linear amplifier design

The designer of a linear amplifier should be concerned with the proper potentials required to make the power tube operate in a linear manner. The word *linear* implies that the output signal of the amplifier is an amplified replica of the input signal. There's no such thing as a perfect linear amplifier, and the designer's problem is to make the practical amplifier (*i.e.*, the amplifier that can be built) as linear as possible.

When a linear amplifier is driven by a complex signal, such as the human voice, nonlinearity results in intermodulation distortion. This unpleasant form of distortion creates a broad, raspy signal that throws annoying "buckshot" into adjacent channels. Proper design and operation of a linear amplifier reduces this distortion to a minimum.

amplifier circuit and mode

There's a lot of confusion with regard to the so-called "grounded-grid" amplifier. Rf power amplifiers are classified according to circuitry and mode of operation. The two classifications should not be confused with one another. For Amateur service, the two most popular circuits are the grid-driven circuit and the cathode-driven circuit. As shown in **fig. 1**, the circuits are remarkably similar, the most obvious difference being the placement of the ground point in relation to the input and output circuits.

The mode of operation refers to the dynamic operating characteristics of the tube (class AB_1, class B, or class C). Characteristics of the classes are given in reference material listed at the end of this article. For linear service, the power tube amplifier is commonly run in either class AB_1 or class B service. Thus, modern equipment may have an intermix of circuitry and mode — the cathode-driven amplifier may be operated in a class AB_1 mode, for example, or the grid-driven amplifier may be operated in the class B mode.

So far, I've not discussed the popular grounded-grid amplifier. This is a sloppy term which usually refers to a cathode-driven amplifier, working in the class B mode. "Grounded grid" implies cathode drive, but in such a circuit the grid may not necessarily be at dc ground potential, especially with respect to screen voltage (see **fig. 2**). Rf ground and dc ground are not always the same in a linear amplifier, and most circuit engineers shudder at the use of the term.

amplifier plate circuit

While this series of articles concerns itself with linear, cathode-driven-amplifier design, the remarks about the plate circuit apply equally well to grid-driven amplifiers. It is desirable to operate any linear amplifier with a very minimum of intermodulation distortion, with high-plate efficiency, and with high power gain. The latter is especially important, as it affords maximum power output with a given amount of drive power. The class B mode of operation meets these requirements.

Shown **in fig. 3** is a graphical representation of a class B amplifier, showing the operating cycle of the tube. This is the portion of the electrical cycle over which the tube grid is driven positive (approaching +e) with respect to the cathode (or the cathode driven negative with respect to the grid). When the grid potential is highly negative with respect to the cathode (approaching −e), the tube is cut off and is inoperative. In the class B amplifier, the operating cycle is about one-half the electrical cycle, or approximately 180 degrees. The transfer curve plot shown indicates that the tube delivers power only over one-half of the electrical cycle and is cut-off during the other half of the cycle. Does this mean that the output signal consists of half-sine waves as shown, and is therefore highly distorted? Not at all.

The amplifier plate circuit (often called the tank circuit) saves the day, since the energy storage ability (Q) of the circuit balances the energy between the halves of the cycle, much as the flywheel stores energy during the operating cycles of a gasoline engine. The plate circuit must, therefore, be designed to have sufficient Q, or energy storage, for good operation. A Q value of 12 is commonly used for linear amplifier service, as it provides ample energy storage and at the same time provides reasonable reduction of harmonics generated in the amplifier.

By William I. Orr, W6SAI

A more accurate, computer-derived summary of pi network values is given in **table 1**. Note that, for a given plate impedance, when the operating frequency is doubled the capacitance and inductance values are halved. (Fifteen- and forty-meter constants are related by a factor of three as 21 MHz is the third harmonic of 7 MHz.)

coil winding

Winding plate coil L1 to a given value of inductance takes an inductance meter, or a degree of expertise and a dip-meter. A simple formula for calculating inductance when the coil dimensions are known is:

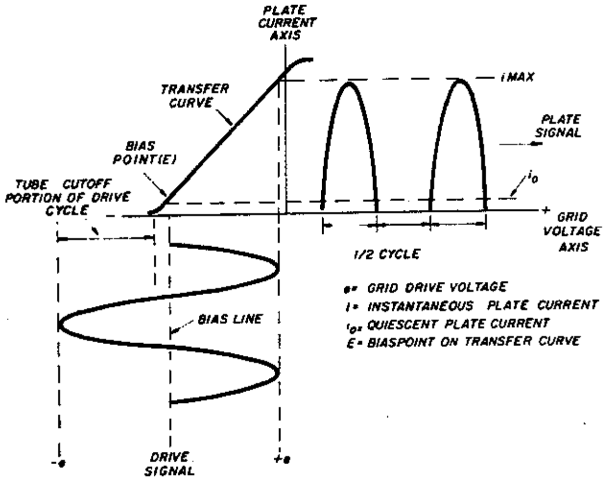


fig. 3. Transfer curve and operating cycle for a class B amplifier. The transfer curve is determined by a static test of the tube where plate current is plotted against grid bias. Once the transfer curve is established, the operating cycle may be determined. The sine wave drive signal (e) is drawn about the bias line, determining both the zero-signal plate current (i_o) and the peak plate current (i_{max}). Note that when the grid driving signal swings negative, no plate current is drawn and the tube is cut-off for one-half cycle. Pulses of plate current only appear when the drive signal is positive with respect to the bias voltage. Thus, the output waveform of a class B rf amplifier consists of a series of half-cycles, much in the manner of a half-wave rectifier. The distorted waveform is restored to a sine wave by the plate tank circuit which, by virtue of its Q, or flywheel effect, stores energy on the active half of the cycle and releases it on the inactive half. Circuit engineers, working from a transfer curve, can determine actual dc operating potentials for a linear amplifier.

$$Inductance\ (\mu H) = \frac{R^2N^2}{9R + 10S}$$

where R is the radius of the coil in inches
S is the length of the coil winding in inches
N is the number of turns

These calculations have been simplified in the ARRL type-A "Lightning Calculator," which is a simple slide rule providing direct read-out of the coil dimensions if the inductance is known. It takes the hard work out of designing coils.

