

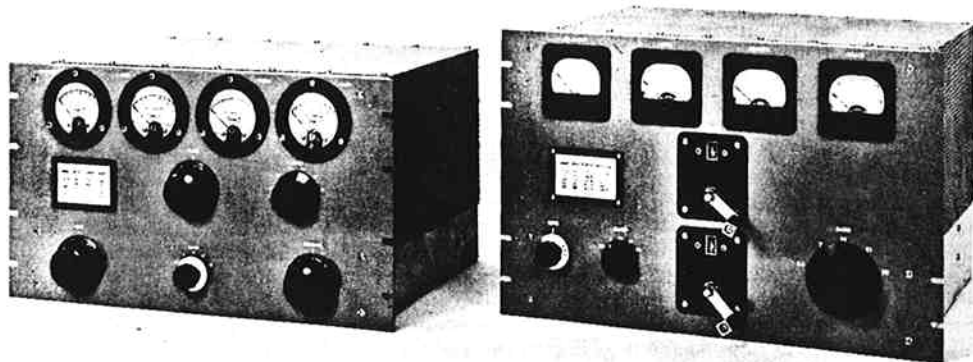


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The Pi-L Plate Circuit in Kilowatt Amplifiers

BY RAYMOND F. RINAUDO,* W6KEV

Improved Harmonic Suppression for Multiband Systems



Two amplifiers built to the same general circuit design and layout. The one on the left uses a pair of 4-125As, that at the right a pair of 4-250As. Both are capable of a kilowatt input on c.w. The 4-250As can handle envelope peaks of 2 kilowatts on sideband.

The Pi-L Plate Circuit in Kilowatt Amplifiers

An extra L network tacked on the pi-network tank helps get rid of those harmonics that multiband antenna systems are only too capable of radiating. This article shows how the circuit was applied to two kilowatt amplifiers — both of which are worth your attention because of their construction ideas, too.

BY RAYMOND F. RINAUDO,* W6KEV

DURING the past ten years the pi network has become almost the standard plate tuning and loading circuit for a radio-frequency power amplifier, whether it ends up with a 6146 or a pair of 4-400s. This came about quite naturally when TVI became a problem because the pi network lends itself very nicely to band switching, with tuning and loading done with capacitors — the capacitors, plate switch and coil being located in a comparatively small shield enclosure. All of this was had along with reasonably good harmonic attenuation: second harmonic down 35 to 40 db. and higher harmonics further attenuated.

However, along with the popularity of the pi network, we have had the development of the three-band beam, the multiband dipole and the multiband vertical. While the multiband antenna is a god send to those with limited acreage, in which category the vast majority of us fall, it serves to bring up another problem because we now find that 35- or 40-db. attenuation of the second harmonic at the amplifier is quite often not enough. The multiband antenna is all too ready to radiate that 20-meter harmonic when the amateur is actually transmitting on 40. Obviously,

* Eitel-McCullough, Inc., San Carlos, Calif.

the antenna under discussion is of the type which requires no tuner between the transmitter and the feed line. A solution to the problem is to put a filter in the transmission line which will pass only the frequencies in one band. But then, when changing to a different band, another filter must be substituted and some of the ease of band change has been lost.

Another way in which the situation can be improved is to use a pi-L network. The pi-L will give 10 to 15 db. more attenuation of the second harmonic than will the pi¹ and even more attenuation of the higher harmonics. This circuit has been used in some commercially-built amateur equipment such as the Collins KWS-1. Further improvement can be had by designing the amplifier plate circuit for a higher loaded *Q*. For example, raising the loaded *Q* from 10 to 20 will increase the harmonic attenuation by 6 db. Unfortunately, one runs into the law of diminishing returns here; the losses in the plate coil begin to be large enough to cause serious heating, and a loaded *Q* of 20 is near the practical upper limit in most cases.

¹ *Fundamentals of Single Side Band*, Collins Radio Company.

The 4-125A Amplifier

With the harmonic problem in mind, a design was worked out in late 1958 for an amplifier which was to replace the pi-network final then in use. The requirements were as follows:

- 1) Operation from 3.5 to 28 Mc., band switched.
- 2) Power input of 1 kw. with 2500 volts on the plate.
- 3) R.f. power output to feed into a 50-ohm coaxial load.
- 4) Standard 19-inch rack mounting with a minimum practical panel height.
- 5) Amplifier enclosed in a shield and incoming power leads bypassed for TVI.
- 6) Harmonic radiation via the feed line to be minimized.
- 7) A minimum amount of cash to be involved.

The result of the above design is the 4-125A amplifier shown in the photographs.

