is the construction and adjustment of a push-pull input circuit which will maintain proper tube balance can be much more difficult than in a parallel amplifier.

A final design option considered was to simply incorporate two single-tube amplifiers on a single chassis and use a hybrid power splitter to feed input power to the amplifiers and a similar hybrid combiner to couple the amplifiers' output together. Although it would be much easier to obtain near optimum plate-line impedance, it was quickly decided that the losses in the hybrids would be greater than predicted circuit losses in a parallel design. Combining two amplifiers requires a high-power dump load, tuning procedures become tricky and metering circuitry is more complex if both amplifiers are operated off the same B+ supply. In addition, construction complexity is increased due to the need to make additional combining components. All of these factors made this approach less desirable than the alternatives.

Parallel Plate Circuit Design

After analyzing all design options it was concluded that building a half-wave stripline, K2RIW-style, plate circuit was the best compromise. The calculated line impedance, loaded and unloaded Q gives an expected line loss of less than 0.05 dB which is under 17 W at full power, or about a loss of 1% in plate efficiency. These losses were considered acceptable given the simple construction. The unbalanced current design of the half wave stripline and its plate-circuit losses may not be considered acceptable for a continuous-duty amplifier. However, intermittent amateur operation of the single-tube 3CX800A7 half-wave stripline, 432-MHz amplifier at 750-W output has

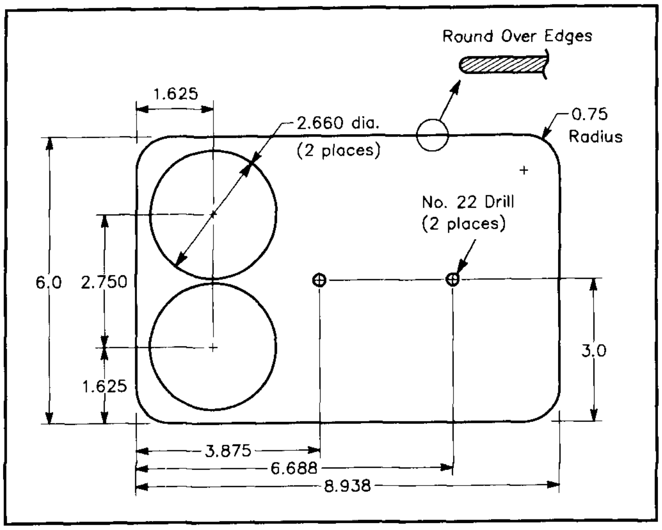


Fig 4—Plate stripline for the parallel 3CX800A7 amplifier is made of 1/16-in. copper or brass. Nickel-less (dull-finish) silver plating is recommended after the plate collets are soldered in place.

resulted in an immeasurable loss in output power and efficiency after 6 years of use. This validates the suitability of this type of circuit for intermittent amateur use. The final decision in selecting the half-wave plate line design is that it is absolutely the easiest design for a typical amateur to duplicate and get operational.

A tube center-to-center spacing of 2.75 in. was selected, as it is the closest possible spacing that could be used with the 2.50-in.-diameter 3CX800A7s, and still leave room for the plate-line-to-tube-contact collets. The closest possible tube spacing is desired, as it will move push-pull responses higher in frequency, and far enough away as to not cause multimoding problems. Swept-frequency-response measurements were made on the plate line. Resistive loading was used in place of a resonant input circuit, to assure that only plate-circuit resonances would affect the results. With the plate circuit tuned to 432 MHz, a significant response was seen at 657 MHz. At first it was assumed that this was a push-pull mode resonance. Some further testing revealed a similar response in the single-tube 3CX800A7 amplifier. The two-tube amplifier exhibited the 657-MHz resonance with the plate line removed, and whether the two tubes' anodes were shorted together or separated. I finally decided that the 657-MHz response was a self resonance in the 3CX800A7. In the neutralization section I describe how I handled this resonance. Another resonance, dependent upon the plate line was found at 878 MHz. This is possibly the 1/4-wave push pull resonance. Fortunately the close tube spacing kept this response to 2 times the operating frequency. After the amplifier was neutralized no significant resonances including the 878-MHz mode, were observed (Naturally with this type of design harmonic resonances will be evident such as a third harmonic resonance observed in this amplifier).

The close tube spacing also lets the plate line be as narrow as possible, so its impedance will be as high as possible. To simplify construction, it was intended to use standard 3-in. high chassis thus mandating that the plate line be as narrow as possible. The only other solution to the plate-line impedance problem would be to use a taller RF enclosure. This would, however, require custom metal work and defeat the simple-to-construct objective. With the chosen 2.75-in. tube spacing, 6 in. became the minimum width of the plate line. The characteristic impedance of the line is 37 Ω. With the selected 8 15/16 in. length and tuning capacitor size, the plate circuit will resonate from about 350 MHz to 445 MHz. This line length was selected to have the amplifier operate optimally at 432 MHz. If you desire to use the amplifier across the entire amateur band (420 to 450 MHz), shorten the plate line to 8 13/16 in. The exact construction dimensions for the plate stripline (W1) are given in Fig 4. Note that the corners of the line are rounded, as are the edges, to minimize the possibility of the plate line arcing to ground or the tuning capacitors.

The hardest part of constructing the amplifier will be cutting the two 2.660-in. diameter holes in the plate line. These size holes are required for the finger stock used to contact the tubes to the plate lines. This leaves only 0.090 in. of material in the plate line between the two holes. If you are going to use a fly cutter to make the holes, be sure to cut the holes very slowly to avoid distorting or ripping the material in the center or at the edges. If a small machine shop with either a CNC vertical mill or simply a rotary table on a standard vertical mill are available, you could contract them to cut the holes. Cutting the holes with a small diameter end mill (about 1/8 in.) will cut clean holes with square edges and a minimum of material distortion. The plate-line material used was 1/16-in. thick brass sheet 6-in. wide by 8 15/16 in. long, which was silver plated. If you don't plan on silver plating the plate line, you may want to use copper instead, although copper is a harder material to machine. Any material thickness between 1/32 and 1/8 in. can be used, as long as the Teflon spacer insulators are adjusted in length.

Since the tube spacing of 2.75 in. is also the same spacing used on the original K2RIW 2 × 4CX250B amplifier, it allows owners of K2RIW-style amplifiers to convert their units to 3CX800A7s. The K2RIW amplifier used different spacing of the tube centers to the RF enclosure sidewall (2 1/8 in.) which could complicate a conversion. These different dimensions may require that the loading capacitor be retained to the side of the plate line as in the original K2RIW amplifier. Also note that many builders of the K2RIW amplifier who used SK-620 or SK-630 sockets (including most of the ARCOS amplifiers) used 2.50-in. tube spacings which would also hinder such a conversion.

The finger stock used to contact the tube anodes to the plate stripline was selected because I found it at a hamfest flea market. It is approximately 1/4 in. high and is rolled over such that it becomes 0.100 in. thick. Looking in the Instrument Specialties catalog the finger stock looks similar to their part number 97-360. Instrument Specialties 97-380 also would be suitable. It is similar to 97-380, but is only 3/16-in. high. If finger stock cannot be located, EIMAC 720829 plate collet for the 3CX800A7 can be used. I prefer the selected finger stock as it is a bit more flexible than the EIMAC collet which makes aligning the socket positions with the holes in the plate line a bit less critical. The EIMAC collet looks as if it is made from Instrument Specialties 97-251 finger stock which also could

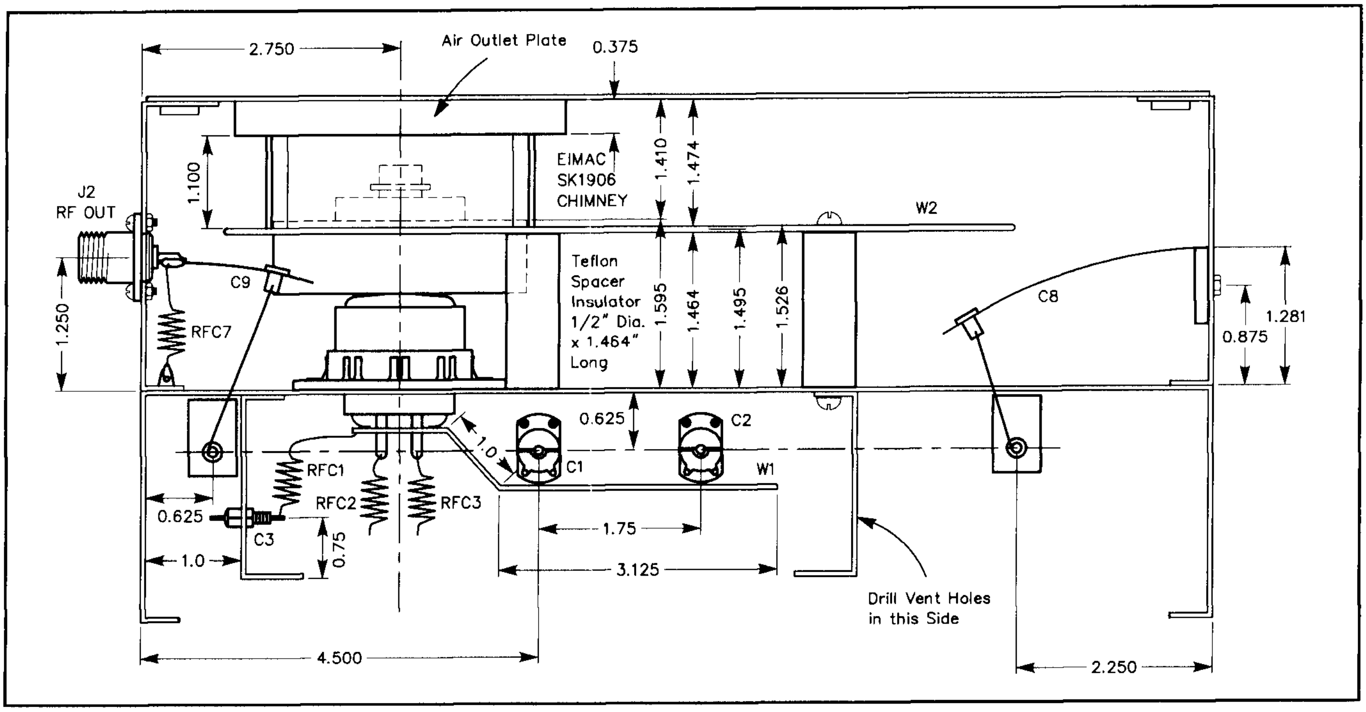


Fig 5—Rear view of the plate and cathode compartments. This view shows alternate mounting of the RF output jack (J9) on the side of the RF output enclosure.

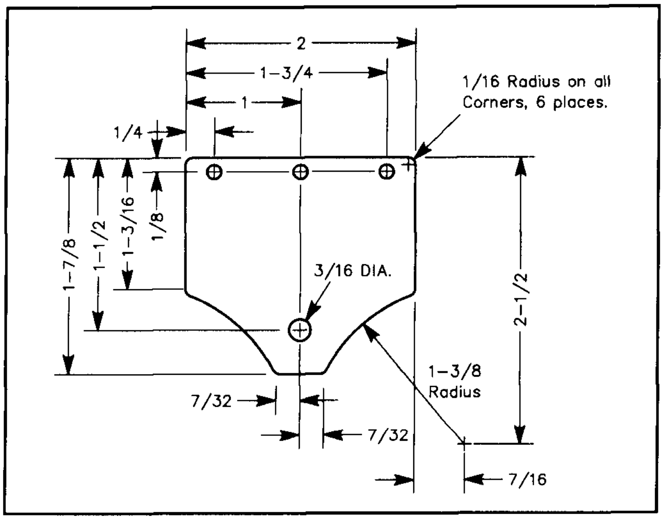


Fig 7—Plate loading capacitor C9 is made of 0.010-0.015 in. hard brass shim stock or beryllium copper. Have the capacitor silver plated to 0.0001-in. minimum thickness. Specify nickel-less plating.

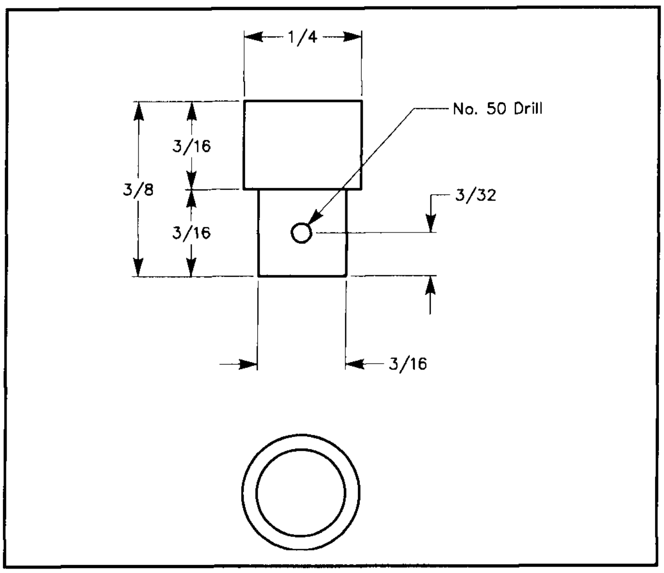


Fig 8—Insulators for C8 and C9 are made from 1/4-in. diam. virgin (electrical grade) Teflon rod.

be used. Most any reasonably sized finger stock can be used. Variations in the inductance of the different finger stock can be compensated for in the positions of the tuning and loading capacitors.

One difference in the 2 × 3CX800A7 amplifier from the original K2RIW design was to locate the output loading capacitor flapper on the tube end of the plate line between the two tubes. Theoretically, this arrangement will result in more balanced power levels delivered from the two tubes. I feel that this arrangement is more important on this amplifier than the original K2RIW amplifier due to the wider plate line. Locating the loading capacitor away from the plate-tuning capacitor also minimizes interaction between the controls. Another benefit of this loading arrangement is that it will help to more evenly distribute the RF current on the tubes and stripline. The amplifier originally was built with the output Type-N connector mounted on the sidewall of the chassis. This arrangement is shown in Fig 5. After initial testing, a concession to esthetics was made and the output connector (J2) was moved to the rear of the amplifier. This necessitated the use of a short coax jumper from the output loading capacitor (C9) to the connector. RG-225, which is Teflon dielectric 50-Ω cable was used

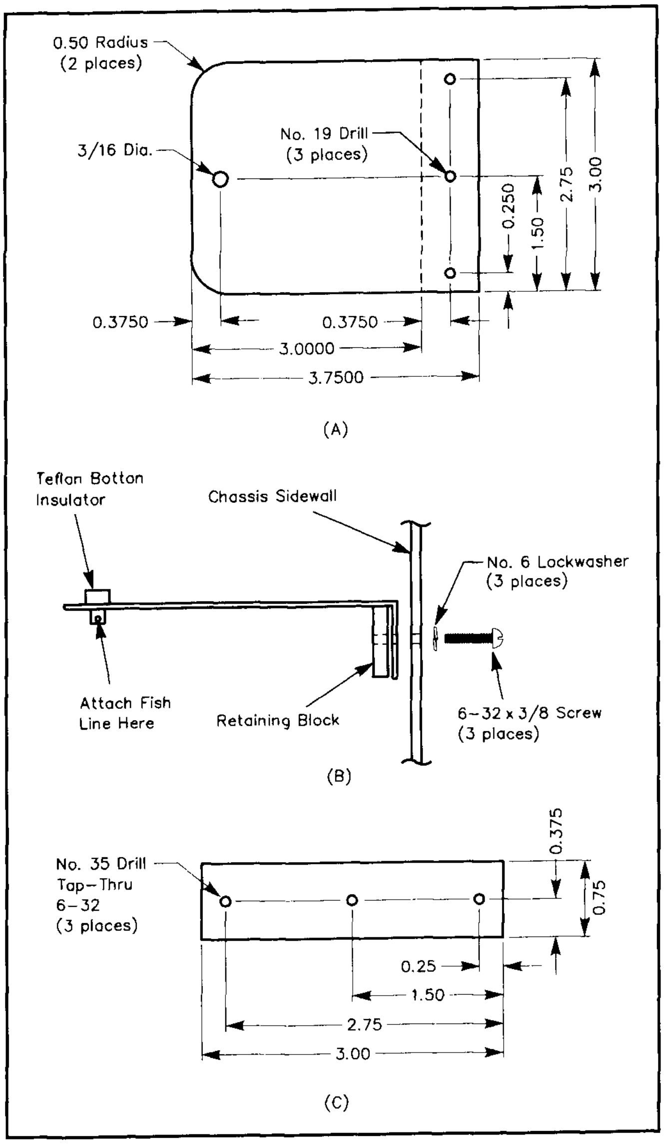


Fig 6—At A, plate tuning capacitor C8 is made of 0.010-in. hard brass or beryllium copper. Silver plating is optional. B shows the capacitor retaining blocks made of 1/8- × 3/4-in. aluminum bar. C shows how the capacitor and retaining blocks are mounted.

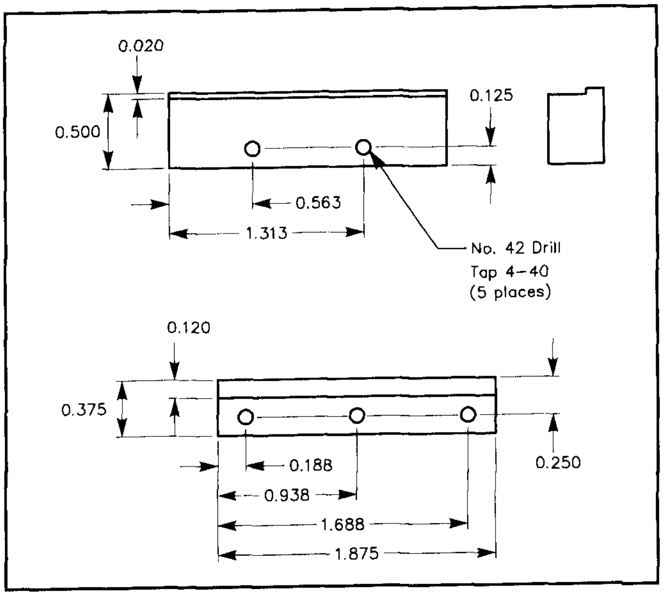


Fig 9—C10 mounting insulator is made from 1/2-in. thick virgin (electrical grade) Teflon rod.

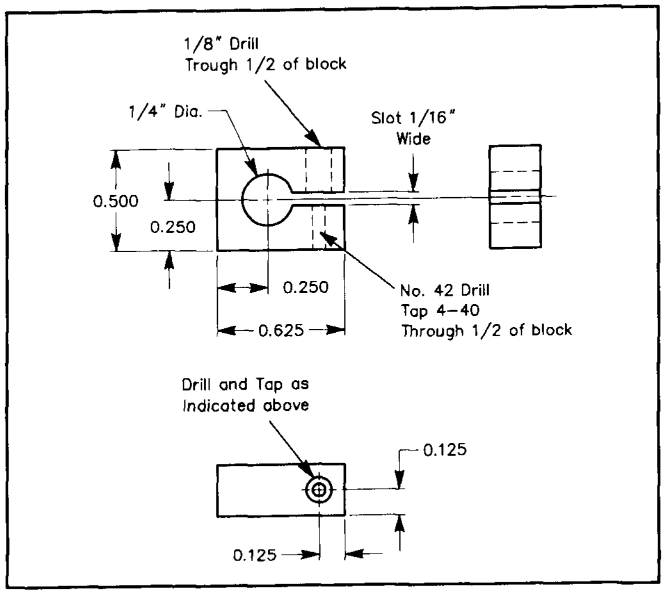


Fig 10—Adjustable stops for the plate tuning and loading controls are made from 1/4-in. aluminum.

for the jumper. RG-225 is similar to RG-214 but with Teflon dielectric and a Teflon jacket. RG-213 or similar polyethylene cables (including foam types and 9913 types) are not usable as the 1500 W from the amplifier will quickly melt such cables. If you cannot locate any high power cable for this jumper it is suggested that the output connector be mounted on the side and the jumper cable be eliminated. The flapper tuning and loading capacitors (C8 and C9) are made from 0.010-in. thick beryllium copper. Hard brass shim stock will work if beryllium copper cannot be located. C8 is shown in Fig 6 and the layout of C9 is covered in Fig 7. Be sure that the edges of the flappers are sanded smooth with fine emery cloth after they are cut to size. This will minimize the possibility of arcs from the plate line to the flappers. The 3/16-in. holes in the flappers are to accommodate Teflon button insulators (Fig 8) which serve to both prevent the flappers from contacting the plate line and they provide a convenient way to attach the fish line to the flappers. C8 is held securely to the chassis by means of a tapped brass or aluminum retaining plate (Fig 6). The loading capacitor is held in place by means of a Teflon insulator which was made from some rectangular Teflon bar stock (Fig 9). The small relief was cut to offer extra protection from arcing to the chassis sidewall. It is not necessary to cut the relief in the Teflon block. The tuning shafts were made from brass as they give a smoother feel when they are turned than aluminum shafts will. The plate tuning capacitor control uses a 6:1 vernier ball drive to impart a slow, smooth feel to the control. A vernier drive was not used on the loading control as its feel is good without any rate reduction. The end of the loading control shaft where the fish line wraps around was turned down to

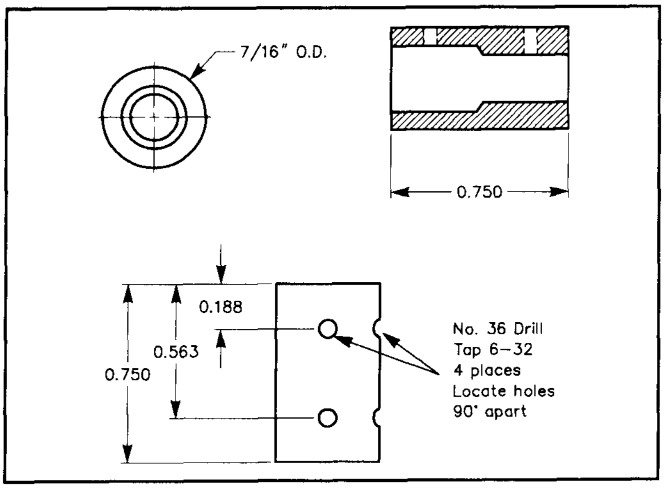


Fig 11—Coupling to adapt 3/16- to 1/4-in. shaft is made from 7/16-in. diam. aluminum rod.

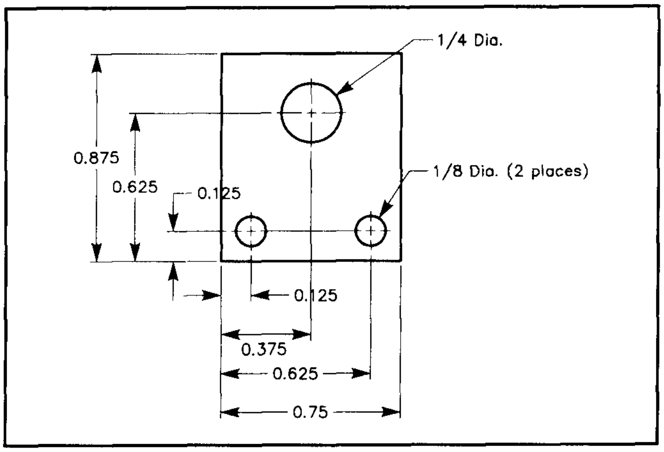


Fig 12—Input circuit capacitor C1-C2 mounting insulators are made from 1/16-in. thick G-10 circuit board material, from which the copper has been removed.

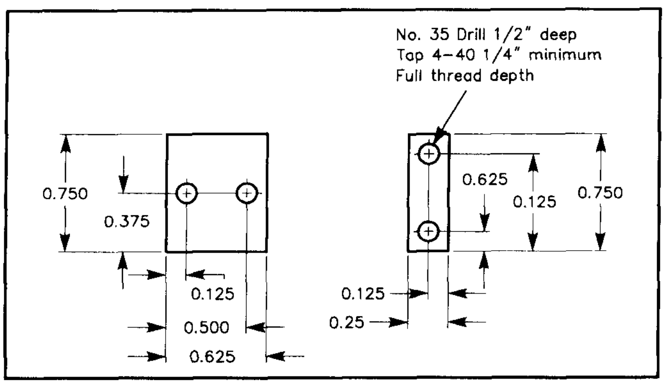


Fig 13—Mounting brackets for the insulators shown in Fig 12 are made from 1/4-in. aluminum or brass bar (aluminum is preferred).

3/16 in. to give a slightly slower tuning rate and to limit the loading capacitor adjustment range. Adjustable shaft stops (Fig 10) were made from brass bar stock. They slip over the tuning and loading control shafts and allow the tuning limits to be set without worrying about how long the dial cord is. Screws mounted on the chassis provide the stop points for the clamps. These stops both control the amplifier tuning and loading range by limiting the tuning shaft rotation to just under a full turn. The stops also prevent accidental breakage of the fish line by keeping the controls from turning too far. The panel bearings were intentionally misaligned to keep the tuning controls in place against the force of the flapper capacitors. Shaft locks as are used on potentiometers can also be used to prevent unwanted tuning shaft slippage.

Input Circuit

The tube spacing is actually more critical in obtaining proper operation of the cathode circuit. This is due to the much higher input versus output capacitance that the 3CX800A7s have. The 2.75-in. tube center-to-center spacing also allows use of a standard 5- × 7- × 2-in. chassis for the input circuit compartment, again simplifying construction. The cathode circuit layout was intentionally made as similar as possible to the original K2RIW amplifier, so the owner of a 4CX250 amplifier could convert his amplifier to use 3CX800A7s. To facilitate such a conversion, the position of the input tuning and coupling capacitors to the tube center line is the same as was used in the K2RIW amplifier.

The actual cathode stripline is different in size and shape from the K2RIW grid circuit due to both the different configuration of the 3CX800A7 sockets and due to the higher input capacitance of the tubes. The resultant input circuit works amazingly well given its simplicity and compromise to past mechanical layout decisions. It will tune from approximately 370 MHz to 510 MHz. When tuned to 432 MHz there are no significant resonances, besides the desired 432 MHz resonance and third harmonic responses in the 1050- to 1200-MHz range.

The cathode circuit is tuned by miniature butterfly air variable capacitors. The sections are connected in series to lower the capacitance, raise the voltage breakdown and to eliminate the effects of the sliding metal contact between their shafts and mounting bushing. If the butterfly capacitors cannot be located standard air variables could be used in place of the butterfly capacitors. The miniature capacitors have 3/16-in. shafts which require the fabrication of 3/16- to 1/4-in. diameter shaft couplings. The couplings are detailed in Fig 11. Garolite G-10 grade insulated shafts are used from the couplings to the front panel knobs. Garolite G-10 is very similar to standard G-10 epoxy printed-circuit substrate. If Garolite G-10 rod cannot be located, commonly available linen bakelite or Delrin rod can be used. The input capacitors are mounted on a small piece of 1/16-in. thick G-10 epoxy PC board (the copper foil is removed). These mounting plates are dimensioned in Fig 12. These epoxy plates are held to the chassis via brackets made from brass or aluminum bar stock (Fig 13). A full layout drawing of the cathode compartment and cathode stripline is given in Fig 14. A side view of the input stripline and tuning capacitors is also shown in the amplifier section view (Fig 5).

Socket Mounting

The sockets are mounted in identical fashion to the

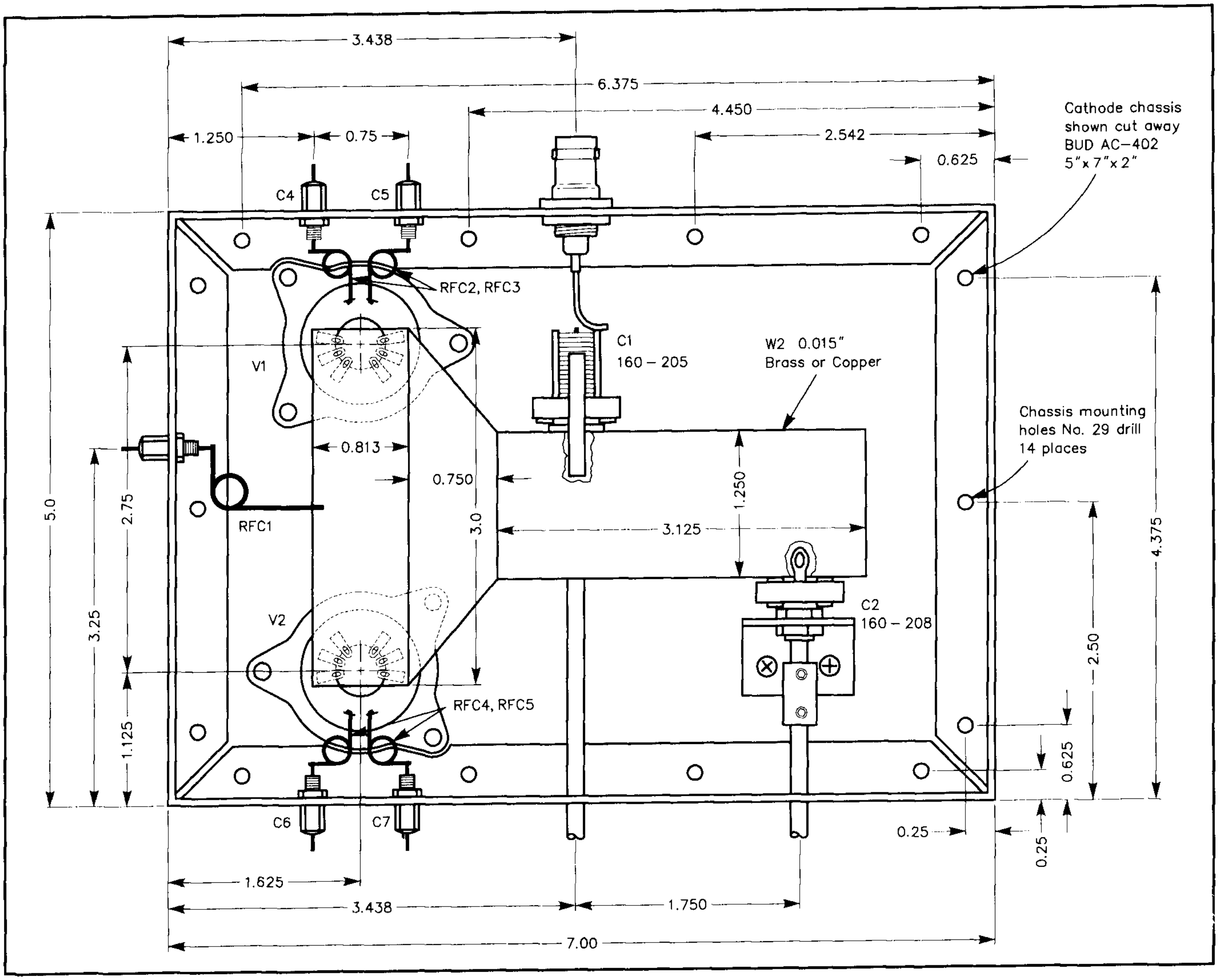


Fig 14—Cathode circuit layout. Enclosure is a 5 × 7 × 2-in. aluminum chassis (Bud AC-402 or equiv.) cut away as shown.

method described for the single tube 3CX800A7 amplifier, so that section should be carefully read. Note that the sockets are mounted mirror imaged that is one socket is turned 180° with respect to the other. This was done to place the cathode pins as close together as possible. This minimizes the width of the cathode line and again the possibility of undesirable push-pull modes present. Some other builders of parallel 3CX800A7 amplifiers have used considerably wider spacings between the tubes. While their amplifiers have worked acceptably, the required drive power was substantially higher than expected leading to the speculation that the wider tubes spacings were causing some form of a push-pull mode response.

Varian part no. 720359 grid-collet assemblies were used for grid grounding. These assemblies use a no. 882931 collet, which is soldered to a 1⁄16-in. brass mounting ring that also has three 4-40 studs for socket mounting. Unfortunately, since the parts for this amplifier were obtained, the price of the 720359 assembly has become quite high. Those interested in saving time may decide that the collet assemblies are worth the expense. Other builders with fewer funds but more time can either obtain the 882931 grid collets and attach them to their own brass mounting plate or they can use finger stock for grounding the grids. The same finger stock which was used on the plate line could also be used for the grid collets. In either case, the simplest construction method may be to use a single 1⁄16-in. thick brass plate that is approximately 5 1⁄2 × 3 in. An alternate grid collet assembly is described in Fig 15.

Air Inlets and Outlets

The air inlets and outlets used on the 2-tube amplifier are different than the other amplifiers. Since a fairly thick plate (3⁄8 in.) was needed to space the EIMAC SK1906 chimneys down from the top cover, the idea of using this thick metal plate as a waveguide-beyond-cutoff RF filter occurred. The attenuation of a signal that leaks through a hole in an RF shield is proportional to the depth of the hole. For holes substantially smaller than a wavelength (less than $\lambda/10$) they will have adequate attenuation if the depth of the hole is twice its diameter. When multiple holes are needed, each individual hole should have sufficient attenuation that the total leakage from all holes in the RF compartment maintains leakage below an acceptable level.

The 3⁄8-in.-thick air chimney spacer plus the 1⁄16-in.-thick cover plate gives a rather substantial depth of 7⁄16 inch. A per-

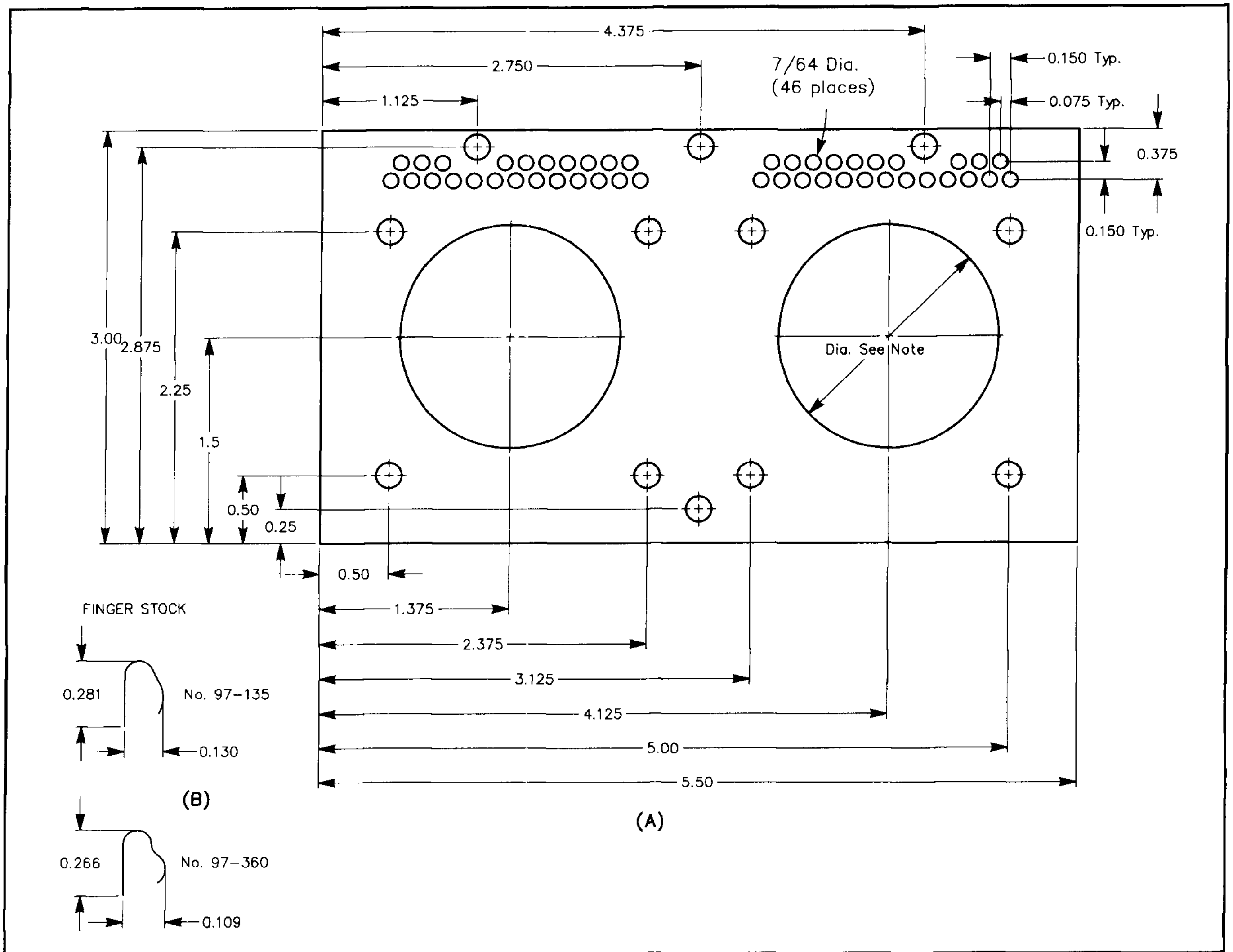


Fig 15—Alternate grid-collet mounting plate for use with finger stock (A); dimensions of the two usable Instrument Specialties finger stocks. The mounting plate is made from 0.062-in. brass or copper, silver plated if desired. The diameter of the large holes depends on the grid-contact method used. For type 97-135 stock, the diameter is 1.600 in.; for 97-360 stock, 1.540 in.; for EIMAC 882931 collet, 1.500 in.

forated sheet of steel with ⅛-in. diameter holes spaced on 3⁄16-in. centers was available to use as a drilling template, to make a symmetrical pattern of exhaust air holes. After the initial ⅛-in. holes were drilled the plate was bolted to the top cover. The holes were then drilled out with a no. 20 drill (0.1660 dia.) in order to have the holes in the plate and top cover match perfectly. These fancy looking air inlets and outlets are actually easy for the home builder to duplicate. The ⅜-in. plate can be obtained from small volume specialty metal distributors (such as the Dillsburg Aeroplane Works).[1] They can be cut with a hacksaw and filed to shape. Although it will be time consuming to drill the large number of small holes in these air outlets, these parts are easier to make at home (and much safer!) than attempting to cut a 2½-in. diameter hole in a ⅜-in. plate with a fly cutter, which you'd have to do to use window screening. The air-inlet plate is described in Fig 16 and the outlet is covered in Fig 17.

The 0.1660-in. diameter holes would act as an effective waveguide at frequencies around 50 GHz. At frequencies around half the waveguide wavelength (25 GHz) an individual hole 0.166 in. diameter and 0.4375-in. deep has about 84-dB attenuation. At 432 MHz (less than 1/100 the waveguide frequency) the estimated attenuation for all 302 holes in combination is over 90 dB! This means that when the amplifier is operated at the 1500-W level, approximately 1.5 µW will leak through the air outlets. There will be about as much RF power leaking through the cracks at the corners of the chassis joints as through the air outlets. To test the effectiveness of the shielding, I probed the amplifier with a microwave power meter having 0.3-µW sensitivity (HP 435A/8481A). Using a short probe connected to the power meter's sensor, less than 6 µW was detectable when the probe was placed up against the air outlets. About 5 µW was read when the probe was held next to the chassis joints. This is substantially better than the window screening used on the air outlet of the single 3CX800A7 amplifier. On the single-tube amplifier, an indication of about 75 µW was read with the probe against the window screening air outlet while it was run at the 750-W output power level. To put these readings in perspective, a commercial 100-W "brick" read over 200 µW near the 12-V power leads, and over

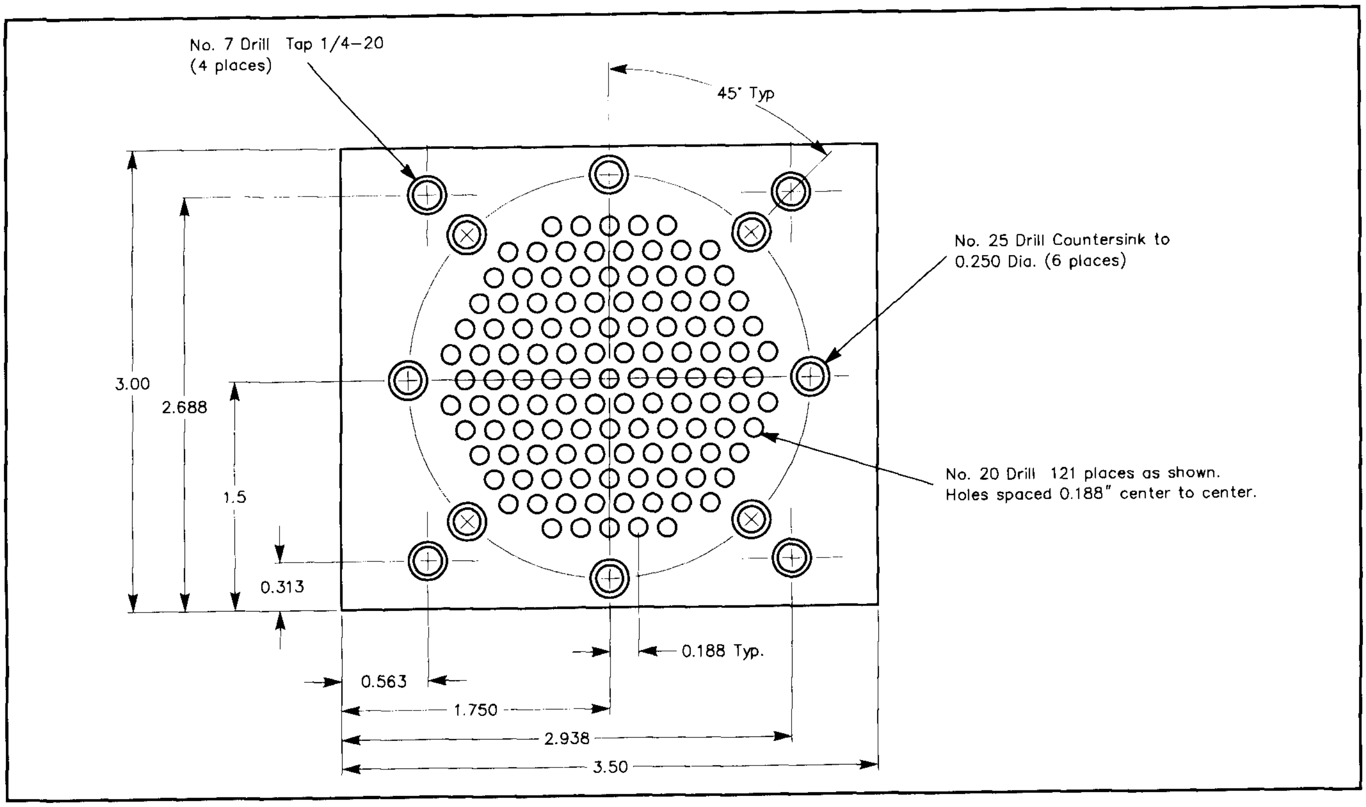


Fig 16—Air-inlet plate is made from 3/8-in. 6061-T6 aluminum plate. The hole pattern is obtained by using a piece of perforated sheet steel as a template. See text for details.

100 mW around its joints and indicator LED holes. After bypassing the power leads the brick leakage was reduced to about 50 μW on its power leads. Another reference point: When the probe was held up to the RG-142 (double-braided shielded cable) from the driver to amplifier, about 30 μW was measured. As a final note on RF field levels, these field strengths are several orders of magnitude lower (more than 1000 times lower) than what emanates from a 5-W hand held. In addition, in normal operation the amplifier will typically be located 2 to 3 feet away from the operator, which further reduces the strength of the RF fields near the operator. In other words, you can feel safe building the amplifier with either the window-screen air outlets or especially the drilled-plate air outlets. As a final note on RF leakage, this amplifier uses an Erie high-voltage EMI feedthrough filter instead of a normal feedthrough or bypass capacitor, to bring the B+ into the plate compartment. In addition, the plate stripline was probed to confirm the electrical center point of the line, to minimize RF leakage through the B+ lead. RF leakage on the high-voltage cable was less than 10 μW, compared to the 100 μW or more measured on other 432-MHz amplifiers, which used conventional HV-bypass capacitors.

Mechanical Construction

The overriding consideration in all design decisions for the amplifier was to make it as easy to duplicate as possible. This mandated the use of standard commercial aluminum chassis. An 8- × 12- × 3-in. chassis was used for the plate compartment, and a 5- × 7- × 2-in. chassis was used for the cathode compartment. An 8- × 12- × 2½ chassis forms a base for the amplifier to be built on. The amplifier was built primarily for portable use on EME DXpeditions. This determined the table-top configuration, rather than a rack-mount assembly. The "cabinet" is formed simply by using oversize top and bottom covers (10¾ × 12 × 0.062-in. thick). Side covers are made from 5½ × 10¾ in. plates, also 0.062-in. thick. The front panel is 5⅝ × 12⅛ in. aluminum, again 0.062-in. thick. The front panel is held to the cabinet by ½-in. aluminum angle stock which was purchased in a local hardware store. The 0.062-in. aluminum sheet can be purchased cut to size from Chassis Kit.[2] Although the plate enclosure is the same size as the original K2RIW parallel tetrode amplifier, this amplifier is constructed in mirror image to it. I did this primarily because of the configuration of the Dayton 4C443 blower I used. This layout of the plate circuit is shown in Fig 18. Drilling and punching drawings for most of the metalwork are given in Figs 19 to 22. These drawings allow you to easily duplicate the amplifier without wasting time laying out the components on the chassis.