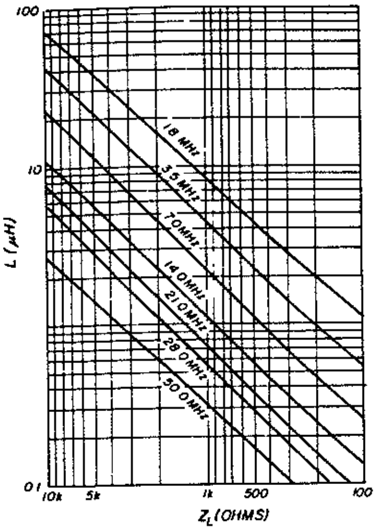


fig. 4. Plot of the plate inductance vs. plate load impedance for the high frequency Amateur bands (Q = 12).

Once the plate circuit has been designed and built, it is a good idea to "breadboard" it up and check it out with a dip-meter before the connections are finally soldered. Coil taps may have to be moved a bit to compensate for capacitance of the components to the chassis and adjacent parts.

amplifier-cathode circuit

The cathode-input circuit provides an impedance match between the 50-ohm coaxial output circuit of the driver/exciter and the input impedance of the cathode-driven amplifier (see **table 2**). The input im-

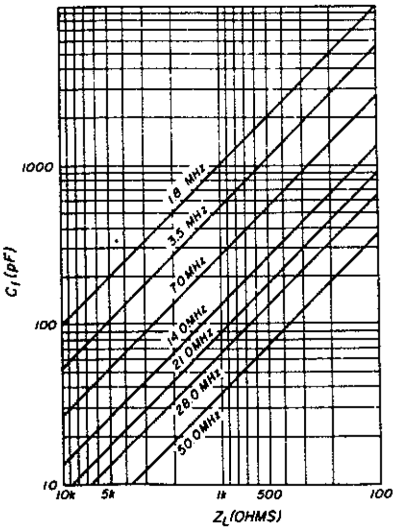


fig. 5. Plot of the tuning capacitance (C1) vs. plate load impedance (Q = 12).

pedance (Z_t) of a cathode-driven tube is related to the ratio of the peak cathode signal voltage to the peak cathode current (sum of grid and plate currents), and is commonly given in the tube data sheet. For the 3-500Z at 2500 volts, it is about 110 ohms. And for two tubes in parallel, it is about 55 ohms, but *only* over the operating cycle.

It is tempting to jump to the conclusion that if the amplifier input impedance is about 55 ohms and the coaxial line impedance driving it is 50 ohms, that no cathode impedance matching circuit is required. In fact, many commercially manufactured amplifiers leave it out for economy's sake. This omission is poor engineering practice, as the circuit *Q* is required in the cathode circuit as well as in the plate circuit. Omission of the cathode-tuned circuit can lead to distortion of the driving signal, increased intermodulation distortion, reduced amplifier efficiency, and driver loading problems. A circuit *Q* of 2 is adequate, and a simple rule of thumb is that the network circuit capacitances at resonance should be about 20 pF per meter of wavelength for one-to-one impedance transformation.

practical amplifier circuit

Armed with the information discussed so far, it is possible to draw up a schematic for a cathode driven, 2-kW PEP linear amplifier using two 3-500Z tubes in parallel (see **fig. 7**). This is a true "grounded-grid" circuit, as the grids are at both dc and rf ground potential.

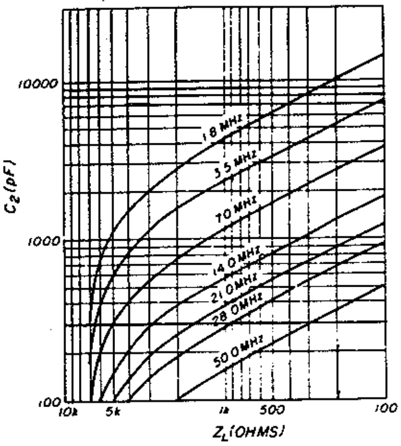


fig. 6. Plot of the loading capacitance (C2) vs. plate load impedance (Q = 12).

Note that plate and grid currents are measured in the cathode return circuit. This requires the amplifier plate power supply to "float" a little above ground potential in order to insert a meter in the negative lead to measure plate current. This removes the lethal plate voltage from the meter. The grid meter is out of the critical rf ground return path, which simplifies the metering circuit. A filament voltmeter is included. Filament voltage should be held to within

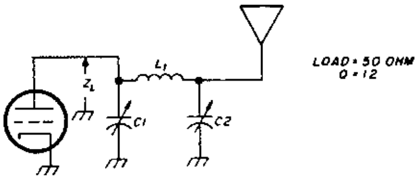


table 1. Computer-derived values for a pi network having a *Q* of 12 and working into a 50-ohm load. Values for C1 include the output capacitance of the tubes. These values are taken from a computer program derived by Bob Sutherland, W6PO.

component		Z_L plate load impedance (ohms)							
	band	1000	1500	2000	2500	3000	3500	4000	5000
C1	160	1060	690	531	430	354	309	265	212
	80	546	364	273	220	182	159	136	109
	40	273	182	136	110	91	80	68	55
	20	136	91	68	55	45	40	34	27
	15	91	61	45	37	30	26	23	18
	10	68	45	34	30	23	20	17	14
C2	160	4421	3487	2865	2440	2105	1849	1594	1186
	80	2274	1784	1473	1263	1082	951	820	610
	40	1137	892	737	632	541	475	410	305
	20	568	446	368	316	271	237	205	153
	15	379	297	246	211	180	158	137	102
	10	284	223	184	158	135	118	102	76
L1	160	8.84	13.26	16.61	20.10	24.13	27.80	31.47	38.63
	80	4.55	6.57	8.54	10.90	12.41	14.29	16.18	19.87
	40	2.27	3.28	4.27	5.50	6.20	7.15	8.09	9.93
	20	1.14	1.64	2.14	2.70	3.10	3.57	4.05	4.97
	15	0.76	1.09	1.42	1.82	2.07	2.38	2.70	3.31
	10	0.57	0.82	1.07	1.36	1.55	1.78	2.02	2.48