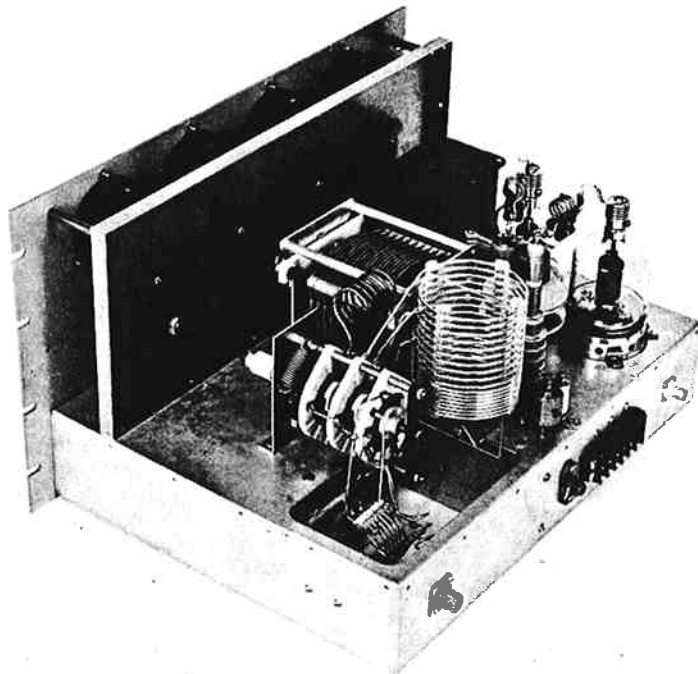
The amplifier uses a pair of neutralized 4-125As in parallel. The grid circuit is tuned, fairly high C , and makes provision for bridge neutralization via bypass condenser C_2 , Fig. 1. The plate circuit is a pi-L network with an operating Q of 15, and plate current is shunt fed. Individual meters are used to measure grid, screen and plate currents and filament voltage.

The amplifier is built on a $13 \times 17 \times 3$ -inch aluminum chassis behind a $10\frac{1}{2} \times 19$ -inch panel. The meters are excluded from the r.f. field by a 7×17 -inch aluminum sub-front panel which is set back two inches from the front panel. The resulting enclosure, which is above the chassis and screened by perforated aluminum, is 11 by 17 by 7 inches. The underside of the chassis is divided into two units by a shield running from

front to back. The grid compartment is 10 by 13 by 3 inches and the output compartment containing the loading capacitors and L net coil is 7 by 13 by 3 inches. The bottom of the chassis is covered by perforated aluminum sheet to allow convection air currents to cool the tubes. No blowers or fans are needed to cool the 4-125As, provided that cooling air is allowed to flow freely past the tubes.

In keeping with requirement (7), maximum use was made of the surplus markets and trades with fellow hams, and the author's own junk boxes were given a thorough going over. No real compromise was made by the use of inferior components, but inevitably several of the parts used are either not too commonly-available surplus items or are once-standard parts which are no longer manufactured. But for each of these, a standard commercial part exists which is as good as or better than the one used and will fit into the space available. The standard part is the one given in the parts list. That the use of used and surplus parts paid off is attested to by the fact that the immediate cash outlay was less than \$20! On the other hand, if the reader wants to build the amplifier using all new parts, the cost will be approximately \$235, including tubes.

As mentioned previously, the grid circuit operates with fairly high C . Approximately 300 $\mu\text{f.}$ is used on 3.5 Mc., 150 $\mu\text{f.}$ on 7 Mc., and proportionally smaller amounts for the higher-frequency bands. A large tuning capacitance is used so that there will be a minimum of clipping of the waveform of the driving signal when the grid is driven positive. A distorted waveform at the grid of an amplifier will mean more harmonic



Chassis view of the 4-125A amplifier. The plate tuning capacitor is at the center. The pi coil for 3.5-21 Mc. is vertical. The 28-Mc. pi coil is mounted horizontally between the band switch and the tank capacitor. The plate r.f. choke and neutralizing capacitor are partially hidden by the plate coil. The filament transformer is at the far end of the chassis between the 4-125As and the sub-front panel.

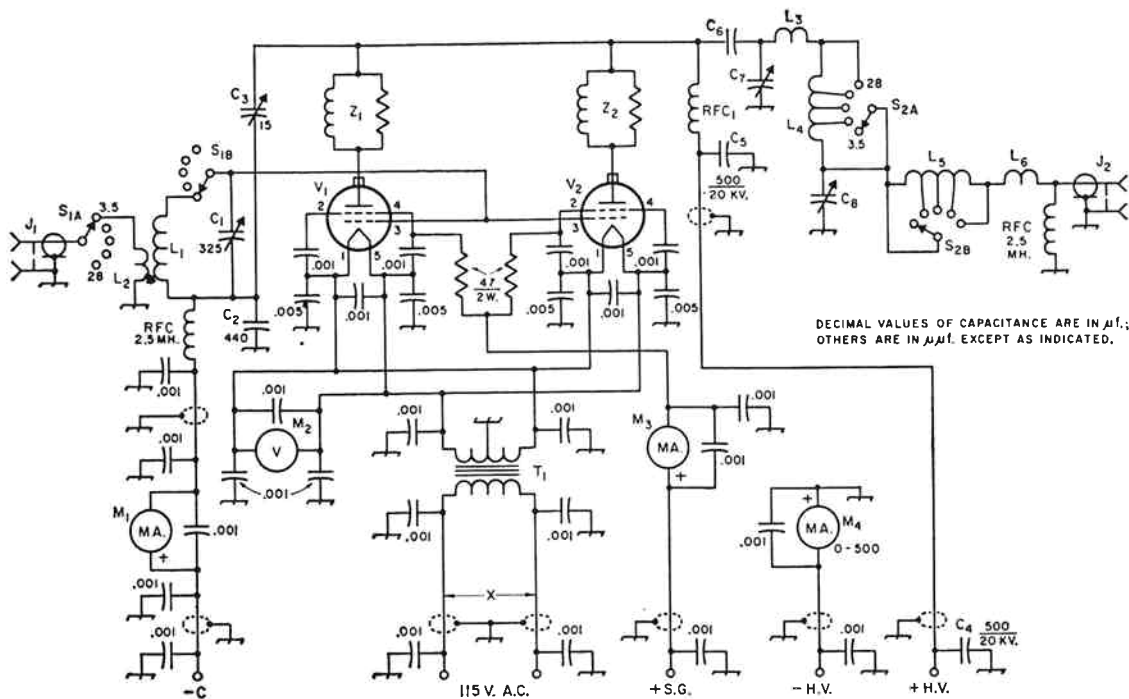


Fig. 1—The amplifier circuit. Either 4-125As or 4-250As may be used at V_1 and V_2 . See specification below for circuit values that differ with the two types. "X" indicates point where the two cooling-fan motors are connected in the 4-250A amplifier. Shielded wiring in supply leads is continued up to the bypass capacitors nearest the r.f. circuit. All 0.001- and 0.005- μ f. capacitors are disk ceramic, 1000-volt rating.