Blind fasteners (PEM nuts or similar) secure the top and bottom covers securely to the chassis, without danger of stripping the threads. Fasteners threaded 6-32 were used in most places. Be careful not to distort the chassis when installing the fasteners. If the chassis lip is bent or mushroomed, RF leakage can occur between the cover-to-chassis joints. As discussed in the air outlet section, the symmetrical vent hole patterns were easily made by using perforated steel as a template. Note that there are vent holes in the side of the cathode compartment and in the amplifier cabinet bottom cover. These holes are very important to allow cooling air to circulate by the socket bases,

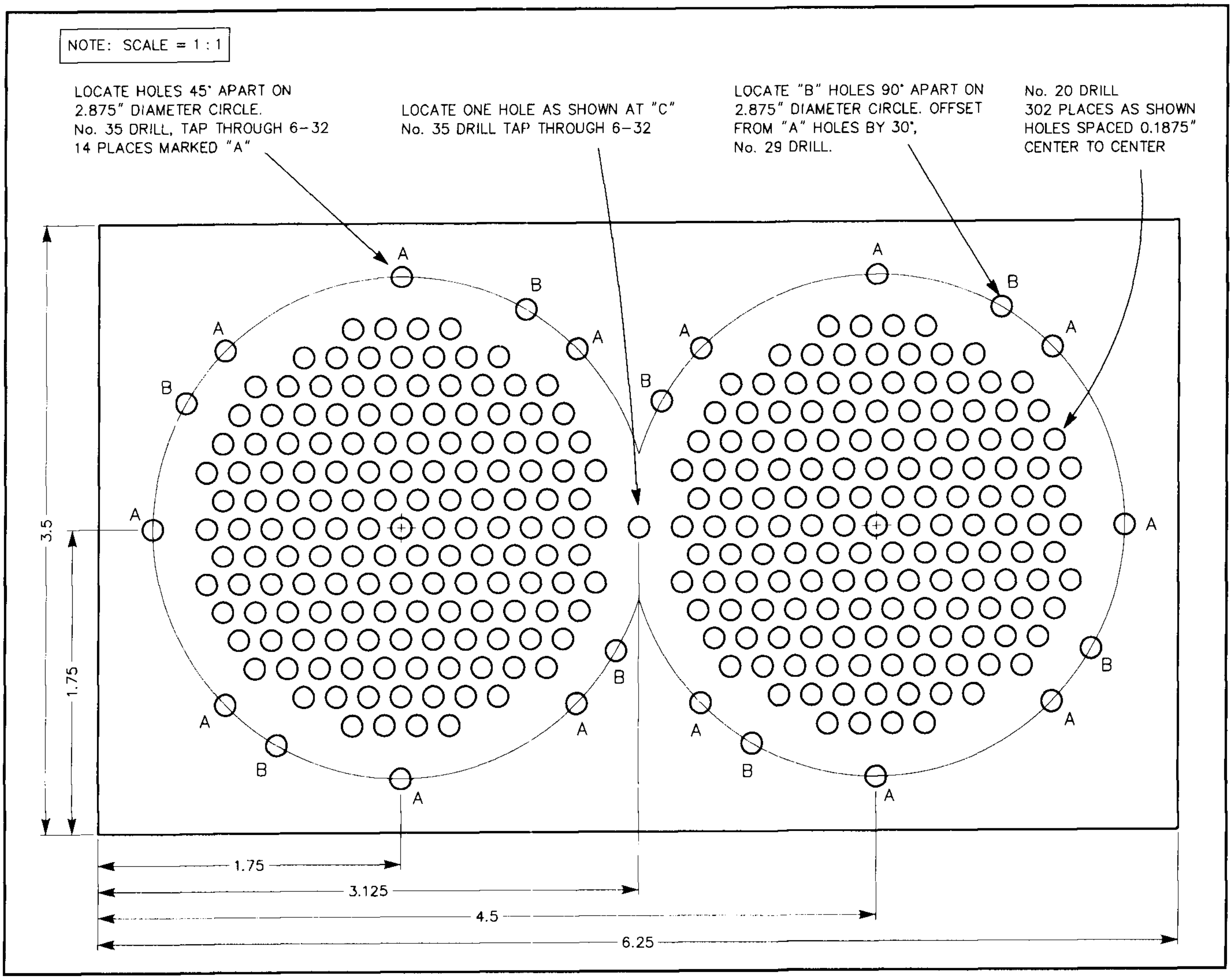


Fig 17—Air-outlet plate is made from 3/8-in. 6061-T6 aluminum plate. See the text and the caption for Fig 16 for details on drilling the hole pattern.

to keep the tube base seals cool. The amplifier must be set off the operating table by feet at least ½ in. to allow this cathode cooling air to escape. If the amplifier must be directly mounted to anything, vent holes should be drilled in the left side panel instead of the bottom.

The amplifier could also be mounted easily on a 7-in. rack panel. The RF deck could be mounted directly to the panel eliminating the need for the side brackets used in the desktop model. Top and bottom covers would be made 8 × 12 in. The meters and filament transformer would then be mounted on the side of the RF deck.

Neutralization

The 2-× 3 CX800A7 432-MHz amplifier required neutralization (as does virtually any UHF tube amplifier) for proper operation. The amplifier was swept from 1 to 1350 MHz to look for any undesired responses. As mentioned previously, an apparent self resonant tube response was evident at 657 MHz. Without neutralization this response was only 3 dB down from the desired parallel 432-MHz tuning. Another resonance in the plate circuit was indicated at 878 MHz which was about 20 dB down from the primary resonance. Additional responses in the 1050 to 1160 MHz range that were 25 to 30 dB down were also observed. Most likely these are third harmonic resonances that are moved lower in frequency by stray capacitance and inductance effects. As with the single tube 3CX800A7 432-MHz amplifier the 2-tube amplifier without neutralization exhibited signs of thermal instability and its maximum power output occurred near a plate current peak not at a dip. Reverse isolation was measured at 17 dB which is only 3.5 dB higher than the gain of the amplifier.

The amplifier was then neutralized by adjusting the grid inductance. Best operation was obtained with the maximum reverse isolation around 420 MHz (38 dB) and 32-dB isolation at 432 MHz. This grid collet fingers were broken off until proper isolation was obtained. A somewhat different pattern was used in removing the grid collet fingers compared to what was done on the single tube amplifier. The proper grid collet finger pattern is shown in Fig 23. Under this condition, maximum power output coincides with minimum plate current and maximum grid current. Power drift was also minimized when

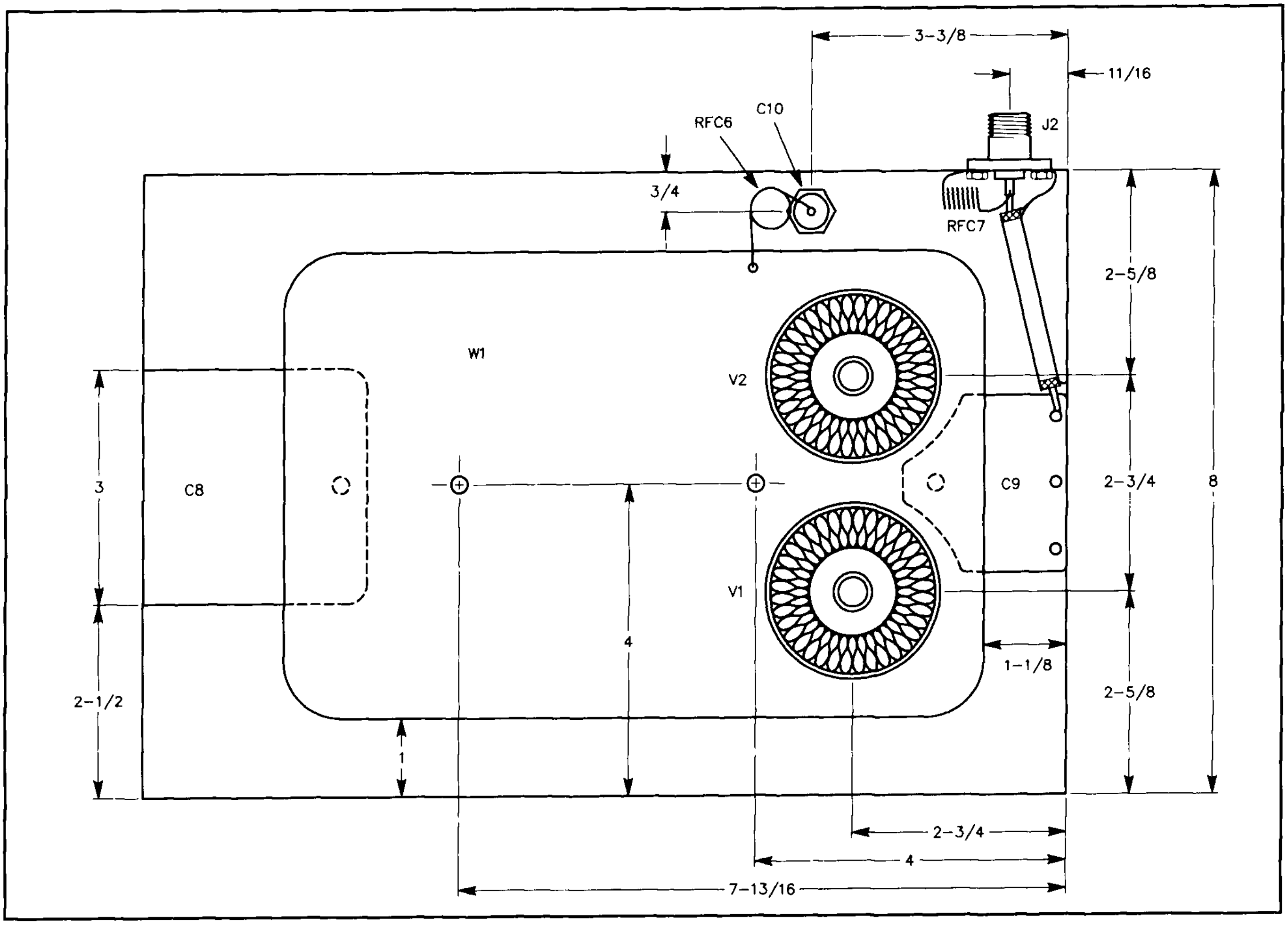


Fig 18—Plate circuit layout. See text for details.

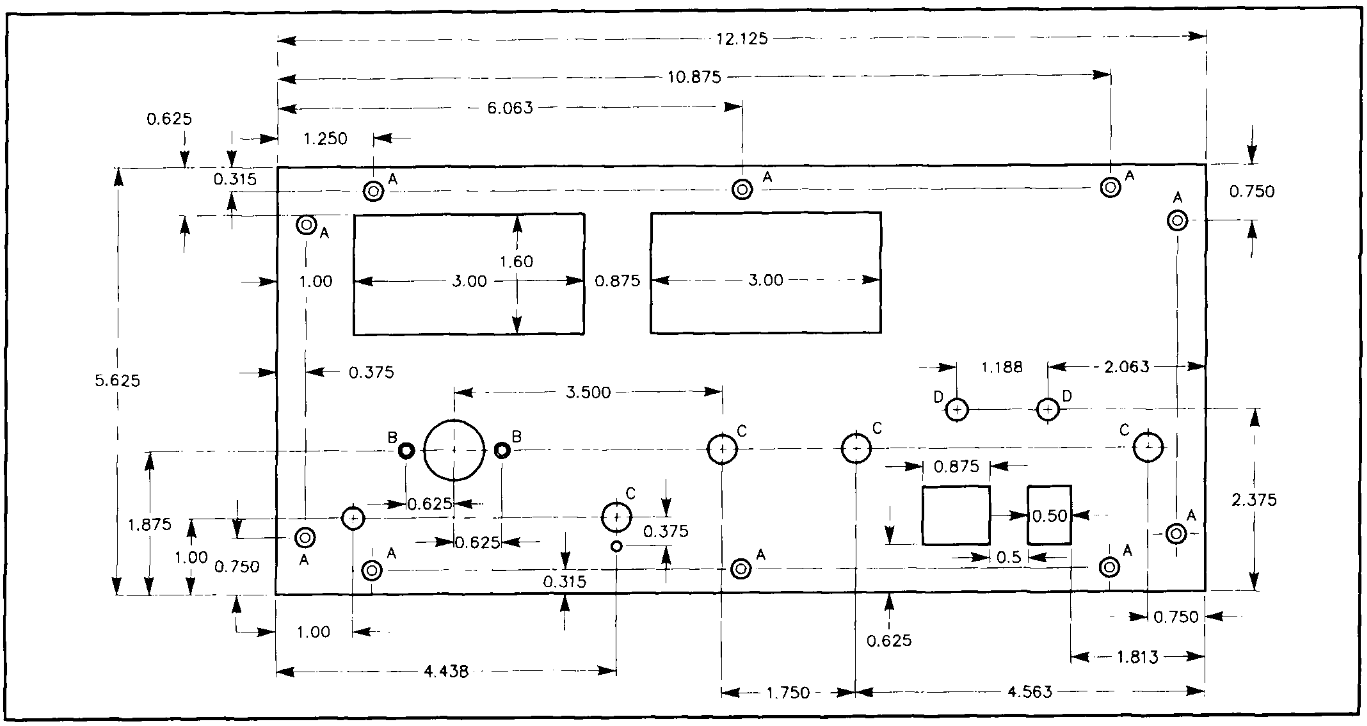


Fig 19—Front-panel layout. See text for details. Hole data: A—0.156 diam, countersink 0.280, 100°; B—0.125 diam, countersink 0.220, 100°; C—0.375 diam; D—0.3125 diam.

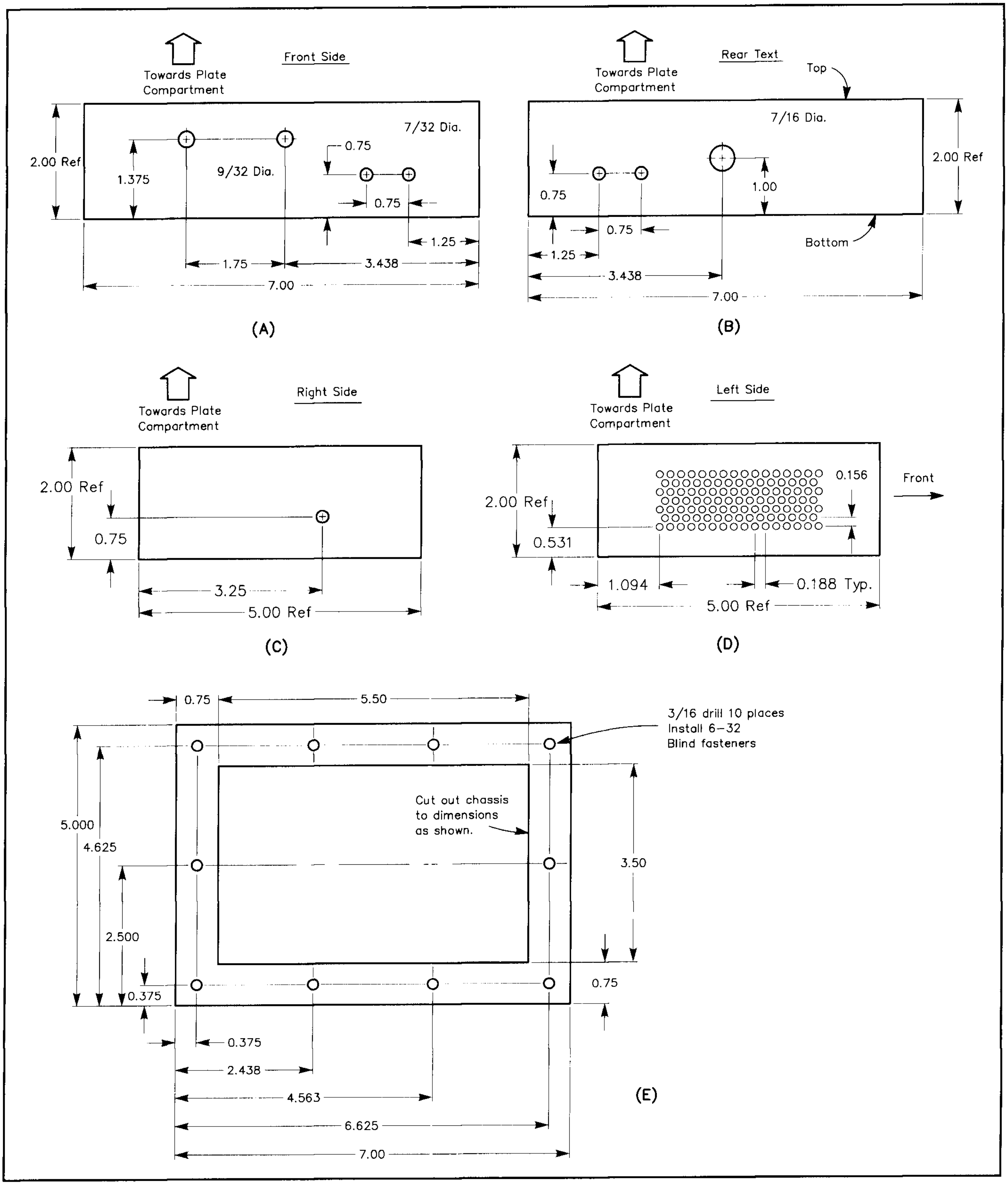


Fig 20—Cathode compartment layout. At A, the front side; at B, the rear side. At C, the left side; at D the right side. See the text and the caption for Fig 16 for details on drilling the hole pattern.

the amplifier was neutralized. A swept response of the amplifier was then measured again. The 657-MHz tube/socket self resonance was reduced by about 20 dB with the amplifier neutralized. The 878-MHz response virtually disappeared. The apparent third-harmonic responses were not affected in magnitude by neutralization. They are high enough in frequency, however, that it is unlikely the 3CX800A7 will exhibit any significant gain there. The magnitude of these responses is also more than 35 dB below the amplifier's forward gain at 432 MHz.

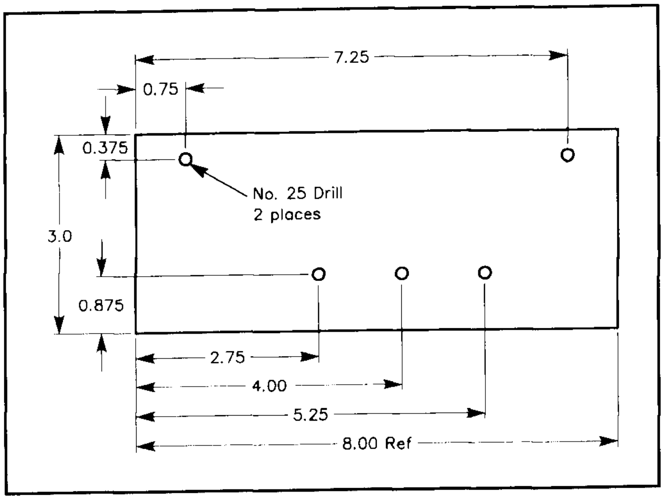


Fig 21—RF enclosure, left side drilling guide.

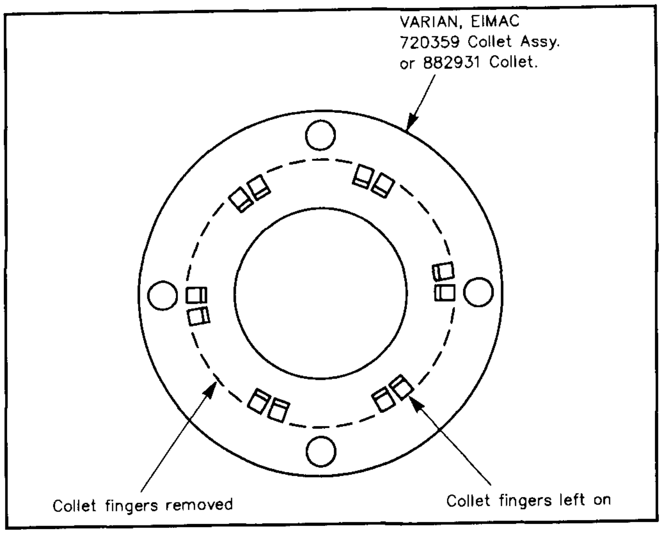


Fig 23—Grid collet modifications. Of every 6 fingers, break off four consecutive fingers as shown. This procedure is necessary to provide the proper grid-circuit capacitance to neutralize the amplifier.

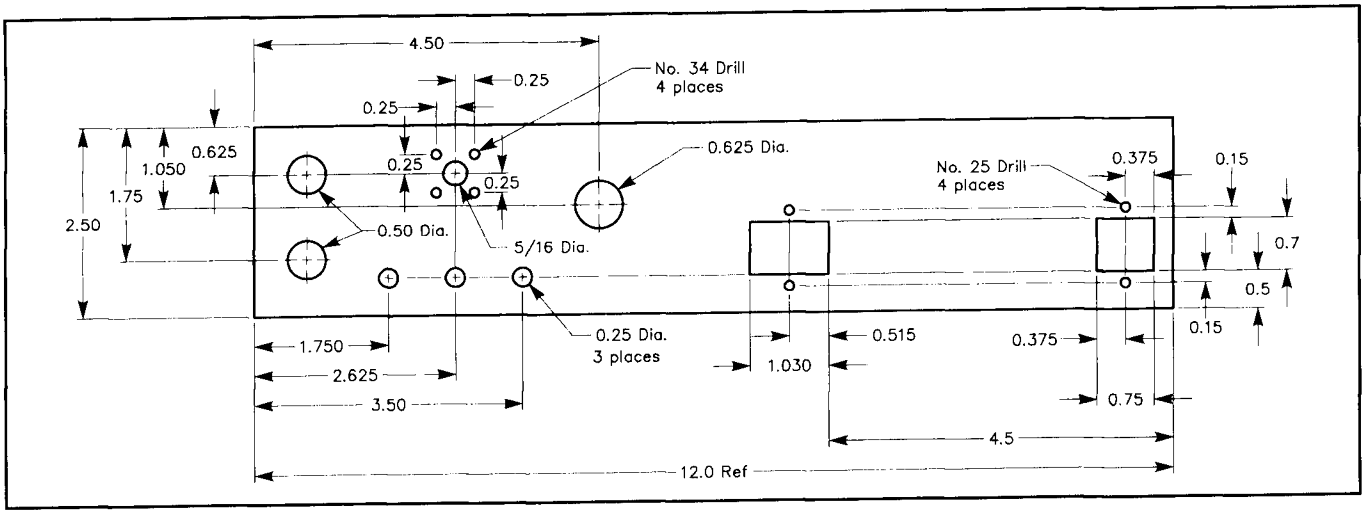


Fig 22—Lower chassis, rear, layout.

Protection Circuits

The 3CX800A7 is a rugged, reliable tube when properly operated. To obtain its high performance (low IMD products and high gain), the grid structure had to be made very fine. This fine grid structure has relatively low dissipation. While not a problem in normal use, should B+ be lost or the antenna be disconnected, enough grid current can be drawn to destroy the tubes. To protect the tubes, both B+ sensing and grid over-current protection is included.

The B+ sensing circuit consists of the B+ meter string (R5-R10) and Q1. These devices sense the presence of B+. The exact pull-in voltage is set by R11 and R12. Q4 is used to switch the T/R relays in combination of a logic circuit (Q3 and Q5) which allows either a low current to ground or a low current +12V to transmit enable the amplifier. If high voltage is not present this circuit prevents the amplifier from switching to transmit mode. If high voltage is lost during transmit, the amplifier is switched to standby.

Q2 is used in conjunction with R4, R14 and R15 to sense grid current. R15 sets the exact amount of grid current at which Q2 will switch K3, the over-current relay. In normal operation should the operator mistune the amplifier, R3 may only chatter, thus limiting the overload condition. If a major failure occurred, such as a missing antenna connection or defective T/R relay,grid current will rise fast enough to lock in the over-current relay, which will drop the T/R switching circuit. To reset the grid current trip, the Operate/Standby-Reset switch (S2) is flipped to Standby-Reset for a few seconds (to allow the 24-V supply to discharge). Switching back to Operate places the amplifier back in the ready-to-operate mode. Although the cathode-bias resistor (R3) will protect the tubes, the most protection is available when an RF relay is used on

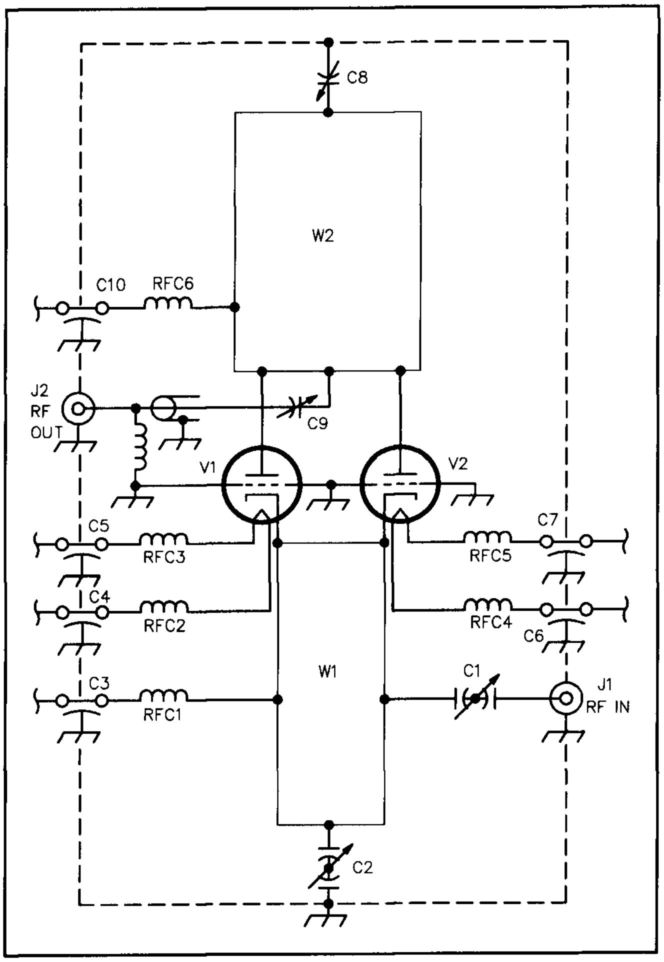


Fig 24—Schematic diagram of the amplifier.

the input circuit. This relay will drop drive power from the amplifier in case of a B+ failure or grid over-current trip.

A thermal time-delay relay (3 minutes) is used to assure the tube cathodes are up to full temperature before drive is applied. The time delay prevents the 24-V control circuitry power supply from turning on until the time delay is complete.

A 50-Ω 100-W resistor should be connected in series with the B+ supply. This resistor will serve to limit the current from the power supply in case of an arc. A fuse in the HV line is another means to protect the tubes from arcs. The HV supply should have as good regulation as possible. I recommend you use a bridge-rectifier circuit with a transformer that has winding resistance as low as possible. The use of a capacitive-input filter is also preferred. Do not use too much filter capacitance (50 µF maximum) as more capacitance will only increase the possibility of damage should a high-voltage arc occur.

Initial Adjustments

If all of the design dimensions and construction methods are closely followed the amplifier will tune up and operate without any "trimming in." For operation at 432 MHz, set the cathode tuning capacitor C2 so its plates are 50% meshed, and the input coupling capacitor C1 so that its plates are 60% meshed. The plate tuning capacitor is preset to have its fixed end $1\frac{9}{32}$ in. from the plate compartment bottom, and the moving end is $\frac{19}{32}$ in. from the chassis. The plate loading capacitor should be located so its fixed end is $1\frac{3}{16}$ from the chassis bottom and its moving end is $1\frac{1}{16}$ in. from the chassis. With these settings the amplifier will be closely tuned for running 1500-W output at a plate voltage of 2250 V.

After verifying that all wiring has been correctly completed, prepare for the application of power by setting the filament voltage adjusting resistor (R17) to maximum resistance (minimum filament voltage). Ac power can then be applied to the amplifier, but do not connect the B+ at this time. Connect an accurate ac-RMS voltmeter to the filament power feedthrough capacitors, C4 and C5. Then adjust R17 for 13.0 V RMS. Set the meter switch, S3 to the FIL position, and adjust R20 for a reading of 130 on M2, which corresponds to 13.0 V. Be sure the filaments are fully warm (3 minutes minimum) before making final adjustments to R17 and R20. The filament voltage is set to the low side of the specified filament voltage (13.5 V ± 0.6 V). This is done to both maximize the filament life and to minimize any cathode back-heating effects. If any trouble is encountered in obtaining full plate current, try increasing the filament voltage.

Next, set the grid over-current circuit. Disconnect B+ from the tubes by removing RFC7 from the plate line. Turn on the B+ (needed to activate the HV-sensing circuit) and ground J6 to switch to transmit. Verify that the HV sensing circuit is working and that the T/R relays (K2 and any RF relays which are used) are switching. Apply a small amount of 432-MHz drive power. Since plate voltage has been removed from the amplifier, be extremely cautious, as the tubes will draw a large amount of grid current (retune C1 and C2 if necessary). Increase drive power until the tubes draw 120 mA of total grid current. Quickly adjust R15 for a grid over-current trip. Note that the relay may chatter and not lock in. If this is the case, adjust for consistent chatter at 120 mA. Now turn off the HV supply and, after verifying that the HV has bled down to zero, reconnect plate HV choke RFC7.

The amplifier is now ready for RF power-on testing. Connect power meters to the input and output lines. Turn power back on, including B+. After the filament is warm, the amplifier should key and draw about 90 mA of plate idling current (at around 2550 V. Apply increasing drive until 300 to 400 mA of plate current is drawn. Adjust the plate tuning and loading capacitors until you observe maximum output. Increase drive and retune the amplifier until full power out is observed (1500 W). Adjust the input tuning (C1 and C2) for minimum SWR under full-power conditions. With a 100-W Bird wattmeter element on the input side, you should be able to completely null out the reflected power. If you cannot, verify that your drive signal is free from spurious signals and check the input circuit for any assembly errors. As a final operational check, verify that the plate-current dip corresponds to maximum power output (within 50 W). Grid current should also roughly peak with the plate current dip, however, improper loading will affect this. If these conditions do not occur, check the grid collets for proper neutralization and check that your load or antenna is capable of handling the power and has a reasonable SWR (1.2:1 or better preferred).

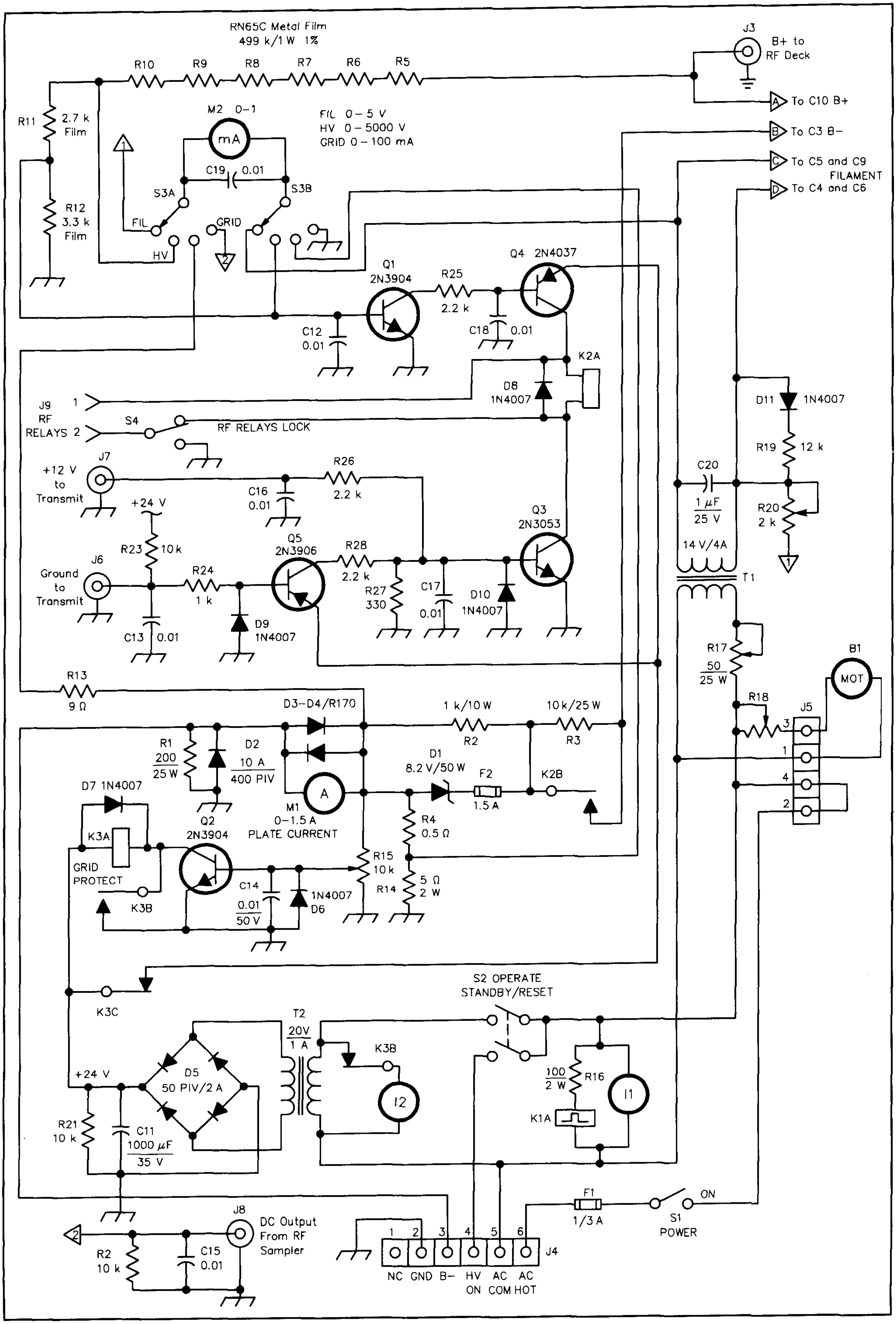


Fig 25—Schematic diagram of the amplifier control circuits.

Table 1

Full Power CW Operating Conditions

Parameter	*Test 1*	*Test 2*
Plate Voltage, Full Load	2230 V	2380 V
Plate Current	1290 mA	1200 mA
Input Power	2877 W	2856 W
Output Power	1500 W	1500 W
Apparent Efficiency	52.1 %	52.5 %
Drive Power	68 W	63 W
Power Gain	13.4 dB	13.8 dB
Grid Current	18 mA	10 mA
Input SWR	1.16:1	1.15:1
Filament Voltage	13.0 V	13.0 V
Idling Current	75 mA @ 2480 V	90 @ 2620 V
Bias Voltage	8.2 V	8.2 V

Notes: 1. Grid current may vary from tube to tube.
2. Plate voltage was measured from the cathode to B+ feedthrough; ie, the bias voltage and voltage drop across the B+ protection resistor are not measured.

Operation

Operation is best (and tube life will be longest) when the amplifier is heavily loaded. If the amplifier is over loaded, grid current is negative and plate current is higher than optimum. When under loaded, grid current rises rapidly as drive power is increased, however output power will not increase substantially. Several different tubes have been tried in both the parallel and single tube amplifiers. All of the tubes gave maximum power output at 432 MHz with very little positive grid current (typical was 7 to 20 mA per tube). The apparent efficiency of the amplifier should be checked (power out/($I_p \times V_p$). If over 50% apparent efficiency cannot be obtained, either the amplifier is not correctly loaded or the plate current and HV meters are not calibrated. If efficiency is over 55%, either the plate meters (voltage and current) or power-output meter are out of calibration. If the antenna has a high SWR, the power meter can indicate high, due to the reflected power traveling up and down the transmission line. Table 1 lists the observed operating conditions for the amplifier. These readings were made after carefully calibrating all metering circuits and verifying power out-

Table 2

Parts List, Parallel 3CX800A7 Amplifier

B1—100-CFM free-air flow blower; Dayton 4C443 or equiv.
C1—Miniature air-variable butterfly. 1.8-5.1 pF per section; Cardwell 160-205.
C2—Miniature air-variable butterfly. 2.2-8.0 pF per section; Cardwell 160-208.
C3-C7—Feedthrough capacitor, 1000 pF, 300 V; Tusonix 327-005-X5UO-102M.
C8—Plate-tuning flapper (see text and Fig 2).
C9—Plate-loading flapper (see text and Figs 3 and 4).
C10—1500-pF, 2500-V, pi-section feedthrough; Murata/Erie 1280-060.
C11—1000-µF, 35-V electrolytic.
C12-C18—0.01-µF/50-V, monolithic ceramic preferred; Sprague 1C10Z5U103M050B.
C19—0.01 µF, 1 kV ceramic
C20—0.5 µF, 25 V.
D1—8.2-V, 50-W Zener diode; IR-Z3307.
D2—100-PIV, 10-A silicon rectifier diode.
D3, D4—2.5-A, 1000-PIV silicon rectifier diode; IR R170 or equiv.
D5—50-V, 2-A silicon bridge rectifier.
D6-D12—1-A, 1000-PIV silicon rectifier diode, 1N4007 or equiv.
F1—2 A, AGC or 3AG fast-blow.
F2—1½ A, AGC or 3AG fast-blow.
I1—120-V pilot lamp, amber.
I2—120-V pilot lamp, red.
J1—Chassis-mount BNC female connector, UG-1094.
J2—Chassis-mount Type-N female connector, UG-58A.
J3—Chassis-mount MHV female connector, UG-931.
J4—6-pin, male chassis-mount connector, Cinch P306AB.
J5—4-pin female chassis-mount connector, Cinch S304AB.
J6-J8—RCA-type phono receptacle; Switchcraft 3501FR.
J9—2-pin female chassis-mount connector; Cinch S302AB.
K1—Thermal time delay, 115-V heater, SPST, NO; Amperite 115NO180B.
K2, K3—Control relay, 24-V dc coil, 4PDT; PB R10-E1-X4-V700.
K4—SPST low-power coaxial relay with BNC connectors, 28-V dc coil.
K5—SPST high-power coaxial relay, Type-N connectors, 28-V dc coil.
M1—Dc milliammeter, calibrated 1.5-A full scale.
M2—0-1 mA dc milliammeter, with appropriate shunt resistors: (0-150 mA grid, 0-3 kV plate, 0-15 V filament).
Q1, Q2—NPN low-current switching transistor, 2N3904 or equiv.
Q3—PNP medium-current switching transistor, 2N3053 or equiv (TO-5 package).
Q4—NPN medium-current switching transistor, 2N4037 or equiv.
Q5—PNP low-current switching transistor, 2N3906 or equiv.
R1—200 Ω, 25-W wirewound.
R2—1k, 12-W wirewound.
R3—10k, 25-W wirewound.
R4—0.5-Ω, 1-W 1%.
R5-R10—499k, ½-W, 1% metal film, type RN-65C.
R11—2.7k, ½-W metal film, select valve to calibrate HV meter.
R12—3.3k, ½-W metal film, select value to adjust HV relay drop-out point.
R13—9-Ω, ½-W metal film, select value to calibrate grid meter.
R14—7.2-Ω, 2-W, wire wound.
R15—10k ¼-W miniature trimmer.
R16—100-Ω, 2-W, select value to adjust time delay (see text).
R17—50-Ω, 25-W wirewound potentiometer.
R18—2500-Ω /50-W wirewound.
R19—12k, ½-W, film.
R20—2k, ¼-W, miniature trimmer.
R21, R23, R27—10k, ½-W, film.
R24—4.7k, ¼ W, film.
R25, R28—2.7k, ½-W, film.
R26—2.2k, 1/4 W
R28—10k, ¼-W, film.
R29—330-Ω, ¼-W, film.
RFC1-RFC5—8 t no. 18 enam, ¼-in diam close wound.
RFC6, RFC7—6 t no. 18 enam, ¾-in. long, ¼-in. diam.
S1—SPST toggle or rocker switch.
S2—DPST toggle or rocker switch.
S3—2P5T rotary switch, non-shorting.
S4—SPDT miniature toggle switch.
T1—Filament transformer, 14-V ac, 4 A; Stancor P-8557.
T2—Control transformer, 20-V ac, 1 A; Stancor P-8604.
V1, V2—EIMAC 3CX800A7 ceramic-metal triode.
W1—Plate stripline (see text and Fig 1).

put via a calibrated directional coupler.

The loading capacitor has enough range to allow the amplifier to efficiently operate from 700 to 1500 W output when the plate voltage is around 2300 V under load. Enough tuning range is available such that load impedance from about 35 to 70 Ω can be handled. If you desire to operate the amplifier at lower power levels, reduce plate voltage.

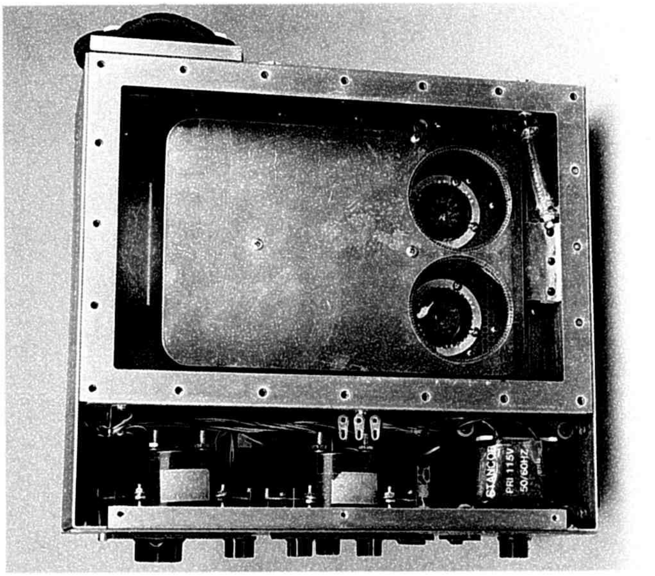
From a cold start, the amplifier will put out about 1450 W and drift up to 1500 W (that is if the amplifier has previously been tuned up at full temperature) over the first few minutes of operation. After this warm-up time, the amplifier will repeatedly come right up to full power. If you are observing more power drift, check all connectors and cables in your antenna system. The legal limit (1500 W) at 432 MHz will melt RG-213 type polyethylene cables in a few minutes. High power and temperature cable such as Teflon-dielectric cables like RG-225 can be used for jumpers as well as Andrew ½-in. SuperFlex cable. "Hardline" cables such as Andrew LDF4-50A or larger sizes should be used for the feed line to the antenna.

A pair of 3CX800A7 tubes provides a cost-effective means of producing the legal limit on 70 cm.

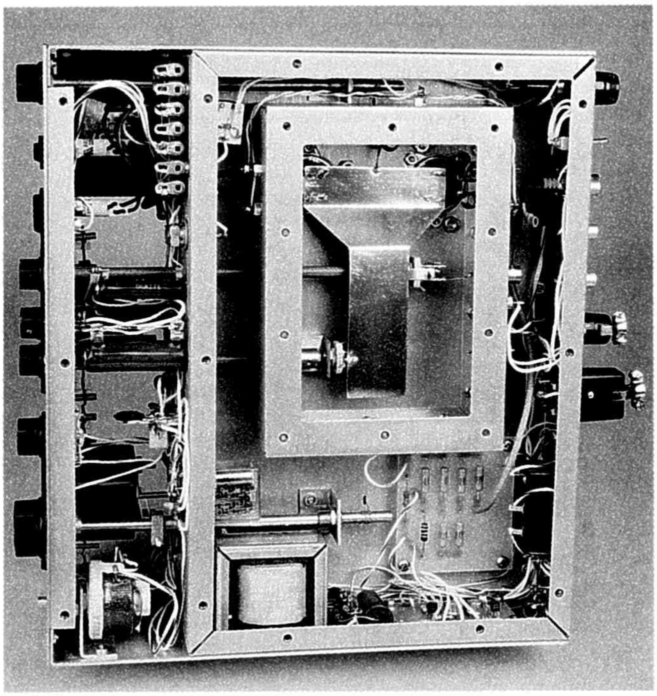
W2—Cathode stripline (see text and Fig 10).

Tube sockets (2 req)—11-pin EIA, EIMAC SK-1900 or E. F. Johnson 124-0311-100.
Grid collets (2 req)—EIMAC 720359 assembly. (EIMAC 882931 can be used).
Grid insulators (2 req)—EIMAC 720189.
Anode collets (2 req)—EIMAC 720829 or finger stock.
Chimneys (2 req)—EIMAC SK-1906.
Fuse holders (2 req)—Bussman type HKP, 2 required.
Panel bearings (9 req)—¼-in. diam.
Ball drive—Jackson 4511/DAF.

RF deck enclosure—8- × 12- × 3-in. chassis; BUD AC-424 or equivalent.
Cathode compartment—5- × 7- × 2-in. chassis; BUD AC-402 or equivalent.
Bottom chassis—8- × 12- × 2½-in. chassis; BUD AC-1419 or equivalent.
Miscellaneous sheet metal—2, 10¾- × 12- × 0.062-in. aluminum (top and bottom covers); 1, 5- × 7- × 0.062-in. aluminum (cathode compartment cover); 2, 5⅝- × 12⅛- × 0.062-in. aluminum (front panel); 2, 5½- × 10¾- × 0.062-in. aluminum (side panels); 3 ft, ½- × 0.062-in. aluminum angle stock (to hold front panel to cabinet); 1, 6¼- × 3½ × ⅜-in., 6061-T6 aluminum (air-outlet plate); 2, 3½- × 3- × ⅜-in. 6061-T6 (air-inlet plate); 1, 6- × 4- × 0.062-in. perforated steel sheet, ⅛-in. holes on 3/16-in. centers; 1, 6- × 4- × .020 brass or copper sheet (for W2 and C8 tuning pointer); 1, 6- × 9- × 0.062-in. brass or copper sheet (for W1); 1, 3- × 6- × 0.062-in. aluminum (C8, C9 and R17 shaft mounting brackets).
Other metal—2 in., 7/16-in. brass rod (for C1 and C2 shaft couplings); 1, 2- × ⅝- × 0.125-in. aluminum or brass bar (C6 retaining plate).
Other items:
10 ft no. 18 enam wire.
100 ft no. 20 insulated stranded hookup wire.
Terminal strips.
HV-meter pc board.
TR-control pc board.
20 wire ties (small).
Cable clamps.
4-in. RG-225 50-Ω Teflon-dielectric cable.
2, 1.43-in. high × ½-in. diam. Teflon or ceramic standoffs.
1 — ½- × ⅜- × 2-in. Teflon rod (to hold loading capacitor).
2 — 1½- × ¼ × ⅜-in. diam. threaded steel standoff.
12-in. ¼-in. dia. Garoite, or Bakelite rod (for C1 and C2 shafts).
½-in. ¼-in. dia. Teflon rod (for C8 and C9 insulators/fishline attachment).
14-in. ¼-in. dia. Brass Rod (for C8 and C9 tuning shafts).
2½- × ⅝- × 1/16-in. G-10 epoxy board (C1 and C2 mounting plates).
3-in. ⅝- × ¼-in. Brass bar stock for C8-9 shaft stops and C1-2 mtg. brkts
3 — ¼-20 × ½-in. long nylon screws.
2' Dacron polyester woven fly line.
Shrink tube.
Assorted grommets.
4, 3-48 × ¼-in. Phillips round-head screws.
8, 4-40 × ¾-in. Phillips flat-head screws.
4, 4-40 × ⅜-in. Phillips flat-head screws.
18, 4-40 × ¼-in. Phillips pan-head screws.
3, 4-40 × ¼-in. brass screws.
2, 4-40 × 1-in. Phillips round-head screws.
46, 6-32 × ¼-in. Phillips flat-head screws.
11, 6-32 × ⅜-in. Phillips flat-head screws.
8, 6-32 × ½-in. Phillips flat-head screws.
28, 6-32 × ¼-in. Phillips pan-head screws.
16, 6-32 × ¼-in. Phillips round-head screws.
2, 6-32 × ⅜-in. Phillips round-head screws.
2, 6-32 × ¼-in. brass round-head screws.
2, 6-32 × 1-in. Phillips round-head screws.
8, 6-32 × ¼-in. hex socket set screws.
22, 6-32 hex nuts.
18, 4-40 hex nuts.
20, no. 4 lockwashers.
32, no. 6 lockwashers.
4, no. 6 solder lugs.
62-6-32 self-clinching blind fasteners for 0.050-in. metal.
Knobs—1, 1⅜-in. diam., ¼-in. shaft AlcoSwitch PKES-120B-¼
1, 1-in. diam., ¼-in. shaft, AlcoSwitch PKES-90B-¼
1, ⅞-in. diam., ¼-in. shaft, AlcoSwitch PKES-70B-¼
2, ¾-in. diam., ¼-in. shaft, AlcoSwitch PKES-60B-¼

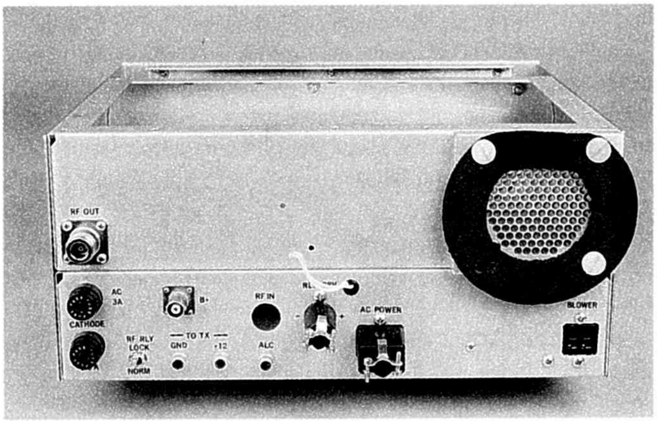


Inside the plate compartment, with the tubes removed.



Underside view, showing the cathode compartment and tuning controls.