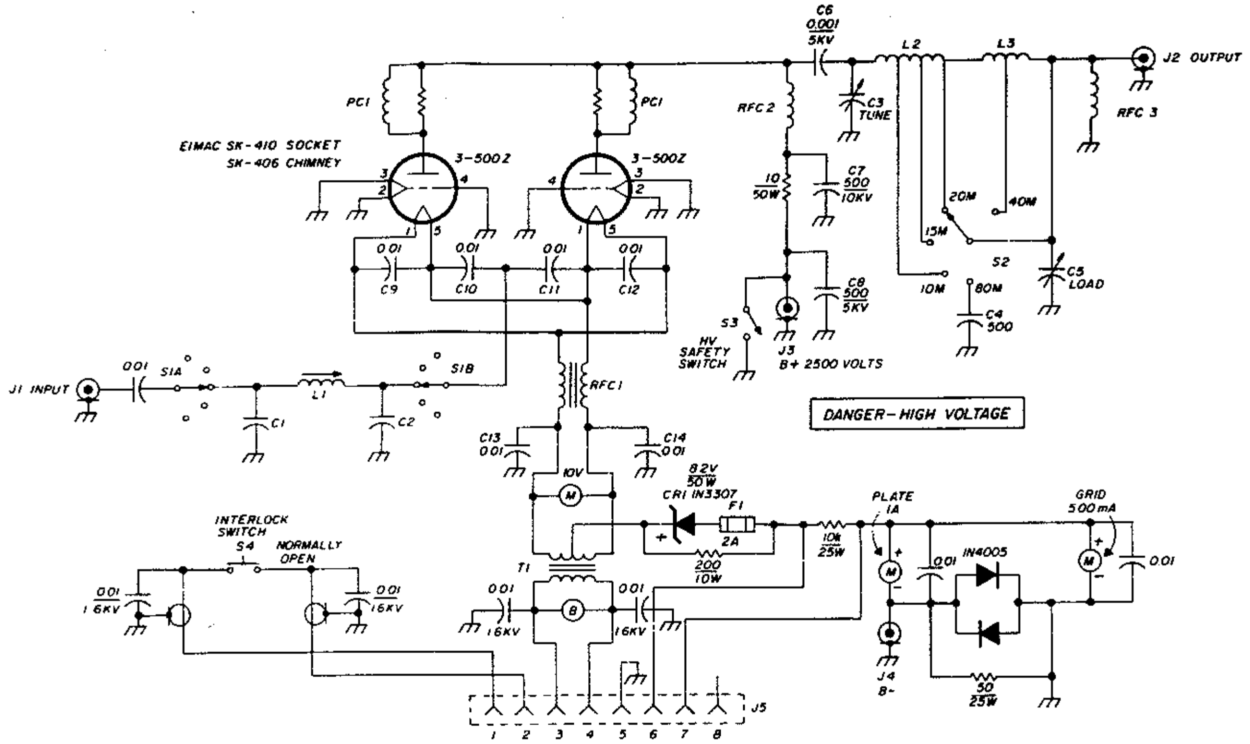


fig. 7. Schematic diagram of the 3-500Z linear amplifier.

C3	250 pF, 4.5 kV plate spacing — Johnson 154-16
C4	500 pF, 4.5 kV
C5	1000 pF, 500 volt plate spacing
C6	0.001 μF, 5 kV — Centralab 858S-1000
C7, C8	500 pF, 10 kV TV-type "door knob"
C9-C14	0.01 μF, 500 volt mica capacitor. Ceramic disc is a suitable substitute if rated 1 kV.
PC 1	Three 100-ohm, 2-watt resistors in parallel
PC 2	Three turns of no. 14 AWG (1.6 mm) wound with 12.5-mm (0.5-inch) diameter and 19-mm (0.75-inch) length connected in parallel with the resistors. The coil may be wound around one of the resistors.
RFC 1	50 μH; 14 bifilar turns of no. 10 AWG (2.6 mm) enameled wire wound on ferrite core 12.5 cm (5 inches) long and 12.5 cm (0.5 inch) in diameter (Indiana General CF-503 or equivalent).
RFC 2	100 μH, 1 ampere dc; 112 turns no. 26 AWG (0.4 mm) spacewound wire diameter on 2.5 cm (1 inch) ceramic form 15 cm (6 inches) long (Centralab X-3022H insulator). Series resonant at 24.5 MHz with terminals shorted (B&W 800).
RFC 3	2.5 mH, 100 mA
T1	5 volts at 30 amps (Chicago-Standard P-4648)
Blower	13 cu. ft./min. Use a no. 3 impeller at 3100 rpm (Ripley 8472, Dayton 1C-180, or Redmond AK-2H-01AX)

flash-over occurs, and much of this destructive energy is dissipated in the resistor.

Many modern-generation Amateurs have never worked with equipment operating at voltages higher than 12 volts. This amplifier, with the high-voltage plate supply, is positively lethal and the operator can be killed if his hands are inside the unit when the high voltage is on. It is *imperative*, therefore, that safety switches be incorporated in the amplifier design. It is poor engineering practice to leave these devices out! S4 is a normally open, pushbutton device that is closed only when the lid is placed on the amplifier enclosure. S3 is a shorting switch that shorts the high voltage to ground when the lid is removed. Construction of this special switch will be covered in a future article. *Always remember — high voltage kills*! Take necessary precautions.

Although not shown on the schematic, it is a good idea to use a filament transformer having a primary winding tapped for 105, 115, and 125 volts. This provides a plus or minus ten per cent adjustment from a normal line voltage of 115 volts. If a closer filament adjustment is desirable, the transformer can be run on the 105 volt tap with a rheostat in series with the primary winding to place the filament voltage "on the nose."

The plus and minus leads to the high voltage supply should be run through high-voltage connectors and high-voltage cable. Test prod wire having a 10-kV breakdown is satisfactory. As an alternative, RG-58/U coaxial cable can be used for high-voltage leads along with PL-259 plugs and reducers and SO-239 receptacles. The shield of the coaxial line is grounded by the connectors. **ham radio**

design considerations for linear amplifiers

Building a high-power, high-frequency linear amplifier and companion power supply is an interesting, challenging, and constructive project. And don't let anybody tell you that you can't do it! Many new hams approach equipment construction with great timidity. Be assured it isn't all that difficult. The toughest part of the work, in fact, is finding the necessary components. This is where flea markets, classified advertisements, surplus stores, and the junk box of neighboring Amateurs play an important part. You can find all the stuff you need, it just takes a little perseverance.