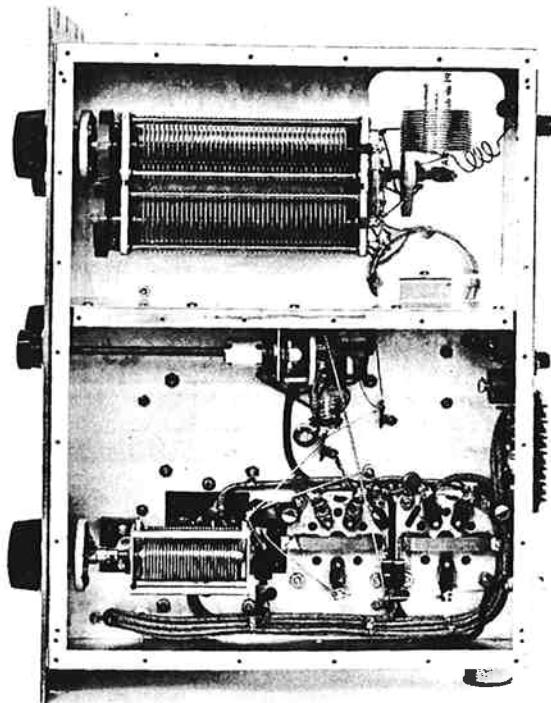
- C_1 —320 μ f., 0.0245-inch spacing (Hammarlund MC-325-M).
 C_2 —440 μ f., silver mica (two 220- μ f. in parallel).
 C_3 —Disk neutralizing, 2.2-15 μ f. (Millen 15011).
 C_4, C_5 —500- μ f., 20-kv. ceramic (Centralab TV-20).
 J_1, J_2 —Coaxial chassis-mounting connectors.
 L_1 —3.5 Mc.: 32 turns no. 20, $\frac{3}{4}$ -inch diam., 16 turns per inch (Air Dux 616T).
 7 Mc.: 14 turns No. 20, $\frac{3}{4}$ -inch diam., 16 t.p.i. (Air Dux 616T).
 14 Mc.: 11 turns No. 18, $\frac{5}{8}$ -inch diam., 8 t.p.i. (Air Dux 508T).
 21 Mc.: 9 turns No. 18, $\frac{1}{2}$ -inch diam., 8 t.p.i. (Air Dux 408T).
 L_2 —3.5 Mc.: 4 turns insulated hookup wire at cold end of L_1 .
 7 Mc.: 3 turns same.
 14, 21, and 28 Mc.: 2 turns same.
 M_2 —0-8 or 0-10 volts a.c.
 M_4 —0-500 ma. d.c.
 RFC_1 —Transmitting choke (B & W 800, National R-175A, Raypar RL-100).
 S_2 —Ceramic, 2 poles, 5 positions (Radio Switch Corp., Marlboro, N.J.); see text.
 V_1, V_2 —4-125A or 4-250A.
 Z_1, Z_2 —4 turns No. 12, $\frac{1}{2}$ -inch diam., $\frac{1}{2}$ inch long, with four 220-ohm, 2-watt composition resistors in parallel.

For 4-125As:

- C_6 —0.001- μ f., 20-kv. ceramic (two Centralab TV-20s in parallel).
 C_7 —250- μ f., 3000-volt variable (Johnson 154-9).
 C_8 —0.001- μ f., 2000-volt variable (two Johnson 154-3 in parallel, ganged).
 L_3 —6 turns No. 10, 1-inch diam., $1\frac{1}{2}$ inches long.
 L_4 —Vari-pitch Air Dux 2408D4, modified as described in text.
 L_5 —Indented Pi Dux 1411A, modified as described in text.
 L_6 —4 turns No. 14, $\frac{1}{2}$ -inch diam., $1\frac{1}{4}$ inches long.
 M_1 —0-50 ma. d.c.
 M_3 —0-100 ma. d.c.
 S_1 —1 section, 2 poles, 5 positions (Centralab 2505).
 T_1 —5 volts, 13 amp. (Triad F9A or F15U).

For 4-250As:

- 0.002- μ f., 20-kv. ceramic (four Centralab TV-20s in parallel).
 300- μ f., 10-kv. variable (Jennings UCS-300).
 0.0012 μ f., 3000-volt variable (Jennings UCSL-1200).
 See text.
 Illumintronic Pi Dux No. 195-2, modified as described in text.
 Vari-pitch Air Dux 1608D6, tapped as described in text.
 6 turns No. 12, 1-inch diam., 1 inch long.
 0-100 ma. d.c.
 0-200 ma. d.c.
 2 sections, 1 pole per section, 11 positions, 5 positions used (Centralab YD sections with P-270 index assembly); see text.
 5 volts, 29 amp. (Stancor P-6492).