Since the 3CX800A7 has relatively high gain, you should be certain that drive power level is stable before blaming the amplifier for any power drift. Also be sure that the drive signal is clean. Several different solid-state brick amplifiers were tried as drivers for the parallel 3CX800A7 amplifier. Some handled the amplifier input circuit well, while others weren't so forgiving. One somewhat "flaky" solid-state driver amplifier was cured with the installation of an isolator between the driver and amplifier. Also be sure that the drive signal is free from spurious signals, such as the 404-MHz local oscillator signal if a 28-MHz-IF transverter is used. While testing the



Rear view, with blower removed.

amplifier I found that one of my transverters put out a substantial amount of 404-MHz LO signal, which was then amplified more by a solid-state driver amplifier than was the desired 432-MHz signal. The result was that drive power was substantially higher than expected and amplifier efficiency was poor. In addition, the input circuit could not be tuned for a low SWR. The installation of a $\lambda/2$ filter between the transverter and solid-state driver cured the problem.

I have already discussed the slight stress on a pair of 3CX800A7s when running at 1500-W output at 432 MHz. This is due to operation about 25% higher in frequency than the specified maximum for the tubes (350 MHz). At 432 MHz, the efficiency of the tubes is starting to drop due to transit time effects. Note that in order to obtain 1500-W output power either the maximum plate current or voltage must be exceeded. Table 1 details full operating parameters for the parallel 3CX800A7 432-MHz amplifier. In Test 1, the plate voltage is maintained within specification and the plate current rating is exceeded. In Test 2, the plate voltage was increased until 1500-W output was obtained within the rated 1200 mA of plate current. For this reason I recommend 1500-W operation be limited to SSB voice service and keyed CW (Morse code). For tuning adjustments, key-down times should be limited to 1 minute or less with an equal or greater off time. If you have a well regulated B+ power supply, it is more desirable to run the plate voltage higher than specified and keep the plate current at 1200 mA. By following these precautions a pair of 3CX800A7s will last 10 to 15 years or more in typical heavy amateur EME or tropo operation. If the amplifier is to be used in a continuous mode such as FM or ATV, I recommend that the plate voltage be limited to 2000 V and the plate current be limited to 1000 mA for the pair of tubes. For continuous transmission modes, the cathodes should be checked for back heating. This is done by reducing the filament voltage until power output starts to drop. The filament voltage should be then increased to just above the point where power dropped. The filament voltage should only be reduced during key-down transmit periods. During warm-up and receive periods the filament voltage should be switched to full voltage.

Using 8874 Tubes

The design could be easily adapted to the Varian 8874 tube, if they are available. If you're going to use new tubes, the 3CX800A7 is preferred. To use 8874s set filament voltage to 6.0 V ac-RMS. Use a 6.3-V, 6-A filament transformer for T1. The plate stripline holes should be sized for the 1⅝-in. diameter of the 8874 plate anode (1.785 in. diameter if the same finger stock is used). The air-outlet holes should be reduced to fit within 1⅝-in. diameter circles. Neutralization may be slightly different with the 8874. Ratings for the 8874 are 2200 V at 350 mA continuous and 500 mA in intermittent service (SSB and keyed CW). At full power, required drive power is 80 to 85 W and about 1200 W output power may be obtained.

Conclusion

The parallel 3CX800A7 432-MHz amplifier is an effective means to obtain 1500 W output in amateur SSB and CW service. The performance of the amplifier is only 1.5% lower in efficiency and 0.6 dB lower in gain than a "perfect" design. This slight degradation in performance is an acceptable design trade off, considering the simplicity of its construction compared with a design capable of better performance. Operation is completely stable at 1500 W output. It has been completely reliable and has very good IMD performance, with low drive requirements.

Kit Availability

Chassis kits are available from Charles Byers, K3IWK, 5120 Harmony Grove Rd, Dover, PA 17315, tel 717-292-4901. Complete kits and factory wired units are available from Lunar-Link Systems, 816 Summer Hill Rd, Madison, CT 06443-1604 , tel 203-421-3377.

A 1500-Watt Output Amplifier for 432 MHz

By Steve Powlishen, K1FO

The change in regulations which now allow amateurs to run 1500 W PEP output power called for a new amplifier. The 1500-W level is of most significance on EME, but other propagation modes such as tropo-scatter also benefit from the new regulations. The design goal was an amplifier capable of running 1500 W continuous output, be extremely reliable, stable, free from power drift annoyances and have excellent linearity (low distortion products).

I considered using solid-state devices. The best commercially available devices usable at 432 MHz are power MOSFETs, such as the Motorola MRF175GU (28 V) and MRF175LU (56 V). These devices contain two transistors in a single package, and are designed for push-pull operation. Each package can deliver 150 W of linear power output (200 W saturated). Reaching the 1500-W level in reliable linear service would require combining 10 amplifiers! At 432 MHz these devices are 45% efficient at best, which means quite a power supply: 28 V at 120 A or 56 V at 60 A, regulated. Consider also the heat sink required to dissipate almost 1800 W. In addition, when all of the power input splitters and output combiners are considered, the overall system gain would not be much greater than 10 dB. Almost twice the drive power required by a triode amplifier would be needed to excite this solid-state amplifier to full output. Lacking better solid-state devices, I decided a 1500-W solid-state amplifier was impractical for amateur construction. My design process was forced back to familiar vacuum-tube ground.

The list of power tubes that work acceptably above 400 MHz is small, especially when you consider price and performance. A list of available tubes and their performance capabilities was compiled. The 4CX250 family was ruled out first. Although they are readily available for reasonable cost in the surplus market, the use of the 4CX250 family would require more than 2 tubes to reach the desired 1500-W output level within the CCS ratings of the tubes. In addition even when the '250 family is run within their CCS ratings their IMD performance (3rd-order IMD down –23 to 25 dB) is somewhat marginal. The only member of the family designed for high linearity (the 4CX350A) is a poor performer at 432 MHz. The thought of pushing two 4CX250-type tubes to the 1500-W output level, even in intermittent amateur service threatened to be an exercise in frequent tube changes.

The 8874 family (8873, 8874, 8875, 3CX400U7 and 3CX800A7) were examined next and met all requirements except 1500-W output on a continuous basis for 2 tubes. Only the 3CX800A7s appeared capable of generating 1500 W output while only moderately exceeding their ratings.

The 3CX600U7 presented an interesting possibility, but with little or no prospect of surplus tubes, the cost of a pair of them plus the time and effort required to build sockets called for a look at the "big" bottles.

There are many benefits to construction of single-tube amplifiers. Better IMD, freedom from balance worries, ability to use coaxial input or output circuits, ease of use in cavity circuits and simplicity of construction are among the features of single-tube design. The 4CX600 family and 7650 were ruled out quickly as simply not in the 1500-W output class with a single tube. Cost considerations made them a poor choice compared to some larger tubes. If you have good surplus connections, a pair of 7650s would make a formidable 432-MHz amplifier. The 4CX1000 family (4CX1000A, 4CX1000K and 4CX1500B), along with the 8877, were discarded because of their poor efficiency at 432 MHz. The 3CX1000A7 has been used at 432 MHz[1] but suffered the same malady.

This left the three final contenders: the 7213, 4CX1500BC and the 8938. The 7213 is capable of 1500-W output by slightly exceeding its CCS ratings. The 7213 will give acceptable performance, but its significantly higher cost new, and scarcity in surplus scratched it from the finals. The 4CX1500BC was an interesting possibility. It is essentially a coaxial-base UHF version of the 4CX1500B. The 4CX1500B is an improved 4CX1000. The improvements are a higher efficiency anode radiator and improved grid and cathode structure for higher linearity. The excellent IMD, power output and low drive appeared to make the '1500BC the right choice. When the project was started, however, the 4CX1500BC was not in full production. The combination of both uncertain availability and higher cost eliminated any low-drive-tetrode versus simple-triode-circuit arguments.

The winner, therefore, was the EIMAC 8938. The 8938 is essentially a UHF version of the popular 8877. It has been used in both commercial and amateur amplifiers in the 400-

Table 1

Parts List

B1—100 CFM free air flow, 50 CFM @0.7", Dayton, 4C443
Note: wire grate on blower input was cut out to increase air flow.
C1—Min. air var. butterfly. 2.2-8.0 pF/section Cardwell 160-208.
C2—Min. air var. butterfly. 1.8-5.1 pF/section Cardwell 160-205.
C3—Plate loading flapper made from 0.010 brass. See drawing.
C4—Fixed plate tuning capacitor, made from 0.062 aluminum. See drawing.
C5—Variable plate tuning capacitor, made from 0.010" brass. See drawing.
C6—1000 pF/4 kV feedthrough, Tusconix 2498-0C1-X540-102M
C7-9—1000 pF/300 V feedthrough type CK70.
C11—1000 µF/35-V electrolytic.
C12-19—0.01 µF/50 V, monolithic ceramic, preferred Sprague 1C10Z5U103M050B
C20—1 µF/25 V.
D1—25 V/50-W Zener diode, RCA SK560/5265A.
D2—100 PIV/10 A silicon rectifier diode.
D3-D4—3.0 A/1000 PIV silicon rectifier diode, 1N5408 or equivalent.
D5—50 V/2 A silicon bridge rectifier diode.
D6-12—1 A/1000 PIV silicon rectifier diode, 1N4007 or equivalent.
F1—3 A fuse, AGC or 3AG fast blow type.
F2—1-1/2 A fuse, AGC or 3AG fast blow type.
I1—120 V pilot lamp amber.
I2—120 V pilot lamp red.
J1—Chassis mount BNC female connector, UG-1094/U.
J2—Chassis mount N female connector, UG-58A/U.
J3—Chassis mount MHV female connector, UG-931/U.
J4—6 pin male chassis mount connector, Cinch P306AB.
J5—4 pin female chassis connector, Cinch S304AB.
J6-7—RCA type phono receptacle, Switchcraft 3501FR.
J9—2 pin female chassis mount connector, Cinch S302AB.
K1—Thermal time delay, 115 V heater, SPST/NO, Amperite 115N0180B.
K2-3—Control relay 24 Vdc coil 4PDT, P&B R10-E1-X4-V700.
M1—DC mA meter, 1.5 A full scale.
M2—0-1 mA dc meter, with appropriate shunt resistors 0-100 mA grid, 0-5 kV plate, 0.5 V filament.
Q1-2—NPN low current switching transistor, 2N3904.
Q3—PNP medium current switching transistor, 2N3053.
Q4—NPN medium switching transistor, 2N4037.
Q5—PNP low current switching transistor, 2N3906.
R1—200 Ω/25-W wirewound.
R2—1000 Ω 12-W wirewound.
R3—10k 25-W wirewound.
R4—0.5 Ω 1-W 1%.
R5-14—499k, 1/2-W, 1% metal film, type RN-65C.
R15—2.7k, 1/2-W metal film, select valve to calibrate HV meter.
R16—3.3k, 1/2-W metal film, select value to adjust HV relay point.
R17—9 Ω, 1/2-W metal film, select value to calibrate grid meter.
R18—5 Ω, 2-W, metal film.
R19—10k, 1/4-W miniature trimmer.
R20—100 Ω, 2-W, select value to adjust time delay.
R21—50 Ω, 25-W wirewound potentiometer.
R23—12k, 1/2-W, film.
R24—2k, 1/4-W, miniature trimmer.
R25-26—10k, 1/4-W.
R28—1k, 1/4-W.
R29-31—2.2k 1/4-W.
R32—330 Ω, 1/4-W.
RFC1-3—7 turns no. 18 enameled wire 1/4" dia. close wound.
RFC5—6 turns no. 18 wire 3/4" long, 1/4" diameter.
S1—SPST toggle or rocker switch.
S2—DPST toggle or rocker switch.
S3—2P5T rotary switch, non-shorting.
S4—SPDT miniature toggle switch.
T1—Filament transformer, 5 V@ 10 A. Stancor P-6135.
T2—Control transformer, 20 V @ 1 A. Stancor P-8604.
W1—Plate stripline. See text and Fig 1. 4.438" × 7.80" × 1/16" brass.
W2—Cathode stripline. See text and Fig 10. 0.020 brass.
V1 Varian, Eimac 8938 ceramic metal triode.
Filament pin contact: Eimac 135310.
Filament collet: Eimac 135307 attached to brass ring.
Cathode collet: Eimac 135306 attached to brass ring.
Grid collet: Eimac 135305 collet attached to 1/16" brass plate.
Anode collet: Make from Instrument Specialties #97-135 finger stock.
Chimney: Varian, Eimac SK-2216.
Fuse holders: Bussman type HKP, 2 required.
Panel bearings: 1/4" dia. 9 required.
Ball drive: Jackson 4511/DAF.
RF deck enclosure: 6.5 × 10.5 × 4", see drawings.
Cathode compartment: 4 × 6 × 2 inch chassis BUD AC-431 or equivalent.
HV meter compartment: 4 × 5 × 2" chassis, BUD AC-1404.
Control circuitry chassis: 4 × 6 × 2" chassis, BUD AC-AC431.
2—10-1/2" × 6-1/2" × 0.062" aluminum top & bottom covers.
1—4" × 6" × .062" aluminum cathode compartment cover.
2—7" high × 19" wide × 0.125" aluminum, rack panel.
2—6" × 10-3/4" × 0.062" aluminum, side panels.
3'—1/2" × 0.062 aluminum angle stock (to hold front panel to cabinet).
1—4-1/2" × 4-1/2" × 1/4"-6061-T6 air outlet plate.
2—3-1/2 × 3" × 3/8"-6061-T6 air inlet plate.
1—6" × 4" × 0.062 perforated steel sheet, 1/8" holes on 3/16" centers.
1—6" × 4" × 0.020 brass or copper sheet (for W2 & C8 tuning pointer).
1—5" × 8" × 0.062 brass or copper sheet (for W1).
1—3" × 6" × 0.062 aluminum, C8, C9 & R17 shaft mounting brackets.
2"—7/16" brass rod (for C1 & C2 shaft couplings).
1—2" × 5/8" × 0.125 aluminum or brass bar for C6 retaining plate.
6'—#18 enameled wire.
100'—#20 insulated stranded hookup wire.
Terminal strips.
HV meter PC board.
TR control PC board.
20—Wire ties (small).
2—2.00" high × 1/2" dia. Teflon or ceramic standoffs.
2—1-1/2" × 1/4" - 3/8" dia. threaded steel standoff.
12"—1/4" dia. Garoite or Bakelite rod (for C1 & C2 shafts).
1/2"—1/4" dia. Teflon rod for C8 & C9 insulators / fishline attachment.
14"—1/4" dia. brass rod (for C8 & C9 tuning shafts).
2—1/2" × 5/8" × 1/16" G-10 epoxy board (C1 & C2 mounting plates).
3"—5/8" × 1/4" brass bar stock for C8-9 shaft stops & C1-2 mounting brackets.
3—1/4-20 × 1/2" long nylon screws.
2'—Dacron polyester woven fly line.

to 500-MHz range. It offers excellent linearity (3rd- and 5th-order IMD products down over 40 dB), an ample 1500-W nominal plate dissipation, reasonable filament power (5 V at 10.5 A) and a modest bias voltage (25 V), which allows a simple cathode-bias circuit. The chief drawbacks of the 8938 are its modest efficiency at 432 MHz (50% typical), relatively low gain (less than 13 dB at 432 MHz) and high cost (in amateur terms) of the tube and socket. The cost of the socket can be eliminated by building one. The cost of the tube is relative. When one considers that the 8938 should easily last 10 to 15 years in heavy amateur usage, it begins to look more competitive with pushed 4CX250s, even without considering its superior power capability.

The next decision was to select the plate-circuit design. Determining which type of circuit would be used, as with the selection of which tube would be used, (and virtually all engineering decisions) became a trade off between advantages and disadvantages of any approach. The design of a 432-MHz amplifier is dominated by the characteristics of the tube or tubes used. The capacitive reactance of the 8938 is low enough that a λ/4 resonant circuit virtually disappears within the tube. This limits the choice of tank circuit to that of a cavity or resonant line of λ/2 or longer.

The cavity offers wider bandwidth (provided a λ/4 cavity can be used) and a more equal distribution of circulating currents through the base of the tube. Both of these features should result in reduced power drift. The wider bandwidth makes any tuning drift that does occur of less an effect. The primary cause of power drift at 432 MHz in a mechanically sound amplifier is RF dielectric heating of the ceramic insulators; primarily the one between the grid and anode. (Or, in the case of a tetrode, the screen-to-anode insulator.) In a symmetrical cavity, the circulating currents are more evenly distributed, and cause a more equal and lesser heating effect than a circuit that appears "single ended" and concentrates the currents toward a side of the tube. A properly designed cavity resonator should also be free from stray resonances that can plague single-line resonators.

But, the cavity approach is not without its drawbacks. First and probably foremost for most amateur constructors, is increased construction complexity. For an amateur designing from scratch who has minimal test equipment one must either construct his cavity with sliding walls so the amplifier can be adjusted to account for any calculation discrepancies versus real-world operation or be prepared to make a test amplifier before the real one is constructed. Such sliding-wall construction most likely requires higher tolerances in building the pieces of the amplifier.

The plate-bypass capacitor can be another headache in a cavity amplifier. A mistuned amplifier can arc a bypass capacitor that could safely handle the dc plate voltage. In general, it is harder to determine the proper output coupling for a cavity versus a capacitively coupled stripline. Again, in normal amateur construction where the prototype is the production model, there may be significantly less cut and try with a stripline. If you are like me and like to build compact equipment that can be mounted in a rack with limited access to the rear, a design that lends itself to all-front-panel tuning controls is desired. This can be difficult with cavity amplifiers.

A capacitively loaded and tuned half-wave stripline was selected for the plate circuit of this amplifier as the advantages of a cavity circuit did not justify its increased complexity and time and cost of construction. A commercial cavity available from EIMAC was prohibitively expensive. A half-wave stripline with simple capacitive input coupling was also used for the input circuit. The design is essentially an adaptation of the K2RIW parallel kilowatt for 432 MHz.[2]

Since the actual circuit is dominated by the output reactance of the 8938, the actual impedance and width of the stripline is not very critical. The actual dimensions for the plate enclosure were based on the desire for a compact amplifier. The small size of the plate enclosure also ensures that strange resonance modes are minimized. The height of the 8938 does not allow standard chassis to be used in the construction. The metal work was done by a local sheet-metal shop and their abilities determined that the enclosure was made with separate top and bottom covers, rather than the more conventional single-cover chassis. The custom chassis work also allowed heavy gauge aluminum to be used (5052 alloy, 0.063-in. thick). The lips where the top and bottom covers attach were made ¾-in. wide to give superior shielding where the parts join. If you cannot arrange for the metal work to be done, construction by using flat plates for all sides, held together with aluminum angle stock will work. This type of construction has been described in an 8874 amplifier for 432 MHz.[3] If you deviate from the dimensions I used for the plate compartment your amplifier will most likely work, however, the size and positions of the plate tuning and loading capacitors will change. If you attempt to change the amplifier design dimensions you are on your own. I am unable (and unwilling) to lend advice on such variations.

A close inspection of the plate line reveals that all the corners are rounded. The edge of the line has a smooth radius applied to it. Several users of 8938 stripline amplifier have reported arcing from the plate line. The spacing between the line and the tuning and loading capacitors was several times greater than what the safe distance for a 4000-V dc plate voltage. What was happening was that the RF plate voltage which swings close to twice the dc voltage was arcing from the field concentration points to the tuning or loading capacitor. When this amplifier was being tested and before the radiused edge was put on the plateline, RF arcs could be consistently drawn off it during full power. If the arc was severe enough a dc arc would also be created, tripping the power supply circuit breaker. Once a strong-enough ionized path was created the dc potential would follow the path. Inspection of the plate components would usually reveal carbon tracks at the sharp corners of the plateline. The ability to create smooth edges was one of the reasons that a solid brass stripline was chosen over use of a printed circuit board.

After the plateline edge was smoothed over, the frequency and intensity of the arc diminished significantly, however an occasional arc would still occur. Inspection of the components showed that the arcs were now starting at the relatively sharp edge of the 0.15-in. thick plate tuning capacitor. Adjusting the tuning capacitor size as to increase its spacing from the plateline did not improve the situation. At this point the dual tuning plate arrangement now used in the amplifier was tried. The theory

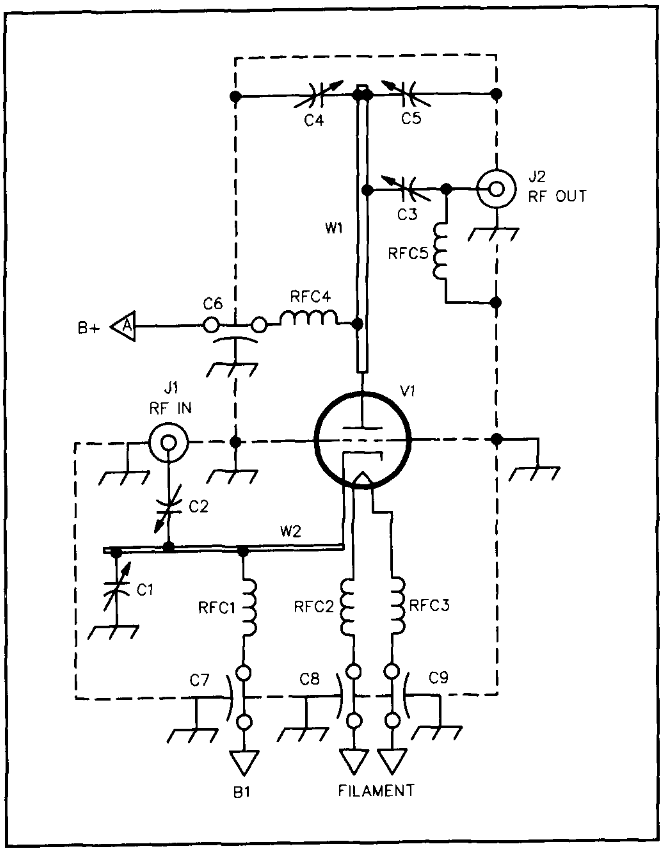


Fig 1—Schematic diagram of the 1500-W linear amplifier for 432 MHz.

behind it was that a capacitor plate on either side of the plate stripline would distribute the field more evenly. This should have the same effect as increasing the spacing of a single flapper to the plateline by four times. The second plate had the desired result and there has not been an arc in the amplifier since it was incorporated. The second plate also offers the ability of being adjusted to set the variable flapper to a desired tuning range. (The mounting holes on the fixed plate are slotted for this purpose.) The fixed plate may be made out of copper, brass or aluminum. You should make it out of material thick enough (0.030 in. or thicker) to allow a smooth radius to be applied around its edge the same as described for the plate stripline.

The plateline is mounted on 2-in. high home made Teflon standoffs. Ceramic standoffs have been used without any problems also. I recommend using brass screws to hold the plateline to the insulators. I also recommend using a brass screw to attach the plate stripline to the plate choke.

The actual choice of the finger stock for the 8938 anode to the plate stripline contact is not critical. I used some stock about 7/16-in. high and with folded-over fingers. I got it at a flea market and I do not know who made it. Do not order the EIMAC anode collect (no. 135304), as it is sized to fit over the anode ring on the 8938. It is too small to fit around the anode radiator. The type of finger stock you use determines the size hole in the

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Fig 2—Schematic diagram of the control circuits for the 1500-W, 432-MHz amplifier.

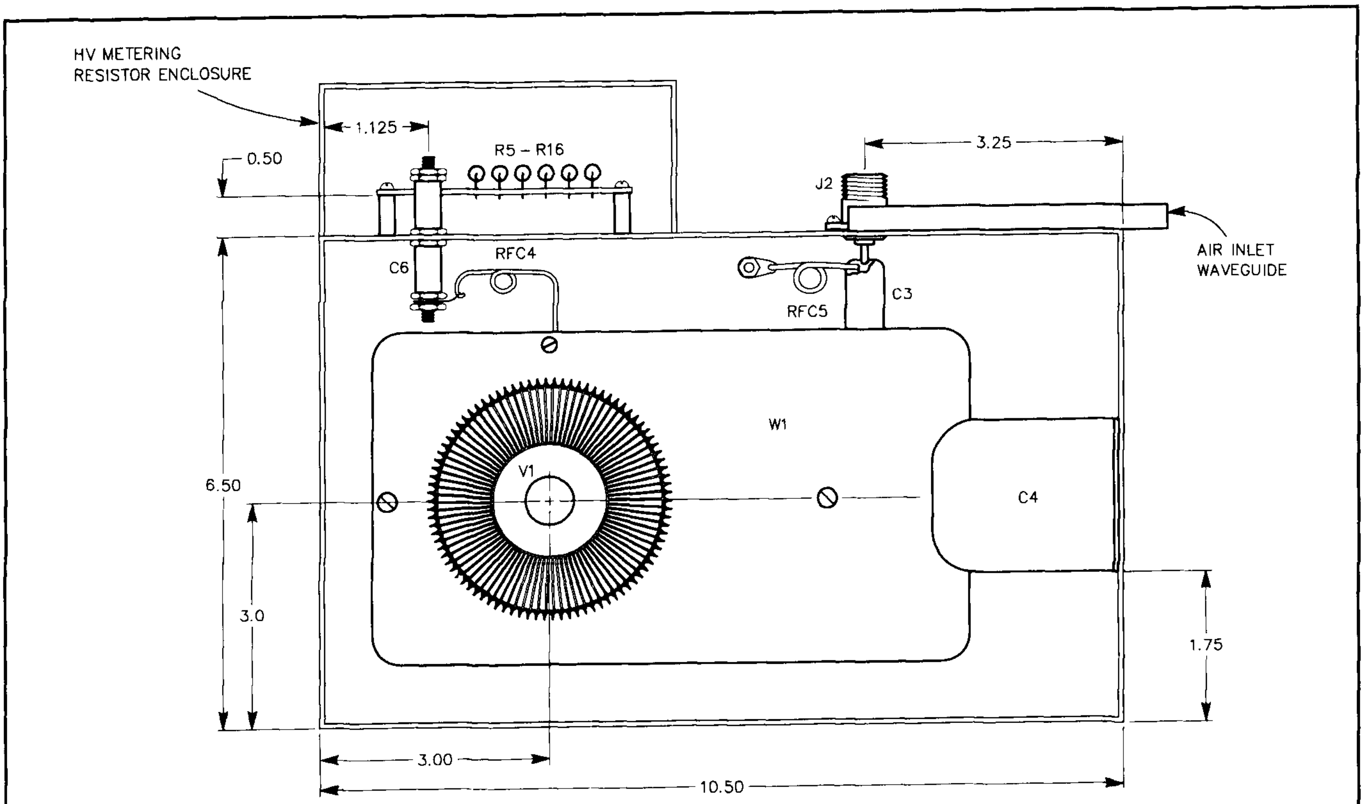
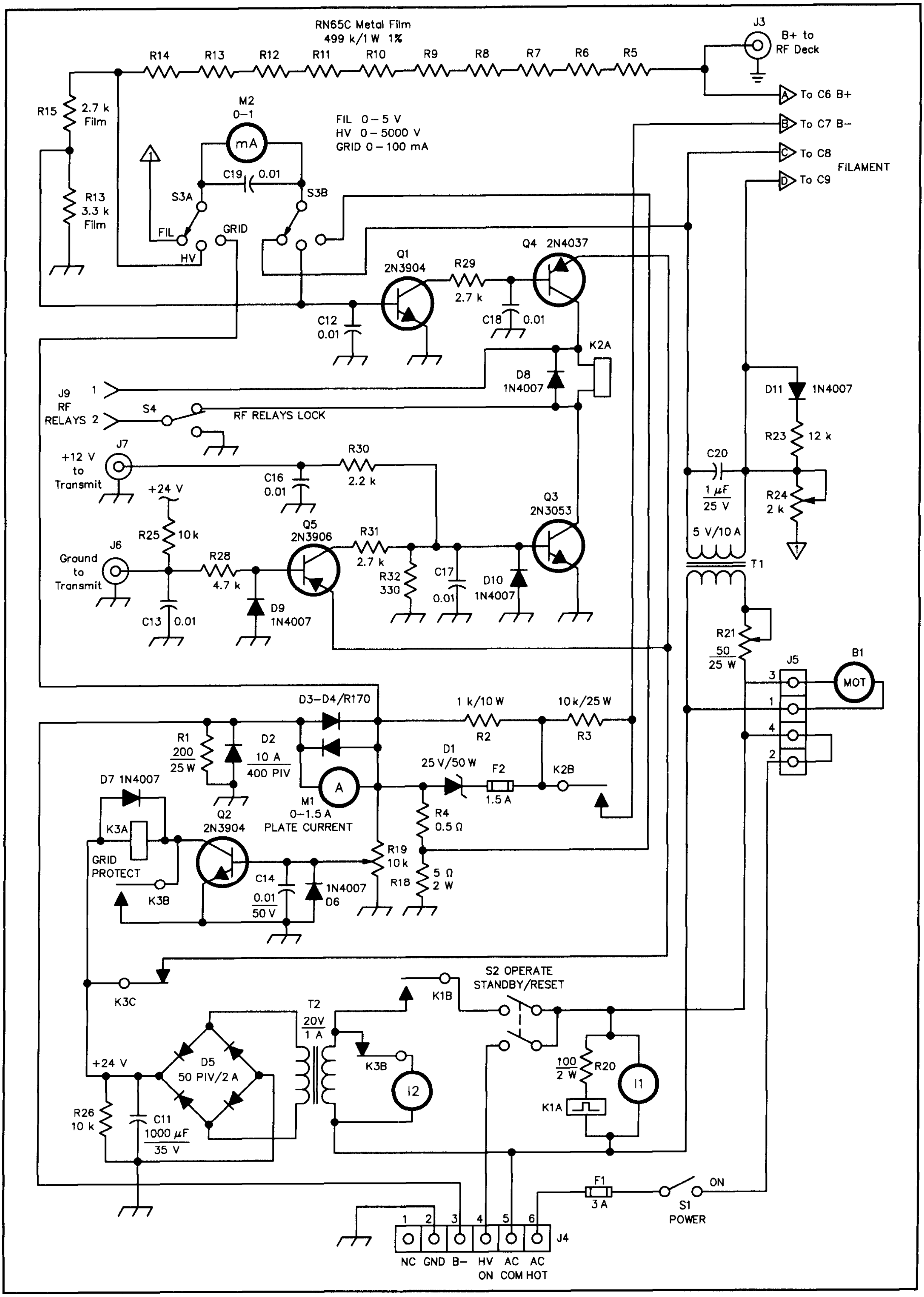


Fig 3—Layout of the plate compartment, showing locations of the plate stripline and the plate tuning flapper capacitor. Also shown is the enclosure for the HV metering resistors.


RN65C Metal Film
499 k/1 W 1%
R14
R13
R12
R11
R10
R9
R8
R7
R6
R5
J3
B+ to
RF Deck
To C6 B+
To C7 B−
To C8
FILAMENT
To C9
R15
2.7 k
Film
M2
0−1
mA
FIL 0 − 5 V
HV 0 − 5000 V
GRID 0 − 100 mA
C19
0.01
S3A
S3B
R13
3.3 k
Film
FIL
GRID
HV
Q1
2N3904
Q4 2N4037
R29
2.7 k
C18
0.01
C12
0.01
K2A
D8
1N4007
J9
RF
RELAYS
S4
RF RELAYS LOCK
D11
1N4007
R23
12 k
+12 V
to
Transmit
J7
R30
2.2 k
C16
0.01
C20
1 µF
25 V
R24
2 k
+24 V
Q3
2N3053
R25
10 k
Q5
2N3906
R31
2.7 k
5 V/10 A
T1
J6
Ground
to
Transmit
R28
4.7 k
R32
330
C17
0.01
D10
1N4007
C13
0.01
D9
1N4007
R21
50
25 W
J5
B1
MOT
D3−D4/R170
1 k/10 W
R2
10 k/25 W
R3
R1
200
25 W
D2
10 A
400 PIV
D1
25 V/50 W
F2
1.5 A
K2B
D7 1N4007
M1
0−1.5 A
PLATE CURRENT
K3A
Q2
2N3904
R4
0.5 Ω
R19
10 k
GRID
PROTECT
C14
0.01
50 V
1N4007
D6
R18
5 Ω
2 W
K3B
K3C
S2 OPERATE
STANDBY/RESET
K1B
T2
20V
1 A
K3B
+24 V
D5
50 PIV/2 A
I2
100
2 W
R20
I1
K1A
R26
10 k
C11
1000 µF
35 V
F1
3 A
ON
S1
POWER
J4
NC
GND
B−
HV
ON
AC
COM
AC
HOT

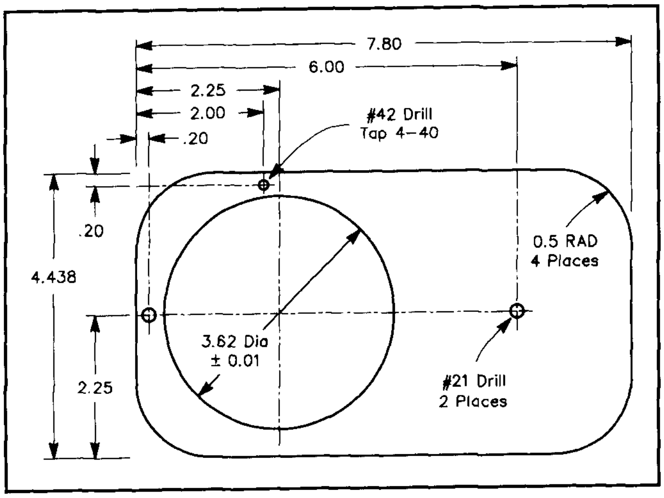


Fig 4—The plate stripline is made from brass sheet, 1/16-in. (0.063-in.) thick. Dimensional tolerance is ± 0.02 in., except the cutout for the anode fingerstock, as noted on the drawing.

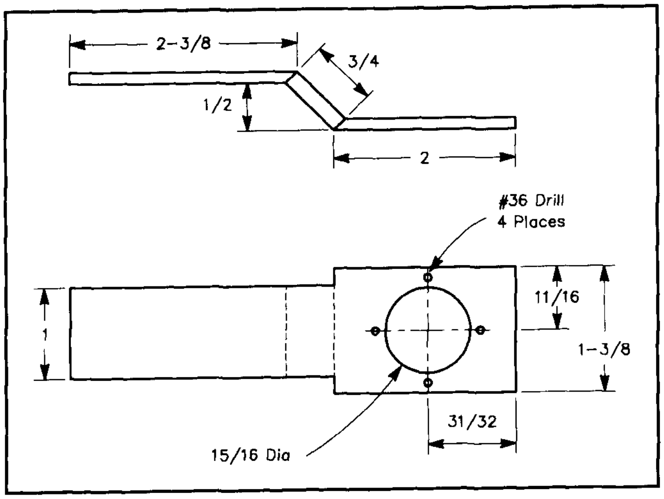


Fig 5—Cathode line is made from 0.020-in. brass, silver plated to a minimum thickness of 0.0001 in.

stripline. A different type of finger stock will slightly change the effective inductance of the stripline, which will alter the amount of tuning capacitance required to resonate the circuit. This is of little concern, especially with the dual-plate tuning capacitor arrangement this amplifier uses.

The choke between the plate-loading capacitor (C3) and ground protects against an arc between the plate line and loading capacitor. It also gives protection against accidental contact between the loading capacitor and the plate stripline. This possibility should be minimized by the Teflon buttons used on both the plate loading and tuning flappers.

The plate and load capacitors are adjusted by the now widely used "fishline" method. The lines are attached to the flappers through home-made Teflon button insulators. They are made from ¼-in. diameter Teflon rod which is put in a drill chuck and turned down with a file. A small hole is drilled through them for tying the tuning line to. This insulation from the flappers makes the selection of the tuning line not critical. Dacron polyester line is preferred if it can be found. Standard monofilament fish line can be used in this arrangement even though it is usually made from a nylon derivative.

The tuning lines are routed to the front-panel controls by Teflon bearings. The bearings are made by putting pieces of ¼-in. Teflon stock in a drill and cutting a grove in it with a hacksaw blade. Teflon bushings are used for feeding the fishline through the chassis. The bushings are made from standoff insulators, by simply pushing the solder pin out of the standoff. The tuning controls use 6:1 Jackson ball drives to impart a slow tuning feel to the controls. The ball drives have provision for attaching pointers to them. The pointers were made out of 0.20-in aluminum sheet and painted red. Tuning-range stops were made by inserting a screw through the ½-in. brass tuning control shaft. A second screw in the tuning control bearing plate limits the plate and load controls to a single turn. This amount of tuning and loading range is more than adequate to tune close to a 20-MHz range for power levels from 500- to 1500-W output. The stops protect the lines and flappers from accidental damage. The pointers on the ball drives allow the tuning controls to be quickly set to different power levels for frequencies of operation.

The grid-grounding ring was made from an EIMAC grid collet (P/N 135505) and a 3½-in. square piece of 1/16-in. brass. The hole for the collet is 2¼ in. in diameter. Twelve mounting holes, drilled to clear 6-32 screws, are equally spaced around a 2¾-in. diameter circle. The outside size and shape of the grid collet plate are not critical. It can be made circular or square. If you do not silver plate your grid collet mounting plate, the side which touches the aluminum chassis should be tinned. This applies to any other copper or brass to aluminum joint. This is necessary to avoid any long term corrosion problems which can be a problem when these metals touch each other. The grid collet contact tabs are broken off in the pattern described in Fig 1 to neutralize the amplifier. Removing the fingers raises the grid inductance which lowers the amplifier's gain at higher frequencies. This is done in order to avoid higher frequency parasitic oscillations. These higher frequency parasitic oscillations can cause dielectric heating of the grid-to-plate insulator, which causes power drift. This condition could also potentially damage the tube by overheating its seals.

If you have not soldered finger stock or collets to a thick brass plate, I suggest you get some extra material and practice first. All the collet assemblies used in this amplifier (plate, grid, cathode and filament) were soldered with a standard propane torch and rosin-core solder. The first step is to thoroughly clean all parts. Steel wool leaves a residue. I use Brillo or SOS pads to clean and polish the parts as their detergents are good grease cutters. Next, wipe down the plate with a low-residue solvent, such as lacquer thinner or acetone, to remove the detergent residue. The finger stock or collets are then fitted (after thoroughly washing and drying your hands!). A shim wedged into the gap in the collet holds it in place. Then a very small amount of liquid resin (the type as used in solder reflow machines) is applied to the joint. The torch is then applied to the brass only. Finger stock is made from very thin tempered beryllium copper.

Excessive heat destroys the temper and will ruin the collet. The reflow resin will change the color or the brass, just as it's getting hot enough to melt the solder. Use the smallest diameter solder you can get (0.20- or 0.30-in. diameter). Apply the solder sparingly to the joint behind the torch flame. Use the torch to sweat the solder into the joint and flow it around the joint. Do not disturb the assembly until you are sure that the solder has set. The excessive resin may be cleaned off with lacquer thinner.

The cathode compartment is built in a standard 4- × 6- × 2-inch chassis. The top of the chassis is cut out to allow a removable cover. The cover gives you access to the cathode compartment. The bottom of the chassis is fastened to the bottom plate of the amplifier compartment. The end of the cathode box away from the tube socket is perforated. A solid bottom cover is used on the cathode box. This is done to force cooling air into the cathode compartment through the grid collet, which passes the socket and cools the filament contacts and seals of the tube.

Figs 2 and 3 detail the rings used to hold the cathode collet (EIMAC no. 135306) and filament collet (no. 135307). You will need a lathe to make these rings. The collets are fastened by screws to a G-10 epoxy circuit board, 1/8 in. or thicker. The second filament contact is made with an EIMAC heater pin contact (no. 135310). To make the socket base, a hole for the heater pin is drilled in the center of the circuit board. The filament pin is inserted. The cathode and filament rings assembled with their collets are placed on the 8938. The circuit board is then put on the 8938. It will be held in place by the filament pin, allowing you to align the collet rings.

The cathode line is made from 0.020-in. brass sheet. Its thickness is not critical. The line is soldered to the cathode ring. Be sure not to get the cathode ring mounting holes filled with solder. The cathode line is tuned and loaded by miniature butterfly capacitors, as in the original K2RIW amplifier. The filament ring uses a fifth screw that bottoms into a tapped hole to connect to the filament transformer. This assures a good contact. If you experience any erratic operation or power drift, be sure to check for good filament contacts. The socket assembly is mounted to the chassis by using 1/2-in. metal standoffs.

EIMAC recommends reducing the filament voltage to 4.3 V for average power outputs of a kilowatt or greater at 400 MHz. Amateur SSB and CW operation is only 25% duty cycle. This is true even in the thick of an EME contest, which is probably the most grueling use of the amplifier. In addition, linear operation with heavy loading (the tuning condition under which best linearity usually occurs) minimizes cathode back heating. I found that for the intermittent operation that characterizes CW and SSB amateur operation, 4.7 to 4.8 V was the optimum filament voltage. There should be some resistance in either the primary or secondary circuits of the filament transformer, to allow a soft filament turn on. High input surges when the filament is cold are the primary failure mode of a power tube filament. EIMAC does not specify a minimum warm up time for the 8938. For maximum tube life, especially in light of the reduced filament voltage used with this amplifier, I recommend a minimum filament warm-up time of 3 minutes. If this amplifier is to be used in a more continuous mode, such as FM-repeater service or ATV, a lower filament voltage should be used.

A filament voltage metering circuit is included in the amplifier. A bridge rectifier and filter capacitor creates a dc voltage which can be read by the 1-mA multimeter. R18 and R19 form a simple dropping network to allow the voltage to be set for a full scale of 5.0 V. Pin jacks are also included on the back panel to allow easy double checks with a high accuracy AC voltmeter.

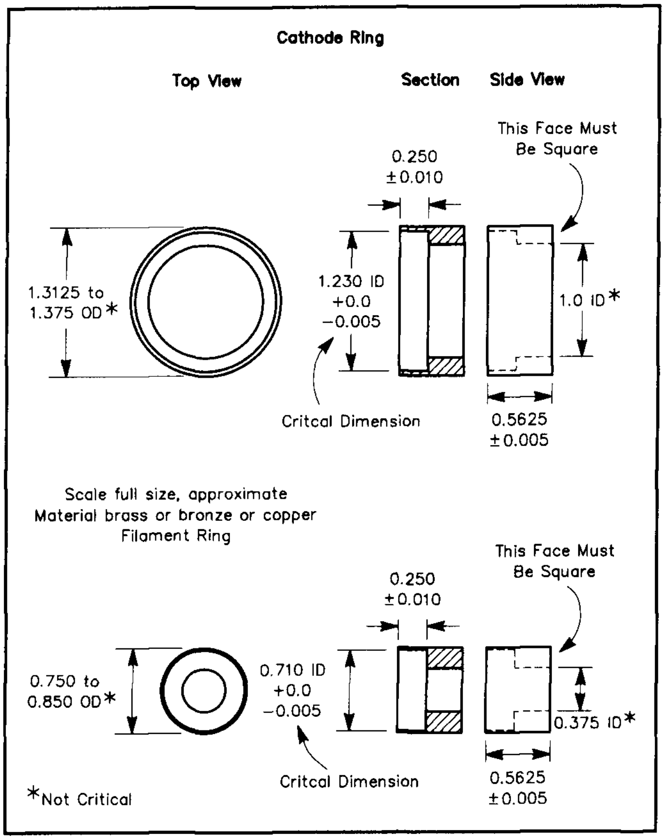


Fig 6—Cathode and Filament rings, made from brass, bronze or copper. Note the critical dimensions given in the drawings.

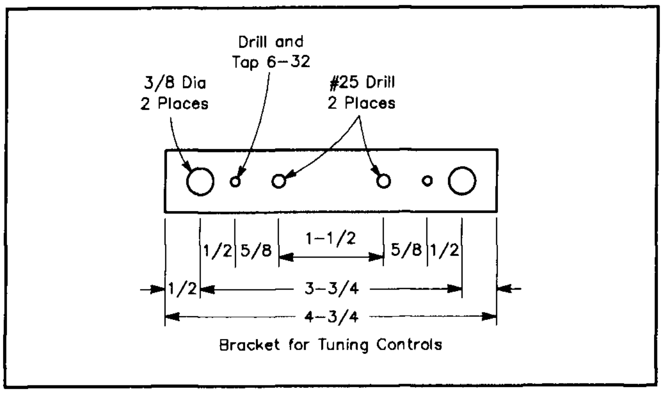


Fig 7—Tuning controls bracket, made from aluminum sheet (thickness not critical).

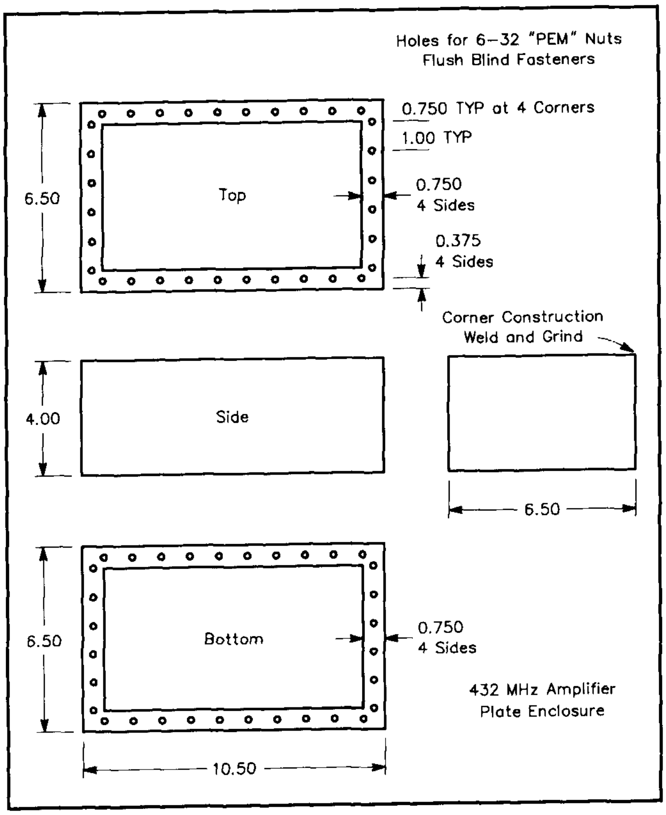


Fig 8—Details of hole drilling and covers for the plate enclosure.

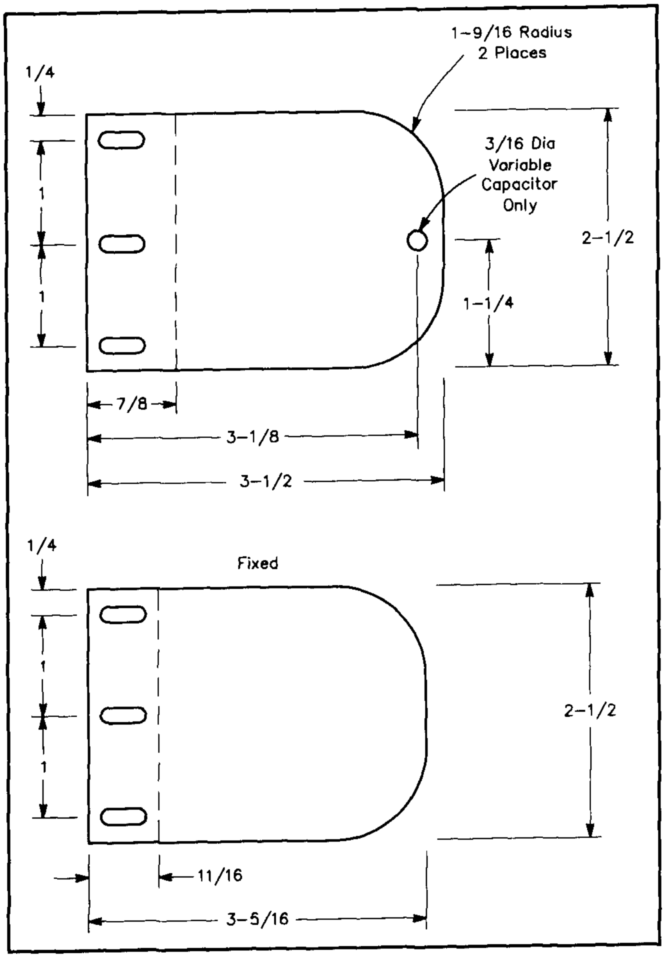


Fig 9—Details of the plate-tuning capacitor. The variable plate (top) is made from spring brass or beryllium copper, 0.010- to 0.015-in. thick, silver plated. The fixed plate (bottom) is made from aluminum or brass, 0.040- to 0.060-in. thick. Do not drill the 3/16-in. mounting hole in the fixed plate.