Before you begin bending metal, punching holes, and wiring, you should have the amplifier completely designed on paper, as outlined in the previous articles of this series. Once this task is done, you can make a parts list and start rounding up the components. You should also start thinking about the physical layout and assembly of the amplifier.

amplifier layout and assembly

Modern design indicates that the linear amplifier be enclosed in a metal cabinet, or box, that is shockproof, rf radiation-proof, compact, and easy to build. Many people build their linear amplifiers on a readily available aluminum chassis and then box up the chassis with aluminum sides and top to form a complete enclosure. This is not a bad idea. The cost is low and the chassis forms a platform and underchassis area that is hard to duplicate with simple tools. Once the enclosure is built, holes are drilled in it for leads and cables, control shafts, and for cooling air to enter and escape. Components within the box are positioned so that rf leads are short and direct and power wires are not coupled to the strong rf field within the box (see **fig. 1**). By paying attention to mechanical detail and armed with a knowledge of circuit design and a dose of common sense, the average Amateur can build a linear amplifier that looks good and works as well as the book says it should.

The object of using an all-metal amplifier enclosure is to keep the strong rf currents and subsequent harmonics within the box. Since these currents travel only on the surface of metal, the box can be made "electrically tight." Whenever a hole is made in the box, or a conductor brought into it, a leakage point is established through which rf energy can escape. It is important that these "rf holes" be reduced to a minimum in number and size, and that their effect upon circuit operation be controlled.

openings into the enclosure

Holes, leads, and shafts break the rf-tight amplifier box. Large holes for ventilation can be used without harm, provided they are screened so that air can enter and leave but rf energy cannot escape. Perforated metal sheet, having many closely spaced holes, is the best screening material to place over the openings. Copper wire window screen is not as effective because of wire corrosion which produces a film of insulating oxidation between the individual wires at the crossover points.

If a perforated sheet is to be used, it may be made by drilling lots of holes in the enclosure wall. Or the hole pattern can be drilled in an auxiliary plate placed over the ventilation hole. If such a plate is used, it should be bolted or riveted to the enclosure with a bolt-to-bolt spacing of about 2.5 cm (1 inch) so that rf energy cannot leak out through the crack between the surfaces. Mating surfaces between the metals should be clean and free of paint (**fig. 2**). A screened ventilation opening should be about three times the size of an equivalent unscreened opening, since the screening material reduces the area of air passage.

By William I. Orr, W6SAI

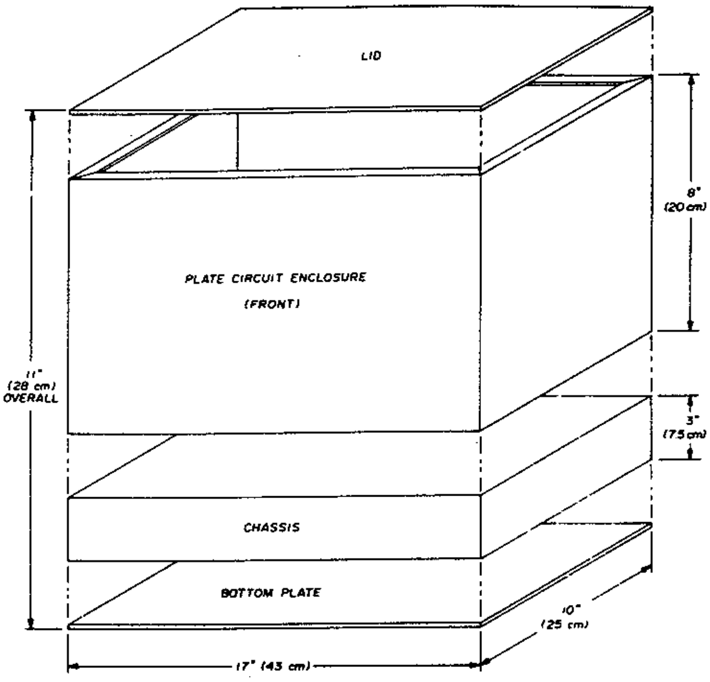


fig. 1. A representative amplifier enclosure. Basic unit is an aluminum chassis with bottom plate. The plate circuit enclosure is made of aluminum stock. For ease in assembly, aluminum channel angle stock is pop-riveted around outer edge of chassis to mate with the bottom of plate circuit enclosure. Angle stock is run up each corner and riveted to the four plates. Additional angle stock runs around the inside edge of the top of the enclosure and is tapped for 6-32 (M3.5) screws, which hold the lid on. Lid may be made of perforated metal for ventilation or may be modified from a solid aluminum sheet as discussed in the text. Additional angle stock may be required to hold bottom plate in place and to make the under-chassis area relatively air-tight. Blower to cool the tubes is mounted on the rear apron of the chassis. The completed enclosure is mounted behind a relay rack panel for appearance.

Control shafts passing into an rf-tight box should be made either of phenolic-insulating rod or of metal, grounded at the point of entry by means of a spring contact (**fig. 3**).

Long, narrow slots in the enclosure should be avoided, or else shunted with a ground strap every few inches; otherwise the opening tends to act as a "slot antenna" through which harmonic energy can readily pass — more easily than through a much larger circular hole, in fact.

Meters mounted in a wall of the shielded box pose a problem, as they are a source of prolific rf leakage. Unless the body of the meter is shielded and the leads well bypassed, it is more prudent and less time consuming to mount the meters outside the enclosure and to filter the meter leads running into the box.