Below the 4-125A chassis. The two loading capacitors at the top, ganged together by means of gears, are separated from the grid circuit by an aluminum shield running from the front to the rear of the chassis. The L net coils are directly behind the loading capacitors. The grid band switch and coil are at about the center of the chassis. The grid tuning capacitor is mounted off the chassis by means of bakelite blocks and is directly under the filament transformer.

signal in the plate circuit and, hence, a more difficult job to suppress it. For example, in Class C, B or AB_2 operation, during the portion of the cycle that the grids of two 4-125As in parallel are driven positive, the grids look like a resistor of about 1200 ohms to the tuned grid circuit, and that portion of the cycle will be distorted unless precautions are taken to prevent it. Waveform clipping is minimized by using plenty of tuning capacitance in the grid circuit. Of course, for AB_1 operation, the amount of C is not important because the grid is never driven positive and looks like an infinite resistance to the tuned circuit.

The grid tank circuit uses individual coils for each band. A link coil of insulated hookup wire is wound over the cold end of each coil. The hot ends of the coils and the links are switched by S_1 , a 2-section, 5-position switch having one wafer. This switch is mounted on the underside of the chassis by means of an aluminum bracket. The coils are mounted between the appropriate switch terminal and a tie point and are oriented so that there is a minimum of coupling between them.

The tube sockets are mounted on the underside of the chassis, and spring clips on the top of the chassis held by the socket mounting bolts

ground the metal tube base shield. Bypassing of the screen and filament terminals is done in the more-or-less standard way. The screen terminals on each socket are connected together by a $\frac{3}{8}$ -inch wide strip of thin copper. Each screen terminal is then bypassed to the nearest filament terminal with a disk ceramic capacitor. A disk ceramic capacitor is connected between the filament terminals and another is used to bypass one side of the filament to ground. The remaining filament terminal is grounded with a short, heavy lead. Grounding one side of the filament has been found to be helpful in eliminating v.h.f. parasitics. Those who expect to use the amplifier for linear service should use bypass capacitors to ground on both filament terminals and ground the filament transformer center tap as shown in Fig. 1. A slightly cleaner signal will result. A 47-ohm, 2-watt carbon resistor is used to feed screen voltage to the screen terminal of each socket and is a parasitic preventive measure.

The pi-L plate tank circuit is made up of individually available coils, capacitors and switch. The switch, which is mounted on the chassis with an aluminum bracket, is made by Radio Switch Corporation of Marlboro, New Jersey. The switch used was bought on the surplus market and has three wafers, each wafer with six contacts. Since the wafers were already there it was decided to make use of them by paralleling the contacts on two wafers and using the parallel combination to switch the coil in the pi portion of the network. The circulating current in the pi coil is about twice as high as that in the L coil. However, the current rating of the switch is 20 amperes, so a single section is all that is really needed to handle the pi coil switching. Also, because six contacts per wafer were available, the sixth contact was used to provide a 3.8-Mc. position; that this is not necessary can be seen by the later description of the 4-250A amplifier. If the builder wishes to retain the 6-position band switch, he should order a Model 86 switch, standard bearing, non-shorting, 30-degree detent, with two Type A wafers. If a 5-position band switch will do, then the builder should order a Model 86 switch, standard bearing, non-shorting, 30-degree detent, with one Type B wafer. The second switch, by virtue of having only one wafer, will cost about three dollars less. The coils used in both the pi and the L are home-brew for 28 Mc. Illumitronic Engineering Pi Dux coils are switched in for the lower-frequency bands. It is of interest to note that as originally built, the pi coil was a Pi Dux 2007A, which is wound with No. 12 wire. After a bit more than two years' use, two of the turns shorted because coil heating had softened the polystyrene insulating supports. The damaged coil was replaced with a Pi Dux 2408D4, which is made of No. 10 wire. An r.f. choke completes the output circuit to ground for d.c. as a safety precaution.

Drive power is fed into the amplifier through a BNC coaxial receptacle and the output power is taken out by means of a U.H.F. receptacle.

Plate voltage is fed in through a Millen 37001 high-voltage terminal.

When the amplifier was completed, it was first tested for parasitics without suppressors of any kind. As is almost always the case with a tetrode or pentode amplifier, it oscillated merrily in the v.h.f. range—at about 150 Mc., as a check with the grid-dip meter showed. The parasitic was killed by the installation of suppressors, Z_1 and Z_2 , in the plate lead to each tube. The test for parasitics is to operate the amplifier with reduced plate and screen voltage and no fixed bias on the control grid, but using a grid leak of about 5000 ohms to ground to develop bias if the amplifier breaks into oscillation. No drive is used and no load is connected to the output. With this amplifier the plate voltage was set at 1000 volts and the screen voltage increased until the plate current was about 200 ma. and the tubes were dissipating about 100 watts each. At this point the screen voltage was between 150 and 200 volts. If an amplifier can be operated in this manner with no current showing on the grid meter, with no change in plate current, and with no detectable r.f. in the amplifier as the grid and plate tuning, loading and band-switch controls are tuned through their full range, then the amplifier can be considered adequately stable. This is a much more severe test than the one often made where full plate and screen voltages are applied and bias is reduced until the tube or tubes are dissipating full rated power with no excitation.

With the components used, the amplifier will operate with up to 3000 plate volts in Class C c.w. or Class AB₁ linear, or up to 1500 volts for Class C a.m. plate-modulated service. Screen voltage for Class C c.w. or plate-modulated a.m.