The high-voltage metering circuit may appear overly complex to some, however, there are a number of reasons why 10 resistors are used in the dropping string. If you're going to measure plate voltage, you might as well build it so it not only reads accurately, but will do so over the life of the amplifier. If you simply want an indication that high voltage is present, a neon lamp will suffice.

Most amateurs do not have an appreciation for the effects of high voltage. I have seen metering circuits where one, two or three resistors were used in the dropping string. This is poor engineering practice for the following reasons: First, all resistors have a maximum allowable voltage drop specification. This is the maximum potential which may be placed across the resistor without ill effects. The ill effects are corona discharge across the resistor. This will show up as noise in a sensitive 432-MHz receiver. A high potential also causes premature aging of the components. Specifically, this accelerates the resistance change all resistors suffer over their life. Second, any excessive voltage across a resistor can lead to catastrophic failure of it and possibly an expensive meter.

When circuit stability is required, good engineering practice calls for a resistor to dissipate less than half its rated value. The resistors in the metering circuit are ½-W units, however, they are only called on to dissipate ¼ W during full plate voltage. The chassis that holds the dropping resistors is perforated on top and bottom, to allow cooling air circulation by convection. Even though the entire resistor string dissipates less than 3 W, that is enough to warm a closed box appreciably. Note also that the dissipation rating of all resistors goes down as the temperature goes up.

The type of resistor selected has a large effect on the long-term accuracy of the circuit. Carbon-composition resistors have the poorest tolerance and greatest resistance change due to both heat and age. Carbon-film types are only somewhat better. Wirewound types are not readily available in the high values required for such a circuit. The only choice was 1%-tolerance military type RN-65 metal-film resistors.

The RN-65 is specified to have ½-W dissipation at 75° C. Most ½-W carbon-composition types are specified at 50° C or lower temperatures. The allowable voltage across an RN-65 resistor is 900 versus 350 for a typical ½-W composition. Proper component selection for something as simple as the plate-voltage meter makes an amplifier much easier to live with during its life.

R15 is used to both keep the B+ metering circuit complete when the multimeter is switched to another position, and to calibrate the meter. The dropping string was purposely selected low (4.99 M versus 5.00 M) to allow for a

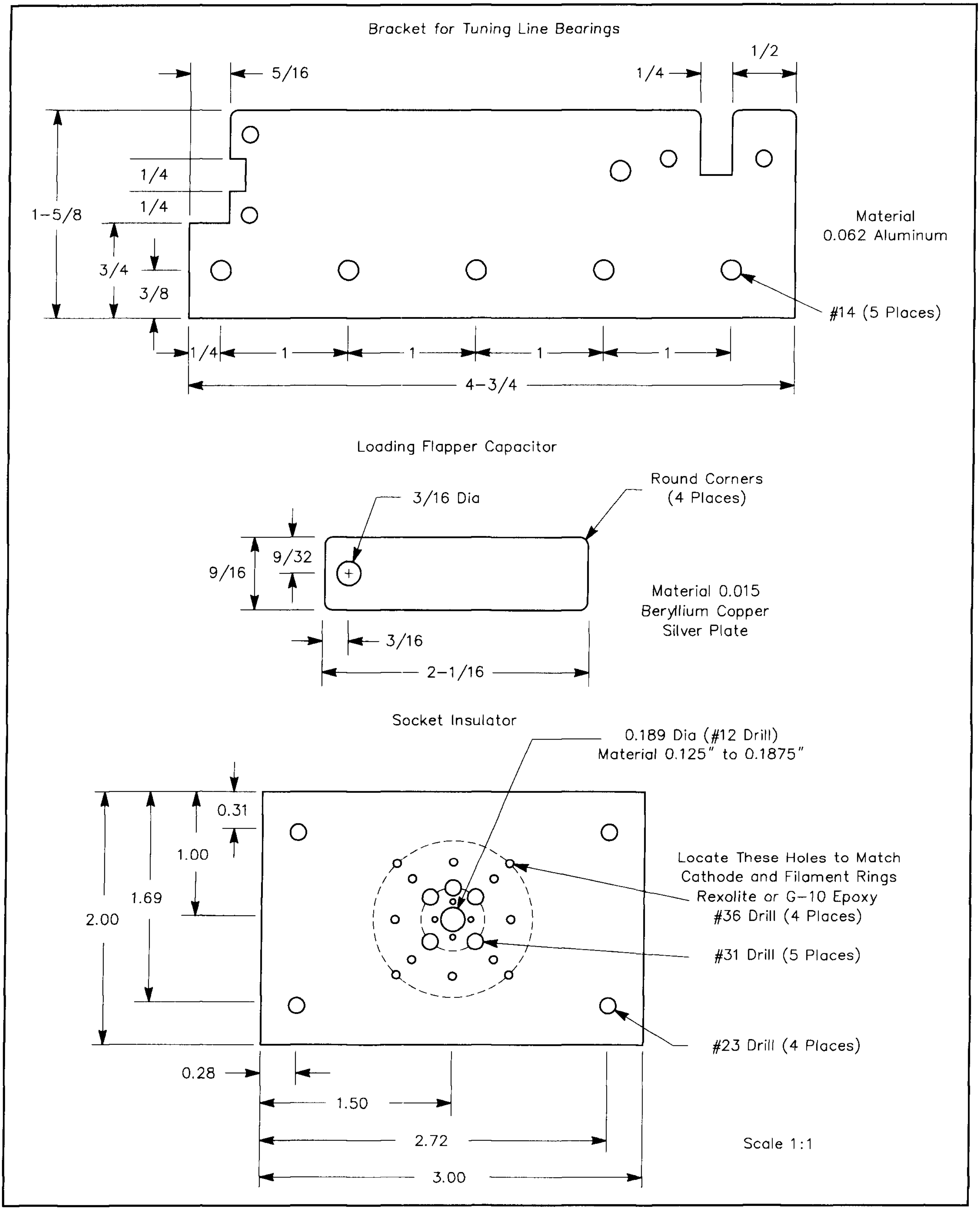


Fig 10—This drawing shows the tuning-line bearings bracket (top), made from 0.062-in. thick aluminum; plate-loading flapper capacitor (center), made from 0.015-in. thick beryllium copper, silver plated; tube socket insulator, made from Rexolite or G-10 epoxy sheet.

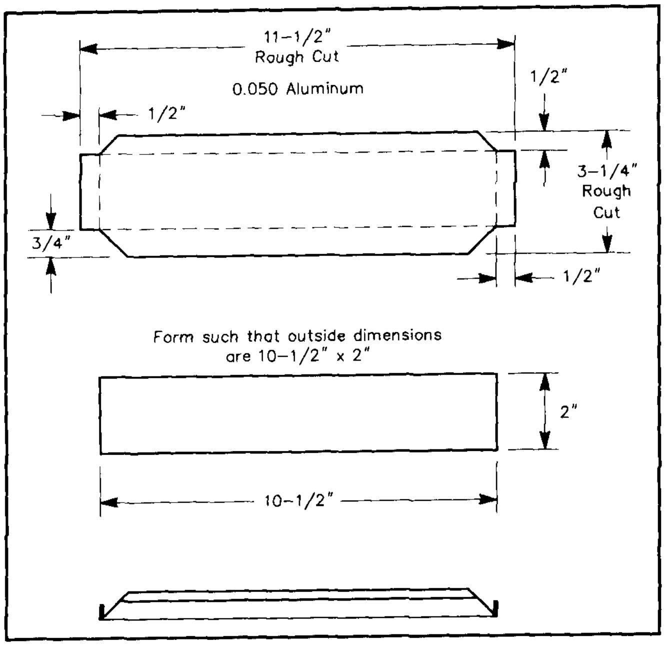


Fig 11—Bottom cover of cathode compartment, made from 0.050-in. aluminum sheet.

calibration adjustment and to generate a voltage that could be used for a high-voltage-present sensing circuit. The 1500-Ω value worked for the multimeter used, which has a 40-Ω internal resistance. Since this resistor is called on to make less than a 5% adjustment to the meter reading, both its initial value and normal aging value changes will have a very small effect on the HV meter accuracy. For example, a 10% change in the resistance of that 1500-Ω calibration resistor will cause a 0.27% change in the meter reading. A value change that small is unreadable on even a very high-quality analog meter movement.

The high-voltage sensing circuit uses a simple switching transistor (Q1) to turn on a relay (K1). The plate-voltage meter dropping string provides the required turn-on voltage to the base of Q1. With the 4.7-kΩ resistor used (R16), the sensing relay pulls in at about 1900 V when high voltage is applied, and drops out at about 1200 V when plate voltage is lost. The voltage at which the relay pulls in can be changed by adjusting R16. To raise the pull-in voltage, increase R16. A quick and sure way to blow a very expensive 8938 is to apply full drive without plate voltage present. The grid will be asked to draw a destructive amount of current during absence of plate voltage. This sensing circuit becomes a cheap piece of insurance. I use this circuit to open a relay in the IF drive to my transverter. With this arrangement I feel secure, even during unattended operation.

Plate voltage is fed from the power supply via RG-59 coax and MHV high-voltage connectors. Coaxial cable is highly recommended in the interest of safety. RG-59 should be capable of withstanding 5500 V dc. The MHV connectors are rated at 5000 V. They provide a ground connection that must be made before the center pin makes contact. One of the worst possible situations is to lose the ground connection between the amplifier and power supply and still have the high voltage connected. The use of MHV connectors prevent this from occurring.

The HV power supply should have a 25-Ω, 50-W resistor in series with the B+ line. This resistor absorbs the energy stored in the filter capacitor in the event of an arc. Chances are pretty good that you will experience arcing when you fire up your 8938. All new tubes go through a process where particles left over from the manufacturing process are burned off or collected to the walls of the tube. A tube such as the 8938 requires relatively close grid-to-plate spacing to make it efficient at 432 MHz. When one of these particles gets between the grid and plate an arc results. In this amplifier, the grid is at ground. The arc has the effect of discharging your 3000-V supply through the grid. The results can be catastrophic. I know of at least one operator who lost his brand new 8938 this way. When a tube suffers any sort of shock, which may happen when the tube or amplifier is moved or shipped, some of the particles can break loose and again induce arcs. Gradually this particle-induced arcing subsides. Even after initial burn in, this resistor protects against RF-induced dc arcs from the plate line, which can easily happen if you forget to connect your antenna. This high-voltage protection resistor has the additional benefits of operator safety and component protection for items such as the meters. In the event of an arc it minimizes the tendency for the B− line to go below ground potential, which is both a safety hazard and potentially destructive to components in the metering and cathode-bias circuit.

When firing up the amplifier for the first time, it is a good idea to add a 50-Ω, 100-W resistor in series with the plate-voltage supply. This resistor gives additional protection against arcing. It is also a good practice when firing up a brand new tube to let the amplifier sit with the filament and plate voltage on for a half hour, to collect any stray particles in the tube that may have broken loose in transit, *before* applying drive. If you have closely followed the dimensions given for the amplifier, the following initial tuning capacitor setting will set the amplifier very close to optimum tuning at 1500-W output with 3300 plate volts under load. If you are using a different plate voltage, different loading and tuning capacitor settings will be required.

- Input tuning and loading, plates approximately half meshed.
- Loading capacitor edge away from the output connector about 1⁵⁄₁₆ in. above the bottom of the plate compartment.
- Variable plate-tuning capacitor free edge 1³⁄₁₆ in. above the bottom of the plate box.
- Fixed plate tuning capacitor: far edge ¾ in. above the top of the plate line.

Once the filament and plate voltages are verified, short R3 and let the amplifier idle. Idling current should be 100-150 mA if your plate voltage is over 3000 V. If you are unsure of operation it might be wise to initially tune up at reduced voltage. I have a 2000-V tap on my plate transformer for that purpose. Next, apply enough drive to get 200 mA or so of plate current. Quickly adjust the input tuning controls for a peak in plate current, reducing drive if necessary to keep plate current within reason. You don't have to be critical, as the input controls will have to be readjusted under full power. Then start adjusting the plate tuning and loading controls for maximum efficiency, gradually increasing drive power.

When you are near the 1500-W output level, put a directional wattmeter in the input circuit and adjust the input tuning and loading for best SWR at full drive. You should easily be able to adjust the input for under 1.2:1 SWR. For those using Bird 43 wattmeters, at 72-W forward on a 100-W slug you should barely be able to see the needle move off the zero mark in the reflected position. Once the input circuit is adjusted, it should never have to be touched unless the tube is replaced or the amplifier is disturbed. You can now go back and repeak the plate controls for best efficiency. If the grid current is high (above 30 to 40 mA) you have too little loading or plate tuning capacitance. If the grid current is near zero or negative, the amplifier is over loaded. On 2 different amplifiers and 2 different tubes, best efficiency was obtained when the indicated grid current was 10 to 20 mA. You will probably have to spend some time trying slightly different loading and tuning combinations before you find the best efficiency point. This should also correspond very closely to the plate current dip as the plate-tune capacitor is moved through its range. If you are in doubt, remember it is safer both in terms of linearity and stress on the tube (back heating) to over load than under load.

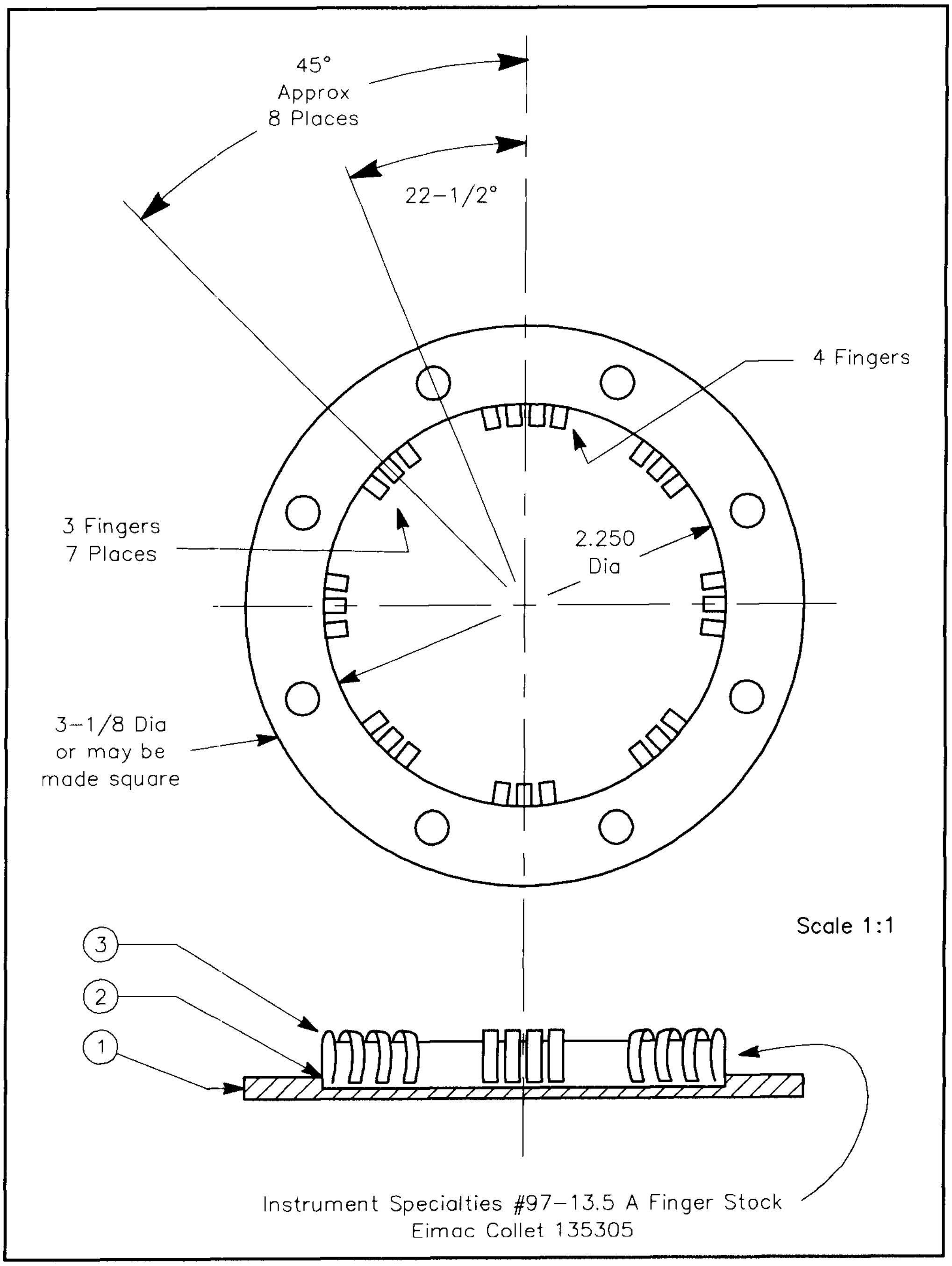


Fig 12—The tube socket finger stock or Eimac collet must be modified before installation. Remove fingers as shown.

Performance of the amplifier has met all expectations. Operation at 432 MHz is completely stable. From a cold start the amplifier, with full drive applied, will come up to 1500 watts output within a few seconds. After this it will hit 1500 watts instantly every time the key is hit. The amplifier has been tested running 1500-W output continuously for over two hours with negligible power drift observed. The amplifier has survived several EME contests (25 hours each of slow-speed CW in 2.5-minute transmissions) and many VHF/UHF contests without a hiccup. The most worrisome part of its operation is how the coax connectors and cable will hold up. RG-213 coax gets very hot and the dielectric will melt with 1500-W power continuously flowing through it. Even RG-331 (½-in. alumifoam) gets warm to the touch during extended CW operation.

There have been many stories floating about telling tales of blown Type-N connectors at high power levels. I have never blown a properly assembled Type-N connector. Type-N connectors were in line during the 2-hour continuous running test also. The connectors are noticeably cooler than the cables which they are connected to during normal operation. I have blown two Type-N connectors on cables I inherited from somewhere. Disassembly of both after the failure revealed poor shield attachment to the connector. My antennas are always tuned for a low SWR (under 1.2:1)

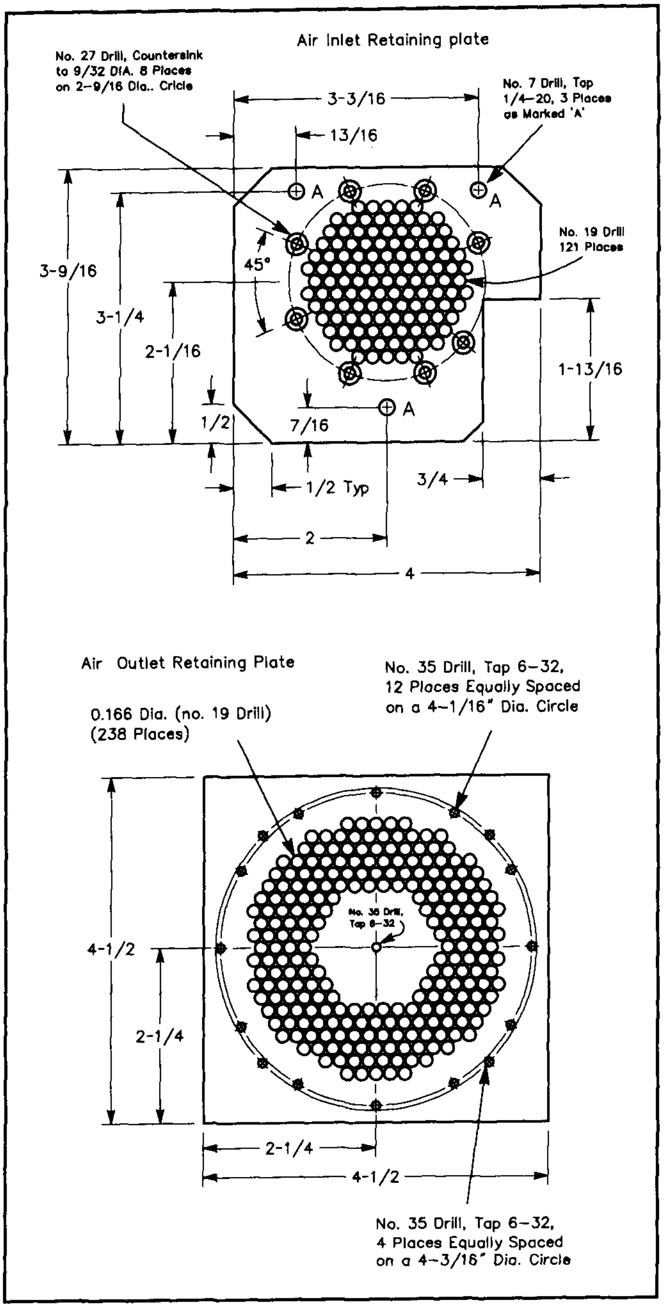


Fig 13—Air inlet retaining plate (top) and air outlet retaining plate (bottom). If you use a blower other than the unit specified in the parts list, you may have to modify the hole locations and sizes shown on the drawing. Make the plates from 0.125- to 0.250-in. aluminum.

and I do not operate the amplifier at full power if the SWR rises above 2:1 for any reason.

Relays become another problem at this power level. I have found that the Transco D type are not suitable for this power level, even intermittently. There is a high-power D type, the DX, but I have not been fortunate enough to obtain any. The Transco Y type has been used without any problems but I have never run continuous power through one for more than a couple of minutes at a time. Dow Key type 60 and 260 relays have been used without any problems, but they do put an impedance bump in the line, as they are not 50-Ω impedance devices. The higher power Amphenol relays (with Type-N connectors) have also been used without problems. There are probably several other relays that can be used. With several companies making copies of some of the various Transco and Amphenol relays, there should be an adequate selection. One of the main causes of relay failure is contact bounce. You may have a system that will work correctly 999 out of 1000 times. With a 1500-W amplifier all you need is that 1 out of 1000 times to put full power to a not-quite seated contact. I highly recommend that you use a delay sequencer that gives the transmit-receive coax relay a minimum or 60 to 80 ms, to be certain it is switched and seated before output power can be obtained.

Specific operating parameters at the 1500-W output level are:

Plate Voltage: 3250 V full load
Plate Current: 880 mA
Idle Current: 75 mA (at 350 W)
Grid Current: 12 mA
Input Power: 2860 W
Power Output: 1500 W
Efficiency: 52.4% (apparent, including drive feedthrough)
Drive Power: 72 W typical, 60 W-85 W depending on tube
Input SWR: 1.14:1
Power Gain: 13.2 dB typical
Bias voltage: 25.2 V

When measuring the performance of an amplifier such as this one, be certain that your measurements are meaningful. I have heard numerous impossible performance claims for various amplifiers. Specifically, the SWR of your test load must be very low. All throughline-type power meters are confused by reflected power. Even Bird wattmeters have limited directivity. When using a load with even moderate SWR (1.5:1), you can obtain several different readings by changing the length of the feed line. Harmonic energy confuses the watt-meter and, in general, makes it read higher than it should. Be sure that your plate-current and plate-voltage meters are really accurate. The approximate efficiency was also checked by measuring the temperature rise of the exhaust air. This measurement indicated that the efficiency of the amplifier may be slightly better than the 52.4% figure that was measured on an inline wattmeter.

If you do not have 3300 V or greater plate voltage available, 1500-W output power can still be obtained from the amplifier. In intermittent keyed CW or SSB service the 8938 can safely handle 1.2-A plate current. At a lower plate voltage, the apparent efficiency of the amplifier is greater, due to the higher drive power required to run 1500-W output. In no case should the 8939 be run at greater than 1.35-A cathode current. Higher cathode currents can cause catastrophic failure of the tube. This failure will occur as the oxide coating on the cathode literally boils off. The cathode current is the sum of the plate and grid currents. The grid current is somewhat unpredictable at 432 MHz, due to transit time and secondary emission effects which may give negative grid current indications if the amplifier is over loaded. To be safe, assume that grid current is 7 to 10% of the plate current no matter what the grid meter indicates.

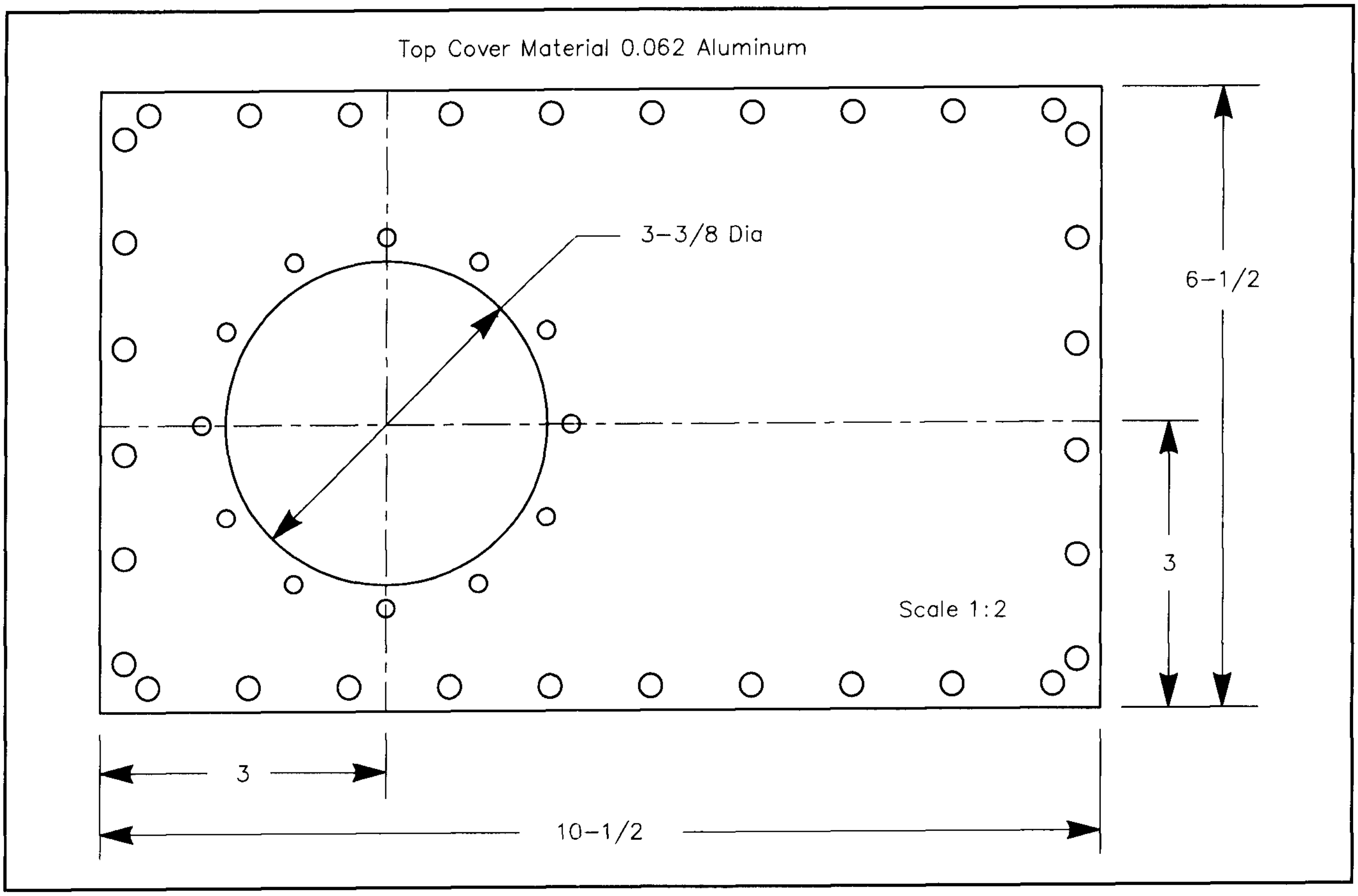


Fig 14—Dimensions of the top cover, made from 0.062-in. aluminum sheet. Note that this drawing is not to scale.

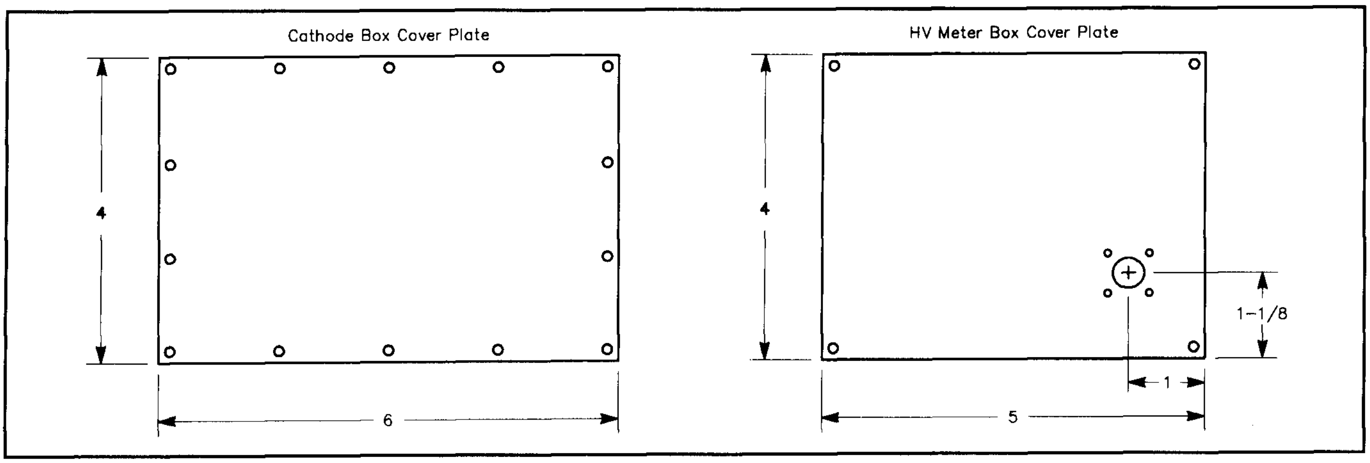


Fig 15—Dimensions and hole-drilling information for the cathode box cover (top) and he HV-meter resistor box cover (bottom).

With a little extra thought in planning and construction, a high-power amplifier can be a pleasant addition to your 432-MHz station. Don't settle for less than an amplifier which is highly linear, easy to tune, stable, reliable and safe, no matter what the power output level.

Notes

[1]J. Chambers, W. Orr, "2-kW PEP Amplifier for 432 MHz," *Ham Radio*, Sep 1968, pp 6-12. Also published as *Amateur Service Newsletter AS-25-1* (San Carlos, CA: EIMAC).

[2]Knadle, R, "High Efficiency Parallel Kilowatt Amplifier for 432 MHz," *Part 1*: *QST*, Apr 1972, pp 49-55; *Part 2*: *QST*, May 1972, pp 59-62, 79. Construction information also appears in *Radio Amateur's VHF Manual*, third edition, pp 299-304 (Newington: ARRL, 1972).

[3]S. Powlishen, "A Grounded-Grid Kilowatt Amplifier for 432 MHz," *QST*, Oct 1979, pp 11-14. Construction information also appears in *The ARRL Handbook for Radio Amateurs*, for the years 1981 through 1986.

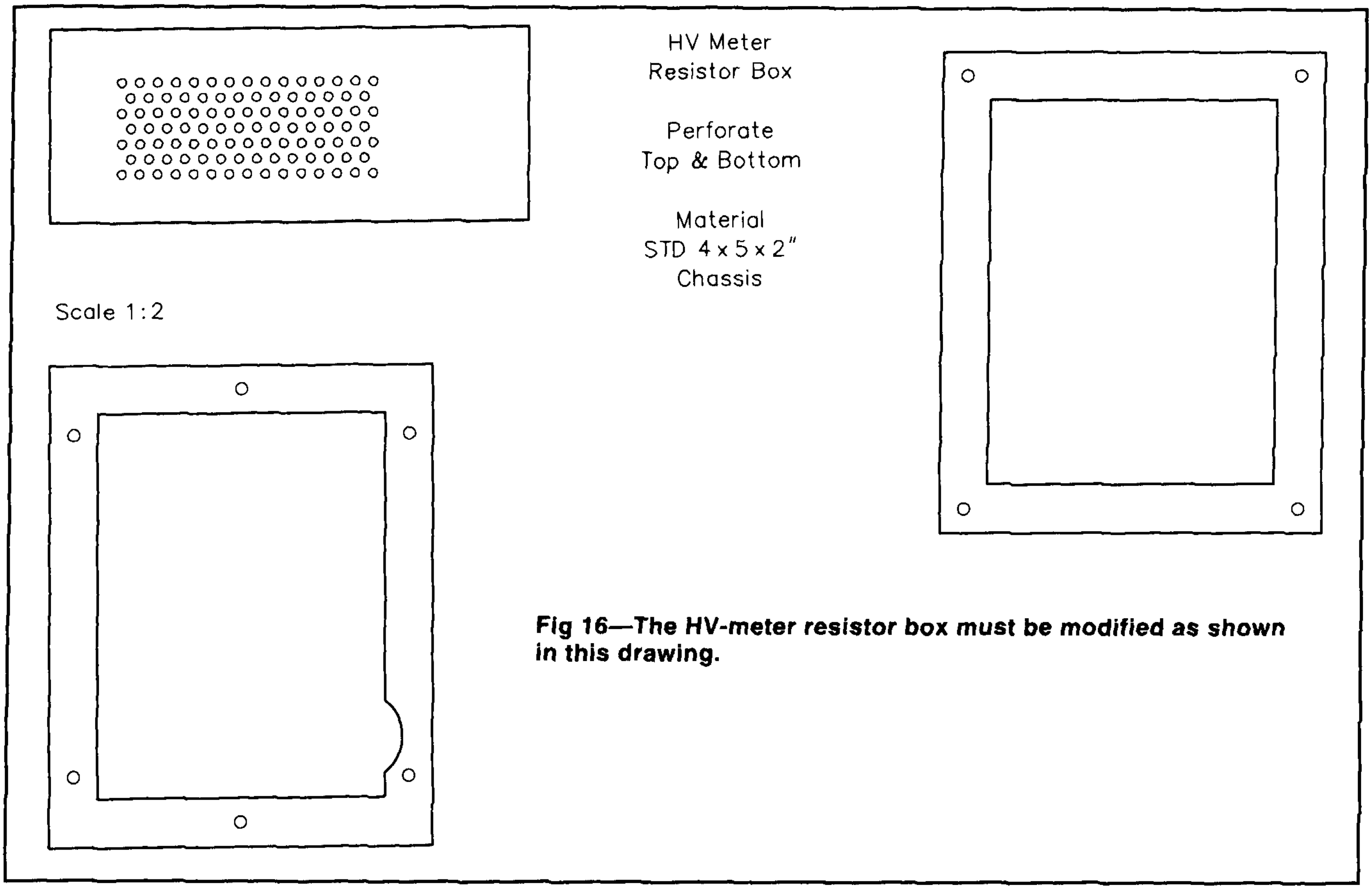


Fig 16—The HV-meter resistor box must be modified as shown in this drawing.

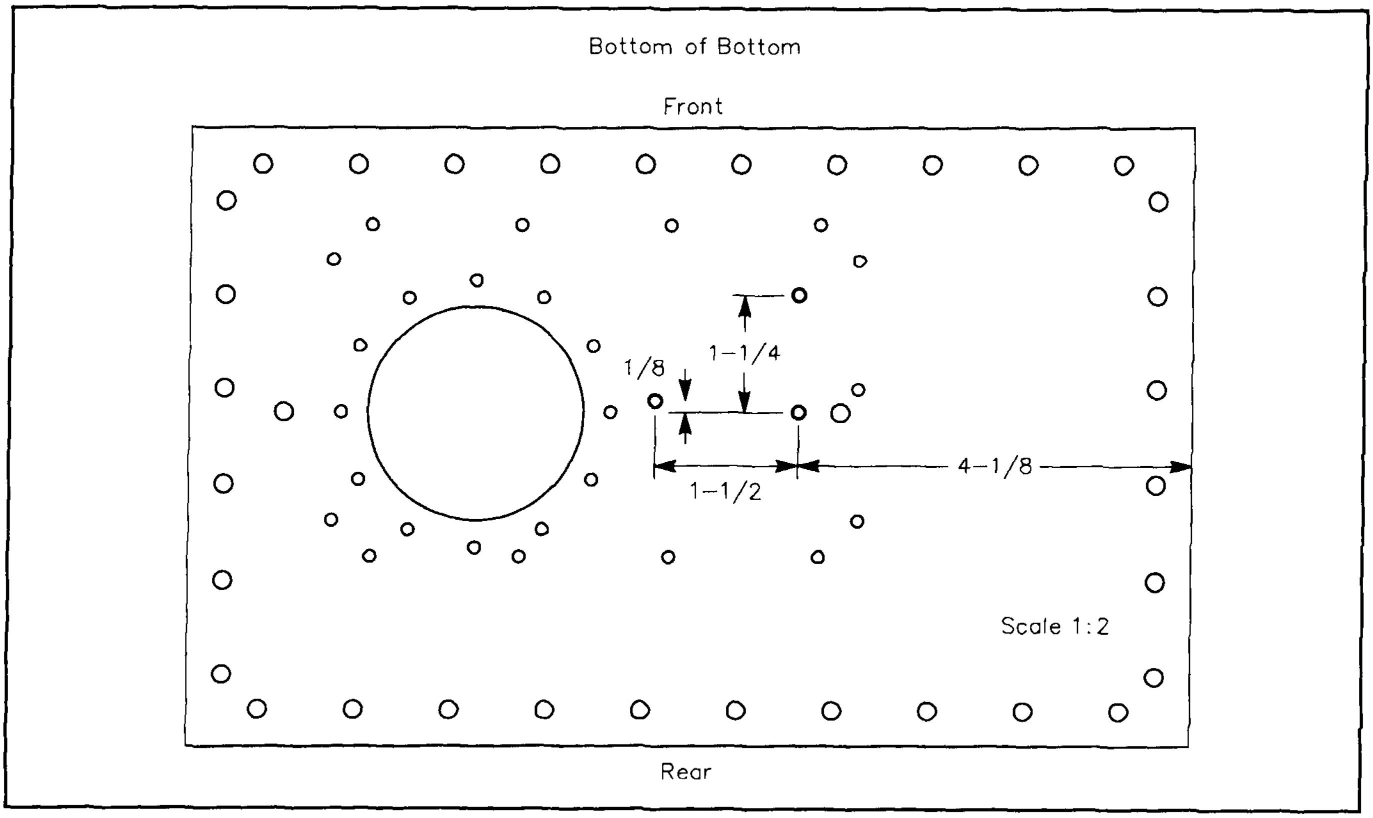


Fig 17—Bottom view of the bottom cover of the amplifier enclosure, made from aluminum sheet (thickness not critical).

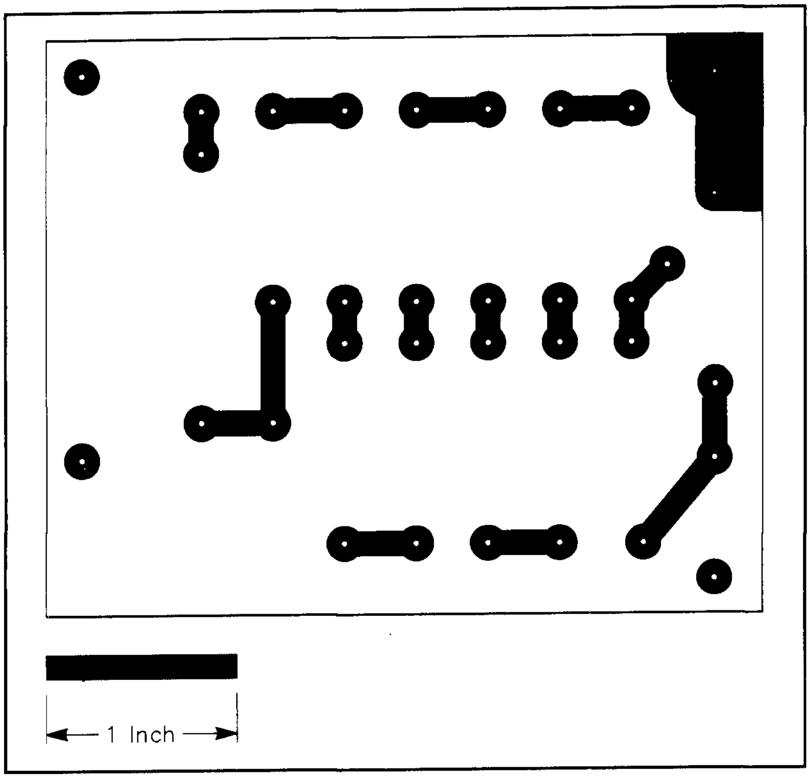


Fig 18—Foil side of the HV-meter resistor circuit board.

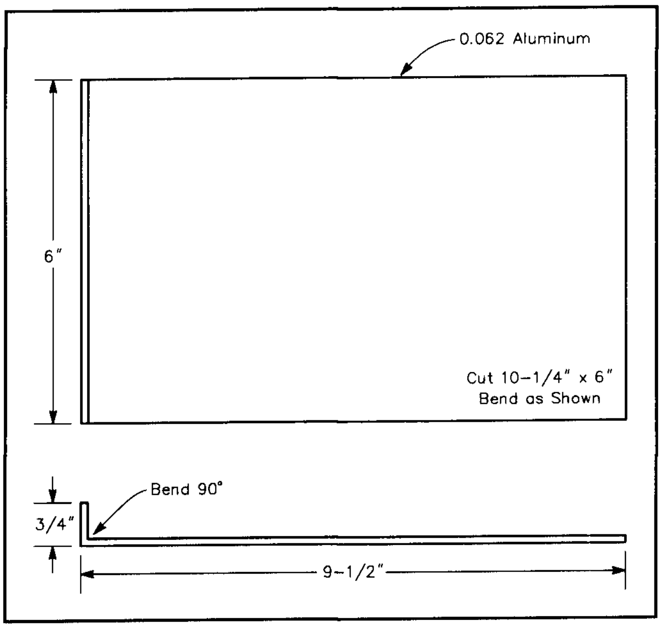
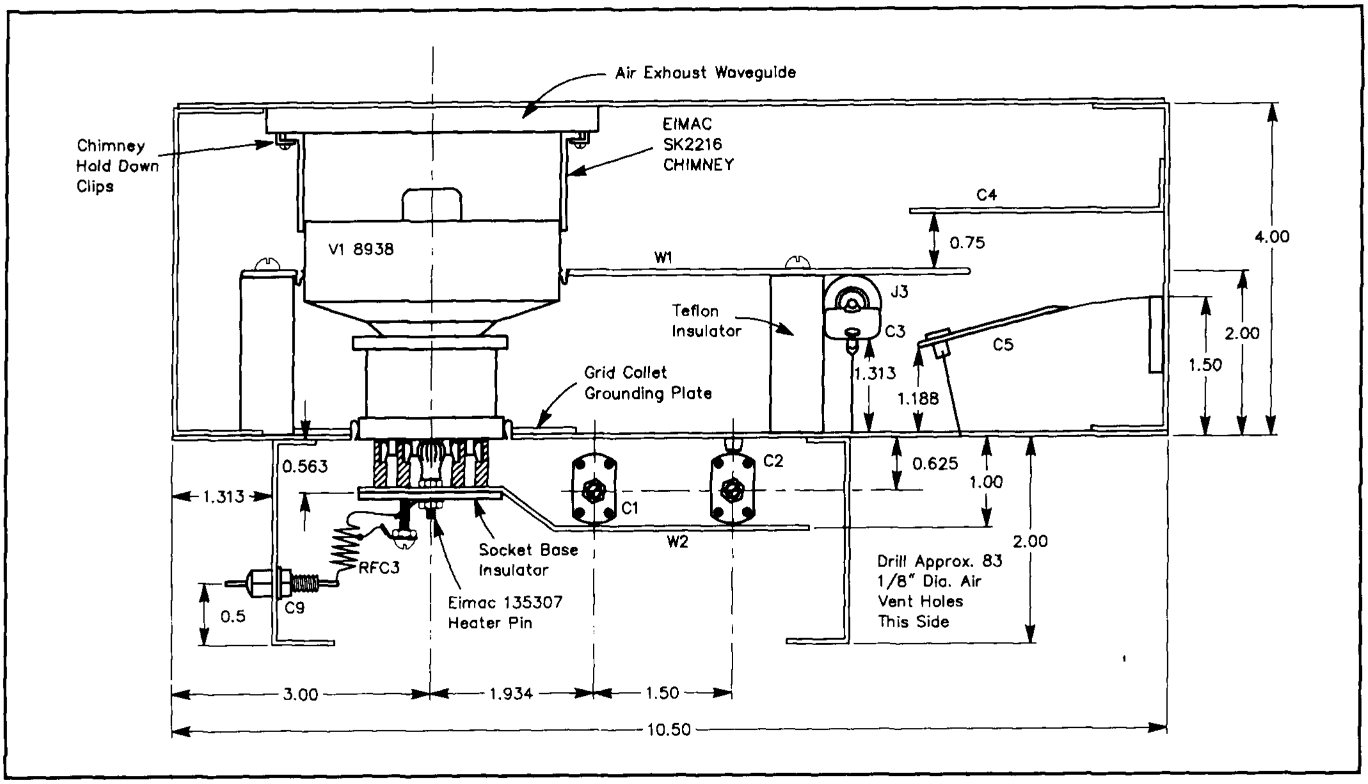
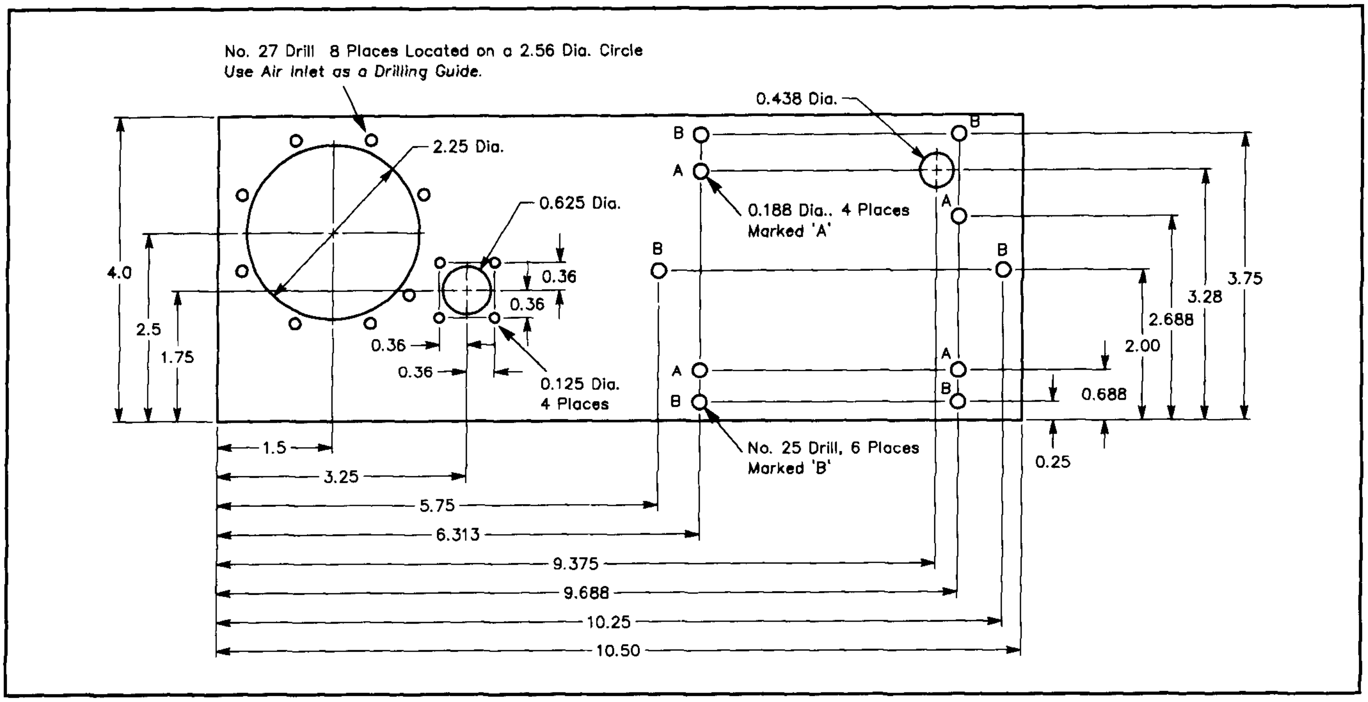
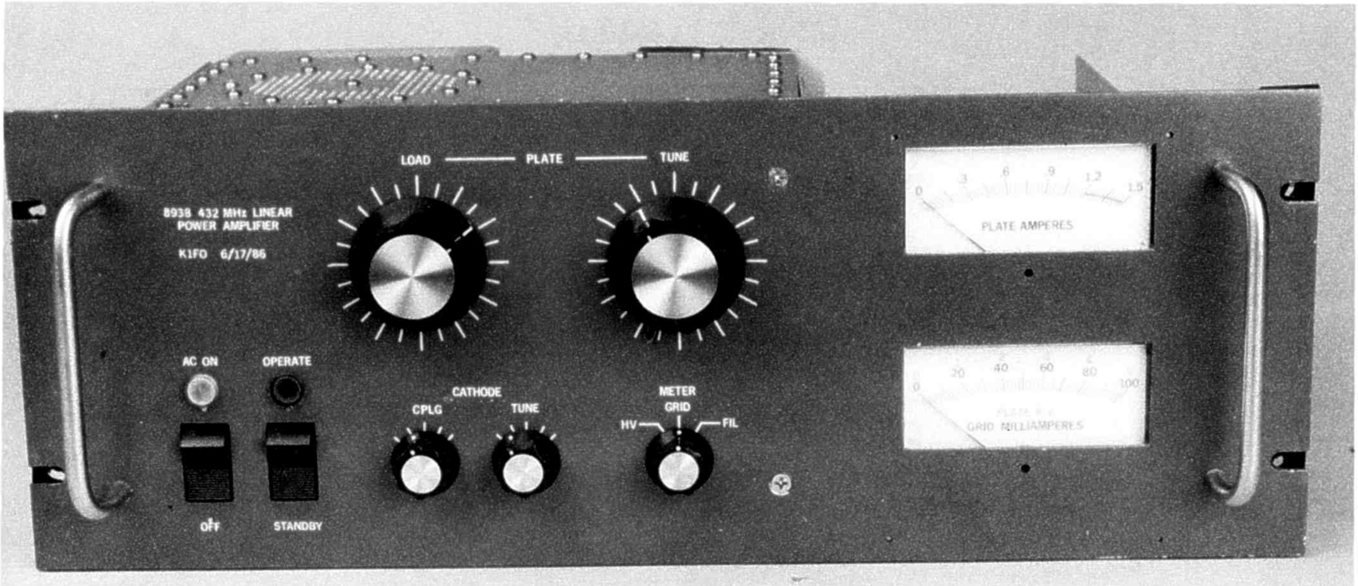


Fig 19—Details of the brackets used to mount the amplifier to the rack panel. Two are required.