pass-through leads

Careful attention must be paid to power and meter

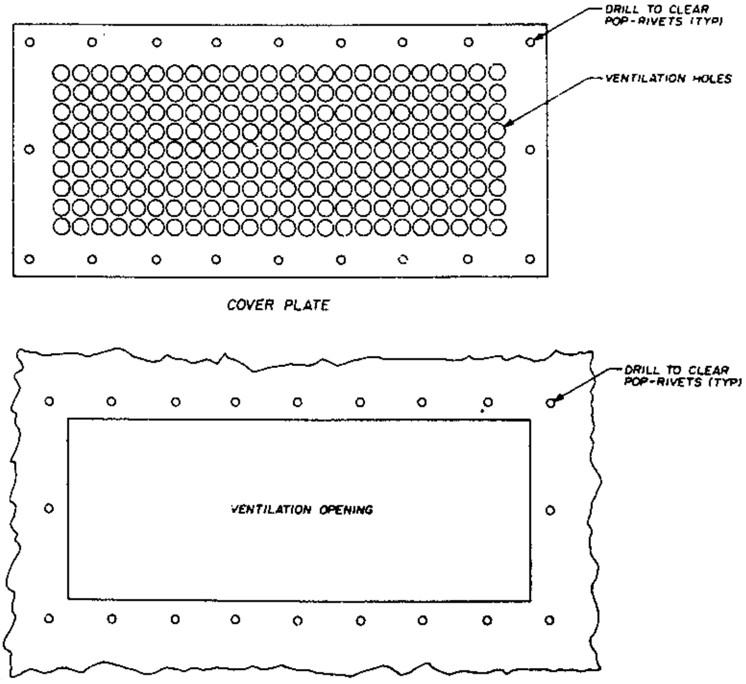


fig. 2. Ventilation holes are cut in sheet aluminum by means of a nibbling tool. Cover plate is cut slightly larger and drilled for ventilation holes. Plate and sheet aluminum are then drilled together for holes to place pop-rivets. If it is necessary to remove the cover plate for insertion of tubes, the plate may be held in position with sheet metal screws or by 6-32 (M3.5) nuts and bolts (provided assembly is such that you can get your hand inside the enclosure to hold the nut in place). Most side ventilation plates are fixed in position; top cover plates are removable.

leads entering and leaving the rf-tight box. Harmonic currents inside the box can easily flow out of the enclosure on these leads or even on the outer shield of a coaxial line if the shield is not properly grounded at the point of entry (**fig. 4**). Unshielded leads entering the box must be carefully bypassed and filtered at the point of entry to prevent rf energy from escaping from the box and flowing down the leads. A combination of bypass capacitors and small filter inductors will close off this escape route. The inductor must have ample capacity to carry the current flowing in the lead. Feedthrough-style capacitors are often used in low-voltage power and metering leads.

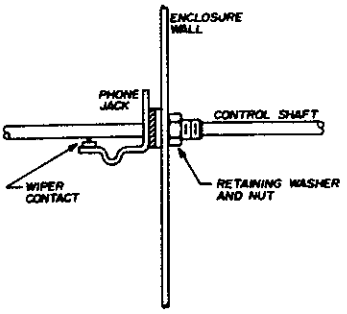


fig. 3. A single-circuit phone jack makes a good grounding device for a 6.5-mm (¼-inch) diameter shaft. The jack is mounted in the shaft hole, which is drilled out to accept the jack. The wiper contact of the jack rides on the shaft as it is rotated. The contact arm of the jack is grounded to the enclosure wall. Jack is positioned so that wiper arm is inside amplifier box.

amplifier wiring within the enclosure

Wiring within the rf-tight box can couple to rf energy because of the storing field within the box. Any lead in the box can pick up fundamental and harmonic energy and feed it outside the enclosure (**fig. 5**). On the other hand, the lead can pick up rf energy from an outside source (your exciter, for example) and leak it into the box causing amplifier instability. The solution for this problem is to bypass or filter all internal power and control leads at each end, dress them close to the chassis, and keep them physically remote from areas of high rf energy.

All these precautions may seem more complicated and time-consuming than they really are. Unfortunately, most circuit diagrams leave off much of the important rf bypassing circuitry since it tends to clutter up the diagram; its existence may be only briefly mentioned in the text. And the filter circuitry is often left out of commercially produced units as a cost-cutting measure.

When you build your own amplifier, you can afford to take the time and do things the right way. Always remember that holes, shafts, and leads are sources of rf leakage from an rf-tight enclosure and, unless protected, are a direct invitation to TVI, harmonic radiation, and amplifier instability. Sadly enough, many modern amplifiers on the market look like they're in an rf-tight enclosure, but, in reality, they are only sitting in an attractive dust cover.

practical amplifier layout

A simple to understand and practical parts layout for a representative high-frequency linear amplifier using two 3-500Z tubes is shown in **fig. 6**. The layout can be adapted to other tubes. The assembly consists of an aluminum box made up from a standard chassis. A bottom plate pressurizes the underside of the chassis and a blower is mounted on the rear apron of the chassis. Air is introduced under the chassis and is expelled through the tube sockets and air chimneys. The heated air from the tubes escapes through the perforated top and side areas of the plate circuit compartment.

The meter and control circuits are placed outside the shielded enclosure. Wiring for these circuits is not critical, and is done with 600-volt insulation hookup wire. High voltage wiring is done with test-

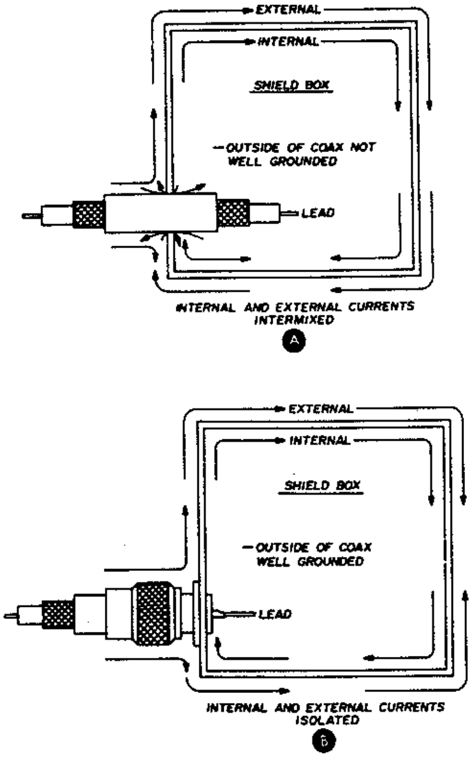
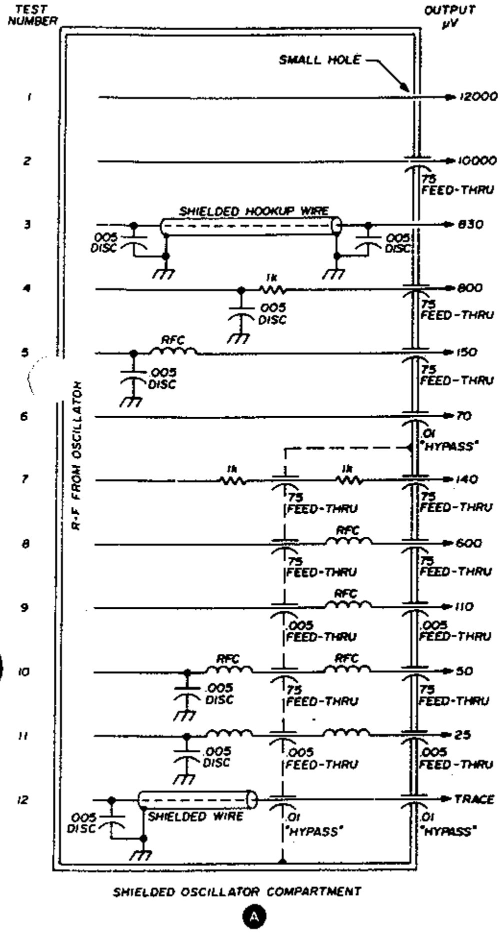


fig. 4. Improper termination of coaxial line can destroy effectiveness of the shield (A). Rf currents within the enclosure can escape via the outside shield of the line as it passes through the hole. Properly grounding the shield of the coaxial line to the box (B) ensures isolation of currents within the box. Rf currents outside the box are also prevented from entering the box.

prod wire of the type used for instrument test leads (10-kV insulating rating) or equivalent high-voltage cable. TV-type capacitors are used for lead filtering (**fig. 7**).