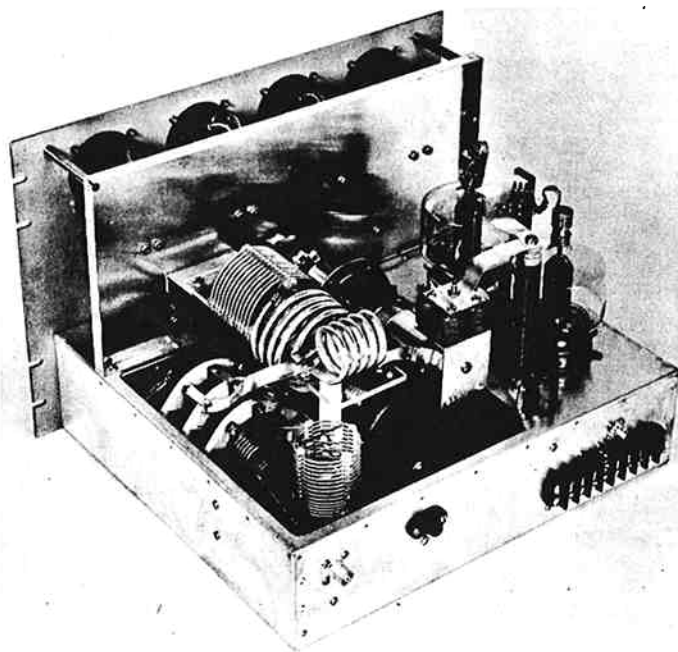
is 350 volts; for AB₁ linear it should be 600 volts. Grid bias should be -100 to -150 volts for Class C c.w., -210 for Class C, plate modulated, and approximately -95 volts for Class AB₁. The exact value of bias for AB₁ should be adjusted for the required idling plate current for the voltage used. Recommended values are as follows, for two tubes: 2000 volts, 85 ma.; 2500 volts, 70 ma.; 3000 volts, 60 ma.

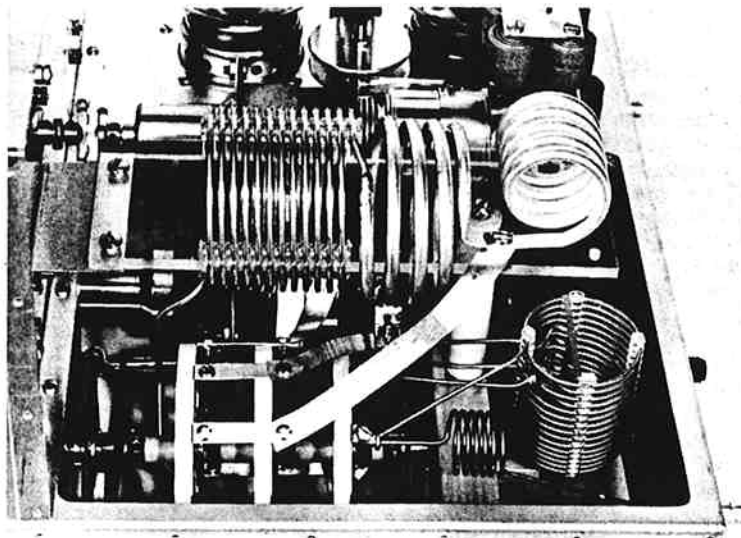
The screen voltage for Class C operation should come from a separate supply of reasonably good regulation. A series dropping resistor from the plate supply is not recommended. For Class AB₁ service, the screen voltage should be well regulated. While an electronically-regulated supply can be used, the simplest method is to use a string of VR tubes in series with a resistor from the plate supply. The reason that Class AB₁ permits this simple method of getting screen voltage is that the screen current excursions are not very great and are well within the capability of VR tubes.

Both the plate tank coil, L_4 , and the L-network coil, L_6 , are mounted on the chassis by means of aluminum angles bolted to the plastic mounting strip furnished with each coil. L_4 is modified and tapped as follows: Turns are removed from the close-wound end until 18 turns remain. Starting from the end of the coil which has the wide-spaced turns, the 21-Mc. tap is at 2 turns, the 14-Mc. tap at the 4th turn, the 7-Mc. tap at the 8th turn, and the 3.8-Mc. tap (if used) at the 16th turn. Since the 16th turn is in the close-wound portion of the coil, it is much easier to make the tap if the turn on each side is pushed in toward the center of the coil.

The L-network coil, L_6 , is modified by removing turns until 13 turns remain. Starting from

In the 4-250A amplifier the band switch is in a chassis cut-out with the pi coil above it. The 28-Mc. L coil and the vertically-mounted 3.5-21 Mc. L coil are between the switch and the rear of the chassis. The plate blocking capacitors are mounted on a bracket held by the vacuum variable plate-tuning capacitor at the center. The plate r.f. choke and its bypass capacitor are beside the 4-250A nearest the rear of the chassis.





Close-up of the 4-250A pi-L plate tank coils and band switch. The horizontally-mounted 6-turn wire coil is L_6 , and the vertically-mounted coil is L_5 .

the L_6 end, taps are placed as follows: 21-Mc. tap at 2 turns, 14-Mc. tap at 5 turns, 7-Mc. tap at 7 turns, 3.8-Mc. tap (if used) at 12 turns.

Non-standard items used are the grid tuning capacitor from the surplus market, the neutralizing capacitor, which National Radio Company no longer makes, the plate tuning capacitor, no longer made by E. F. Johnson, and the loading capacitor, C_8 , which is made up of two capacitors taken from a surplus BC-653 transmitter. The two E. F. Johnson units specified for C_8 will simplify the ganging of the two because they have the shaft out the back as well as the front. The two surplus capacitors did not have this feature and, consequently, gears had to be used for ganging.