Air Exhaust Waveguide
Chimney Hold Down Clips
EIMAC SK2216 CHIMNEY
C4
0.75
4.00
V1 8938
W1
J3
Teflon Insulator
C3
C5
2.00
1.50
Grid Collet Grounding Plate
1.313
1.188
0.563
0.625
C2
1.00
1.313
C1
W2
Socket Base Insulator
2.00
RFC3
Drill Approx. 83 1/8" Dia. Air Vent Holes This Side
0.5
C9
Eimac 135307 Heater Pin
3.00
1.934
1.50
10.50


No. 27 Drill 8 Places Located on a 2.56 Dia. Circle
Use Air Inlet as a Drilling Guide.
0.438 Dia.
2.25 Dia.
0.188 Dia., 4 Places Marked 'A'
0.625 Dia.
4.0
2.5
1.75
0.36
0.36
0.36
0.36
0.125 Dia. 4 Places
3.75
3.28
2.688
2.00
0.688
0.25
No. 25 Drill, 6 Places Marked 'B'
1.5
3.25
5.75
6.313
9.375
9.688
10.25
10.50



The 1500-W amplifier makes a compact, easy to use package.

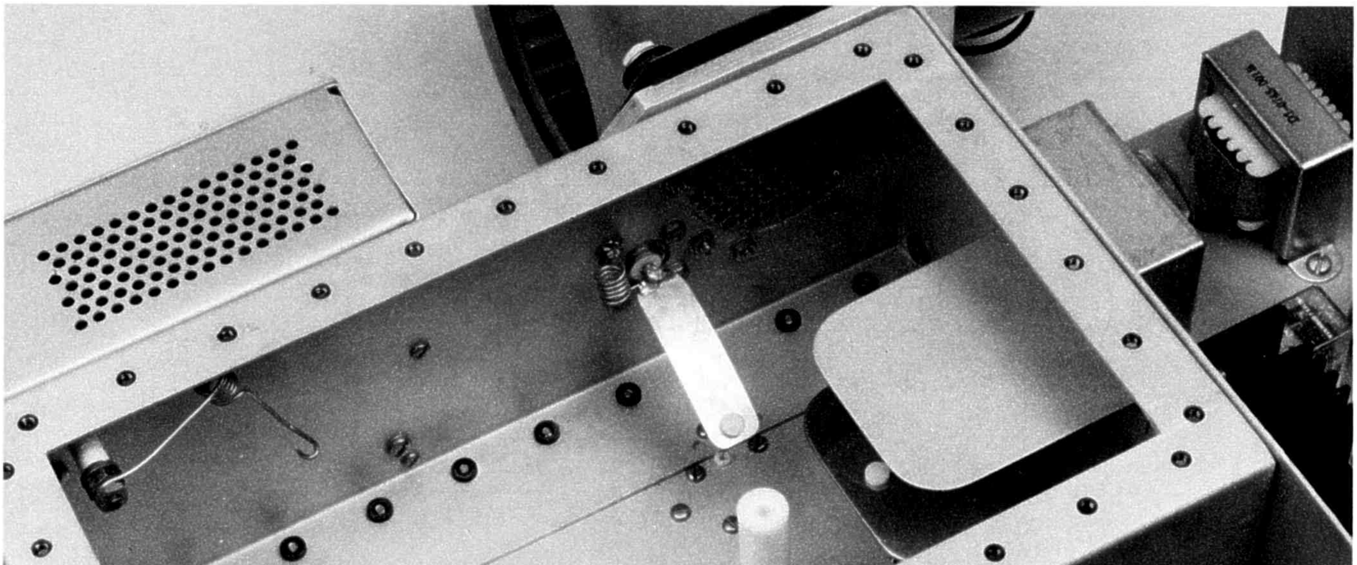
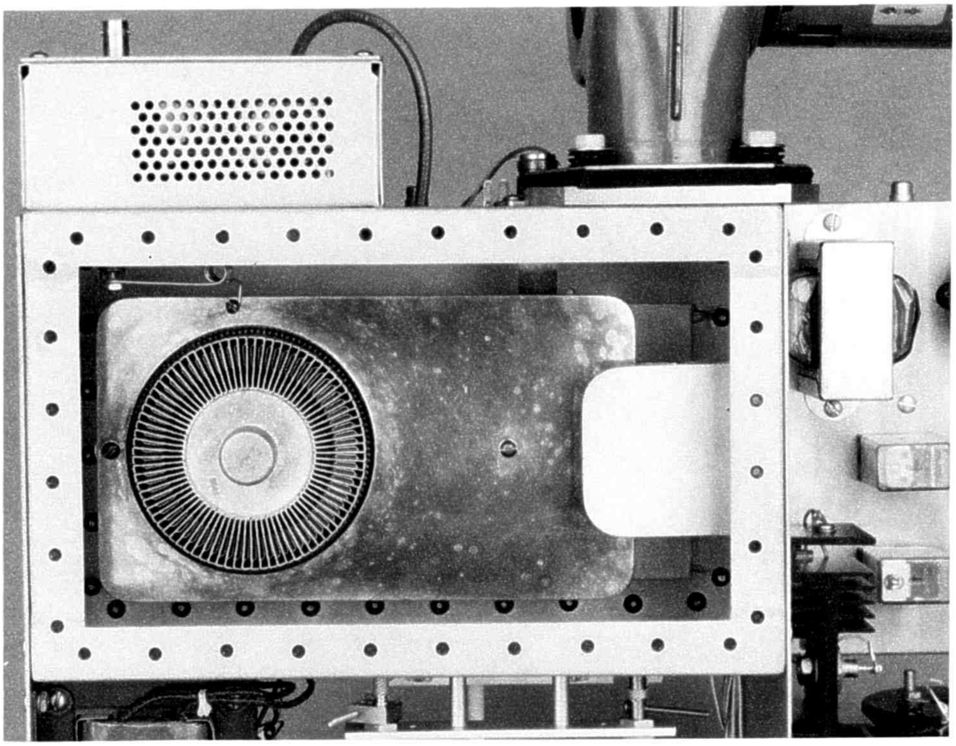
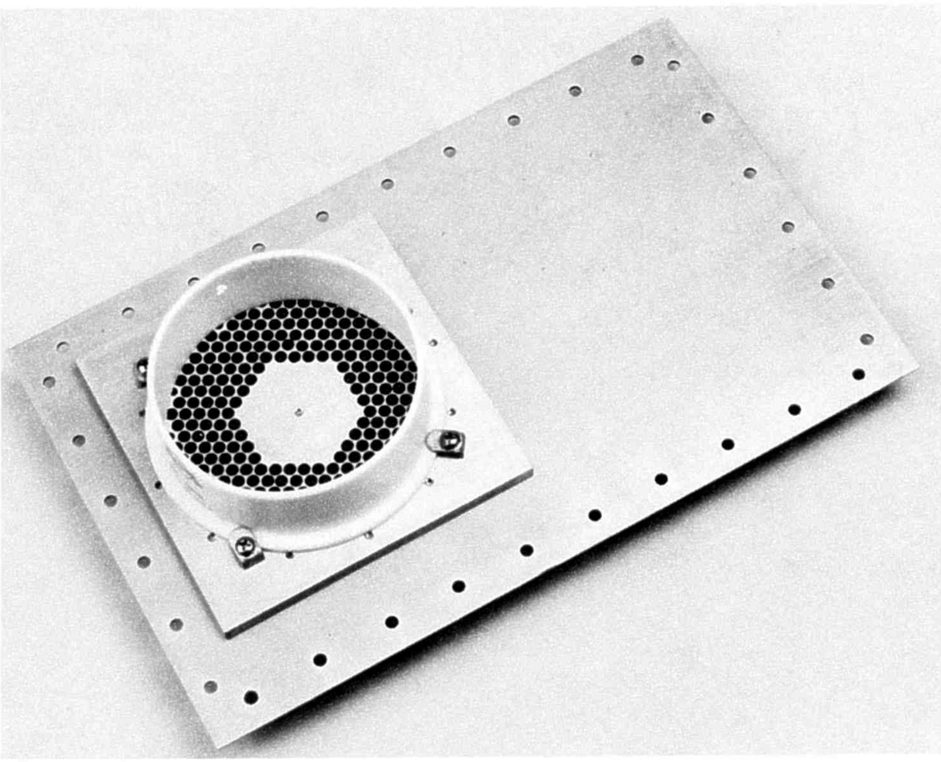


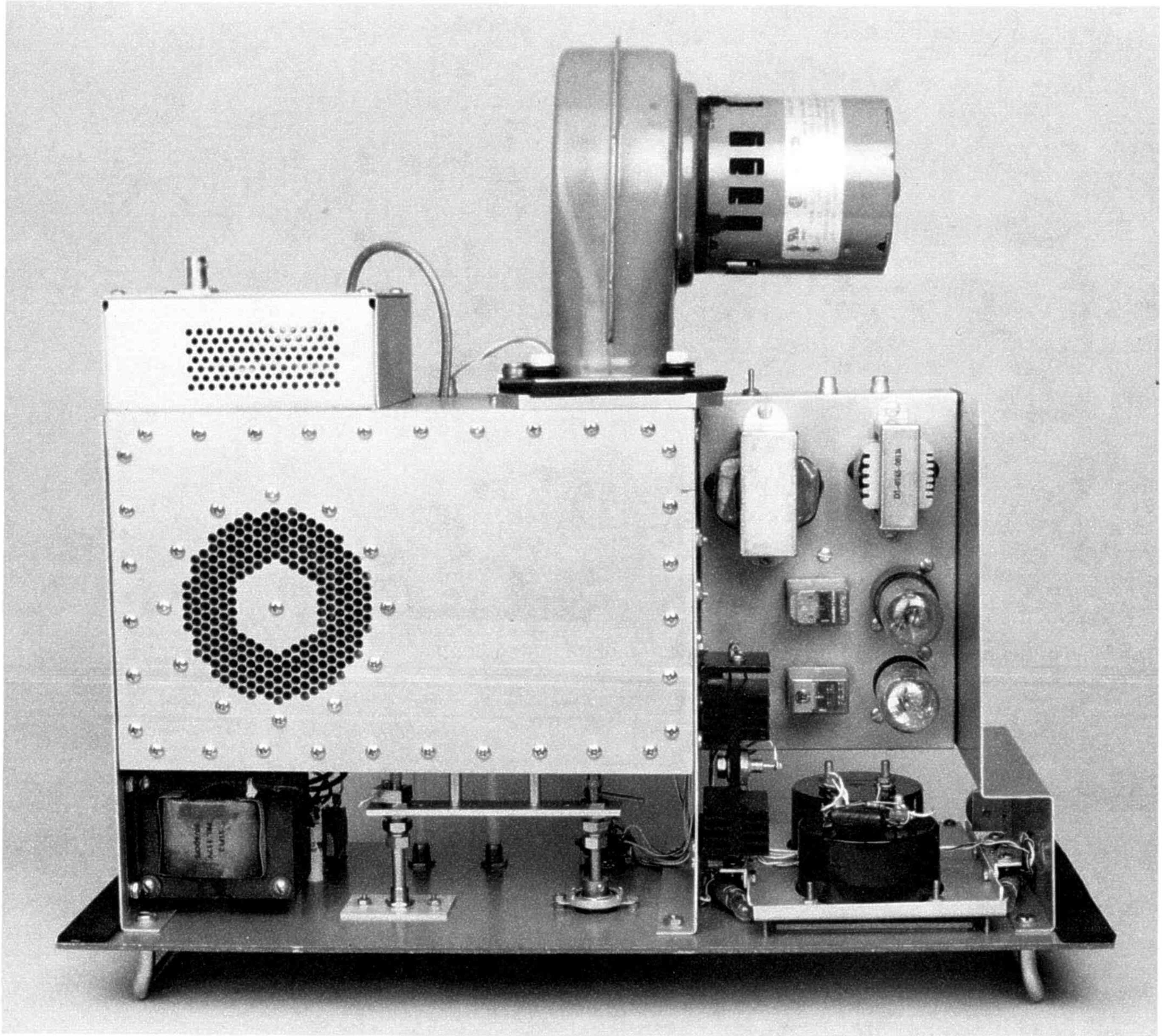
Plate compartment with plate line and tube removed. The large plates are the tuning capacitor; the small strip at top center is the ouput loading capacitor. The standoff supports the plate line.



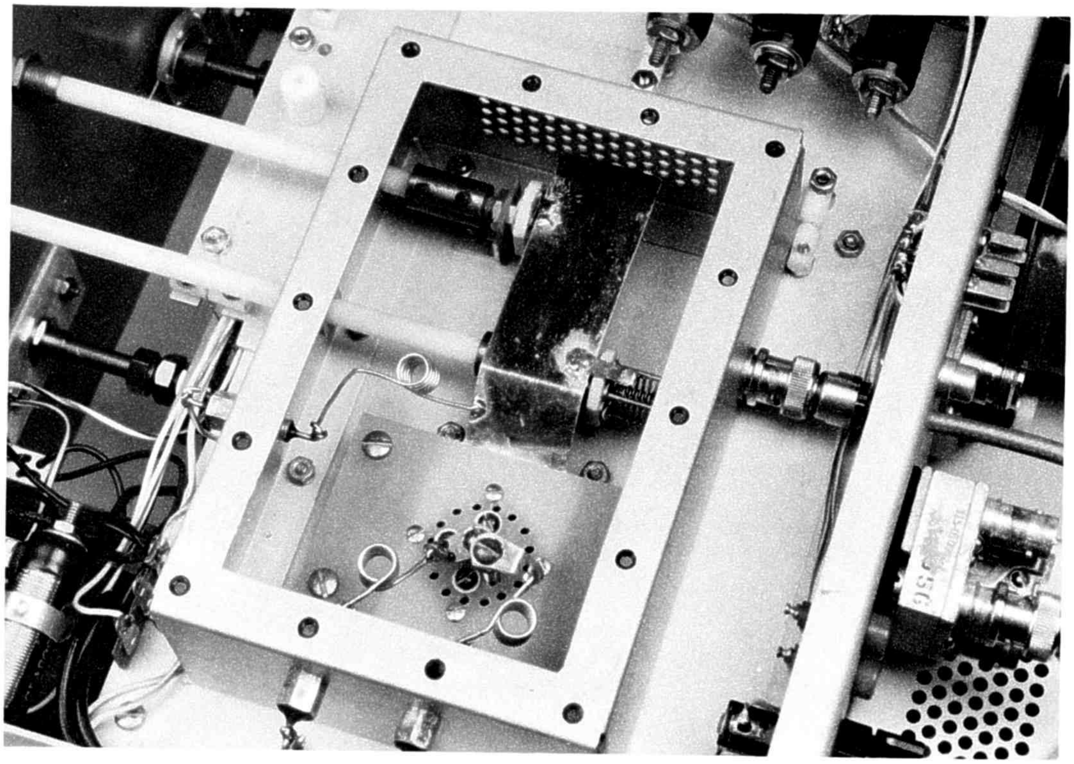
Top view of the amplifier, showing the plate line and plate tuning flopper.



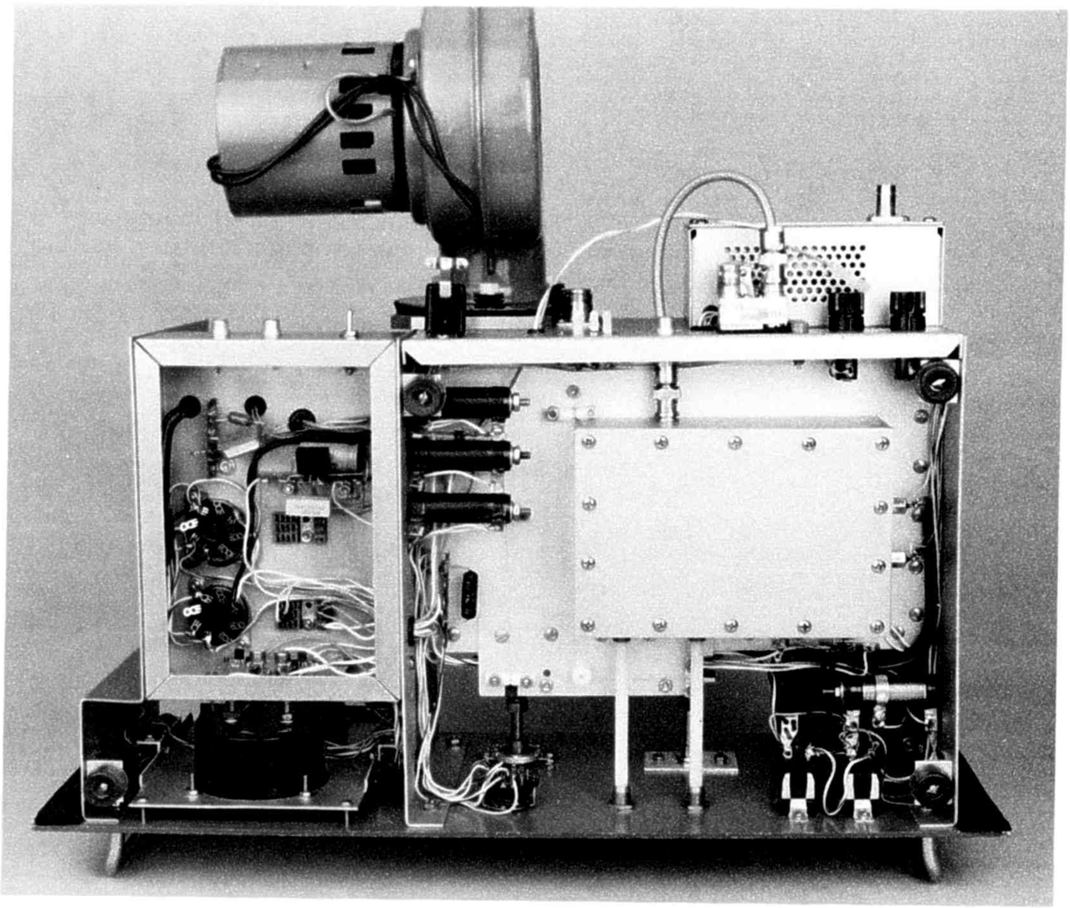
Top corner of the plate compartment showing the chimney and an outlet RF shield.



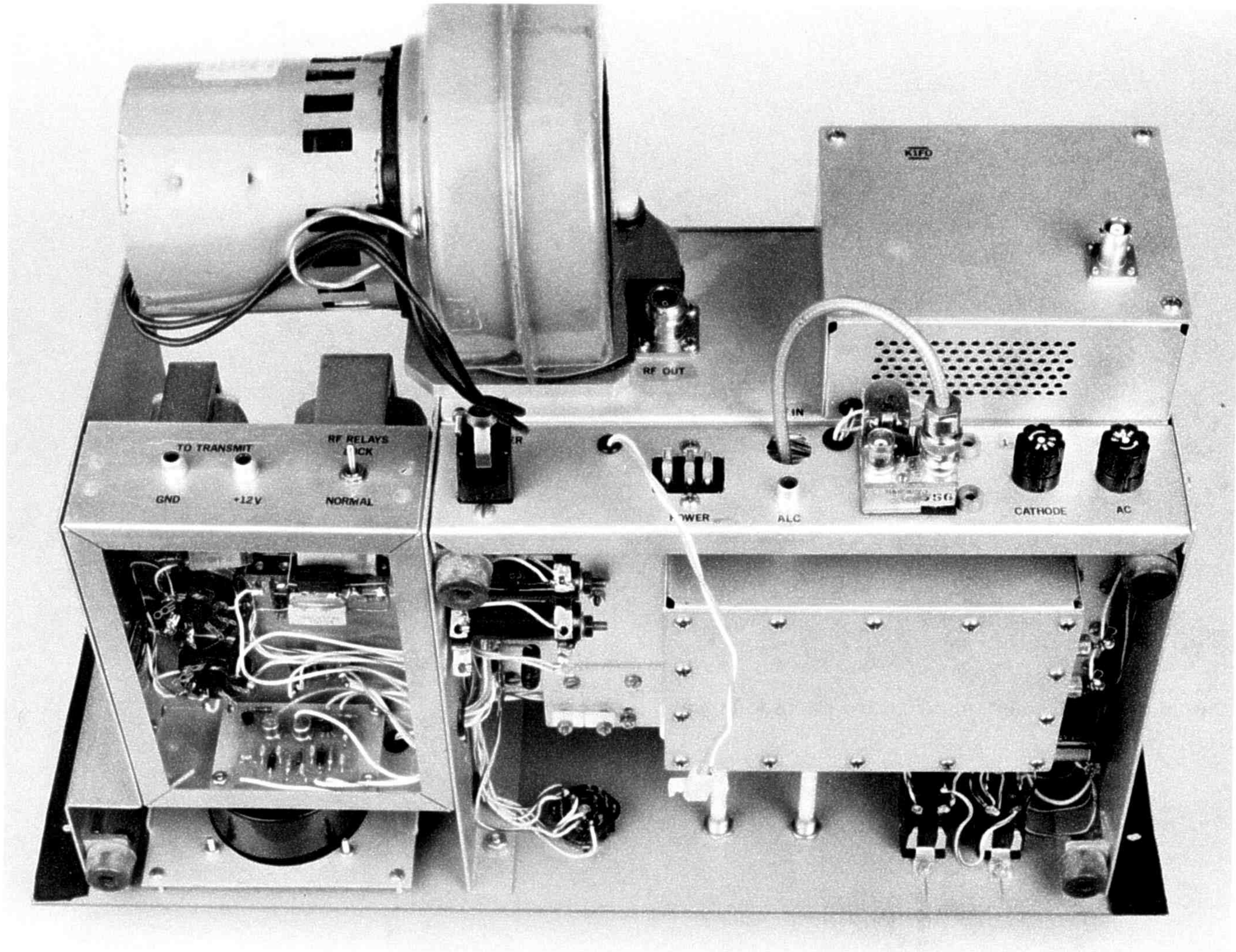
Top view of the amplifier with plate compartment cover in place.



Cathode compartment, showing the cathode line and tuning controls.



Underside view of the 8938 amplifier, with the cathode-compartment cover in place.



Rear view. The RF-input relay is mounted on the main chassis, to the left of the fuse holders. RF input to the amplifier is by the cable routed through the chassis to a connector on the cathode compartment. The connector on the subchassis above the relay carries high voltage.

A 1296-MHz Linear Power Amplifier

By Bill Olson, W3HQT

The linear amplifier shown in Fig 1 uses a Mitsubishi power amplifier module and a handful of other components to deliver up to 3 watts output from 1240 to 1300 MHz.

The M67715 module has 50-ohm input and output impedances. No impedance-matching networks are used, and no alignment is required. An input signal of 10 mW (10 dBm) will result in about 3 watts output. The M67715 is fairly rugged; Mitsubishi specifies it will tolerate an output SWR of 20:1.

Fig 2 is the schematic diagram of the amplifier. The module requires two positive supply voltages and a regulated bias supply. The higher supply voltage (V_{cc2}) can be up to 16 V dc, but the lower voltage (V_{cc1}) cannot exceed 9 V dc. A 7809 three-terminal regulator connected to the V_{cc2} supply provides the 9-volt V_{cc1} and bias voltages. Chip capacitors are used to bypass the V_{cc} and bias terminals directly at the module. Fig 3 shows an inside view of the amplifier.

U1 and U2 are fastened directly to a piece of 2-in. aluminum channel, which is in turn attached to a heat sink. Mitsubishi specifies a total efficiency of about 25% for this

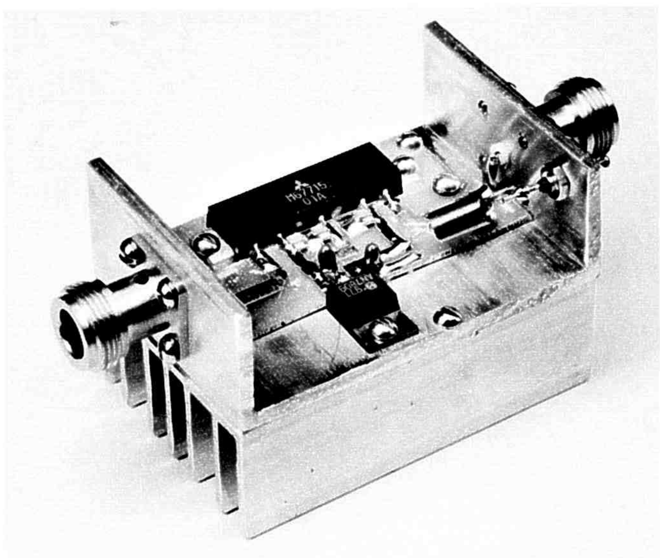


Fig 1—A simple but rugged 1296-MHz linear power amplifier.

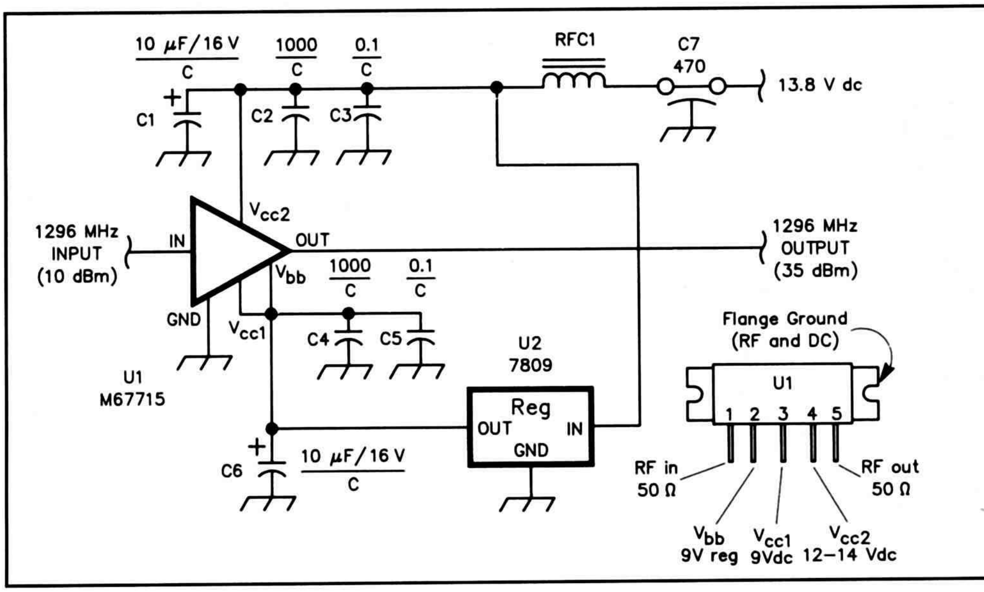


Fig 2—Schematic of the 1296-MHz linear power amplifier.

C1, C6—10-µF, 16-V dc chip electrolytic.

C2, C4—1000 pF, ceramic chip, NP0.

C3, C5—0.1 µF ceramic chip, NP0.

RFC1—5 + no. 28 bare or enam wire on FB-43-5111 ferrite bead.

module; for 3 watts output the module dissipates about 9 watts. The heat sink shown in Fig 1 may be conservative, but was of convenient size. A U-shaped aluminum shield should be used to cover the aluminum channel when the amplifier is in use.

Parts, kits and complete amplifiers are available from Down East Microwave.

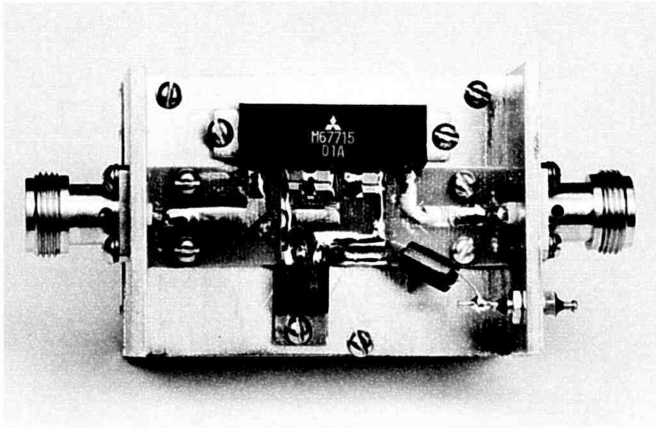


Fig 3—Inside the amplifier. U1 is at the top and U2 at the bottom. Mount the circuit board to the heat sink before installing the Type-N connectors.

A Quarter Kilowatt 23-cm Amplifier

By Chip Angle, N6CA

(From *QST* for March and April 1985)

The amplifier project described here and shown in Figs 1 through 25 offers the following features.

1) Covers 1240 to 1300 MHz.
2) Linear operation.
3) Grounded grid 7289/2C39 cavity amplifier, single tube.
4) Power gain ranges from 12 dB to 20 dB depending on output power, input power, loading, anode voltage and grid voltage.
5) 50-Ω input and output—no stub tuner required.
6) Power output greater than 200 W with about 12-W drive.

The amplifier described here is a tried and proven design. It works well, is reliable and can be duplicated.

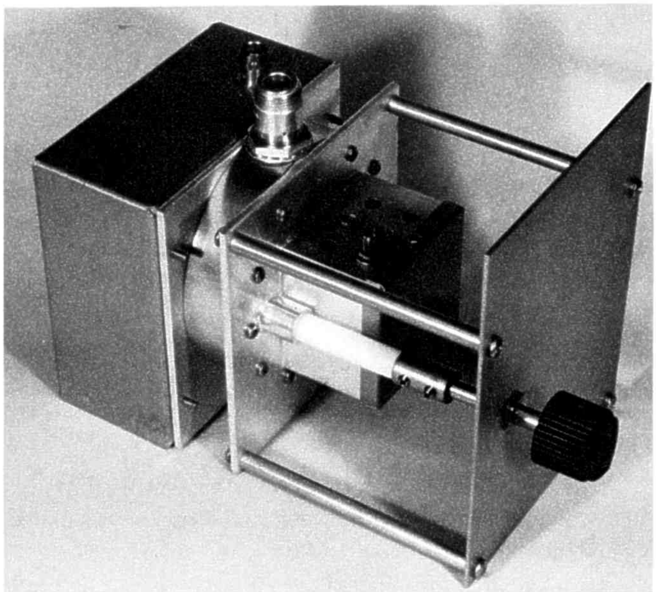


Fig 1—The completed 23-cm amplifier.

General Design Approach

A cavity amplifier is similar to a conventional amplifier designed for lower frequencies. The tube anode excites a resonant circuit, and power is in turn coupled into a load, usually 50 Ω. Instead of using coils and capacitors, as at lower frequencies, the cavity provides the resonant circuit necessary to tune the amplifier output.

The anode cavity of this amplifier is a squat cylinder. Cylinder height is set by mechanical tube requirements. The inside diameter of the cylinder sets the highest resonant frequency. Any capacitance added from the top to the bottom of the cavity will lower its resonant frequency, as will increasing the cavity diameter.

This amplifier uses ⅛-inch-thick copper plates for the cavity top and bottom and a thick-wall aluminum ring, cut from tubing, for the walls. This heavy construction virtually eliminates all resonant frequency variations caused by thermal and mechanical changes.

Fig 2 is the schematic diagram of the cavity amplifier. The circuit is simple. Filament voltage enters the RF deck through C4, C5, RFC1 and RFC2. High voltage is fed to the anode through RFC3. C8, the anode bypass capacitor, is homemade from Teflon dielectric sandwiched between a copper plate and the chassis.

The input pi network easily tunes the entire band at any power level. It is made from two Johanson piston trimmer capacitors and a "coil" made from copper wire. An input cavity is not necessary at 23 cm.

Output coupling is through a rotatable loop that serves as a variable loading control. This allows amplifier-tuning flexibility; it may be tuned for maximum gain or for maximum power. Light loading can produce stable power gains of up to 20 dB.

Amplifier tuning is accomplished with a homemade cylindrical coaxial capacitor with Teflon dielectric (C6). There are no moving metal parts to cause erratic performance. The Teflon rod/tube screws in and out of the coaxial capacitor, increasing or decreasing the capacitance by changing the amount of Teflon dielectric inside the cylinder. With the rod all the way in, the dielectric is all Teflon; with the rod all the way out, the dielectric is all air.

Teflon has a relative dielectric constant (relative to air = 1) of 2.05, which means that the value of the capacitor with the Teflon rod all the way in is twice the value of the capacitor with the rod all the way out. Full capacitance will pull the resonant frequency of the amplifier down to 1240 MHz. Use of only one

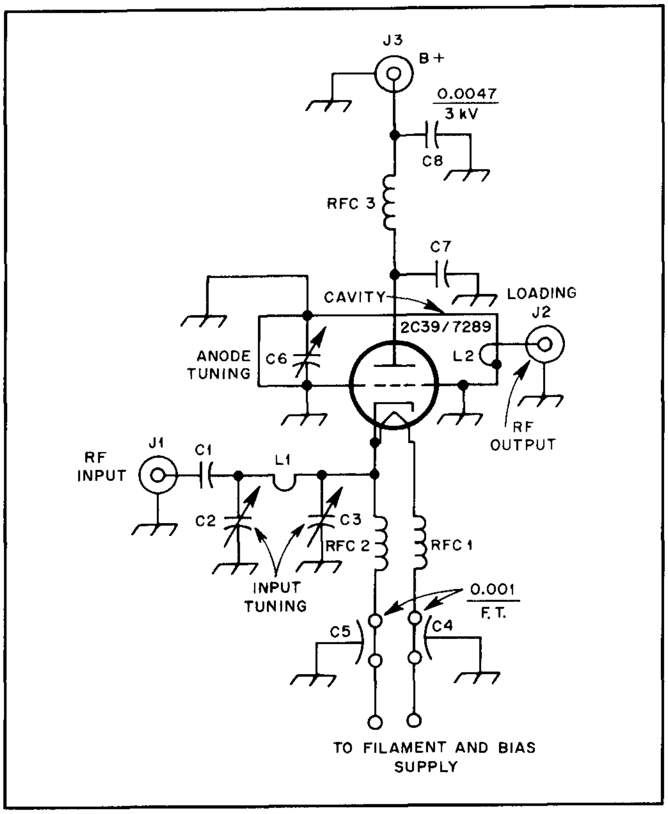


Fig 2—Schematic diagram of the 23-cm amplifier.

C1—3-pF dipped mica capacitor.
C2, C3—1- to 10-pF piston trimmer capacitor (Johanson no. 3957, 5201 or equiv.).
C6—Anode tuning capacitor. See text and Fig 12.
C7—Anode-bypass capacitor, 90 pF. Homemade from copper plate and Teflon sheet.
C8—Disc ceramic, 0.0047-µF, 3-kV capacitor.
J1—5-mm SMA connector, chassis mount, female.
J2—Modified Type-N connector. See text and Fig 8.
J3—Female chassis-mount BNC connector.
L1—Loop of no. 18 bus wire soldered between C2 and C3. See Fig 16.
L2—Output coupling loop. Part of output-connector assembly. See text and Fig 8.
RFC1, RFC2—5 t no. 20 tinned, 3/16-in. ID.
RFC3—3 t no. 20 tinned wound on a 20-Ω 1-W carbon-composition resistor.

anode tuning adjustment means the amplifier will have more gain because shunt capacitance has been minimized.

Thermal Considerations

The cavity walls are formed by a thick-wall aluminum ring, which is sandwiched between two thick copper plates. RF and thermal properties of these two metals are reasonably close, whereas brass is rather poor in both respects. The 7289/2C39 tube used in this amplifier is being run at 2 to 2½ times its normal dissipation rating; therefore it's important to have a cavity that remains thermally stable.

Most previously described amplifiers have used sheet brass in their construction. This has usually meant constant retuning of resonance to maintain output power at or near maximum.

The copper and aluminum construction in this amplifier has solved all thermal stability problems. The amplifier can easily be run key down for over an hour at 200-W output without retuning. This, of course, is obtained only with a good tube and water cooling.

Water cooling keeps the internal structure of the tube thermally stable. When air cooling is used for output levels of 100 to 150 W, output power fluctuations are a direct result of internal tube changes. These changes vary from tube to tube and must be tested for. In some cases, perfectly good RF tubes have had poor thermal stability. Such tubes can make good drivers at lower power levels.

Construction

Hand tools are great if you are skilled and patient. Most people want to hurry up and finish their new project. If that's you, then have a machine shop make all of the parts, leaving only the final assembly up to you. It should cost you about $200. The parts are not difficult to fabricate, but the process is time consuming. If you have the time and patience to do it yourself, this amplifier can be very inexpensive.

Gathering the Materials

All of the materials used in this amplifier are fairly common and should be available from suppliers in most metropolitan areas. Some suppliers have "short sale" racks where they sell odd pieces cut off standard lengths or sheets at reduced prices. The parts for this project are small enough that they may be fashioned from cutoff stock. Surplus-metal houses have some great buys, so start there if one is nearby.

The key to successfully completing this project is careful layout work before cutting or drilling any parts. Invest in a can of marking dye, a sharp scribe, an accurate rule, vernier calipers and several center punches. These tools are available at any machinists' supply shop. The marking dye will make cutting and filing lines much easier to see. Measure all dimensions as carefully as you can and then recheck them before cutting. Mark with a sharp scribe because the sharper the scribe, the finer the marked line, and the finer the marked line, the closer your cut will be to where it should be. Remember—the accuracy of your drilled holes is only as good as your center-punching ability, so use a fine punch for the first mark and then a bigger one to enlarge the mark enough for drilling.

Access to a drill press is a must. It's extremely difficult to drill holes accurately with a hand drill. Although not absolutely necessary, you should have access to a lathe or milling machine to do the best possible job.

Other tools that will aid you with this project are a nibbling tool, a set of files and some sharp drill bits. If you don't already have one, purchase a file card to clean aluminum and copper shavings out of your files as you work. Clean, sharp files are faster and more accurate to work with. You'll also need an assortment of sandpaper for the final finishing work.

The Template Approach

It's best to fabricate a single template for marking and drilling the anode plate, anode bypass capacitor, cavity ring, grid plate and front panel. The template shown in Fig 3 has all of the holes for these parts. If you use the template, you'll only have to make the careful measurements once — after that, it's simple to mark and drill the rest of the parts.

The template approach offers several other advantages. A template makes it much easier to maintain accuracy between the anode plate, cavity ring, grid plate and front panel; these parts will fit perfectly because they were all drilled from the same master. The template approach also makes it possible to set up a small production line if you decide to build more than one of these amplifiers and combine them for higher power, or if a friend wants to build an amplifier along with you.

See Fig 3 for complete template dimensions. Start with a piece of 1/16-inch-thick aluminum stock that is larger than you need and degrease it with soap and water. Dry it off and spray it with marking dye. Scribe a 4-inch square on the stock and cut the template to size. A shear will make this job much easier, but it can be cut with hand tools and filed to size.

Carefully measure and scribe all holes. Note that holes A and B are on the circumference of circles. Use a compass to scribe the circles, and then locate the holes. After you have marked and checked all holes, centerpunch and drill them. The holes should be drilled with a 1/16-inch or smaller bit. Recheck all measurements. If you goof, start again. The time you spend making the template as perfect as you can will save you much time and aggravation when you make and assemble the other parts.

When you finish the template, mark the front side for future reference. All plates that will be made from the template are marked and drilled from the front side (as viewed from the front panel).

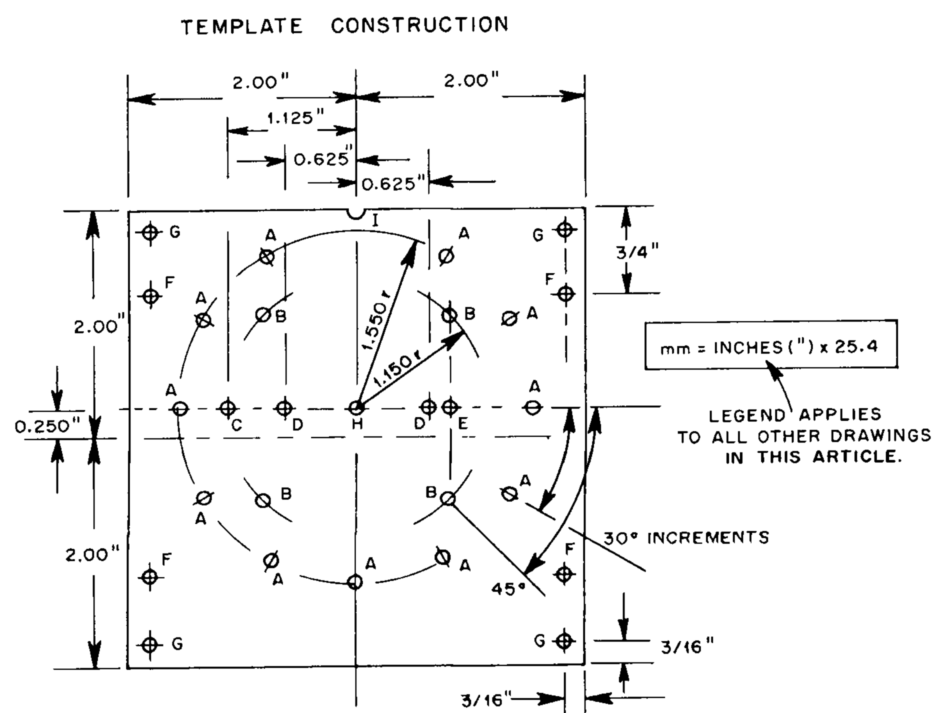
Making the Copper Plates

Once you have completed the template, it will be easy to make the copper plates. The anode plate, grid plate and anode-bypass-capacitor plate are all made from 1/8-inch- thick copper. See Figs 4, 5 and 6 for the dimensions of these pieces.

Measure and cut the three plates to the proper dimensions. Carefully break (deburr) all sharp edges to avoid small cuts to your fingers and hands.

Clean the plates with alcohol and spray them with marking dye. Clamp the aluminum template to each plate and carefully scribe the correct holes. Remember that all plates do not have the same holes. The anode plate uses holes A, B, C, F and H; the grid plate uses holes A, C, D, G and H. The anode-bypass-capacitor plate uses holes B, E and H. Use a small center punch to punch all holes accurately and lightly. If they then look accurate, enlarge them enough for drilling.

Copper isn't the easiest metal to work with. It's very stringy, and drilling it can be frustrating. You'll need the proper drill bits for best results. Special drills can be purchased, but that's not really necessary. You can use a grinder to carefully



HOLES USED:
RING — A
ANODE PLATE — A, B, C, F, H
GRID PLATE — A, C, D, G, H
ANODE BYPASS-CAPACITOR PLATE — B, E, H
FRONT PANEL — C, G
I = RING ALIGNMENT NOTCH

- ALL HOLES 1/16" DIA. OR SMALLER
- MATERIAL: 1/16" ALUMINUM
- ALL DIMENSIONS IN INCHES
- ALL PLATES ARE VIEWED FROM FRONT PANEL
- HOLE DESIGNATIONS ARE MAINTAINED ON ALL DRAWINGS

Fig 3—Complete dimensions for the aluminum template.

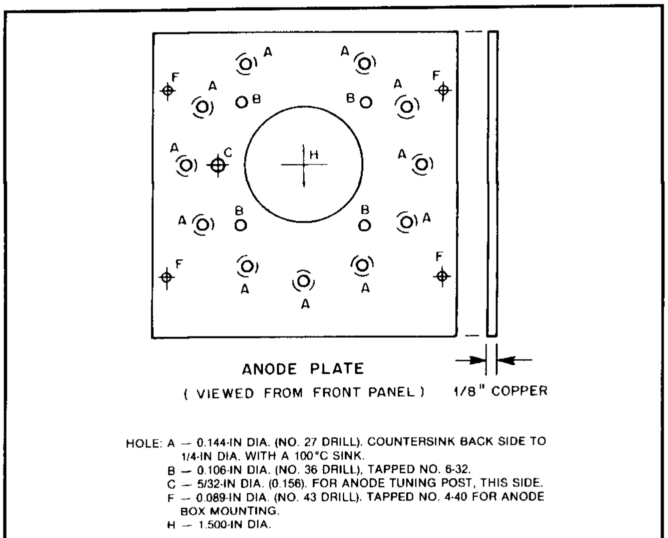


Fig 4—Drilling details for the anode plate. See Fig 3 for additional information on hole location.