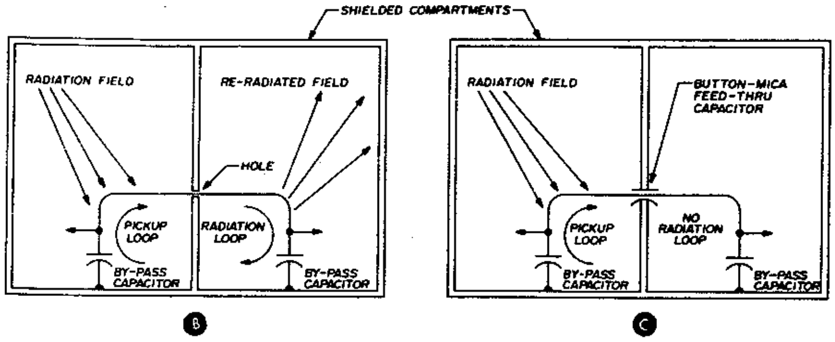


fig. 5. Tests of lead-filtering techniques (A). A signal generator having an output of 12,000 µV was placed in a metal box and rf leakage via various paths was measured. Very complex shielding was required to remove the last vestige of signal from the power lead. A combination of rf choke and capacitors, such as tests 8 or 9, does the job in adequate fashion. A very effective filter (not shown here), consists of a 0.001-µF feedthrough capacitor with a series rf choke. Both ends of the choke are additionally bypassed with a 0.01-µF disc capacitor. Energy can be conducted from one area to another as this test shows. Lead-through hole in partition (B) conducts energy from one compartment to the other. Proper bypassing (C) attenuates leakage. (Courtesy Radio Publications, Inc.)

Low voltage leads enter the amplifier enclosure via 1-kV feedthrough capacitors, which are also shunted at the point of entry with a larger value of capacitance to suppress low-frequency rf energy and transients which can pass through most feedthrough capacitors with little attenuation. A simple homemade rf choke and bypass capacitor are placed on each lead inside the enclosure. Note that all capacitors used on the 120-volt ac power line should be rated at 1.6 kV in accordance with the Electrical Underwriter's Code. Don't use run-of-the-mill disc bypass capacitors on the power line, as it is a source of random voltage transients which can easily puncture the standard 600-volt-working capacitor.

Power leads from the panel controls to the terminal strip on the rear of the amplifier must either pass through the box or go around it. It is easy to pass through the enclosure without breaking the rf seal with a short section of 1.3-cm (0.5-inch) diameter thin-wall electrical conduit with wall fittings on each end of the section (**fig. 8**). An rf tight passageway through the amplifier for various wires is formed by the conduit. Coaxial fittings are used for the input and output rf connections and are mounted to the wall of the box.

The mouth of the blower is covered with a small piece of copper window screen. While not the best material, this screen doesn't reduce the air flow as much as a perforated metal sheet would do.

While all this hum-drum filtering and bypassing might seem like overkill, it is the *only* way to achieve an amplifier that is rf radiation proof and one that keeps rf energy where it belongs. The rf energy leaves the box only via the output circuit where harmonics can be suppressed by means of a suitable lowpass filter before they reach the antenna. Without the filtering and bypassing, the harmonics suppressed in the antenna circuit would pass down the power leads or be radiated directly from the amplifier circuitry.

B-plus safety switch

A quick way to kill yourself is to remove the amplifier cover and fiddle around inside the box when the high voltage is turned on. Even the best of us might forget to turn things off and disconnect the amplifier from the supply before work is performed. A B-plus shorting switch will pay big dividends in operator longevity. It is simple to make (**fig. 9**). The shorting ring is made of spring brass and is depressed when the amplifier lid is in place. When the lid is removed, pressure is taken off the shorting ring and it makes a direct contact between the high voltage circuit and the chassis. This short circuit results in a blown line fuse if the amplifier is inadvertently turned on when