The tuning and loading adjustments of the pi-L plate circuit are exactly the same as with a pi network. Plate circuit loading is increased by reducing the capacitance of C_8 . Whenever the loading capacitance is changed, the plate circuit must be retuned to resonance with the plate tuning capacitor, C_7 .

When the amplifier is first tested, it should be neutralized. The neutralizing capacitor, C_3 , is adjusted so that there is about one-half inch spacing between the two plates; then, with plate and screen voltages off and a load connected, excitation is applied and the grid circuit is tuned to resonance. The excitation level is set so that the grid current is only a few ma. Then plate and screen voltages are applied and the plate circuit is tuned to resonance. Plate-circuit resonance is best indicated by the peaking of the screen-grid current as the plate tuning capacitor is tuned through resonance. The loading control is adjusted so that the screen current is about 60 ma. If the plate input is less than desired, increase the grid drive and plate loading until the correct

plate current is flowing with screen current at 60 ma. The plate circuit must be retuned to resonance with each change of loading.

The check for neutralization is to tune the plate circuit through resonance, observing both screen and grid currents. When the amplifier is correctly neutralized, the grid-current meter will show a small current peak at the same setting of the plate tuning capacitor that gives a peak in screen current. Neutralization should be done on the 21-Mc. band.

After the amplifier has been neutralized it should be checked for parasitic oscillations, using the procedure given previously. In some cases, parasitics will make it difficult to find the correct neutralization setting. But if construction details are followed, particularly those pertaining to bypassing and the installation of suppressors, parasitic oscillations should not be a problem.

The 4-250A Amplifier

Quite some time after the 4-125A amplifier had been completed and had been operating satisfactorily, a design for a de luxe version was worked out. In this case, the requirements were the same as before except that the rig had to be capable of 2-kw. p.e.p. input for sideband service, and all the parts used were to be currently-available new items. The result is the 4-250A amplifier shown in the photographs.

The 4-250A amplifier uses essentially the same circuit as the 4-125A version. However, the plate circuit was designed for an operating Q of 18 instead of 15, in order to take advantage of the heavy-duty plate coil and switch which were to be used. An examination of the photographs shows the similarity of the two rigs in the mechanical layouts and the method of making the shield enclosures. Because all new parts were

used, the second amplifier turned out to have a better appearance both inside and out than did the first one.

The 4-250A amplifier is built behind a standard 19-inch rack panel $12\frac{1}{4}$ inches high. The chassis is 17 by 15 by 4 inches and the shield enclosure above the chassis is 17 by 12 by $7\frac{3}{4}$ inches. The vertical sub-panel is set back three inches from the front panel. The grid-circuit compartment is $6\frac{1}{4}$ by 15 by 4 inches and is separated from the rest of the under-chassis space by a shield which runs from front to back. The remainder of the underside of the chassis is opened up to the upper compartment by cutting out that portion of the chassis top. This increases the available space for the plate-circuit components and makes it much easier to connect the various parts together. The filament transformer is mounted in the plate-circuit area on the under-chassis shield which forms the grid compartment. Both the shield enclosure above the chassis and the bottom cover are made of perforated aluminum, which allows convection currents to help keep the tubes and parts cool. The 4-250As require forced-air cooling of the base, and small Barber-Coleman fans are used to blow air directly upward at the tube base pins and through the holes in the tube socket and tube base.

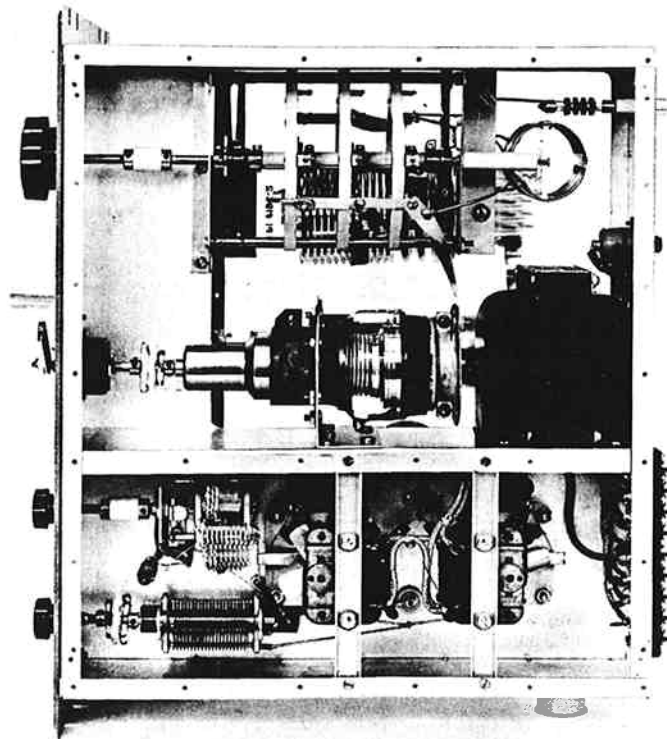
The grid circuit coil turret is made up of commercial coil stock and rotary switches. Two rotary switch wafers are used where only one is really needed to do the necessary switching. The coils are mounted between the wafers on the

switch lugs and the axes of all the coils are parallel. The arrangement used with the 4-125As where coils for adjacent bands are at right angles is better, because odd resonances in unused coils are less likely to cause trouble. However, this arrangement has been perfectly satisfactory in performance and is more rugged mechanically.