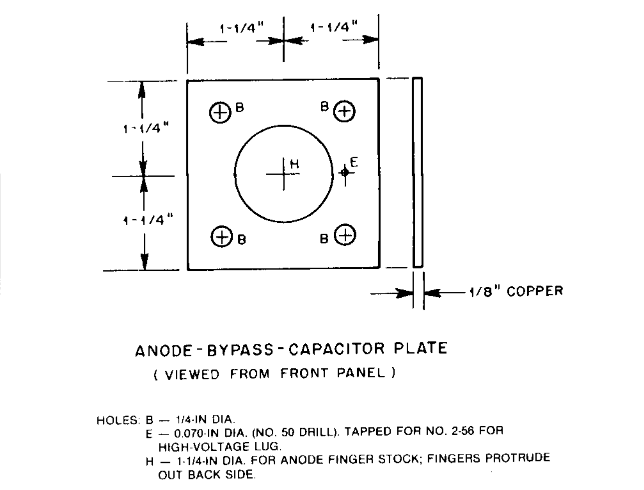


Fig 6—Drilling details for the anode-bypass-capacitor plate. See Fig 3 for additional information on hole location.

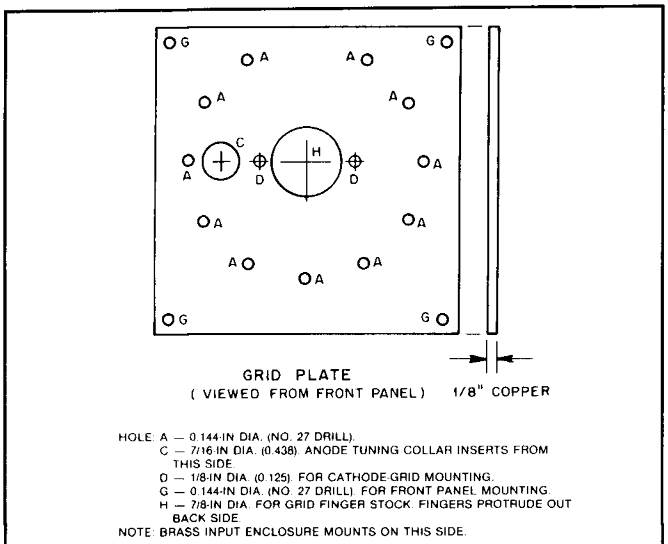


Fig 5—Drill details for the grid plate. See Fig 3 for additional information on hole location.

remove the sharp points on the outer edge of the cutting surface of each side of a standard drill bit. This will eliminate any tendency for the copper to grab. Practice on an old bit and be sure to grind it symmetrically. Modified drill bits can still be used on aluminum and other metals.

Always start with a smaller drill and work up to the final hole size. It's safer and more accurate. The larger holes can be cut with a flycutter, or you can drill a series of smaller holes around the inside of a larger hole and file to finish. Either way is fine. Use lots of cutting fluid to lubricate the drill bit, and wear safety glasses and an old shirt. Remember, some cutting fluids are not to be used on aluminum.

Start with a no. 50 (0.070-in.) or smaller bit and drill pilot holes at each of your punched marks. The details for finishing each hole are listed in the drawings. Some holes are countersunk or tapped. Pay attention to the details and take your time.

When you are through drilling, you must deburr each hole. Copper is soft, so it tends to rise up around the hole during drilling and deburring. Use a flat file for the initial cut, and then remove any remaining material with a countersink. File the copper plates flat again because a flush fit on both sides of the aluminum ring is very important.

When all copper work is done, you should be able to stack the plates and see all pertinent holes align correctly. Enough tolerance is included in the dimensions to accommodate minor errors. After the holes are drilled, it can be difficult to tell which side of each plate is which, so mark the front side of each plate with a permanent marker.

Machining the Ring

The aluminum ring that forms the cavity wall is cut (sliced) from a length of 3½-inch OD tubing with a ⅜-inch wall thickness. See Fig 7. The tubing ID is approximately 2¾ inches. The dimensions of the ring are the most critical in this amplifier. Tolerance of the ring thickness is ±0.005 inch to maintain full band coverage.

The ring can be hacksawed or bandsawed out of the tubing, but take extreme care to be accurate. Cutting tubing straight isn't easy. Clamp the tubing to prevent rotating on the bandsaw. The final finish cut is best done on a lathe or milling machine, but careful filing will work.

Once the ring is the correct thickness, deburr the sharp edges and spray it with marking dye. Notice that the outside and inside diameters are not concentric. This is normal for large tubing and is not a problem. Lay the ring flat and find the thickest wall section. Scribe a line across the wall at this point, across the center of the ring, and across the wall on the other side. The scribed lines on each side of the ring will be used to align the template. The output connector will be placed at the thick wall section.

Carefully align notch I on the template with the line scribed on the thickest wall section on the ring. Clamp the

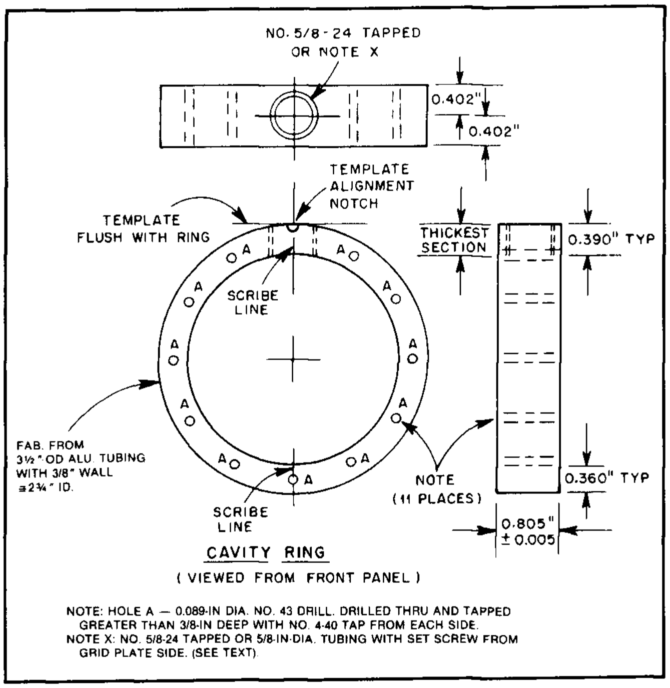


Fig 7—Details of the cavity ring. See Fig 3 for additional information on hole location.

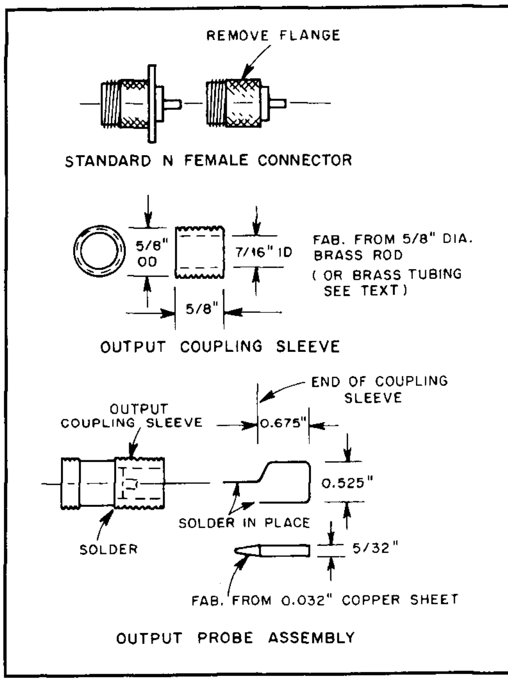


Fig 8—Output-probe/connector assembly details.

template onto the ring. Mark each of the 11 holes labeled A on the template. After you mark the holes and remove the template, check alignment with the copper plates just in case. If everything lines up, center punch all eleven holes on one side of the ring only, and drill each hole completely through the ring. Use lots of cutting fluid. File the ring flat before and after deburring, taking care not to change the wall thickness. Tap each hole to accept no. 4-40 machine screws. Each hole will have to be tapped to a depth of at least ⅜ inch from both sides because long taps don't exist. The inside of the ring doesn't need to be polished.

The hole for mounting the output connector can now be drilled. There are two ways to mount this connector, and either scheme works fine. Read ahead to the section on making the output connector for more information. The first method of mounting the output connector involves tapping the ring with a no. ⅝-24 tap and using a lathe to cut matching threads on the output connector coupling sleeve. Large taps are expensive, but both a tap and die for Type-N connectors come in handy if you do a lot of building.

If you don't have access to a lathe or a large tap, the second method is easier. Make the output connector coupling sleeve from ⅝-inch-OD brass or copper tubing and drill the ring to just clear it. Then drill and tap the grid-plate side of the ring above the output connector to accept a setscrew. Use the setscrew to secure the output connector.

Output Connector

A standard Type-N chassis-mount female connector (silver plated) is used for the output probe/connector. See Fig 8. First, remove the flange with a hacksaw and file flush with the connector body. Next, make the output coupling sleeve that is right for your application (threaded or unthreaded, depending on how you fabricated the ring). The sleeve will be the same length in either case. The output coupling loop is fashioned from a piece of 0.032-inch-thick copper sheet that is ⁵⁄₃₂ inch wide. Bend it to the dimensions shown in Fig 8. We will solder the output connector together later.

Grid Compartment

The grid compartment measures 2 inches square by 1½ inches high. See Fig 9. It is made from brass and can be sawed out of square tubing or bent from sheet stock. The cover can be made from any sheet metal.

Two small PC boards (Fig 10) hold the finger stock that makes contact with the filament pin and cathode ring on the 2C39 tube. These boards are cut from ¹⁄₁₆-inch-thick, double-sided G-10 glass-epoxy stock. The copper pattern is identical for both sides of each piece. Mark and drill or file the holes first and then cut the boards to size. Small boards are difficult to hold while drilling them. Mark each side of each board and score the copper foil with a sharp knife.

The unwanted copper can be removed easily by heating the foil with a soldering iron and lifting it off. Use a flat file to deburr the boards. Do not use a countersink because the copper foil must be as close to the holes as possible to facilitate soldering the finger stock in place.

The input connector is a 5-mm SMA type. This is an excellent RF connector, especially for low-power UHF applications. Although an SMA is recommended, any small, screw-on connector will do. If you really feel you have to use a BNC then do so, but it's a lousy connector at frequencies above 200 MHz. Remember to move the connector hole to accommodate its larger size.

The input connector must be as close as possible to the first input capacitor. Lead length of the input dc blocking capacitor must be as short as possible. The 3-pF capacitor is

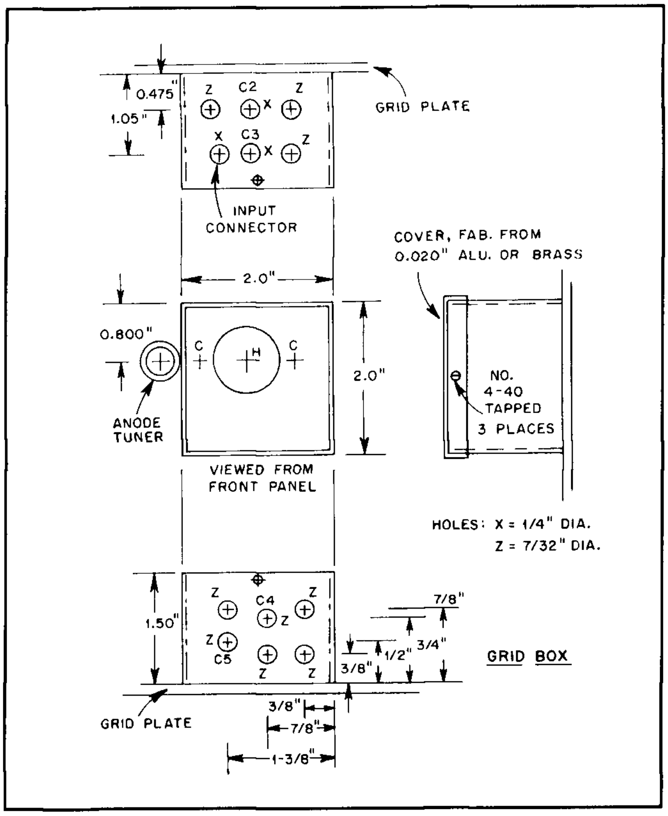


Fig 9—Input compartment details.

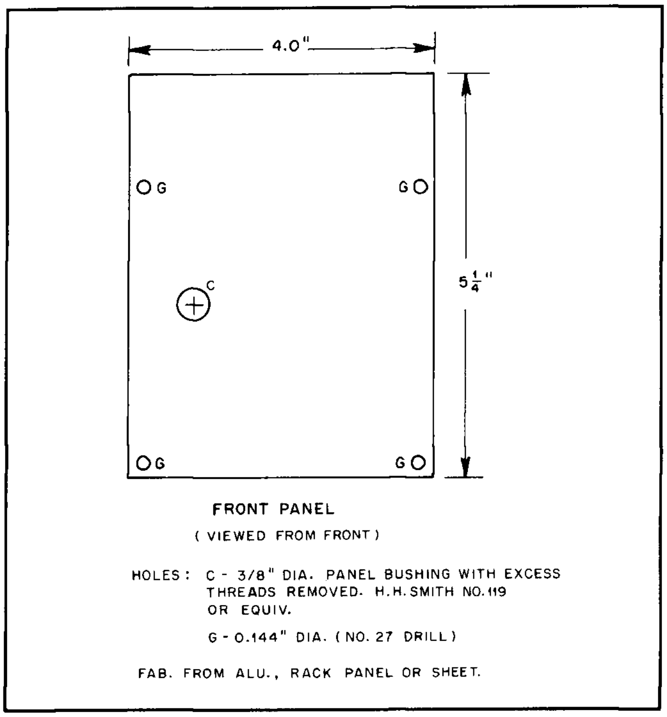


Fig 11—Front-panel details.

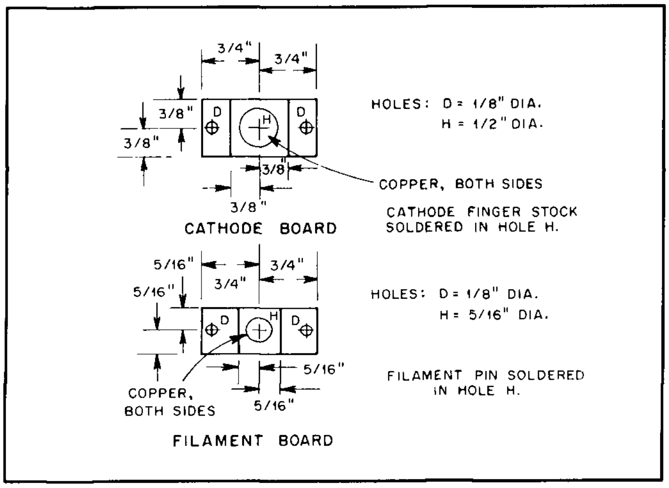


Fig 10—Cathode and filament PC-board details.

series resonant at 1200 MHz only with short (1/16-inch or less) leads.

Miscellaneous Bits and Pieces

There are still several small, but very important parts to fabricate. The front panel is shown in Fig 11. It is made from a piece of 1/8-inch-thick aluminum sheet. Some builders may wish to mount the amplifier on a rack panel. Wash and dry your front-panel material and spray it with marking dye. Clamp it to the template and mark the holes. Check the hole alignment with the copper grid and anode plates. If all lines up correctly, center punch and drill the holes. The only front-panel control is for the anode tuning capacitor, which is adjusted by a 1/4-inch shaft protruding through a 3/8-inch panel bushing in hole C.

The anode tuning collar, shown in Fig 12A, is made from a piece of 1/2-inch-OD brass rod. This rod has a 3/8-inch hole drilled through its center, and it is turned down to 7/16-inch OD for half its length. The inside of the 1/2-inch-OD end is tapped to a depth of 1/4 inch to accept 3/8-24 threads. This collar will be inserted into hole C on the grid plate. Fig 12B also shows the anode tuning post. It is simply a length of 5/32-inch-OD brass rod that inserts into hole C on the copper anode plate. This rod will form one plate of the anode tuning capacitor; the cavity wall is the other plate.

The anode tuner (Fig 12C) is machined from a piece of 3/8-inch-OD Teflon rod. One end of the rod is drilled out with a no. 21 drill. The outer wall of this end is threaded with a 3/8-24 tap. This is the end that will thread into the anode tuning collar and slip over the anode tuning post. The other end is turned down to fit inside a 1/4-inch shaft coupler.

Fig 13 shows the remaining parts. The tuning shaft (A) is made from a piece of 1/4-inch brass rod. A coupler (B) to connect the tuning shaft to the anode tuner may be purchased or made. This also applies to the front-panel spacers (C). The Teflon dielectric for the anode bypass capacitor (D) is made from 0.010-inch-thick Teflon sheet. Use the template to locate holes B and H. Teflon washers and inserts (E) are used to insulate the mounting hardware for the anode bypass capacitor from the chassis. The inserts are made from 1/4-inch-OD Teflon rod. The washers are made from Teflon sheet. Sharpen a piece of 3/8-inch OD tubing and chuck it up in a drill press. This tool will cut neat, round washers from the sheet.

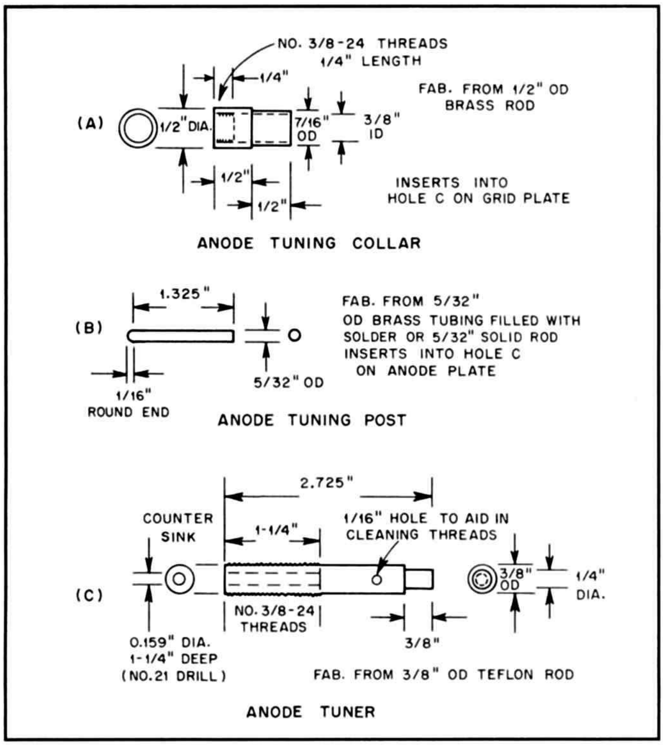


Fig 12—Anode-tuning capacitor details.

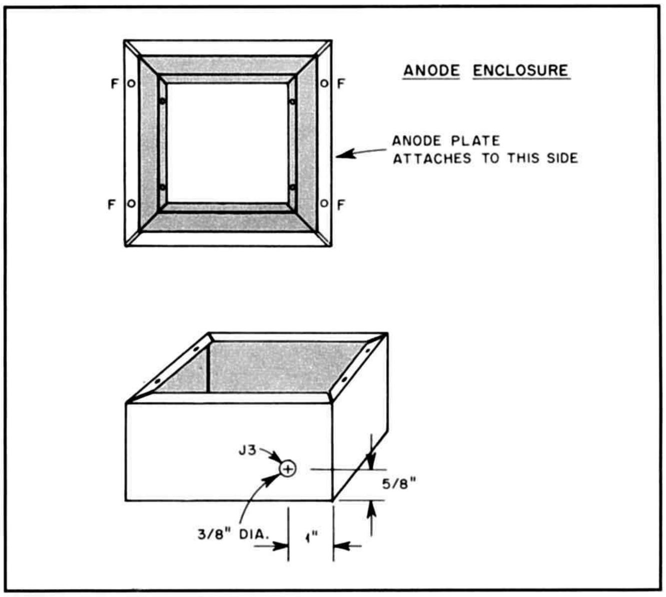


Fig 14—Anode enclosure details.

The box that encloses the anode compartment (Fig 14) is fabricated from a Bud AU-1083 utility cabinet. Clean the chassis and spray it with marking dye. Secure the template to the side of the enclosure that contacts the anode plate and scribe the holes labeled F. Make sure that these holes line up with the holes on the copper anode plate. If they do, center punch and drill them to size. If air cooling is used, the blower will mount to this box.

Soldering the Subassemblies

Once all copper and brass parts are drilled and deburred, they should be cleaned with alcohol and Scotch-Brite, a non-metallic pot cleaner, and washed in alcohol again. Set the pieces aside and avoid touching them. Fingerprints will inhibit soldering.

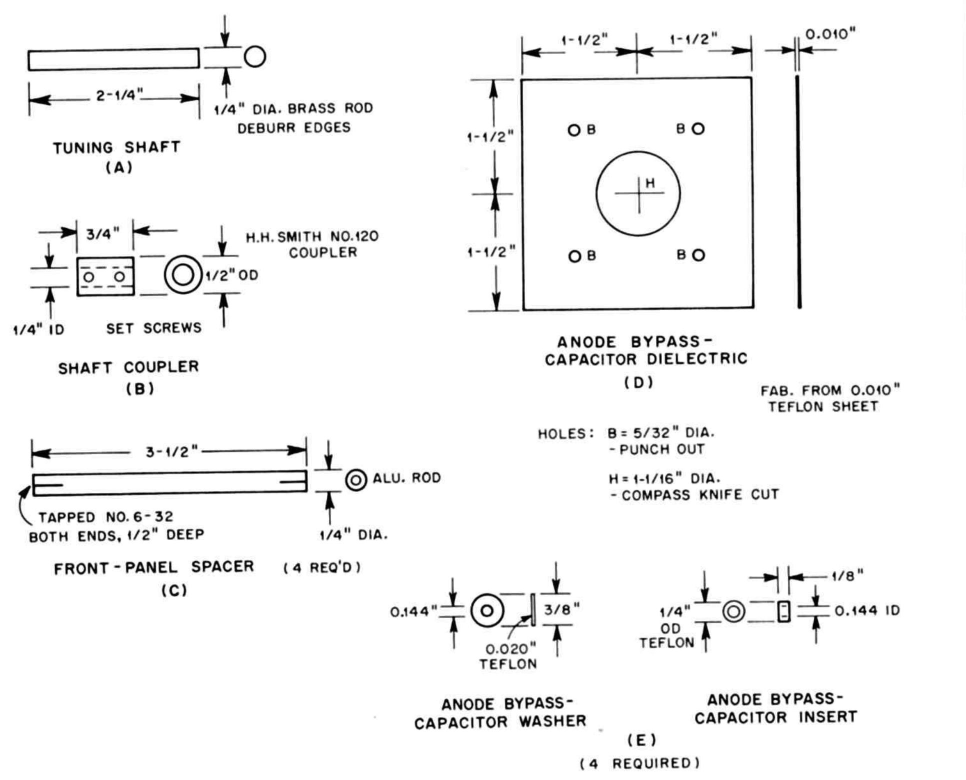


Fig 13—Miscellaneous parts necessary to complete the amplifier.

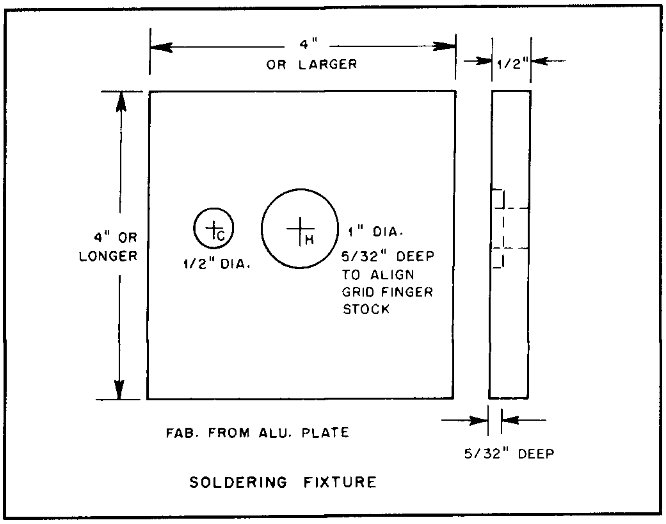


Fig 15—Dimensions of the soldering fixture. See Fig 3 for additional information on hole location.

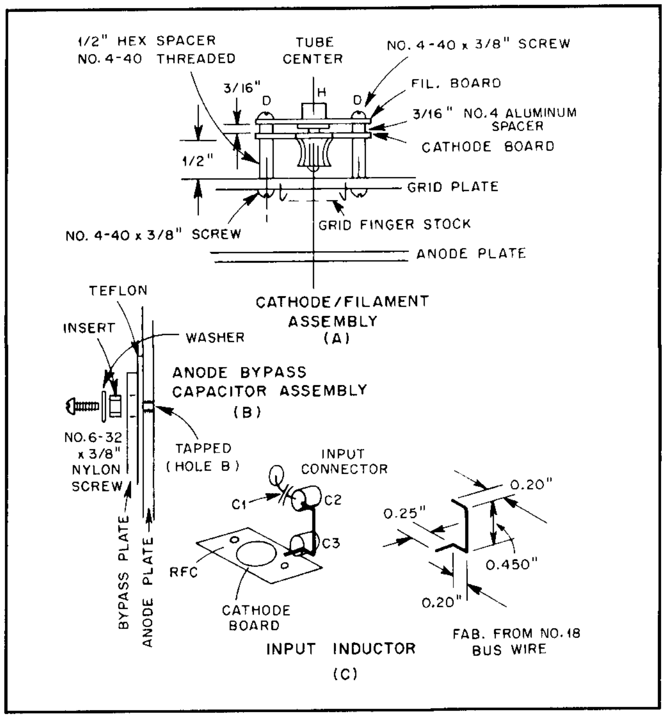


Fig 16—Assembly details for the filament and cathode boards (A), the anode-bypass capacitor (B) and the input pi network (C).

The best way to solder the heavy brass and copper parts is to first build the soldering fixture shown in Fig 15. This soldering fixture, made from ½-inch-thick aluminum plate, will evenly heat the entire assembly to be soldered. Even heating will allow you to do a much better soldering job than you could otherwise.

The aluminum soldering fixture should be preheated on a stove or hot plate until bits of solder placed on its surface just melt. At this point, reduce the heat slightly. Avoid excessive heat. If the copper parts placed on the fixture suddenly turn dark, the heat is too high.

Solder the grid plate assembly first. You will need the copper grid plate, grid finger stock, anode tuning collar and brass input compartment.[1] Look at the drawings again to be sure that you know which parts go where. Insert the grid finger stock into hole H on the grid plate. As viewed from the front-panel side, the curved fingers will protrude out the back side, away from you. Apply liquid or paste flux and set the grid plate in the soldering fixture. The finger stock will fit in hole H in the fixture, allowing the grid plate to rest flush with the surface of the fixture. Next, apply flux to the anode tuning collar and insert it in hole C of the grid plate. Part of the tuning collar will slip into hole C in the soldering fixture. Make sure the collar seats flush with the grid plate. The flux should start to bubble at this point. Carefully apply solder directly to the joints of the installed parts. The solder should melt almost immediately and flow bright and smooth. Next, place the square brass input compartment in place and apply flux. In a few seconds, it can be soldered by running solder around the joints, inside and outside. If you have trouble getting it to flow on both sides, merely tap the brass box aside (1/16 inch) and return it to its original position.

Now comes the hard part—getting the soldered assembly away from the heat without disturbing the alignment. A pair of forceps is recommended, but long pliers will do. Carefully lift the assembly off the soldering fixture and set on a cooling rack. Do this without moving any part. The cooling rack can be any two pieces of metal that will allow clearance for the protruding parts. You can expedite cooling by using an ordinary hair dryer in the "cool" position to gently blow air across the assembly. While the grid assembly is cooling, assemble the output connector. See Fig 18. Place the modified Type-N female connector, threaded end down, on the soldering fixture. Apply flux to the top and install the output coupling sleeve. Allow both parts to heat before applying solder. Carefully remove the soldered output connector from the fixture. When it has cooled, solder one end of the loop to the center pin of the N connector and the other to the output coupling sleeve. Now place the anode plate on the soldering fixture and allow to heat. Apply flux to hole C. Insert the anode tuning post (5/32-inch-OD brass tube) and allow to heat; apply solder. Remove the parts and cool as before. This completes the work with the soldering fixture. Be sure to let it cool off before handling! Save the fixture for future construction; you never know when you might want it again. The anode plate and the anode-bypass-capacitor plate must be filed and then sanded flat on their butt surfaces to assure that there are no solder bumps or sharp points to puncture the Teflon dielectric. This must be done after soldering. The Teflon sheet is adequate insulation for many times the anode potential of this amplifier, but only if the surfaces it separates are smooth! Next, clean the cathode and filament PC boards. Install the finger stock in hole H of the cathode board. Apply flux to both sides of the board. Heat with a hot iron and apply solder around the circumference of hole H, soldering the finger stock on both sides of the board. Use the same technique to install the filament pin. After all parts have cooled, use a spray can of flux remover to clean them. Slight scrubbing with

"Scotch-Brite" pot cleaner will finish them nicely. Congratulations: You have finished the pieces and are now ready to bolt the amplifier together.

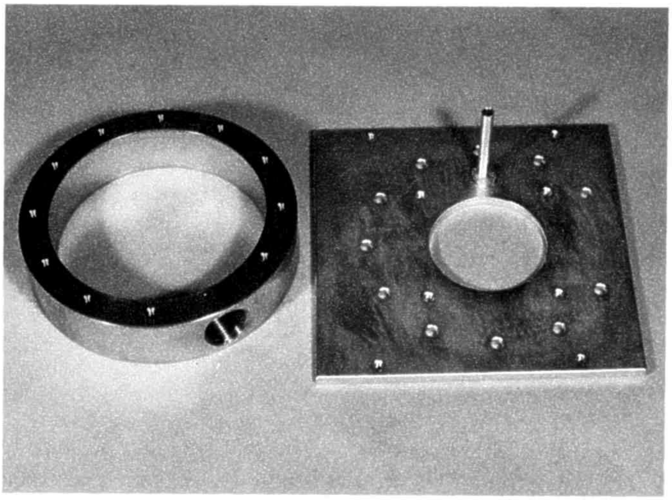
Silver Plating

Over the years, many people have pushed silver plating as the only way to go. You may wish to silver plate the amplifier components before soldering them together, but it is not necessary. The RF skin conductivity of aluminum and copper is pretty good at 23 cm; these materials are much better than brass. In actual testing with four amplifiers, there was no difference in performance among tin-plated, silver-plated and unplated versions. A nickel-plated amplifier exhibited 3-dB less gain than the others.

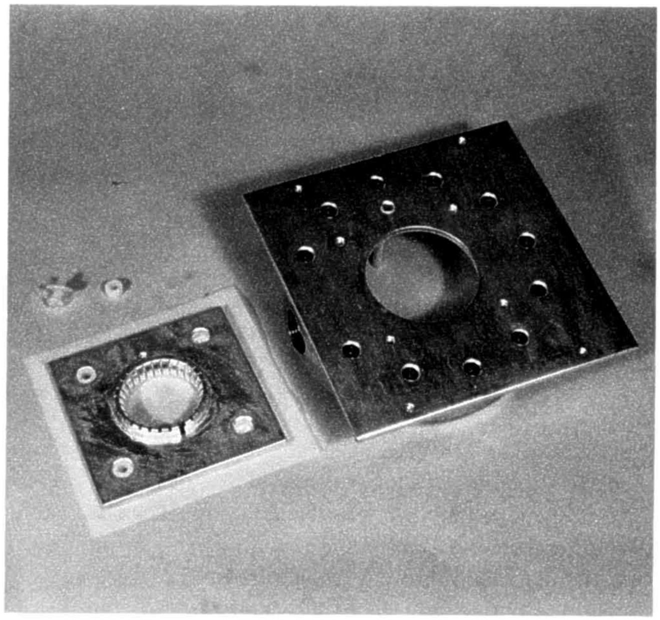
Assembly

After fabrication of all parts, assembly is simple. Figs 16 through 18 show assembly details. Loosely fasten the grid and anode plates to the ring. Mount the input connector and capacitors on the input compartment. Loosely install the cathode and filament boards and their respective spacers. See Fig 16A.

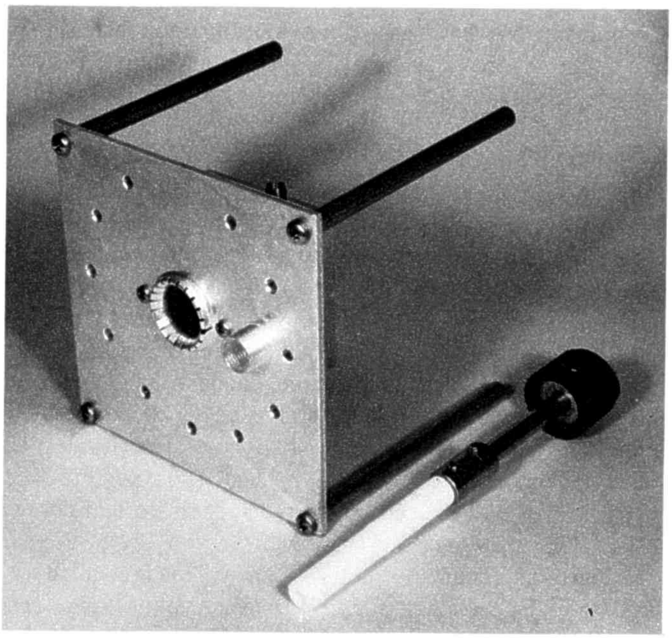
Now insert a 7289/2C39 tube. This will center up all finger stock. Place the Teflon anode tuner in its collar on the grid plate and screw it most of the way in. Now tighten all of



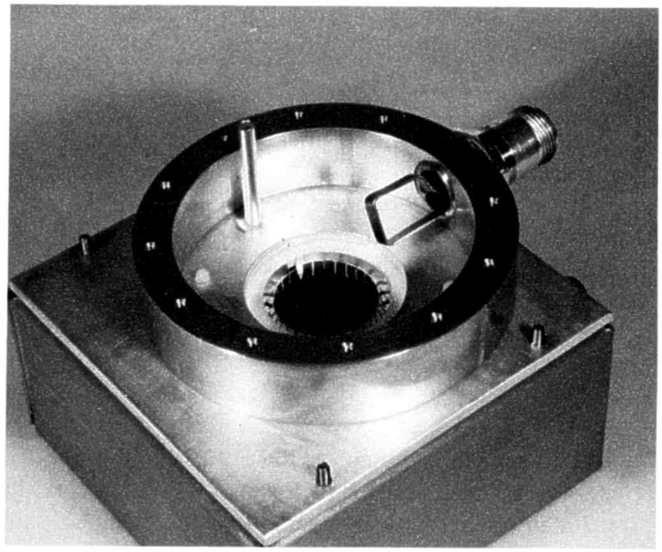
(A)



(C)

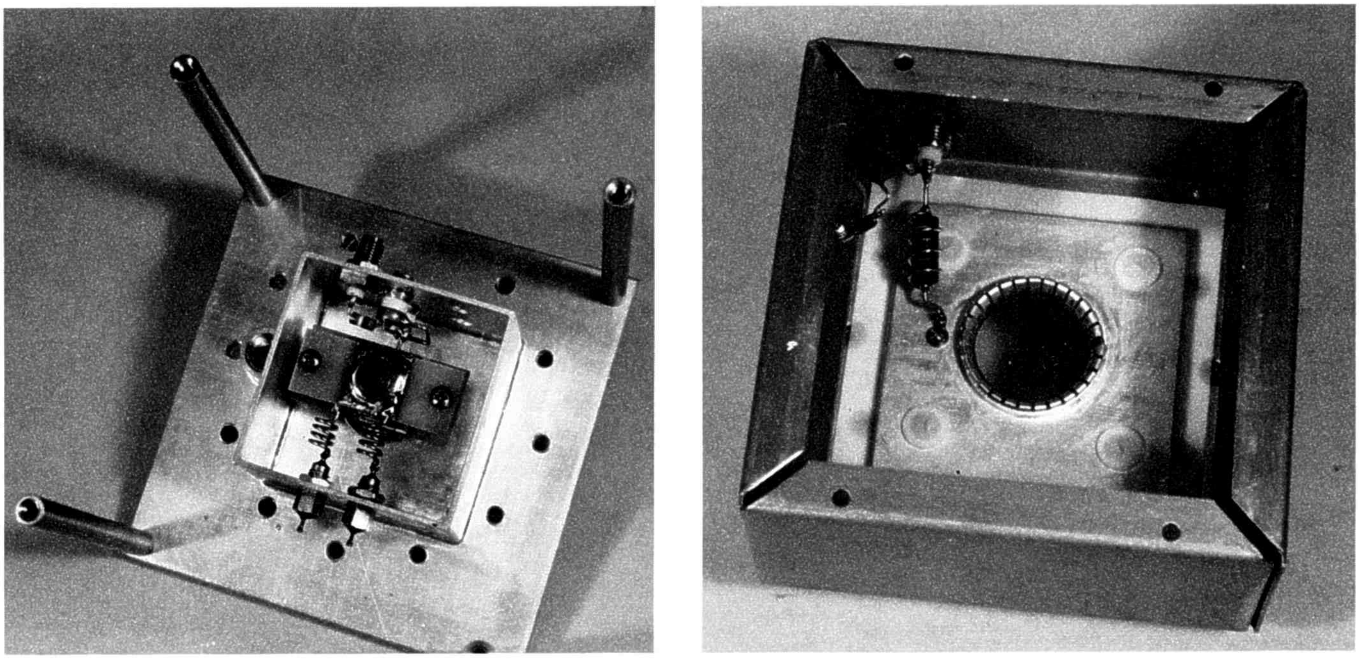


(B)



(D)

Fig 17—The completed cavity ring and anode plate with anode tuning post soldered in place are shown at A. The photo at B shows the grid plate with finger stock, input compartment and anode tuning collar soldered in place. The completed anode tuner is at the right. C shows the cavity ring attached to the anode plate. The anode-bypass capacitor is ready for installation. At D, the interior of the cavity as seen from the grid plate side is visible. The output probe/connector assembly is installed. The anode-bypass capacitor and anode enclosure had been installed on the anode plate.



(A) (B)

Fig 18—At A, the interior of the completed input compartment is visible. The photo at B shows the interior of the anode compartment with the anode bypass, RFC3, C8 and J3 installed.

the screws. The 7289/2C39 tube should slide in and out snugly, and the anode tuner should screw in and out smoothly. The Teflon sheet and anode bypass capacitor plate can be installed now (Fig 16B). Assemble the remaining input components, the filament feed-through capacitors and RFCs (Fig 16C). Screw the output probe into the cavity ring (or push in the probe and tighten the setscrew, depending on which method you chose). Install the high-voltage connector and other parts in the anode box. Mount the amplifier on the front panel and install the anode tuner shaft. This completes the assembly.

Power Supplies

The filament and bias supplies for the cavity amplifier are shown schematically in Fig 19. The manufacturer's specification for the 7289/2C39 filament is 6.0-V ac at 1 A. The use of a standard 6.3-V ac, 1-A transformer only slightly increases the tube emission without much loss of tube life. The filament should be allowed to warm up before operating the amplifier, so the filament, bias and high-voltage supplies incorporate separate primary switches.

Biasing

Many biasing schemes have been published for grounded-grid amplifiers. Fig 19 shows a bias network that satisfies all of the following operating requirements:

1) External bias supply referenced to ground.
2) Low-power components.
3) Variable bias to accommodate tube-to-tube variations.
4) TR switchable with relay contact or transistor to ground.
5) Bias-supply protection in case of a defective or shorted tube.

U2 provides a variable bias-voltage source, adjustable by R1. The output of U2 drives the base of Q1, which is used to increase the current-handling capability of the bias supply. Q1 must be mounted on a heat sink. J1 is connected to the station TR switching system so that R1 is grounded on transmit and disconnected on receive. The approximate range of the bias supply is 6 to 20 V. Z1 and Z2 provide protection for R1 in case of a shorted tube. The amplifier can be run without Z1 and Z2 if you keep the anode voltage below 1100 V.

High-Voltage Power Supply

A safe, reliable high-voltage power supply is described here. Of course, you can use any readily available HV supply; keep in mind, however, that the 7289/2C39 anode potential should never exceed 1400-V dc at full load and that the amplifier will withstand 1900-V dc at low cathode current and cut-off-bias conditions. For maximum power output, assuming adequate drive power is available, anode voltage under full load should be about 1200- to 1400-V dc. Fig 20 is a schematic diagram of the high-voltage supply. A power transformer (T2) that delivers 900- to 1050-V ac is ideal. The type of rectifier circuit used will depend on the type of transformer chosen. Each leg of the rectifier is made from two 1000-PIV, 3-A silicon diodes connected in series. Each diode is shunted with a 0.01-muF capacitor to suppress transient voltage spikes, and a 470-kΩ equalizing resistor. Filtering is accomplished with a string of four 360-µF, 450-V electrolytic capacitors connected in series. R3-R6 equalize the voltage across each capacitor in the string and serve as bleeder resistors. Of course, a single oil-filled capacitor may be used here if available. Whatever type of filter you use, the total capacitance should be about 80 µF at a voltage rating of at least 1500-V dc. This value allows

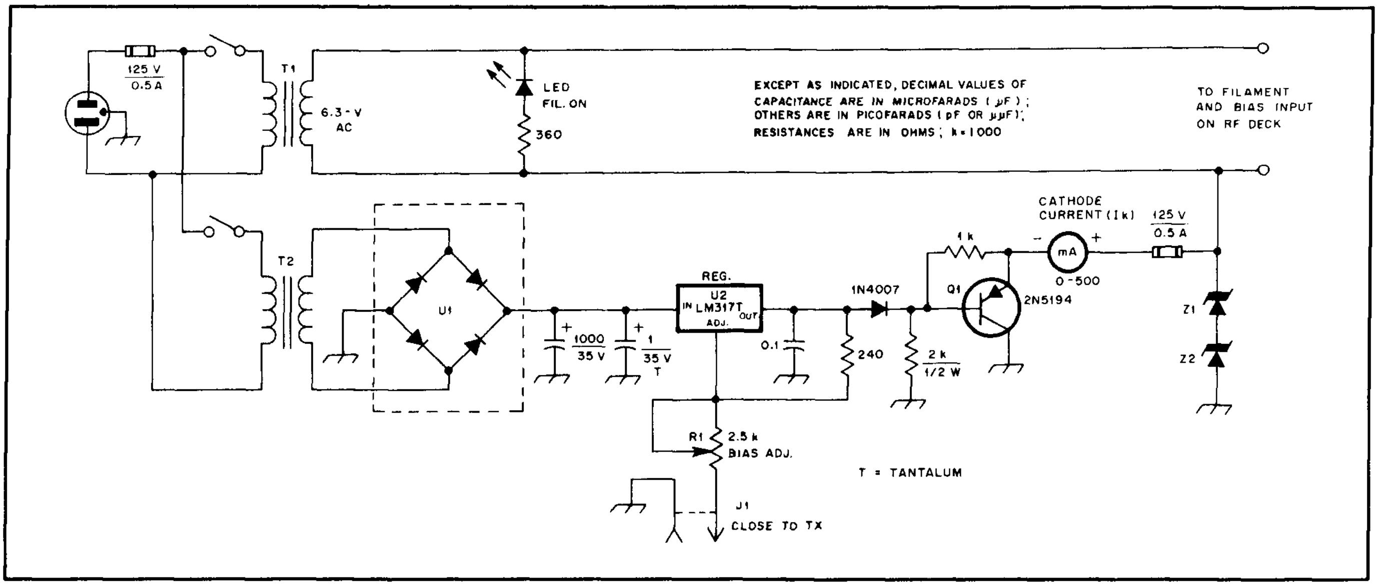


Fig 19—Schematic diagram of the cavity amplifier filament and bias supplies. All resistors are ¼-W carbon types unless otherwise noted.

J1—Female chassis mount phono connector.
T1—Filament transformer. Primary 117-V, secondary, 6.3 V at 1 A.
T2—Power transformer, Primary 117 V; secondary, 24 to 28 V at 50 mA or greater.
U1—Bridge rectifier, 50 PIV, 1 A.
U2—Adjustable 3-terminal regulator (LM317 or equiv).
Z1, Z2—20-V unipolar metal-oxide varistor (General Semiconductor SA20 or equiv.) or two 20-V, 1-W Zener diodes.

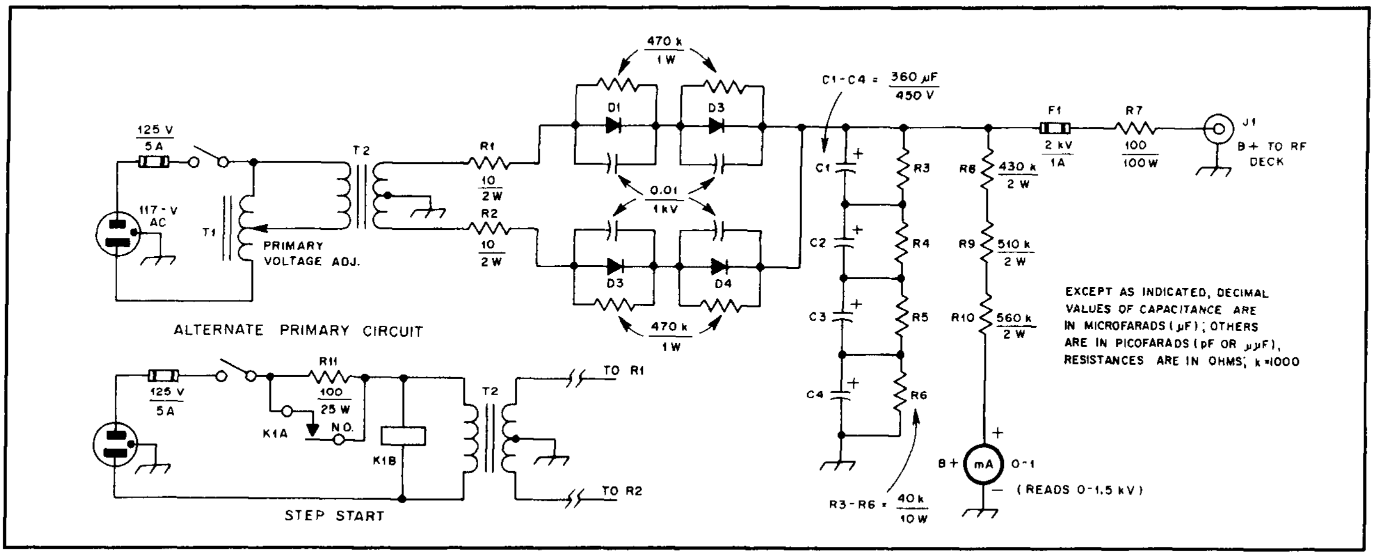


Fig 20—Schematic diagram of the amplifier high-voltage supply.