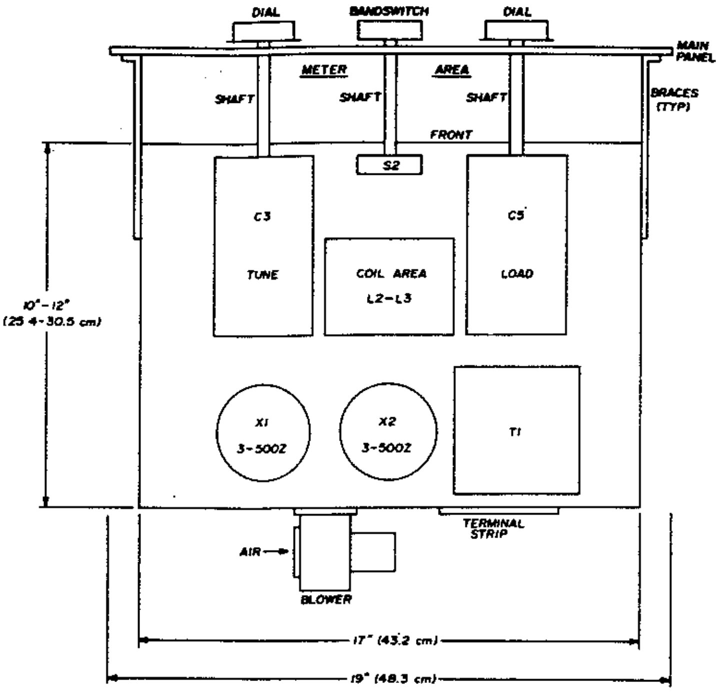


fig. 6. A practical layout for a linear amplifier using two 3-500Z tubes. This is representative of a layout using any popular tube or tubes available for the Amateur service. A 43-cm (17-inch) chassis is used, with depth chosen to allow proper placement of components. Tuning and loading capacitors are mounted symmetrically on the main panel with the plate bandswitch between them. Panel meters are placed across lower portion of the panel. An area for the plate coils lies between the two capacitors, immediately behind the bandswitch. The 3-500Z tubes, air system sockets, and chimneys are near one rear corner of the chassis with the air blower placed on the rear apron between the sockets. To the side of the tubes is the filament transformer. To reduce transformer heating caused by infra-red radiation from the tubes, the transformer (which is normally black in color) is given a coat of white stove enamel. This reflects the heat from the tubes and reduces transformer operating temperature. The fixed-tuned cathode input circuit and bandswitch are located beneath the chassis, and the switch control shaft is brought out to the panel. Some Amateurs gang the input and output circuit band-change switches, but this is not necessary. The bottom of the amplifier is sealed with a metal plate, and the top area is made up of perforated aluminum sheets to permit ample tube ventilation.

the lid is removed. It also makes sure the filter capacitors are discharged before hands can be poked inside the amplifier.

metering circuits

When you have power tubes in your linear amplifier that may cost upwards of $100, it is a smart and thrifty idea to take good care of them. As far as metering goes, it is wise to monitor both grid and plate current (and screen current if a tetrode tube is used) plus filament voltage. And a plate voltmeter is a handy thing and necessary if you run close to the maximum power level.

The meters are mounted outside the rf-tight box to remove them from the strong rf field of the amplifier. A single meter may be used as a matter of thrift to measure either grid or plate current if an appropriate switching circuit is employed, such as shown in **fig. 10**, where one meter does the work of two.

For economy and simplicity, a 0-1 mA dc meter is used. The scale will read 0 to 100 mA for grid current and 0 to 1000 mA for plate current. The scale need not be re-inked, since the user merely adds zeros to the reading to get the exact current value.

The meter is converted into a simple voltmeter circuit by a series-connected resistor. This voltmeter then reads the voltage drop across a shunt resistor placed in the circuit to be monitored. The whole circuit is inexpensive, accurate, and easy to make up. It does not require precision resistors — inexpensive one-percent metal film resistors will do (or carbon resistors in pinch).

As an example, suppose a 3.9-kilohm series resistor (a standard value) is used. The 0-1 mA meter is now turned into a voltmeter which reads 3.9 volts full

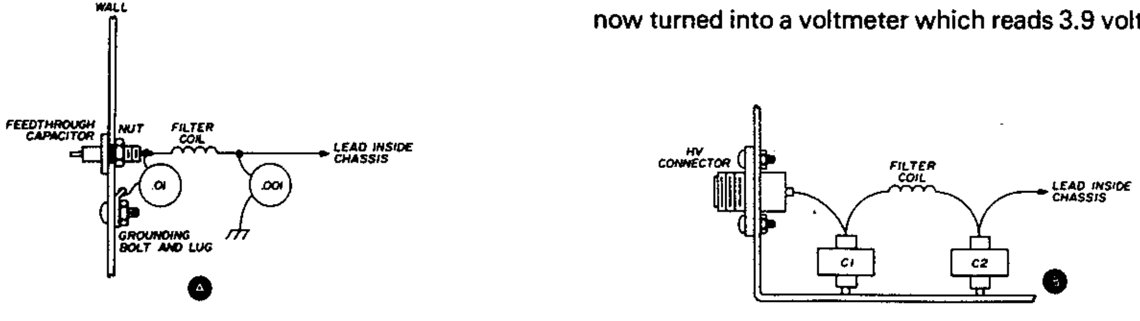


fig. 7. A simple filter circuit (A) for low voltage leads is made up of a 1000-volt feedthrough capacitor (Nytronics CP09A3 style, 0.01-μF, with case grounded and mounting stud). These, or similar capacitors can often be found in surplus stores. The disc capacitors are 1 kV (Sprague 5GA-D10, or equivalent). The filter coil is ten turns of no. 16 AWG (1.3 mm), 1.3-cm (½-inch) diameter spaced to 3.2 cm (1¼ inches) long. The coil and capacitors are placed inside the chassis. High-voltage filter circuit (B). A high-voltage chassis connector (Millen or equivalent) is used. The capacitors are 500-pF, 10-kV TV-type, with stud mounts. Some Amateurs use a high-voltage coaxial connector for the B-plus lead and run the high voltage in RG-8/U coaxial cable with the outer sheath grounded as a safety factor.

scale. All that is necessary now is to design a shunt which will produce a 3.9 volt drop across it at the desired full scale reading of the meter. Let's say we want 100 mA (0.1 amp) full-scale deflection for grid-current measurement. The shunt resistor (by Ohm's law) is:

$$\text{Shunt resistor (ohms)} = \frac{E}{I} = \frac{3.9}{0.1} = 39\ \text{ohms}$$

This, also, is a standard resistance value. If you want

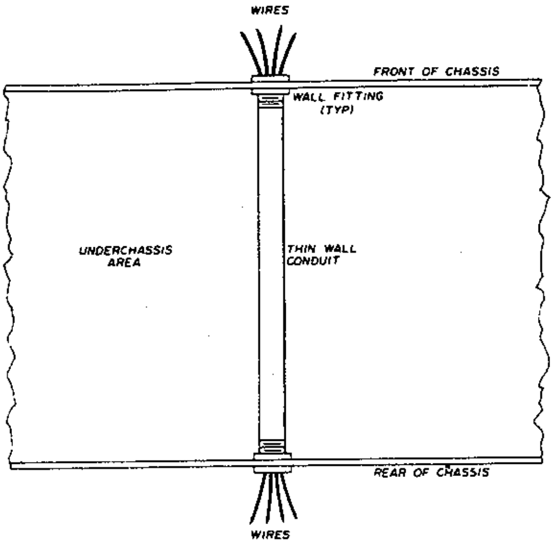


fig. 8. Wires can be passed through an underchassis area by using a short length of thin wall electrical conduit as a passageway. Conduit is attached to the chassis walls by means of metal wall fittings. Conduit and fittings can be purchased at electrical contractor or large home improvement store.