The cooling-fan motors are mounted on homebrew shock mounts to reduce noise. Rubber grommets with the same spacing as the motor mounting studs are mounted in the support channels which hold the motors, then a sleeve of length equal to the thickness of the grommet is slipped into each grommet. A large washer is placed on each side of the sleeve before the mounting screw is passed through and threaded into the motor mounting stud. Two shock mounts are needed for each motor. The grommet size used is that which fits into a $\frac{3}{8}$ -inch hole. A $\frac{1}{4}$ -inch diameter sleeve $\frac{1}{4}$ inch long is just the right size to fit the grommet hole. There is no reason, though, why larger grommets and sleeves cannot be used.

Vacuum variable capacitors are used for plate tuning and loading. These require 24 and 30 turns, respectively, to cover the full capacitance range. Counter dials which read each tenth of a turn are used to drive them. The dials are made by Gates Radio Company, Quincy, Illinois, part No. M3401F. These were chosen because they are r.f. tight and do not require much space behind the panel.

Bottom view of the 4-250A amplifier. The plate band switch, at the top, is mounted on aluminum brackets. The vacuum variable loading capacitor is at the center and the filament transformer is between it and the rear of the chassis. The bracket which supports the loading capacitor also supports the plate tuning capacitor. The grid band-switching turret and tuning capacitor are at the front of the grid compartment. A cooling fan is mounted directly below each tube socket.



The plate-circuit switch is made by Radio Switch Corporation. It is a Model 88 with 36-degree detent and three Type A wafers. Two of the three wafers are paralleled and switch the pi coil. The remaining one handles the L coil.

The Illunitronic coils used in the plate circuit both require modification. The 28-Mc. pi coil should be removed and replaced with one of slightly greater inductance consisting of 5 turns of 3/16-inch copper tubing, 1 5/8 inches in diameter and 2 inches long. The remainder, L_4 , of the pi coil should be modified by removing turns from the wire end, leaving 12 1/2 turns. Turns are removed from the close-wound end of the L coil, L_5 , until 15 turns remain. The 28-Mc. L coil, L_6 , is home-brew. The taps on the pi coil are placed as follows: 28 Mc.: junction of L_3 and L_4 ; 21 Mc.: 2 3/4 turns from the 28-Mc. tap; 14 Mc.: 5 3/4 turns from the 28-Mc. taps; 7 Mc.: 9 3/4 turns from the 28-Mc. tap. The taps on L_5 are as follows: 28 Mc.: at junction of L_5 and L_6 ; 21 Mc.: 3 turns from the 28-Mc. tap; 14 Mc.: 5 turns from the 28-Mc. tap; 7 Mc.: 9 turns from the 28-Mc. tap. An r.f. choke is used to complete the d.c. circuit to ground at the coax output connector as a safety measure should the plate blocking capacitor, C_6 , break down.

A type BNC receptacle is used to feed drive power into the amplifier and a type C receptacle at the output. The d.c. plate voltage is fed into the amplifier via a Millen high-voltage terminal, type 37001.

Many combinations of plate, screen and bias voltages can be used, as a look at a tube-data sheet will show. The following voltages are typical:

	C.W.	A.M. Phone	AB ₁ Linear	
Plate	2500	2500	3500	volts
Screen	500	400	555	volts
Grid	-150	-200	-105*	volts

* Set to give 45-ma. plate current per tube with no drive power.

The tune-up procedures are the same as for the 4-125A. Also, the amplifier should be checked for parasitics as described previously. Best linearity is achieved by increasing the loading on the amplifier until the power output just starts to fall off; during this adjustment, the drive power is held constant.

In operation, there is little to choose between the two rigs for the c.w. man. At 1-kw. input on c.w., the amplifiers handle identically; however, the 4-250As are easier to drive. For a 2-kw. p.e.p. input on s.s.b., the 4-250A amplifier stands alone. Which version the builder chooses depends upon his requirements as balanced against the necessary cash outlay. It should be pointed out that a third version combining the better or less-expensive components of the two designs presented could be built around 4-250As and result in an amplifier not costing much more than the strictly economy 4-125As.

Design of the Pi-L Network

The design of the pi-L tank circuits has been covered be-

fore in excellent articles presented in *QST*.^{2,3} However, two different approaches are again presented here for those who would like to apply the circuit to transmitters of their own design.

The first method is to use values of components for the pi network with which the builder is already familiar and alter them suitably to make the pi-L work. Figs. 2A and 2B show a pi and a pi-L network, either of which will match a power amplifier tube to a 50-ohm load.

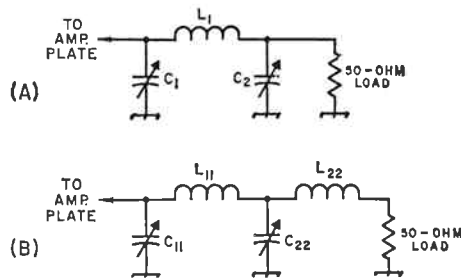


Fig. 2

First, the capacitance and voltage rating of C_1 and C_{11} are exactly the same for both circuits. The capacitance of C_{22} will be about one-half to two-thirds that required for the pi capacitor, C_2 . The voltage rating of C_{22} must be three or four times that required for C_2 . The inductance L_{11} will be greater than L_1 by about 25 per cent. The inductance L_{22} , which has no direct counterpart in the pi, will have an inductance of about one-third to one-half of L_{11} . The circulating currents in L_{11} are the same as in L_1 ; therefore, a coil made of a wire size suitable for a pi net will also be good for a pi-L. The currents flowing in L_{22} are much smaller than those in L_{11} , so it can be made of smaller wire. For example, if L_{11} must be made of No. 10 wire, L_{22} could be made of No. 14 or 16.