C1-C4—Electrolytic capacitor, 360 μF, 450 V.
D1-D4—Silicon rectifier, 1000 PIV, 3 A.
F1—High voltage fuse, 2 kV, 1 A.
J1—Chassis mount female BNC or MHV connector.
R3-R5—Wirewound resistor, 40 kΩ, 11 W.
T1—Variable autotransformer, 500 VA.
T2—High-voltage transformer, Primary 117 V; secondary, 900 to 1050 V at 500 mA.

adequate "droop" of the anode voltage under high-current loads to protect the amplifier in case of RF overdrive or a defective tube.

Protective Circuitry

Some type of start-up protection should be incorporated in the primary. Fully discharged filter capacitors look like a dead short at supply turn-on. Initial surge current (until the capacitors charge) may be high enough to destroy the rectifiers. R1 and R2 provide some surge-current limiting, but either of the two primary configurations shown in Fig 20 should be used. T1, a variable autotransformer (Variac and Powerstat are two common trade names), is ideal. In addition to allowing you to bring the primary up slowly, (and charging the capaci-

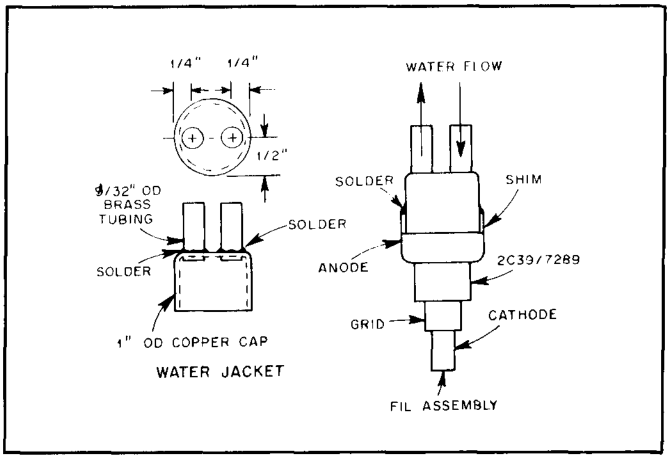


Fig 21—Details of the solder-on water jacket.

tors gradually), it also allows full control of amplifier output power by varying anode voltage. The second method, a "step-start" system, uses a resistor in the T2 primary to limit the turn-on surge current. When the capacitors have charged, K1 is energized, shorting out R11 and applying full voltage to the T2 primary. F1 and R7 protect against high-voltage arc-overs or short circuits. If sustained overcurrent is drawn, F1 will open and remove B+ from the RF deck. Use a high-voltage fuse here; standard fuses may arc when blown and not interrupt the B+. R7 provides current limiting to protect the amplifier and power supply in case of a high-voltage arc.

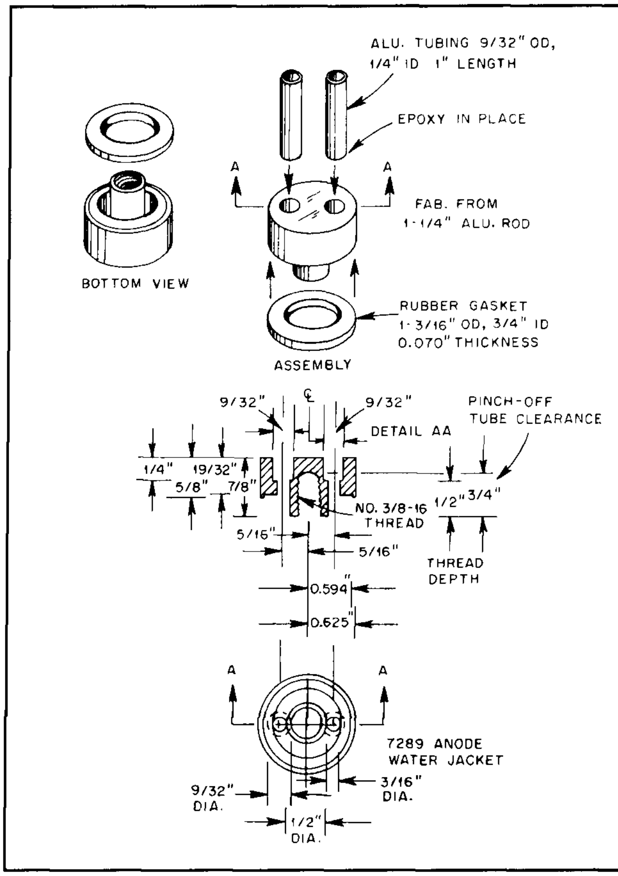


Fig 22—Details of the screw-on water jacket.

Safety

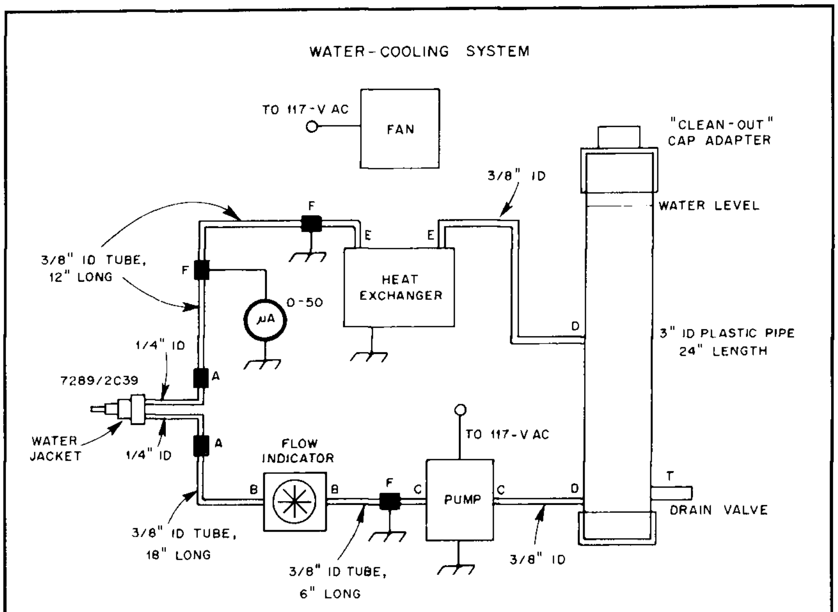
An HV meter should always be used to monitor the status of the power supply. The values for R8-R10 shown in Fig 20 will give a 1500-V dc full-scale reading on a 0-1 mA meter. RG-58 or -59 coaxial cable should be used for the high-voltage interconnection between the power supply and the RF deck. Ground the shield at both ends for safety and a good dc return. Safety must be observed when working with all power supplies. These voltages are lethal! Always disconnect ac power and then discharge the filter capacitors before working on the power supply. Never guess or make assumptions about the status of a power supply. Assume it is hot.

Metering

Cathode-current monitoring is all that's really necessary for observing amplifier dc performance. Cathode current (IK) is the sum of the plate (IP) and grid (IG) currents. Normally, when this amplifier is driven to 300- or 400-mA IK, the grid current will be around 40 to 50 mA. The inclusion of a grid-current meter is not really necessary and only makes biasing and TR switching complicated. Cooling desired output power and the level of drive power available will dictate what type of cooling to use. For intermittent duty (SSB, CW) at output levels less than 50 W, air cooling is satisfactory. Any small blower may be easily mounted to the aluminum box surrounding the tube anode. For high-duty-cycle modes and/or output levels greater than 50 W, water cooling is highly recommended. Greater than twice the normal air-cooled output power can be obtained from a water-cooled tube, and water cooling is quiet.

Tube Modification and Water Jacket

The first step is to remove the air radiator from the tube. The air radiator screws on, so it may simply be unscrewed without damage to the tube. First, place a hose clamp around the tube anode. Secure the radiator fins in a vise and grip the hose clamp with a pair of large pliers. Gently unscrew the tube from the radiator. If the hose clamp slips slightly, tighten it. Some 7289/2C39 tubes use an air radiator that is attached with setscrews. To remove the radiator, simply remove the setscrews and pull the radiator off. The air radiator will be replaced with a water jacket that allows water to be circulated past the tube anode and through a heat exchanger, where it is cooled and circulated past the tube anode again. Two different types of water jackets are described here. The water jacket shown in Fig 21 will work with any type of 7289/2C39. It is fabricated from a 1-inch-OD copper tubing cap and two short pieces of 9/32-inch OD brass tubing. The copper tubing cap should be available from a local hardware store or plumbing supply house. Brass tubing is available from many hobby stores and metal supply houses. Mark and drill the copper cap so that the brass tubing is a snug fit. Thoroughly clean the parts until they shine. Push the tubing into the holes in the end cap and degrease the assembly with alcohol. Use plenty of flux and solder the seam around each section of tubing. Allow the jacket assembly to cool. Meanwhile, thoroughly clean the 7289/2C39 anode to a bright finish. Check the water jacket for fit. In some cases, you'll have to use a 0.005- to 0.010-in.-thick copper shim to fill the gap between the copper cap and the tube anode. This shim helps eliminate pin holes in the solder. Using plenty of flux, solder the water jacket to the tube anode. Solder it quickly with a hot, high-wattage iron. Allow the tube to cool in the air after soldering to avoid thermal shock and possible breakage. After the tube has cooled, use plenty of alcohol to remove all traces of flux from the tube and water jacket. The second type of water jacket is shown in Fig 22. This jacket will work only with 7289/2C39 tubes that have a screw-on air radiator. It is designed to thread onto the tube anode just like the air radiator did. This jacket is machined from a piece of 1¼ inch aluminum rod. The water inlet and outlet tubes are made from 9/32-inch-OD, ¼-inch-ID aluminum tubing that is epoxied in place. A rubber gasket seals the jacket against leaks. If you have access to a lathe, you should have no trouble duplicating the jacket. You could have one made up at a local machine shop. Complete screw-on water jackets are also available from Angle Linear.[2] After you unscrew the air radiator from the 7289/2C39, check for and remove any burrs from the tube anode. The anode surface must be flat if the rubber gasket is to be effective. Screw the water jacket onto the tube. Tighten by hand only. Do not use any tools, or you could damage the tube or jacket! Do not use the water inlet and outlet tubes for leverage—they have thin walls and break easily.



PART	DESCRIPTION
A	1/4" TO 3/8" REDUCER.
B	1/2" NPT TO 3/8" TUBE ADAPTER.
C	3/8" TUBE TO PUMP ADAPTER.
D	3/8" OR 1/2" NPT TO 3/8" TUBE ADAPTER.
E	3/8" TUBE TO EXCHANGER ADAPTER.
F	3/8" OD COPPER TUBE W/WIRE SOLDERED TO IT. (SEE TEXT).

Fig 23—Details of the water-cooling system. Recommended pumps are (1) Little Giant Pump Co. Model 1-42A or larger, available from most hardware stores; or (2) Calvert Engineering, Cal Pump Model 875S (160 gal/h), available from Calvert, 7051 Hayvenhurst Ave., Van Nuys, CA 91406, tel. 818-781-6029. The flow indicator (Model 15C; requires two ½-in. NPT connectors) is available from Proteus Industries, 240 Polaris Ave., Mountain View, CA 94043, tel 415-964-4163.

Water System

Fig 23 depicts the complete water-cooling system. Recommended pumps and accessories that have proven reliable and effective are listed in the caption. Any small pump, such as a fountain pump, that can deliver 160 to 200 gallons per hour can be used here. Most inexpensive pumps are not self-priming, which means that they won't pump water if they have air in the rotor. Although water can be forced through the pump for the initial prime, my system uses gravity priming. The water reservoir is a 2-foot length of 3-inch-OD plastic pipe that is available from hardware or plumbing stores. It is usually sold for use in residential sewer systems. The outlet is at the bottom and the inlet about halfway up the column. The inlet is located here to eliminate aeration that ionizes the water and reduces its effectiveness. The outlet feeds the pump directly. The pump and the reservoir outlet port should be mounted in the same plane. The pump should be oriented so that air bubbles will rise into the impeller output port and can be blown out once the pump starts running.

Flow Indicator and Heat Exchanger

Water cooling is best described as "super quiet." There is no noisy fan to hear to reassure you that the tube is receiving adequate cooling. If water flow is reduced or cut off during amplifier operation, tube damage is virtually assured. Flow interlocks and switches to shut down the amplifier if water flow is reduced are hard to find and expensive. Flow indicators, however, are inexpensive and reliable. A flow indicator has a spoked rotor that turns as water passes through the unit. If the wheel is turning, there is water flow; if not, you have a problem. Changes in flow rate can be observed by watching for speed changes in the rotor. A small lamp illuminates the flow indicator, making it easy to see rotation. The flow indicator should be mounted where it can be seen from the operating position and monitored during operation. Heat exchangers, or radiators, remove the heat from water as it passes through. For this application, a small automobile transmission-oil cooler works great. Most auto-parts stores and speed shops have a good selection. Some come with mounting brackets. Look for a cooler with the input and output ports on the top so air bubbles will rise to the top and move on without becoming trapped. Trapped air degrades cooler performance. If you use the amplifier for high-duty-cycle modes such as ATV or FM, or for long, slow-speed CW transmissions (EME, for example), you should use a small axial Whisper fan to increase the effectiveness of the heat exchanger. A fan isn't necessary during normal operation, or even for sustained operation at moderate power levels, but is highly recommended if you plan prolonged operation at maximum power. Locate the fan so the warm exhaust air won't heat up other equipment.

Hoses and Fittings

Most hardware stores carry a complete line of brass fittings and adapters that can be used for this project. Brass, however, will eventually corrode and pollute the water supply. Plastic fittings are cheaper and don't corrode, but they are harder to find. Recreational vehicle suppliers are my main source for these parts. They are used extensively in drinking water systems for mobile homes and travel trailers. Procure the fittings when you have the rest of the parts in hand, as there are many variables to consider. You can use any relatively soft, thin-wall vinyl tubing for all water lines. The main runs are made from ⅜-inch-ID hose, while ¼-inch-ID stock is used to connect to the 7289/2C39 water jacket. The ¼-inch-ID tubing fits snugly over the 9/32-inch-OD inlet and outlet tubes on the water jacket, so no clamps are required. All other hose connections should be secured with stainless-steel clamps to prevent leaks. Any leaks mean air in the system and deterioration of cooling performance.

Safety

The anode of the tube, and hence the water jacket and water, are in direct contact with the high-voltage supply, so some safety precautions must be observed. Approximately 12 to 18 in. of tubing should run between the 7289/2C39 jacket and any other component in the cooling system. This will allow enough resistance in the water to provide adequate current limiting, should the water contact any components that are grounded. It is best to ground the water supply at the pump. This can be accomplished by replacing a short section of the tubing that runs to the flow indicator with a piece of brass or copper tubing. Solder a wire to this metal tubing and connect the other end of the wire to your station ground. Use at least 24 in. of vinyl tubing between the anode cooling jacket and the ground point. On the warm-water side of the 7289/2C39, run 12 in. of vinyl tubing to a small metal fitting or short section of metal tubing, and then another 12 in. of vinyl tubing to a grounded point (this can be at the heat exchanger). You can measure the water leakage current to ground by placing a microammeter between the metal fitting that connects the two vinyl hoses and ground. Leakage current should be less than 10 mA with clean water and an anode potential of 1 kV. As the water ages, the leakage current will rise; when this happens, replace the water. Grocery stores carry distilled water for use in steam irons. It may be deionized and not truly distilled, but it works fine for about four to six months in this application. Filters can be purchased from scientific supply houses, but it's not really worth it because deionized water is so cheap. Do not use tap water under any circumstances! When you turn on the water system for the first time, run a gallon of water through it for half an hour to wash out fabrication impurities. Replace with clean water before using the system to cool the amplifier. Water was chosen because it's inexpensive, nontoxic, nonflammable, and easy to clean up if you have a leak. Better liquid coolants are available, but they are toxic. Don't use them!

Cooling Performance

Fig 24 is a graph of several transmit/receive cycles on a water-cooled, 500-W output, 23-cm power amplifier. For this test, two of the amplifiers described here were coupled with a hybrid combiner. This particular cooling system used one gallon of water. Experiments indicate that, during extended operation, the water temperature rises only 30 to 35 F° above ambient room temperature. Typically, the tube anode and water average 10 to 15F° above ambient during casual operating. Flow rates in this system are typically ⅓ gallon per minute per tube, which is more than adequate. At this rate, more than 300 W of dissipation from a single inefficient 7289/2C39 were required to boil the water in the water jacket. The water should not be allowed to boil because this will heat the rubber gasket.

Tubes

It is not really necessary to buy a new 7289/2C39. Used

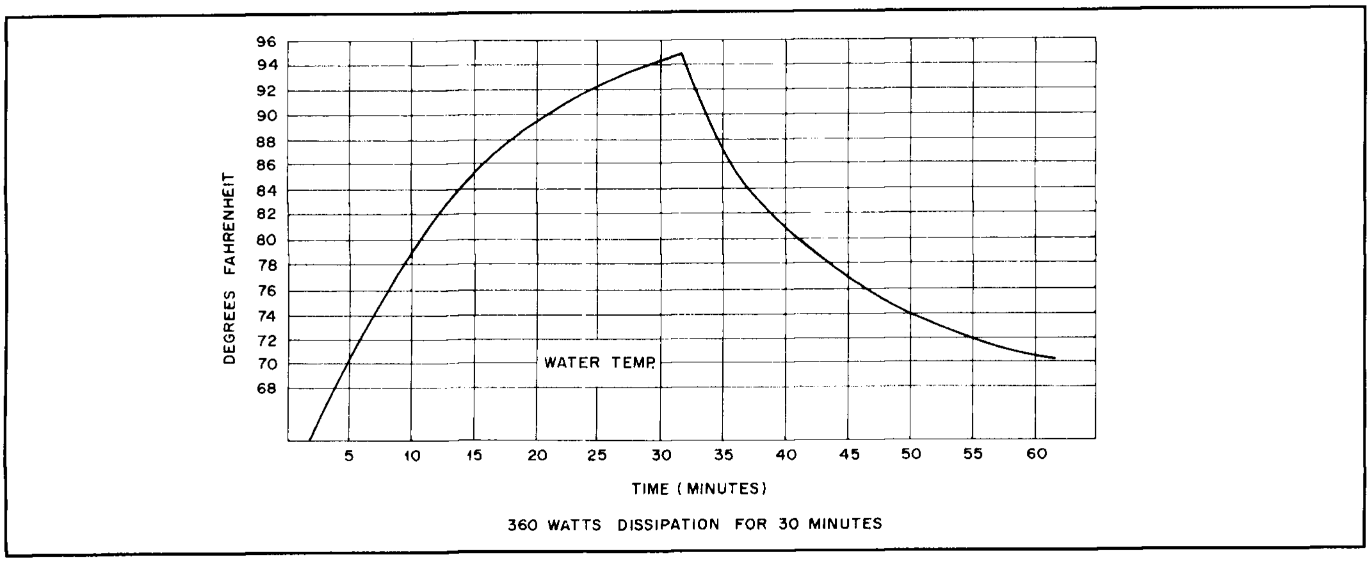


Fig 24—Performance graph of the water-cooling system.

tubes can be found surplus for a few dollars and, in many cases, will perform as well as a new tube. Most used tubes have been sitting around for several years, so it's a good idea to run them through the dishwasher to clean them up and then run the filaments for about 24 hours. This will restore operation in many cases. If you buy a new tube, you should be aware that the 7289/2C39 is being run far in excess of its ratings in this amplifier. The manufacturer's warranty will not cover tubes run in this application. Contrary to popular opinion, glass tubes will work. Physically, they are not as rugged as the ceramic version, but the glass-to-metal seal seems to provide better shelf life than the ceramic seal. The glass tubes make great driver tubes and will work fine for power levels up to 100-W output. Pulse tubes (7815, 7211) are not recommended because of their poor thermal stability at high power levels. Also, they generally are 30 to 40 MHz lower in resonant frequency in this amplifier compared to the 7289/2C39. Some 7289 tubes can be as much as 30 MHz lower in frequency. Minor length adjustment of the anode-tuning post may be required to accommodate amplifier and tube differences.

Tube Insertion

Extreme care must be exercised when inserting the 7289/2C39 tube. Never force the tube in place as damage (bending) of the cathode finger stock may result. Observe the layout of the finger stock to get an idea of how the tube inserts. Carefully position the tube so it is straight as you gently push. It should slide in snugly without any solid resistance.

Testing

After you have completed all of the parts for the amplifier, it's time to test everything before hooking it all together. Test the water-cooling system by turning it on and watching for steady water flow as indicated on the flow meter. The tube and water jacket can be removed from the cavity amplifier for this test. Check all of the power-supply voltages first without connecting them to the RF deck. Then, without the tube in place, hook the bias and filament supplies to the cavity and check the voltages again at the tube finger-stock connections. Connect the high-voltage supply to the RF deck and bring the voltage up slowly with a variable autotransformer. Monitor the high-voltage on the anode bypass capacitor plate, and look and listen for any possible arcing between the anode-bypass-capacitor plate and ground. Use extreme care when measuring and testing the high-voltage supply. If everything looks okay with the power supplies, shut them off and disconnect them. You can make a safe, low-power test of the cavity resonance without applying any voltage. With the tube in place, insert a 2-inch-long coupling loop on the end of a piece of coaxial cable between the spring fingers of the anode down into the cavity. Connect the amplifier output probe/connector to a device capable of detecting low-level RF at 23 cm (for example, a spectrum analyzer or microwattmeter). Feed a signal from an L-band signal generator into cable attached to the wire coupling loop that you inserted into the cavity. Set the signal generator for various frequencies in the 23-cm band and tune the amplifier anode tuner. There will be a sharp peak in output at cavity resonance. This testing method can be used to determine cavity tuning range, anode-bypass-capacitor effectiveness and resonance of various tube types for use in this amplifier. Any cavity amplifier can be tested completely without ever applying high voltage. The better your test equipment, the easier the amplifier is to test. If all dimensions were followed strictly, the amplifier will tune as designed.

Amplifier Hookup

Installation and operation of this amplifier is relatively straightforward, but as with any amplifier, several precautions must be followed. If these are adhered to, it will provide years of reliable service. The amplifier is designed to be operated in a 50-Ω system and should never be turned on without a good 50-Ω load connected to the output connector. Never operate it into an antenna that has not been tuned to 50 Ω! Drive power to the amplifier should never exceed 15 W. Never apply drive power in excess of 1 W unless all operating voltages are present and the tube is biased on. Otherwise, the tube grid-dissipation rating will be exceeded and you will probably ruin it. As in all TR-switched systems, some type of interlock or sequencing of transmit and receive functions should be incorporated. In most systems, the sequence for going into transmit is something like this: First, switch the antenna changeover relay from the receiver to the power amplifier. Next, bias the power amplifier on. Last, key the exciter and apply drive to the amplifier. To go to receive, unkey the exciter, remove operating bias from the amplifier and switch the antenna relay back to the receiver. If the antenna relays are switched while the power amplifier is operating and putting out power, damage to the relay contacts and/or the amplifier is likely. If there is a momentary removal of the antenna while the power amplifier is biased on, it may oscillate. This can damage the TR relay, the tube, or even the receive preamplifier.

Tune Up and Operation

This is it—the big moment when you will see your project come to life! Connect an accurate UHF power meter and a 50-Ω antenna or load to the amplifier output connector. A Bird Model 43 wattmeter with a 100- or 250-W, 400- to 1000-MHz slug will give reasonable accuracy, depending on the purity of the drive signal. Apply filament power and tube cooling, and allow 3 to 5 minutes for the filaments to warm up. Turn on bias supply (the amplifier will draw maximum current if the anode voltage is applied without bias). Apply 300 to 400 V to the anode. There should be no current flowing in the tube as indicated on the cathode-current meter. Ground J1 on the bias supply to apply transmit bias and observe cathode current. As R1, the bias control, is turned clockwise, quiescent idling current should increase. Set for about 25 mA. Apply 1 W of RF drive power. Turn the anode tuner while observing the RF output power meter and tune for maximum output. The output should go through a pronounced peak at cavity resonance. Adjust C2 and C3 on the input tuning network for maximum amplifier output. If possible, use a directional wattmeter between the driver and the amplifier input to check that best input SWR and maximum amplifier output occur at roughly the same setting. Depending on the amount of drive power available, you may want to tune the amplifier for maximum power output or maximum gain. Fig 25 shows what you can expect from different drive levels. Once the amplifier is tuned

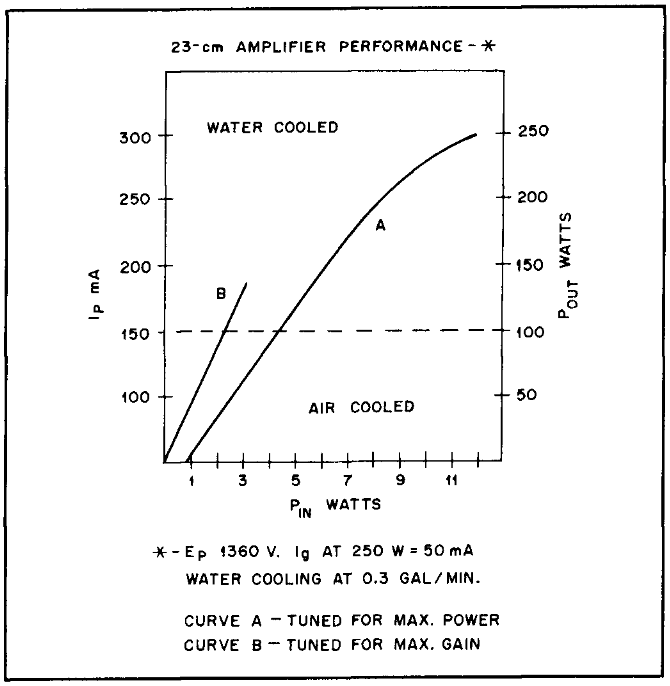


Fig 25—Performance of the cavity amplifier under different drive and plate-current conditions.

for best input SWR and maximum output with 1 W of drive, anode voltage and drive power can be increased. Increase both in steps; be sure to keep the anode tuner peaked for maximum output power. When you get to the 100-W output level, very carefully readjust the input circuit for maximum output. The input capacitor closest to the cathode is critical and should need to be rotated less than 90 degrees maximum. Maximum output power will be roughly coincident with best input SWR. Increase the drive power and keep the anode tuner peaked for maximum output. Increase the drive until you reach the desired output level, but do not exceed 400-mA IK! At 1300-V dc and 350-mA IK, output power with a good tube should be about 230 to 250 watts. At lower anode voltages, IK will be higher for the same output power. Higher anode voltages result in higher gain, lower drive levels, lower grid current and lower plate current for a given output power. The anode tuner's tuning rate is approximately 5 MHz per turn. Clockwise rotation of the tuner lowers the resonant frequency of the cavity. This control will require readjustment as you make large frequency excursions within the 23-cm band (for example, if you go from 1296 weak-signal work to the 1269-MHz satellite segment). You should also check the input SWR if you move more than 15 MHz. Generally, amplifier tuning does not change much after initial setup. You should be able to turn it on and use it without retuning as it heats up. Slight adjustments may be necessary, however, depending on cooling, inherent thermal differences from tube to tube and duty cycle of the operating mode. Always keep the anode tuner peaked for maximum output, and check it from time to time, especially while you are first learning how the amplifier operates.

The output loading control is the output connector and probe assembly. Loading is changed by minor rotational adjustment of the Type-N connector. First loosen the jam-nut (or setscrew) slightly. While observing output power and keeping the anode tuner peaked, rotate the loading control ±30 degrees maximum for greatest output power. This should be done only once and should not need repeating unless another tube is installed. Even then it may not be required.

Notes

[1]The finger stock for this project is available from Instrument Specialties, P.O. Box A, Delaware Water Gap, PA 18237. Contact them for the name of the closest distributor. The part numbers for this amplifier are: anode bypass capacitor plate, no. 97-70A; grid plate, no. 97-74A; cathode board, no. 97-420A; filament board, no. 97-280A

[2]25309 Andreo Ave., Lomita, CA 90717.

A 2304-MHz 80-Watt Solid-State Amplifier

By David T. Hackford, N3CX

(From *Eastern VHF/UHF Conference Proceedings*, 1992)

It's always been difficult to generate more than 10 watts on the 13-cm band. The surplus TRC-29 cavity will produce 10-15 dB gain, but is hard to find. To generate this much power, you were limited to forced-air or water cooling. Water cooling provides better stability, but is difficult mechanically, and is not conducive to portable operation.

Fortunately, microwave power transistors are now available at reasonable cost. This amplifier uses two 40-W Class-C amplifier assemblies combined with 3-dB hybrid couplers. This is not a project for beginning buildings. The enclosures are made out of milled brass stock, and a channel is milled in the box for the transistor flanges. The milled channel for the flanges is made deep enough that the circuit board can be soldered to the brass box with the transistor leads resting on the traces. Rivets through the circuit board at grounding points are required for good RF grounding.[1] The Sage Wireline 3-dB hybrid couplers (octave bandwidth) are easily made. If you're not familiar with this line, write for the *Designers Guide to Wireline & Wirepac*.[2] Also see the article by W3HQT [3].

Specifications for the single 40-W amplifiers I built are given in Table 1.

These amplifiers saturated at about 45 watts output. At 28 V, maximum current consumption is about 6 amps. Gains up to 8 dB are possible with some devices.

After building an amplifier you always want to do the big operational test. I ran mine in a January VHF Sweepstakes, and took it to the '91 June VHF outing. Both the single and combined amps worked normally. Running the dual amp, you'll need a good 28-V, 15-amp supply. With the losses in the phasing lines and the combiners adding up to approximately 1.5 dB, 15-20 W drive is needed to get 80 W out for that weak new grid or to get those birds off your new EME array. Fig 1 shows the art work I used for a single SD1870/TTC2223-18. Fig 2 is a schematic diagram of the single-device amplifier. Fig 3 is a photograph of two amplifiers combined with Sage Wireline com-

Table 1
Typical Specifications for Amplifier Using Two SD 1870/TCC2223-18 Transistors

Power In (W)	Power Out (W)	Gain (dB)
V_{cc} = 25 V		
8	30	5.75
10	36	5.55
V_{cc} = 28 V		
8	36	6.55
10	40	6.00

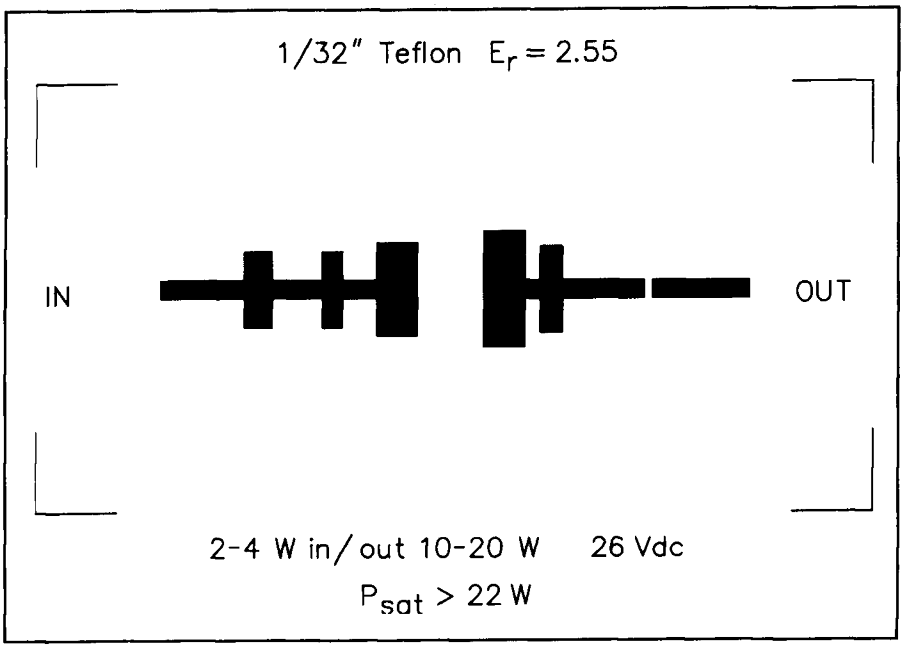


Fig 1—Full-size artwork for the amplifier circuit board.

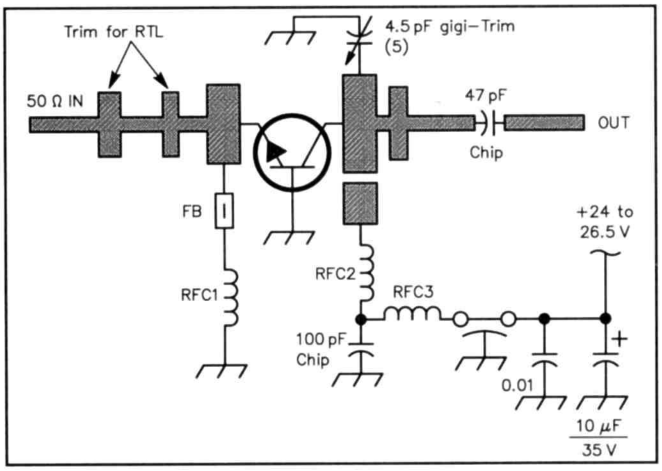


Fig 2—Schematic diagram of an amplifier stage. Two 40-watt stages are combined at their inputs and outputs to derive 80-watts total output.

biners. Fig 4 shows the power divider.

I'd like to thank David Mascaro for his help in testing the amps and transistors in the prototypes. Also Dick Comley, N3AOG, for his vertical mill workmanship and Paul Drexel, WB3JYO for his encouragement.

Notes

[1]Rivets are available from Frontier Microwave, RD 1 Box-467, Ottsville, PA 18942.

[2]SAGE Laboratories Inc., 11 Huron Drive, Natick, MA 01760-1314 (ask for sample of the line and a copy of *Designers Guide to Wireline and Wirepac*).

[3]B. Olson, "Solid-State Construction Practices," *QEX*, Jun 1987, p 11.

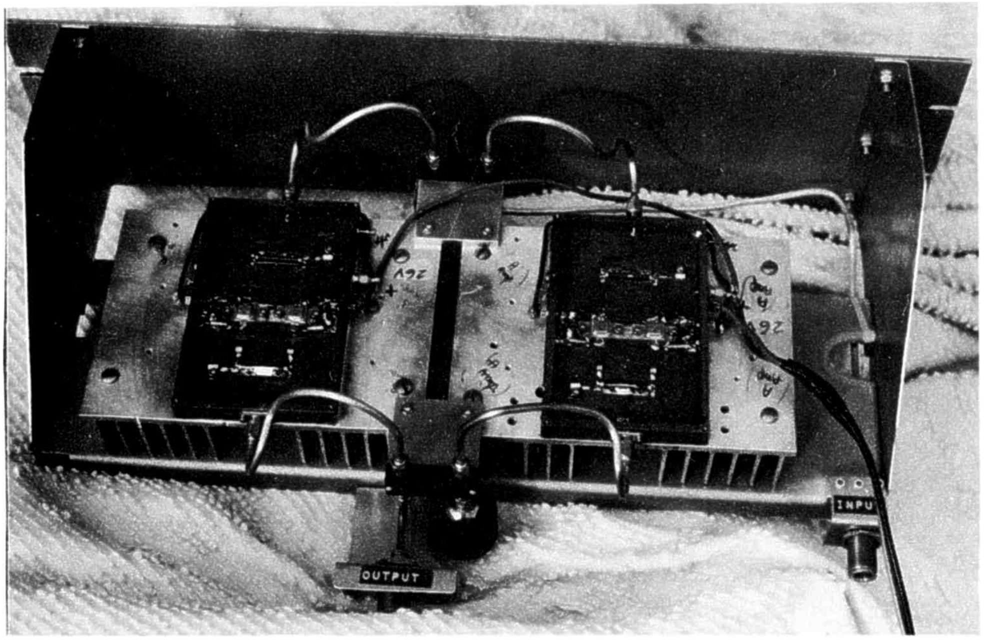


Fig 3—Photograph showing two amplifiers with inputs and outputs combined with Sage Wireline combiners.

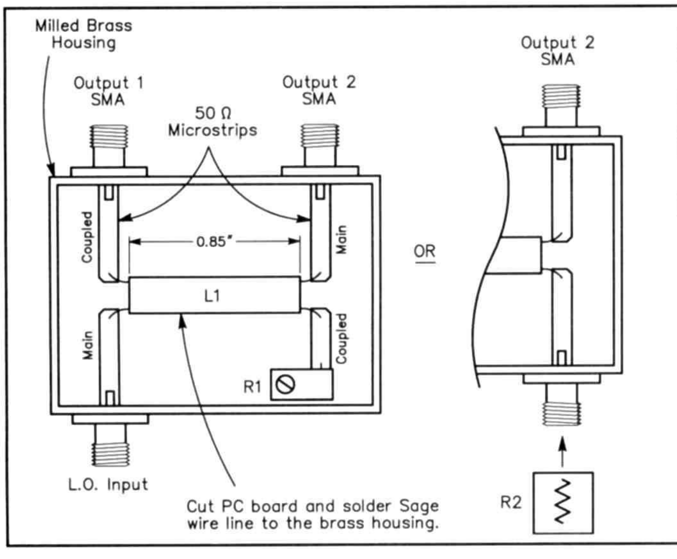


Fig 4—WA3JUF's two-way 2304/2160-MHz power divider.
L1—Sage 3-dB wireline
R1—50-Ω microstrip type termination
R2—50-Ω termination

A 7289 Amplifier For 3456 MHz

By B. W. Malowanchuk, VE4MA

(From *Microwave Update 1991*)

The recent rise in 3456-MHz activity due to the availability of surplus material and the no-tune transverters, has created a need for a reproducible high-power amplifier. This article describes a power-amplifier design for 3456 MHz, using a water-cooled 7289 or 7211 triode. The prototype amplifier has produced output powers of 35 W, with a gain of 10 dB and plate efficiencies of 10%. The detailed amplifier design has been previously published.[1] This paper focuses on the physical construction and operating characteristics of the amplifier.

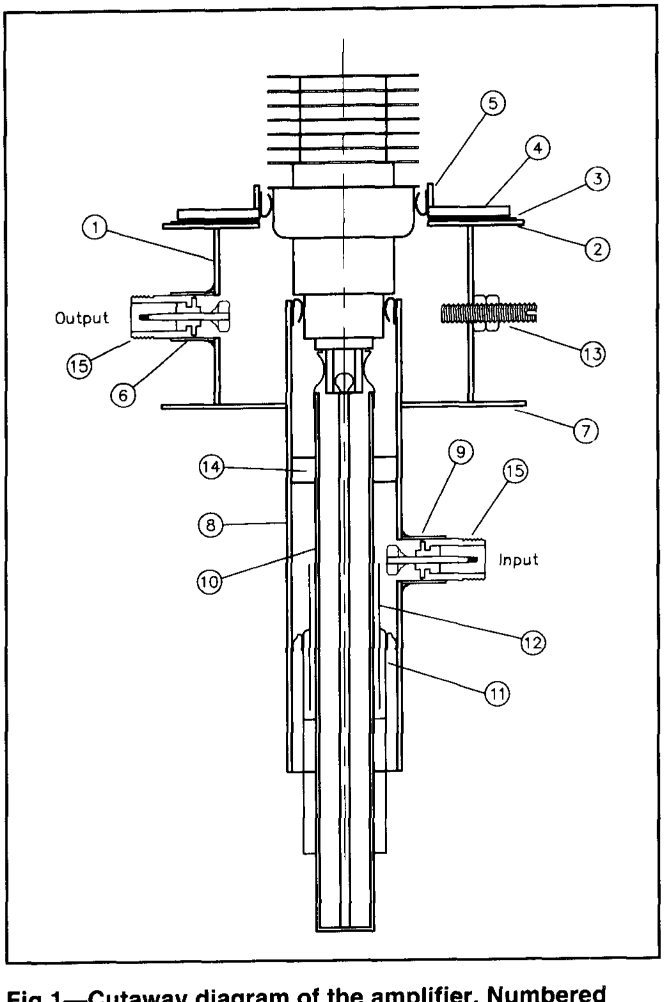


Fig 1—Cutaway diagram of the amplifier. Numbered components refer to the steps given in the text.

Amplifier Design

The amplifier design followed previous cavity amplifier work.[2,3] The anode cavity is a three-quarter wavelength capacitively tuned line. The output coupling uses a capacitive probe. A five-quarter wavelength cathode cavity is used in order to have it physically extend outside the anode cavity. The cathode timing uses a sliding RF short. Cathode coupling is again by capacitive probe.

Amplifier Construction

The full-size cross section drawing of the amplifier is shown in Fig 1. Most of the material required for construction should be fairly easy to locate, although some parts may require machining, or improvising with surplus material you have available. Referring to Fig 1, the construction of the numbered parts of the amplifier discussed in sequence:

1. Part No. 1 is the outside wall of the anode cavity. The material is copper or silver-plated brass stock with a 2-in. outside diameter and 1/16-in. wall. The anode cylinder is 1.5 in. high and is drilled 0.67 in. from one end, to accept the output coupling probe (Part 6) and anode tuning capacitor (Part 13). These pieces are on opposite sides of the cavity (Fig 2).

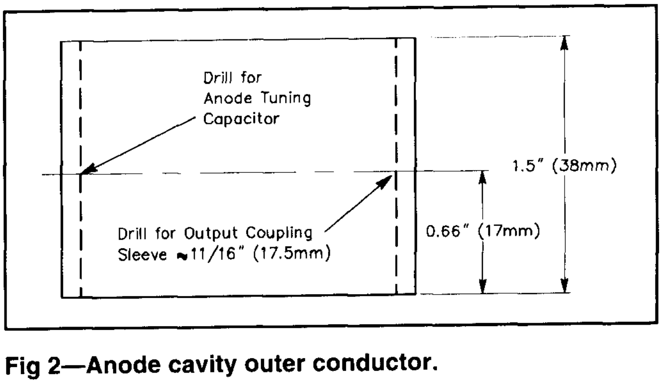


Fig 2—Anode cavity outer conductor.

2. Part No. 2 is the top plate of the anode cavity (See Fig 3). It is a 3-in. square plate of copper or silver-plated brass, 1/16-in. thick. It is drilled and tapped to accept four machine screws, which secure parts 2, 3 and 4 of the anode-bypass capacitor together. Cut a 1 3/8 in. hole in the center to provide electrical clearance from the anode.

3. Part No. 3 is the plastic insulator for the anode-bypass capacitor (Fig 4). It is 3-in. diameter and 0.0035-in. thick. The material used was "drafting" Mylar, which gives a much higher capacitance than Teflon. Higher dielectric-constant materials such as Kapton are desirable. The material should be as thin as possible to minimize radiation hazards. The center hole is 1.125-in. diameter.

4. Part No. 4 is the upper plate of the anode-bypass capacitor. As shown in Fig 5, it is a 2.5-in. diameter disk of 1/16-in. copper or silver-plated brass. The center-hole diameter will depend on your choice of finger stock for the anode contact. I used 1.25-in; see Part No. 5.

5. Part No. 5 is a support collar for the anode finger stock. Very small finger stock, such as Instrument Specialties 97-380, can be soldered directly to the inside of the center hole in Part No. 4. This finger stock is fairly fragile, so take care during tube insertion or removal. A support collar adds considerable strength.

Another option is to use larger finger stock and support it above Part No. 4 using Part No. 5. If this is done in a normal manner, the anode cavity length will have to be compensated for or you may be able to mount the finger stock upside down without compensation, to achieve good results.

Fig 6 reflects construction with this latter method and the dimensions for Parts 4 and 5 also reflect this choice. The finger stock used was similar to Instrument Specialties 97-135.

6. Part No. 6 is the sleeve for the output coupling probe and is shown in Fig 7. It is cut from a coupling for 1/2-in. copper water pipe, which conveniently is a good fit over a flangeless UG-58 A/U type-N female connector. It is slotted with a hacksaw to allow a small hose clamp to tighten the sliding joint (see discussion on Part 15). The sleeve should be made longer if extended input/output couplers are used.

7. Part No. 7 is the anode cavity bottom plate. It is a plate similar to Part No. 2, but no machine screw holes are required (See Fig 8). The center hole diameter of approximately 7/8-in. is a tight fit over Part No. 8.

The interfaces between Part Nos. 1, 7 and 8 are in a high-current area, so that connections should be soldered using a silver solder if possible.

8. Part No. 8 (Fig 9) is the inside conductor of the anode cavity and outside conductor of the cathode cavity. It uses a 3-7/8-in. length of 3/4-in. copper water pipe. A length of 97-380 finger stock is soldered to one end for the grid connection. At 1 5/8-in. from the other end, the pipe is drilled for the input probe.

9. Part No. 9 is the sleeve for the input coupling probe (Fig 10). This part is different from the output sleeve because of the small diameter of Part No. 8. The sleeve should be made longer if extended input/output couplers are used.

10. Part No. 10 is the inner line of the cathode cavity. It is not detailed here because it is fairly complex to build. It contains the filament and cathode connections. The important dimensions are the diameter of 7/16-in. and overall length of approximately 5 in.

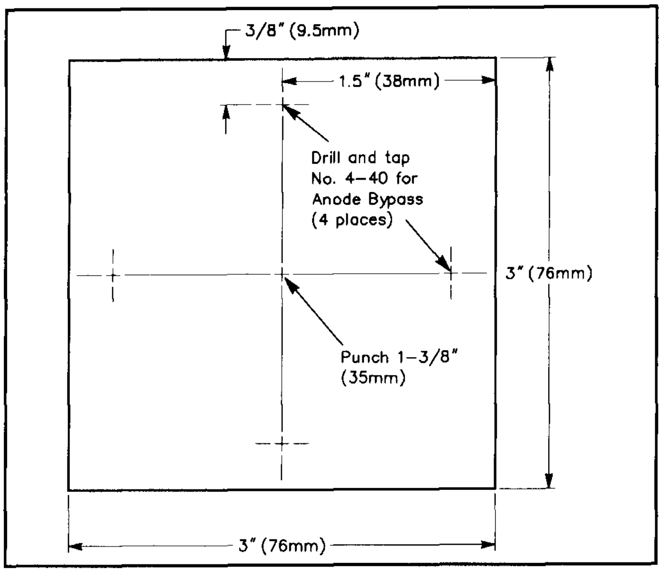


Fig 3—Anode cavity top plate.

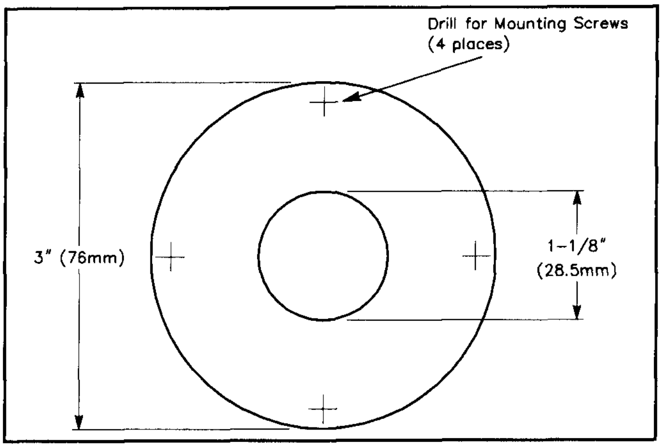


Fig 4—Anode bypass insulator.

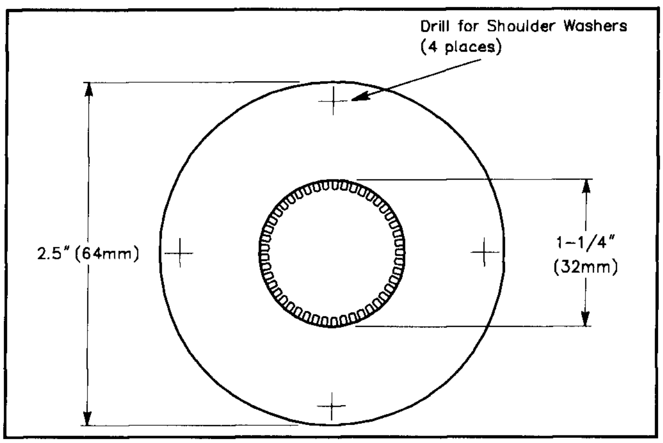


Fig 5—Anode bypass capacitor plate.