to read plate current at 1000 mA (1 amp) full-scale, the appropriate shunt resistor is:

$$\text{Shunt resistor (ohms)} = \frac{3.9}{1}$$

$$= 3.9\ \text{ohms}$$ (a standard resistance value)

Simple, isn't it? No expensive precision resistors are needed and everything is figured out by simple mathematics. Other full-scale meter readings can be worked out by changing the value of the shunt resistor.

inexpensive perforated metal sheet

A good way to make a ventilated rf-tight metal box is to use perforated aluminum sheet stock found in many hardware stores and home improvement centers. Ideally, the holes should be small and closely spaced so that it seems as if there is more open space than solid metal. As an alternative, you can make your own perforated sheet from solid aluminum sheet and an electric drill. The trick is to make up a drilling jig out of a small steel plate (**fig. 11**). This sounds like doing it the hard way, but once the jig is made, it can be used rapidly and can be reused time and time again. It is a worthwhile addition to the home workshop. The jig is held in position on the sheet with a pair of C-clamps and the holes easily and quickly drilled with an electric drill to the pattern you wish.

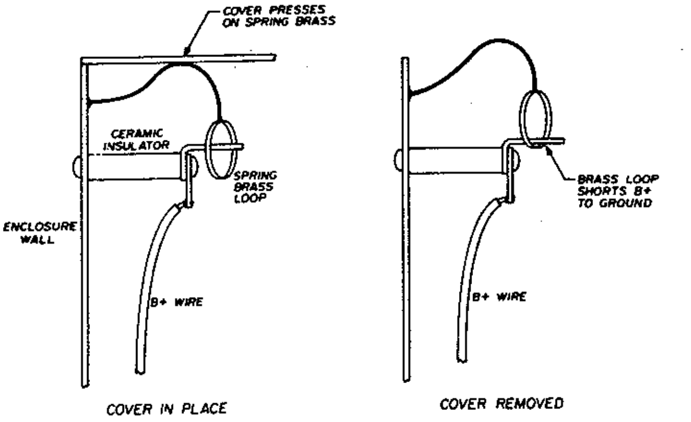


fig. 9. Inexpensive high-voltage shorting switch. The B-plus lead is connected to a ceramic standoff insulator. A short length of brass rod projects out from the insulator. A shorting ring made of spring brass loop encircles the rod as shown in the left illustration. When the lid is in place, the loop is centered around the rod. When the cover is removed the spring brass straightens out and the loop is offset, shorting the B-plus wire to ground.

amplifier layout

If you look through the various Amateur magazines and handbooks (particularly those of the pre-1970 era) you'll see plenty of homebrew linear amplifiers. They bear a remarkable similarity as far as layout goes. Indeed, so do most of the linear amplifiers currently on the market. Time spent in seeing how others solved their problems is a big asset when

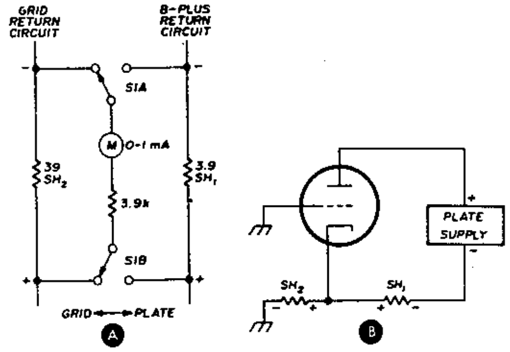


fig. 10. Meter-switching circuit (A), using an inexpensive 0-1 mA dc meter to measure either grid or plate current. In the grid position, the full-scale reading of the meter is 100 mA. In the plate position, the full-scale reading is 1000 mA. A simplified amplifier circuit (B) showing the dc current paths of the meter circuit. Note that the B-plus supply is "above ground" by virtue of the meter shunts.

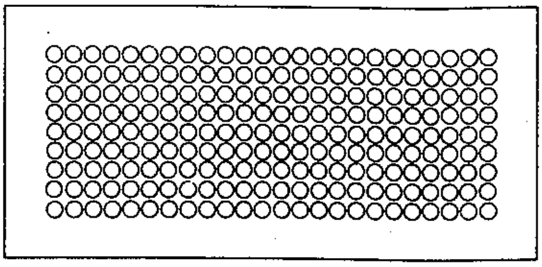


fig. 11. A drilling jig made of sheet metal 3.2-mm (1/8-inch) thick is handy for making your own perforated stock for areas requiring ventilation. Jig is about 20 cm (8 inches) long and 7.5 cm (3 inches) wide. Holes should be about 6.5 mm (1/4 inch) in diameter.

it comes to laying out the components for your own linear amplifier.

You should lay the parts out on the chassis before you start drilling holes and bending metal. Some Amateurs make a cardboard mock-up of their amplifier and slide the components around in a three dimensional layout to make sure that one part does not mechanically interfere with another and that the dials fall on the panel in a symmetrical pattern.

Once general parts placement has been ascertained, the sides, back, bottom, and top of the enclosure can be laid out and cut from sheet aluminum. The finished parts can be held together by means of bent-over edges on the sheets or by means of aluminum angle stock cut to fit. Some people use nuts and bolts to hold everything together, while others use sheet metal screws or pop-rivets. The top of the enclosure is held in position with removable screws so that it can be taken off for tube installation.

The amplifier box is supported from the panel by spacer rods cut long enough to leave space for the meters between panel and amplifier. Shaft extensions can be used to couple the panel controls to the control shafts extending from the amplifier wall.

If your assembly is completely knock-down and the chassis plate is replaceable, the amplifier circuitry and tube complement can be changed at will while still retaining the panel, circuitry, and main body of the amplifier. But you'll never need this, since hams rarely rebuild their equipment!

recommended reading

The new 21st edition of the *Radio Handbook* is now available and has a greatly expanded section on design and construction of linear amplifiers. Photographs show many different designs using popular power tubes. The new *Radio Handbook* is available from Ham Radio's Bookstore. Also read "A Beginner's 50 Watt Rig" by Bill Wildenhein, W8YFB, in the July and August, 1978, issues of *Ham Radio Horizons*. This is a goldmine of design, construction, and layout information. You should also read "Custom Design and Construction Techniques for Linear Amplifiers Using the 8877," by Merle Parten, K6DC, in the September, 1971, issue of *QST*. A reprint of this article can be obtained at no cost from the Amateur Service Dept., EIMAC, Varian Division, 301 Industrial Way, San Carlos, California 94070. Ask for bulletin AS-45.

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