This approach will allow the intrepid experimenter to convert his present pi-network output circuit to a pi-L without much pain. But for those who prefer a more formal method, the following is offered:

Just as the pi is designed as two L networks placed back-to-back, the pi-L is designed as three L nets placed back-to-back. In Fig. 3, a pi-L tank circuit is broken down into its

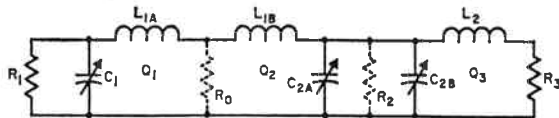


Fig. 3

three equivalent Ls. The first L matches the desired tube load resistance R_1 to a resistance R_0 and is composed of C_1 and L_{1A} . The second L matches R_0 to the resistance R_2 and is made up of L_{1B} and C_{2A} . The third L matches R_2 to the load R_3 (the transmission line) and consists of C_{2B} and L_2 . R_1 is determined from the approximate formula:

$$R_1 = \frac{E}{2 \times I}$$

where E = plate voltage applied to the tube
and I = plate current in amperes.

First, the value of Q_1 is selected. Q_1 is the operating Q of the plate circuit and is usually chosen to be between 10 and 20. Knowing R_1 and Q_1 the capacitive reactance X_{C1} of the plate tuning capacitor C_1 is calculated from:

$$X_{C1} = \frac{R_1}{Q_1}$$

Also, calculate R_0 from:

$$R_0 = \frac{R_1}{Q_1^2 + 1}$$

Then, calculate the inductive reactance X_{L1A} of the inductance L_{1A} from:

$$X_{L1A} = R_0 Q_1$$

This completes the calculation of the reactances for the first L network.

² Miedke, "Pi and Pi-L Design Curves," *QST*, November, 1955.

³ Grammer, "Simplified Design of Impedance-Matching Networks," *QST*, March, April and May, 1957.

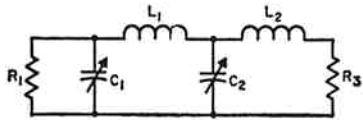


Fig 4

Before proceeding with the second L network, which consists of L_{1B} and C_{2A} , the value of R_2 should be selected (R_2 must always be greater than R_0 and R_3). Although it is possible to arrive at operating values for L_{1B} and C_{2A} by first selecting Q_2 (the Q of the second L network), it is best, from an equipment designer's viewpoint, to calculate R_2 to match the voltage capability of available tuning capacitors. This is done from:

$$R_2 = \frac{E^2}{P}$$

where E = r.m.s. voltage across R_2

P = Amplifier power output in watts.

Because the peak voltage must be considered when determining capacitor voltage breakdown (peak voltage equals 1.41 times r.m.s. voltage) and some safety factor is desired, it is best to let E equal one-half the capacitor breakdown voltage. For a kilowatt transmitter, it is suggested that 1000- to 2000-volt capacitors be considered. Convenient values of power output can be calculated by assuming an efficiency of 75 per cent for a c.w. or plate-modulated amplifier, and 60 per cent for a linear. Don't forget that for an a.m. phone rig, the power output at the crest of a 100-percent-modulated envelope is four times the carrier output.

Having calculated R_2 , proceed with determining Q_2 from:

$$Q_2 = \sqrt{\frac{R_2}{R_0} - 1}$$

Calculate X_{C2A} (capacitive reactance of C_{2A}) from:

$$X_{C2A} = \frac{R_2}{Q_2}$$

Calculate X_{L1B} (inductive reactance of L_{1B}) from:

$$X_{L1B} = R_0 Q_2$$

Next, the capacitive and inductive reactances for the third L network, C_{2B} and L_2 , are calculated. First, calculate Q_3 , the Q of the third L net, from:

$$Q_3 = \sqrt{\frac{R_2}{R_3} - 1}$$

where R_3 is the load that the amplifier will be working into, usually 50 ohms for coax feed lines. It can be almost anything else but must be less than R_2 . Then determine X_{C2B} , the capacitive reactance of C_{2B} , from:

$$X_{C2B} = \frac{R_2}{Q_3}$$

Then calculate X_{L2} , the inductive reactance of L_2 , from:

$$X_{L2} = R_3 Q_3$$

Since the inductances L_{1A} and L_{1B} are in series, these are combined in one coil, L_1 . The inductive reactance is equal to the sum of the separate parts

$$X_{L1} = X_{L1A} + X_{L1B}$$

Similarly, the two capacitors C_{2A} and C_{2B} are in parallel and are combined in one capacitor, C_2 . X_{C2} , the capacitive reactance of C_2 , is obtained by

$$X_{C2} = \frac{X_{C2A} X_{C2B}}{X_{C2A} + X_{C2B}}$$

The actual values for the capacitors and coils can be determined for any frequency from:

$$C = \frac{10^6}{2\pi f X_C}$$

$$\text{and } L = \frac{X_L}{2\pi f}$$

where C = Capacitance in μmf .

L = Inductance in μh .

f = Frequency in Mc.

The complete pi-L network with the combined inductances and capacitors is shown in Fig. 4. QST