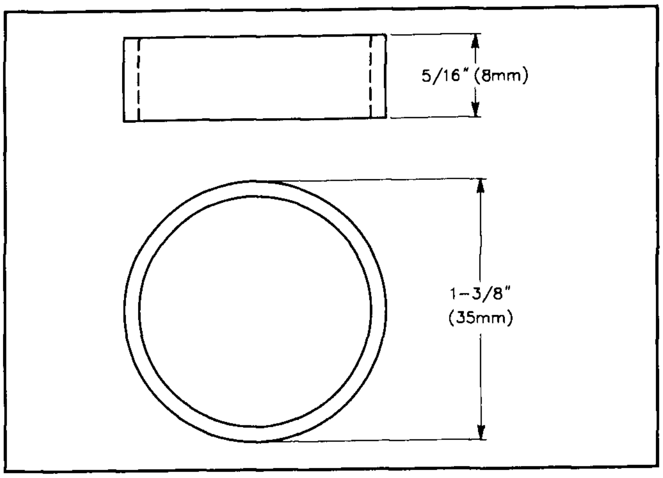


Fig 6—Anode finger-stock support ring.

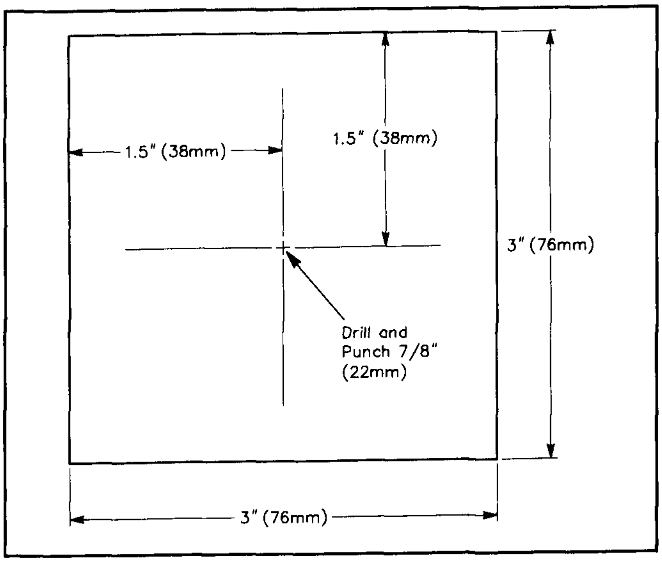


Fig 8—Anode cavity bottom plate.

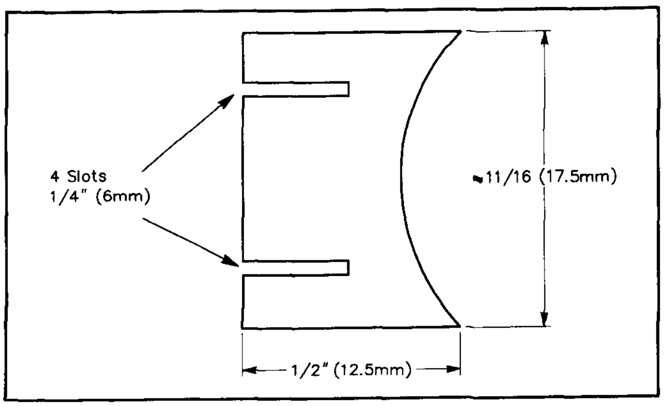


Fig 10—Input probe mounting sleeve.

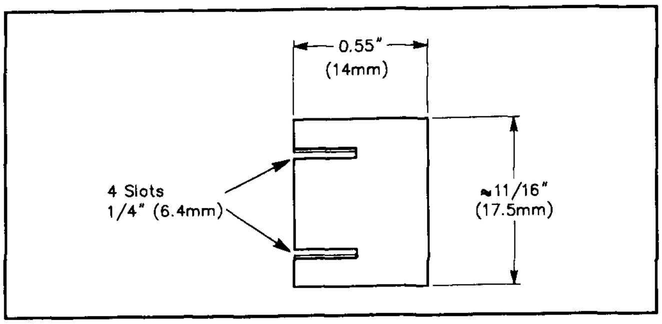


Fig 7—Sleeve for output coupling probe.

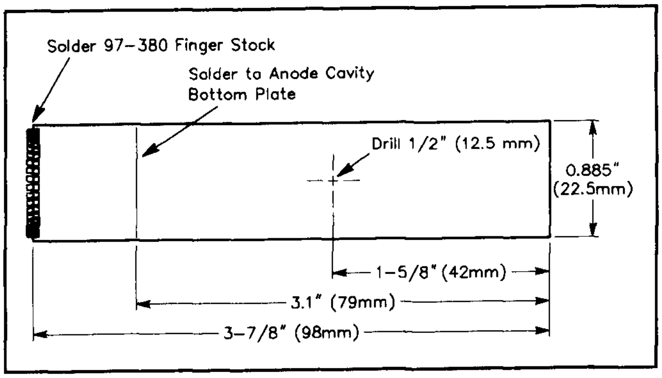


Fig 9—Anode cavity inner conductor and cathode cavity outer conductor.

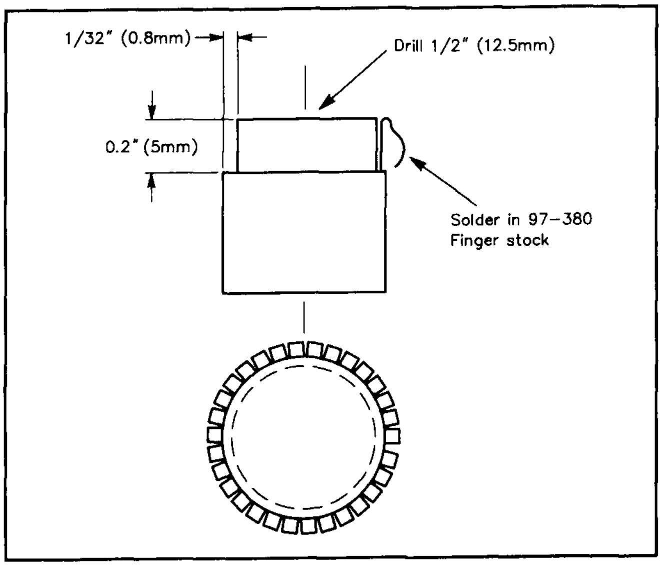


Fig 11—Tunable cathode short.

This assembly is probably best constructed from surplus parts.

11 and 12. Parts Nos. 11 and 12 form the tunable cathode-RF short. They really are a moving RF-bypass capacitor. Part No. 12 is a half wavelength piece of ½-in. brass tubing, which slides along Part No. 10, which has a layer of Teflon or Mylar tape wrapped on part of its length (1-4 in.) from the outside end. This forms a coaxial capacitor.

The center of the sliding capacitor is connected to the inside surface of Part No. 8 by Part No. 11 (Figs 11 and 12). Part No. 11 is created from a ½-in. copper water pipe "end cap." The closed end of the cap is drilled ½-in. to accept Part No. 12. The closed edge of Part No. 11 is turned down on a lathe (or in a drill press with a file) for a depth of approximately

1/32 in. and a length of approximately 0.2 in. The depth of the groove is chosen to let the finger stock make connection to Part No. 8 without excess mechanical tension.

A piece of 97-380 finger stock must be soldered to this groove. The soldering operation is delicate since you do not want to overheat the finger stock and Part No. 12 must be held concentrically while it is soldered.

The tunable RF short is extended outside the cathode cavity by two push rods soldered to the outside open end of Part 11. These can be made of 1/16-in. brass, and should be connected to a crossbar to ease adjustment.

13. Part No. 13 is the anode-tuning capacitor. This part deserves special attention, since the tuning will be rather sharp. I used a surplus 3/8-in. diameter brass bolt, which was threaded for 1-in. with 24 threads per inch (tpi). This worked reasonably well, but 32 tpi would be a better choice.

A threaded bushing 1/4-in. long is soldered into or onto the wall of Part No. 1. A similarly threaded nut with a split ring washer to provide tension on the threads will be required. The anode capacitor parts should be silver plated if possible, to minimize tuning noise as the metals oxidize.

14. Part No. 14 (Fig 13) is a Teflon insulator which holds Part No. 10 concentric inside Part No. 8. It can be held captive inside Part No. 8 by lightly center punching the walls.

15. Parts No. 15 are the input/output capacitive coupling probes. These can be made from UG-58A type-N connectors, with the mounting flange removed. This arrangement does not give much adjustment range, due to the short body length (Fig 14). A larger probe could be made by extending the UG-58 connector with a short length of 1/2-in water pipe and 1/4-in. rod.

The length of the extension should be made in multiples of a half wavelength so that the impedance variations will not be critical. The capacitive probe is completed by attaching a 10-32 brass nut to the end of the connector. The nut should protrude out from the coaxial section by 0.2 in.

Operating Results

The amplifier was tested using several GE 7289s of known quality with the following results:

Power Output	35 W
Power Input	3.5 W
Power Gain	10 dB
Anode Voltage	1300 V
Anode Current	269 mA
Grid Current	11 mA
Anode Efficiency	10%

A power gain of 10 dB was also measured at 20-W output, so saturation was not evident. The idling current was set to 100 mA, as thermal drift is minimal at that level.

Keep grid current low. High grid current causes heat that warps the grid, which changes amplifier tuning and makes the tube prone to arcing.

The amplifier is capable of more output power with additional driver power and anode current. High anode voltage would improve the output power and gain, but at a great risk of arcing.

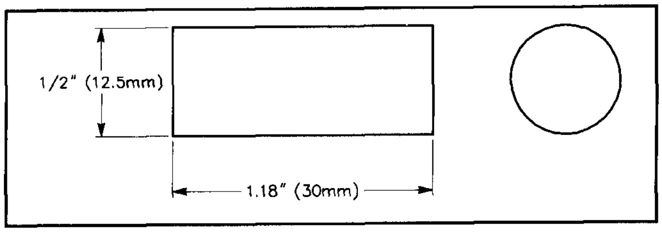


Fig 12—Half-wave stub.

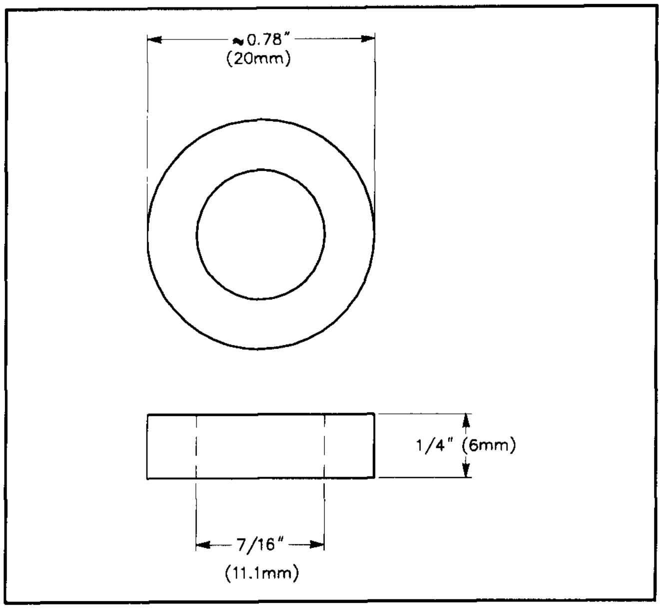


Fig 13—Cathode insulator.

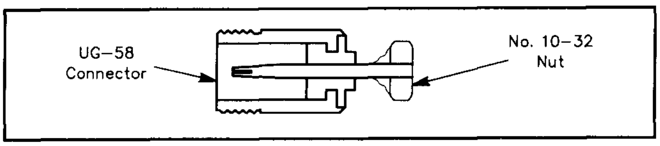


Fig 14—Input/output coupling probes.

Further Work Required

Although the amplifier met the original design objectives, an article by DJ6EP[4] suggests a major improvement in anode efficiency and output power by using an improved anode-bypass capacitor. This technique needs to be evaluated.

The ultimate output power of the amplifier needs to be explored fully, as EME contacts appear practical with this type of amplifier and a reasonably sized dish.

Notes

[1] B. Malowanchuk, "High Power Tube Amplifiers for 2304 MHz," *Proceedings of Microwave Update '89*, pp 88-98.

[2] Buzz Miklos, "Coaxial Cavity Amplifiers," *Proceedings of the Central States VHF Conference*, 1985.

[3] B. Malowanchuk, "2304 MHz Power Amplifier Using 7289 or Similar Tube," *Proceedings of Microwave Update '87*, pp 108-112.

[4] R. Wesolowski, "9-cm Band Tube PA Stage," *VHF Communications*, Issue 4, 1989.

A 125-Watt Amplifier for 902 MHz

By Ken Schofield, W1RIL

(From *QEX* for April, 1988)

This amplifier is a scaled version of an old friend, originally designed for 23 cm. A later version using water cooling, appeared in the Crawford Hills VHF Club *Technical Report*. In addition to scaling the dimensions to the 33-cm band, other changes to the original design include:

1. Additional reactance loading in the anode cavity.
2. Changes to output circuit with additional sliding drawer to facilitate easy loading adjustment.
3. Waveguide-beyond-cutoff air ducts to reduce RF leakage.
4. Use of aluminum wall stock instead of brass.
5. Use of micrometers as tuning devices.

Power output on 33 cm is 125 W with 10 W drive, a gain of just over 10 dB. Efficiency is about 40%. The amplifier is thermally stable with air cooling. During a 4-hour operating stint, power remained at the 125-W level, with no tuning adjustments necessary throughout the period.

You don't need a machine shop to construct this amplifier. Much of the drilling can be done with a small electric drill, but a small drill press makes the work easier. A drill press is especially handy for "fly cutting" the holes for finger stock. These holes can be opened up by drilling a series of small holes and finishing with a file, if necessary.

A drill press and a compound vise can serve as a small milling machine. The addition of a "dead center," bolted to the press table, turns it into a small vertical lathe. The Teflon shoulder washers for the amplifier can be easily made in this manner. It's just a matter of learning to work vertically, instead of horizontally!

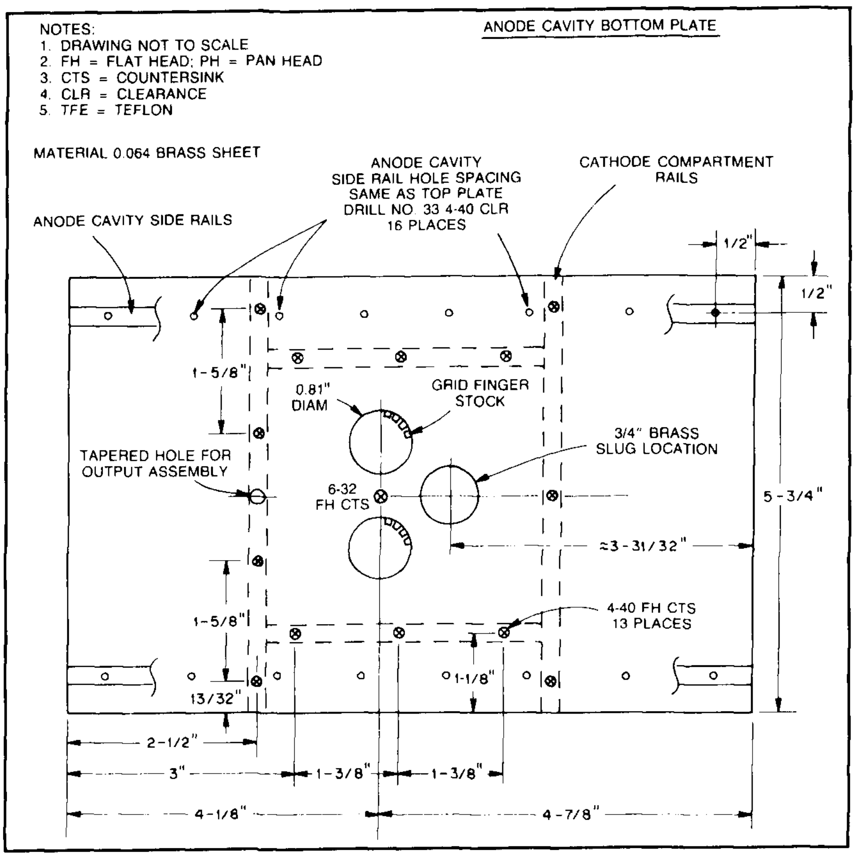


Fig 1—Construction information for the anode cavity bottom plate.

Input Circuit

An electrical λ/2 stripline is used in the cathode circuit. A portion of the cathode circuit includes the internal construction of the 7289 tubes. The line is adjusted capacitively on one end, and adjustable capacitive coupling provides input matching.

Output Circuit

The anode cavity is a capacitively loaded λ/2 circuit, tuned with a sliding drawer on one end. Loading adjustment is accomplished by a variable loop, formed by the output stud and the second sliding drawer on the other end of the cavity. Micrometers make tuning and loading adjustments smooth and postive.

Cooling and Mounting

The amplifier is adequately cooled by air pressure forced through ⅜-in. OD, beyond-cutoff, aluminum tubes in the sides of the cathode and anode compartments. Air is also blown across the plate fins of the tubes via a plenum. Both cooling and mounting can be successfully combined on a pressurized chassis, by mounting the amplifier on its side with the 6 air ducts protruding through the chassis. An additional cutout in the chassis allows air to be directed by the plenum to cool the finned anode plates.

You can make a suitable plenum from clear plastic mounted on ⅜-in. studs, which replace the 4 corner screws on the top plate. This cover also prevents accidental contact with the HV bypass capacitor. I use IPS *Weld-On 16* to cement the plastic.

Construction Considerations

Refer to Figs 1-14. It is important to keep the tube-socket locations in the several layers in proper alignment. Perhaps one of the best ways to accomplish this is to lay out the top bypass plate, drilling small pilot holes for the tube centers. Then, you can use this plate as a template to make like holes in the cavity top and bottom plates. Location of the Teflon shoulder washer and other critical holes are done in like manner. The cathode line can be held in place with its support hole and the tube centers located easily.

The air ducts are pressed into the aluminum walls in a vise. First, drill out the walls with a smaller drill, then ream the holes to accept the beveled end of the ⅜-in. tube approximately halfway through the wall. When pressed in flush, the tubes lock in firmly and make good electrical contact with the wall stock. The slippery characteristic of Teflon is used as a bearing surface to convert the rotary motion of the tuning micrometers to the push-pull motion required to move the tuning and loading drawer slides. Very little play is experienced

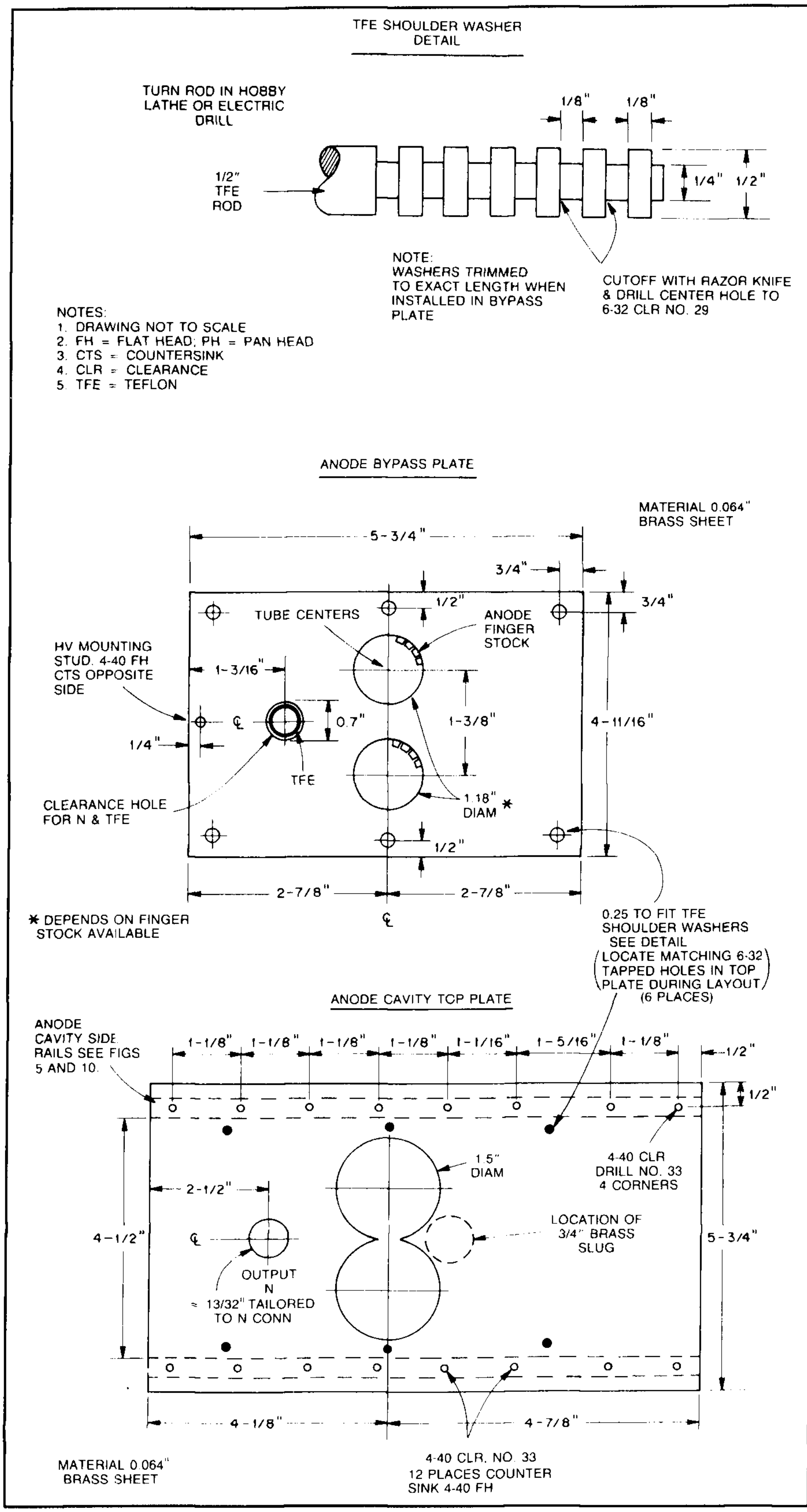


Fig 2—Details of the anode bypass plate and anode cavity top plate.

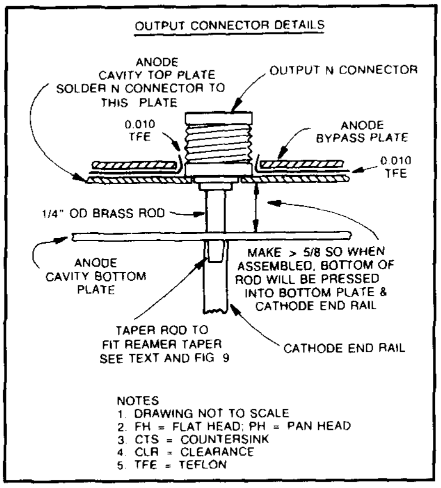


Fig 3—Output connector details.

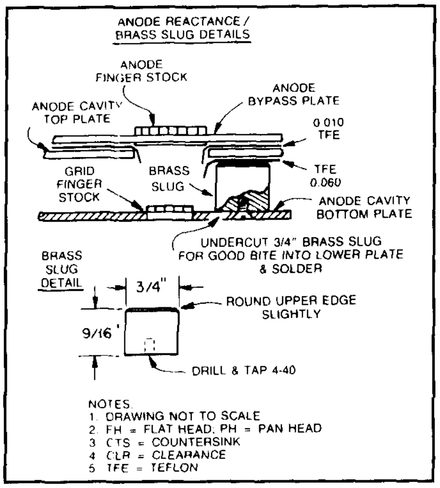


Fig 4—Construction and assembly of the brass slug that provides additional reactance in the anode cavity.

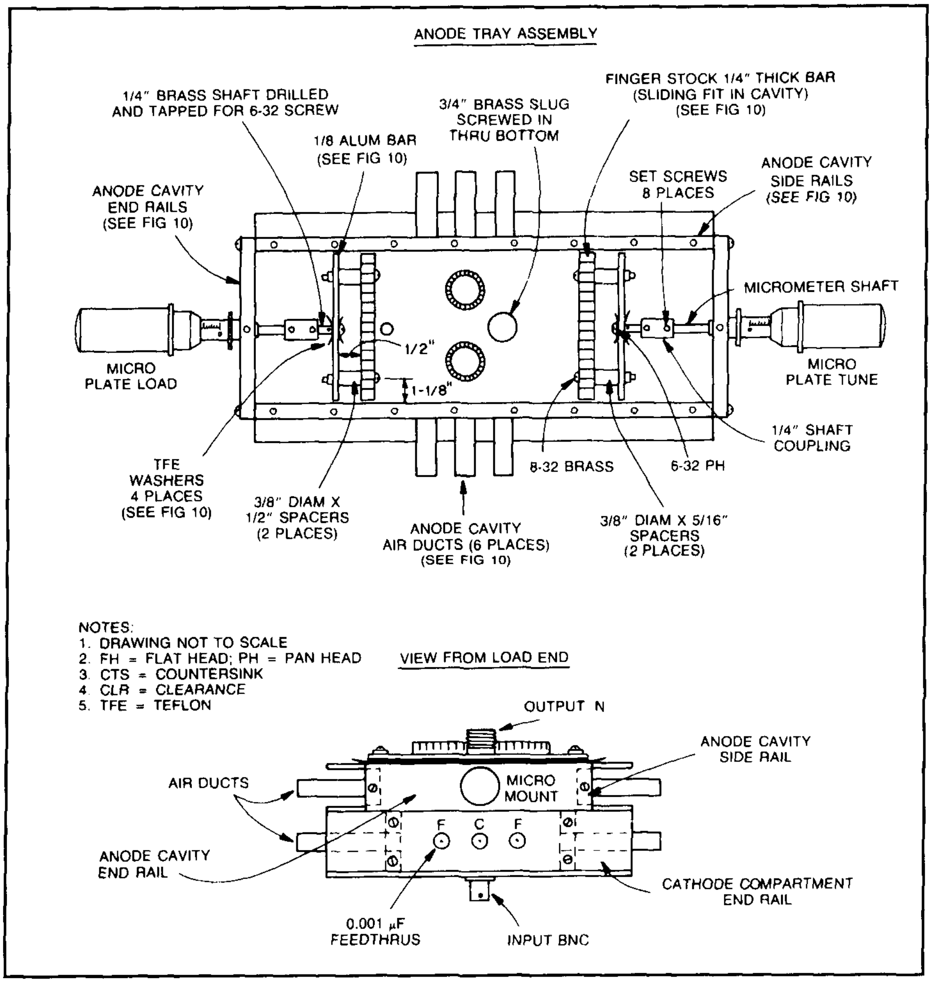


Fig 5—Assembly of the anode cavity.

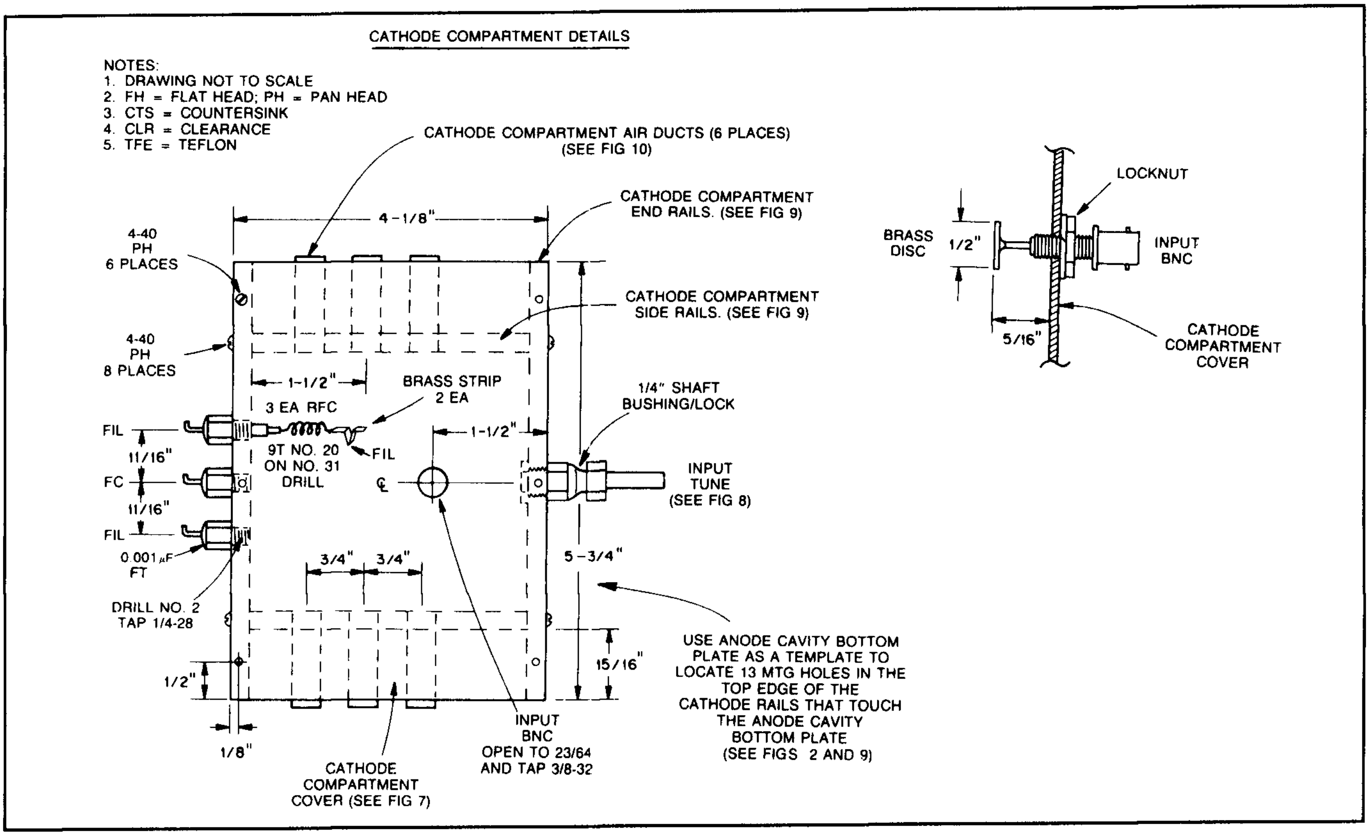


Fig 6—Cathode compartment details.

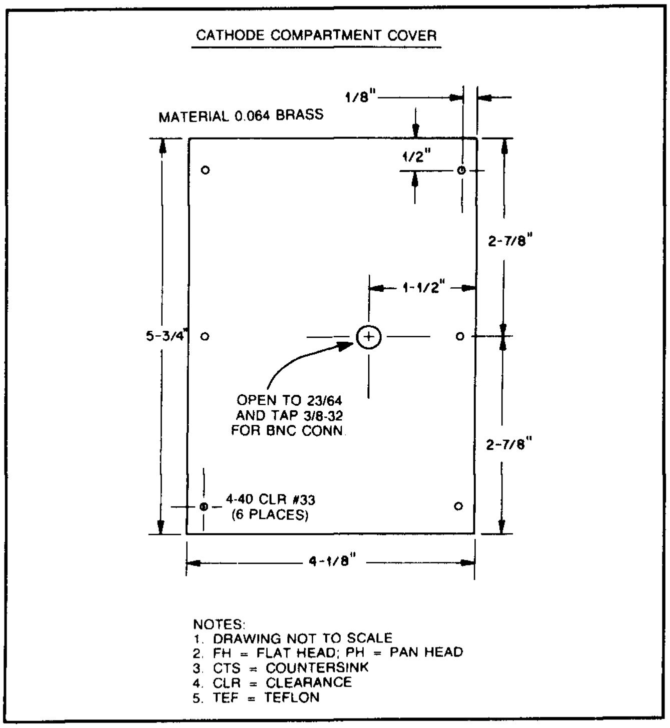


Fig 7—Cathode compartment cover drilling information.

using this method. Finger stock used in the grid and cathode areas is Instrument Specialties no. 97-251. You can use the same stock on the tuning slides. The anode finger stock was obtained at a flea market, and was formed into a ring. This ring is 7/16-in. high and can be formed from Instrument Specialties no. 97-139 stock.

Do not use nylon shoulder washers on the plate bypass capacitor, as they will break down! Teflon washers work well, even with voltages greater than 1400.

Tuneup and Results

Preset the load drawer to approximately 1/4-in. from the load stud, and the tune drawer to approximately 3/4 of the way out. Apply 500 V to the anode and adjust the bias circuit for a no-drive cathode current of 50 mA. Apply drive and adjust the cathode circuit for maximum cathode current. At the same time, adjust tuning and loading for maximum power output. Slowly increase anode voltage while maintaining no-drive cathode current at 50 mA by adjusting the bias, while repeaking all controls.

Adjust input SWR if necessary by variying the input BNC connector disc spacing. At the 10-W drive level, with 1100 plate V, anode current should be about 290 mA and output power should be about 125 W.

A consumer-grade microwave leakage detector indicated no RF leakage near the air ducts. When coupled tightly to the tube anodes, the detector's meter barely moved.

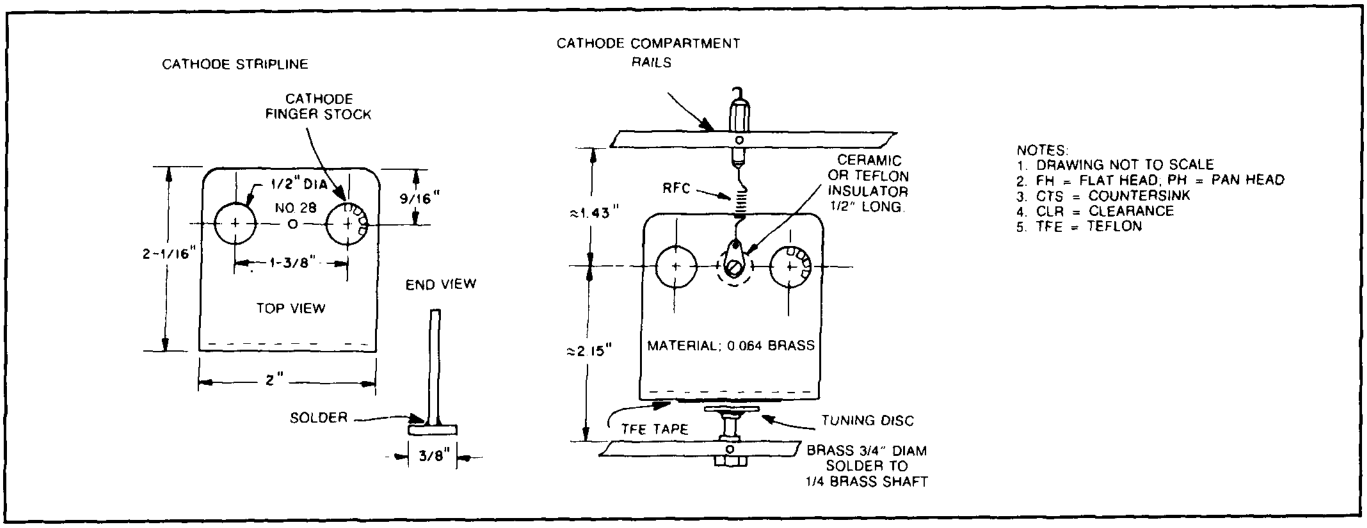


Fig 8—Construction and assembly of the cathode stripline.

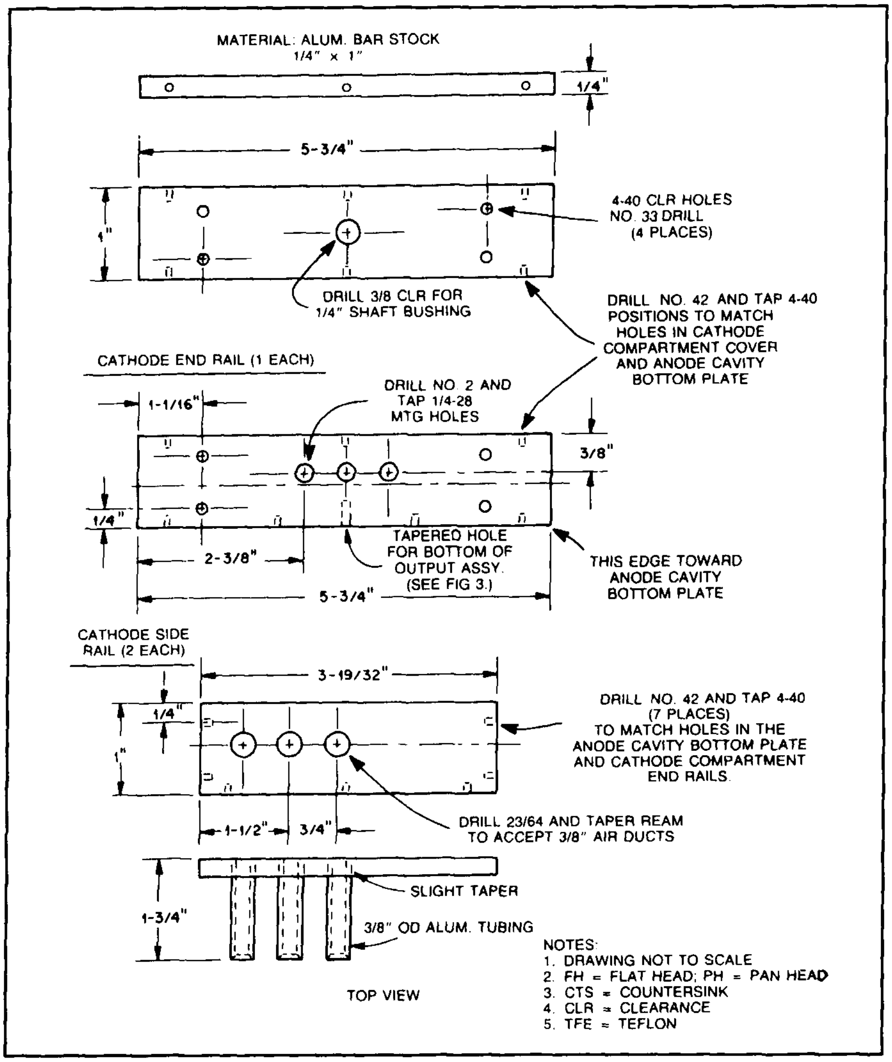


Fig 9—Construction information for the cathode compartment end rails, side rails and air ducts.

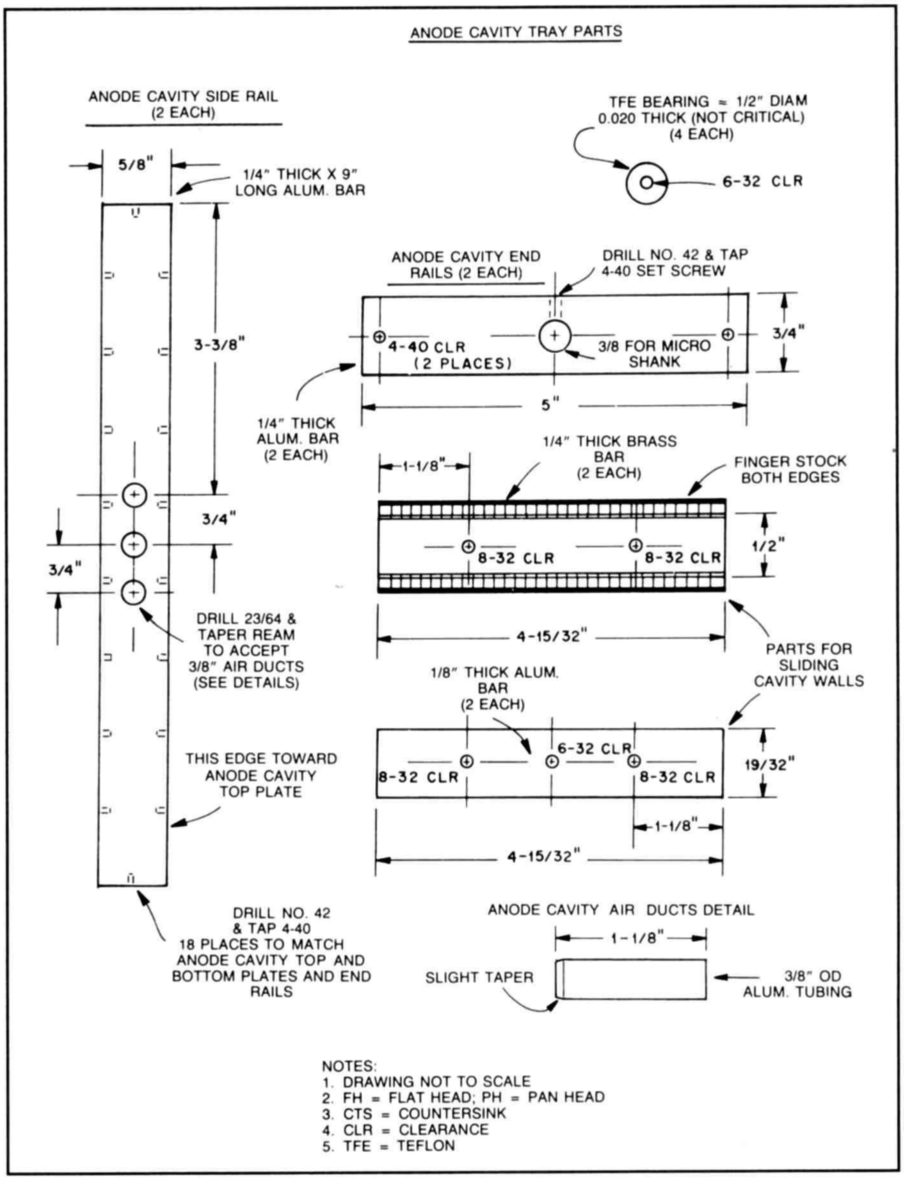


Fig 10—Construction information for the anode cavity parts.

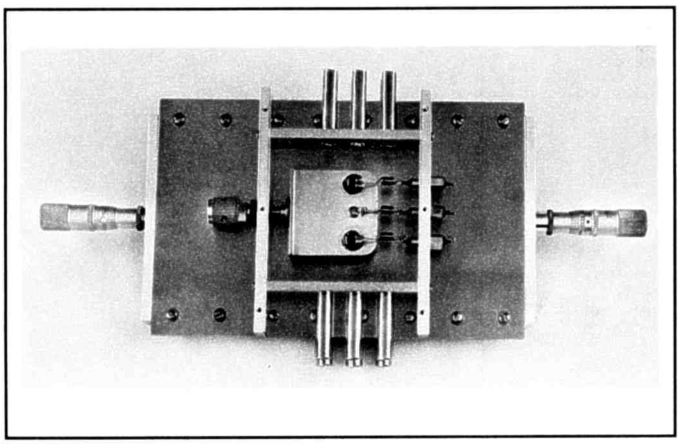


Fig 11—View of the anode cavity with the anode bypass plate and anode cavity top plate removed.

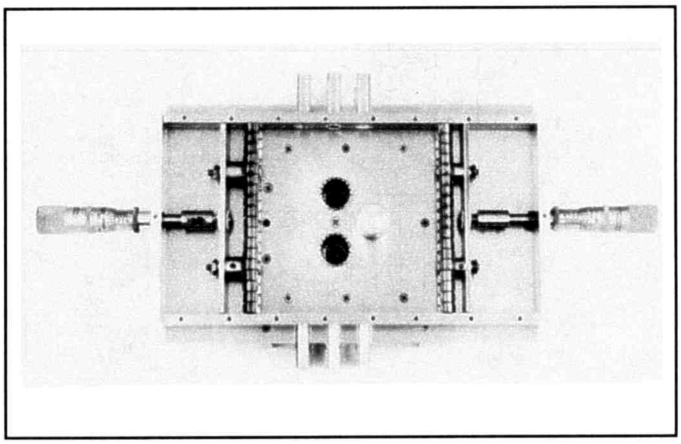


Fig 12—View of the cathode compartment with the cover removed.

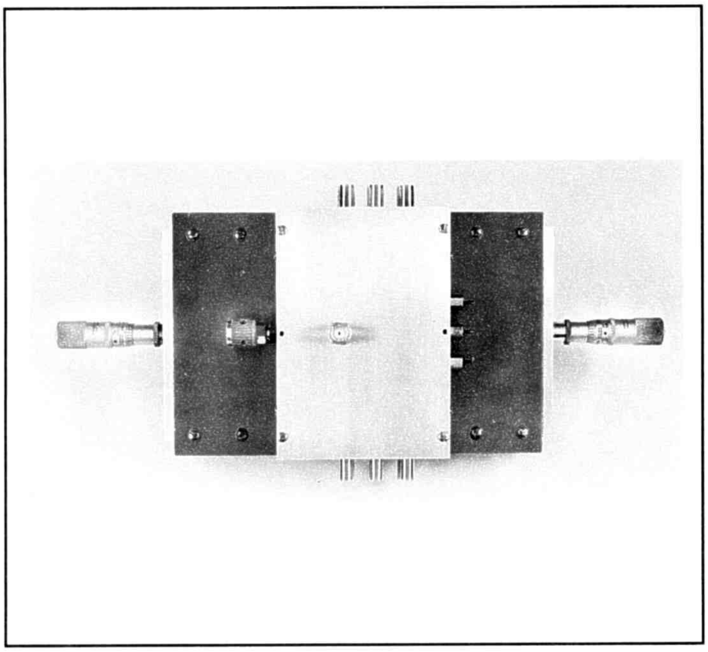


Fig 13—Underside of amplifier with the cathode compartment cover in place.

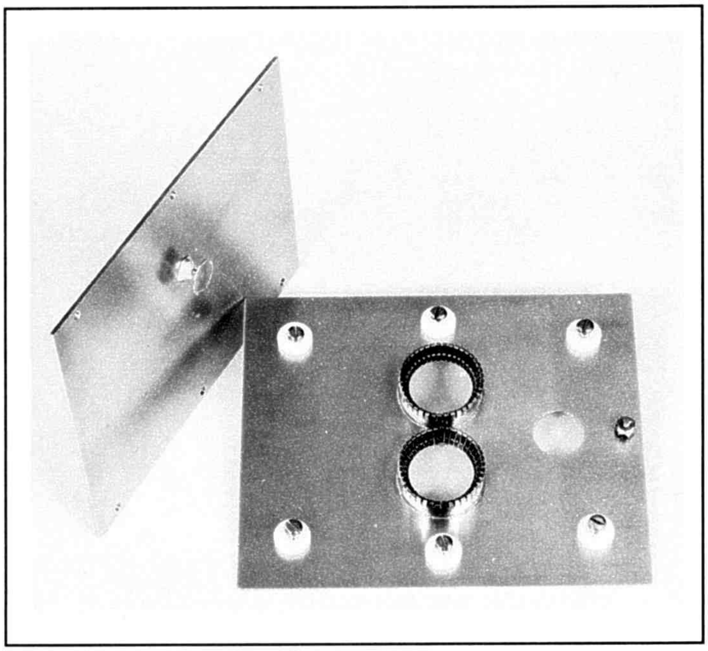


Fig 14—Cathode compartment cover and input coupling disk (left) assembled anode bypass plate (right).