PENTODE LINEAR AMPLIFIERS

KILOWATT GROUNDED-GRID LINEAR AMPLIFIER WITH PARALLELED GL-813's

GL-813 pentodes have been popular with radio amateurs for years. And their smooth adaptability to grounded-grid linear amplifier circuits should continue their well-earned reputation for versatility.

SCANNING the SPECTRUM

Some Comments on — GROUNDED-GRID OPERATION of TETRODE AND PENTODE TUBES IN LINEAR AMPLIFIERS

There has recently been greatly increased interest and popularity of using tetrode and pentode transmitting tubes in grounded-grid linear amplifier circuits. The information below has been compiled to serve as a guide to operating other tetrode and pentode tube types in the circuit published in this issue for the GL-813 beam pentode.

CAUTION: Although the 813 operates satisfactorily with the high-mu triode connection shown in the schematic diagram, Fig. 1, on page 4 of this issue, some other tube types should not be operated as high-mu triodes. With some tube types, the control grid may draw excessive grid current when the cathode is driven with sufficient power for grounded-grid operation. This is especially true when the tube is operated as a zero-bias high-mu triode (both control grid and screen grid grounded directly), since grid current can begin flowing as soon as driving power is applied because there is no grid bias voltage to overcome. A majority of the combined control-screen grid current, as read on a single meter, may flow through the control grid, thus greatly exceeding the grid dissipation rating of the tube. It is a good idea to determine experimentally, with meters connected in both control grid and screen grid DC connections to ground, how much current is drawn by each grid with the grounded grid amplifier operating with normal drive, plate voltage and plate current.

The use of fixed bias on the control grid in the GL-813 amplifier circuit tends to limit the control grid current, and keep grid dissipation within ratings.

A tabulation of the DC connections recommended for the popular types of amateur radio power tubes is given in TABLE 4. Technical data sheets for specific tube types can be obtained from the manufacturer of that type. For General Electric types, write to: Technical Data Section, Power Tube Department, General Electric Company, Schenectady, New York.

TABLE 4 RECOMMENDED DC CONNECTION FOR PENTODE AND TETRODE TUBES IN GROUNDED-GRID AMPLIFIER SERVICE

TUBE TYPE		COMMENTS
4-65A 4X150A 4D21/4-125A 701A	4-400A 4-1000A 5D22/4-250A	Only tetrode connection recommended, triode connection not recommended, but may be possible with careful checking of grid currents. Fixed bias should be used for triode connection, as in 813 circuit.
803 813 814	828 837	Triode connection suitable, first check grid current. Pentode connection also recommended.
807 1625		Not recommended for grounded-grid operation because of beam forming plates connected internally to cathode; may cause instability. Some tubes can be modified if these connections are brought out of bulb on separate leads; see QST and ARRL SSB Handbook for details. With modification, recommended for triode connection.

KILOWATT GROUNDED-GRID AMPLIFIER

Using only hand tools, an amateur can construct a high quality flexible linear amplifier in less time than it takes to round up the relatively few parts required.

The popularity of amateur transmitters in the 75- to 150-watt power class usually provides a ready-made exciter when the time comes to add a more powerful final amplifier to the amateur station. Because pentodes have a low driving power requirement, a power dissipating device must be employed when these tubes are driven from a 100-watt class rig.

A grounded-grid amplifier circuit provided a satisfactory solution; and, experience indicates that the GL-813 operates efficiently in grounded grid.[1] Also, this tube operates well as a high-mu triode, thus eliminating the need for a separate screen voltage supply.

To provide for a 1-kilowatt power capability as a linear amplifier, two GL-813 tubes are connected in parallel and operated in a grounded-grid circuit, with both the screen grids and beam forming plates at zero DC and r.f. potential. The tubes run in class B at an efficiency of 60 to 70 percent, depending upon the plate voltage.

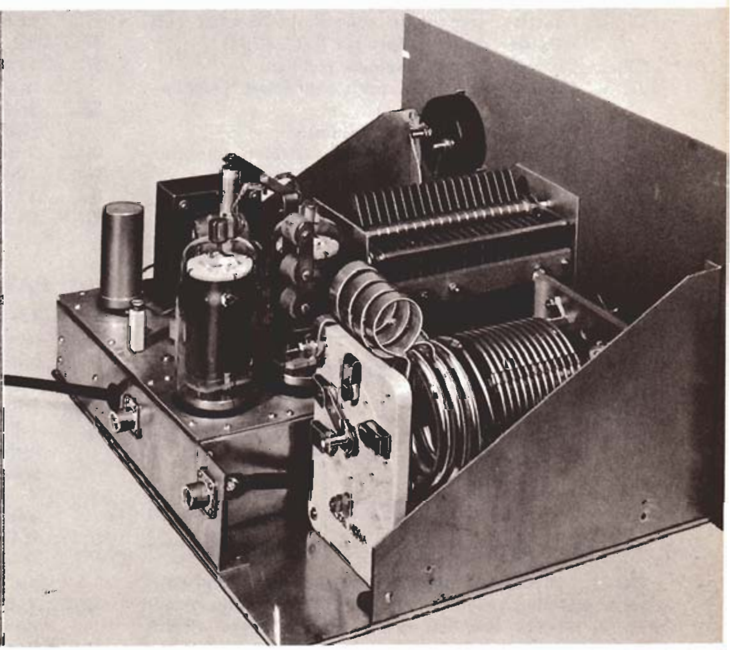
THE CIRCUIT, shown in the schematic diagram, Fig. 1, is quite simple, since no tuned grid circuit is required. The r.f. driving power is fed directly into the filaments of the two GL-813's. A dual r.f. choke (RFC$_2$) in the filament circuit isolates the filament transformer.

High voltage is applied to the GL-813 plates, connected in parallel, through RFC$_3$. Three blocking capacitors in parallel keep high voltage from reaching the pi-network tuning plate circuit. A ready-made tapped coil (L$_1$) and split-stator tuning capacitor on the input side of the pi-network provide nearly optimum L/C ratios on all amateur bands from 3.5 to 30 megacycles. One section of C$_1$ is in the circuit on 14, 21 and 28 megacycles, when S$_2$ is open. Both sections are in parallel on 3.5 and 7 megacycles, where greater maximum capacitance is required, S$_2$ being closed by a linkage from the switch on L$_1$.

A large variable capacitor (C$_2$) — 1500 mmf maximum — across the output side of the pi-network eliminates the need for several fixed capacitors, and a tap switch to add them to the circuit as needed. The output circuit will match impedances from 50- or 70-ohm unbalanced feedline and loads.

THE CONTROL GRIDS on the GL-813's, bypassed to the chassis at each tube socket, receive from 0 to 100 volts of negative bias from the built-in bias supply, depending

LEFT REAR VIEW of the linear amplifier. A ⅛-inch thick sheet of aluminum 14½ x 17 inches in size forms the main chassis and is fastened to the panel with chassis support brackets. The plate circuit connections are made with $\frac{1}{16}$ x ½-inch copper strip, while the GL-813 plate leads are No. 10 braided copper wire.



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[1] As in the Barker & Williamson, Inc., models L-1000A, L-1001A and LPA-1.

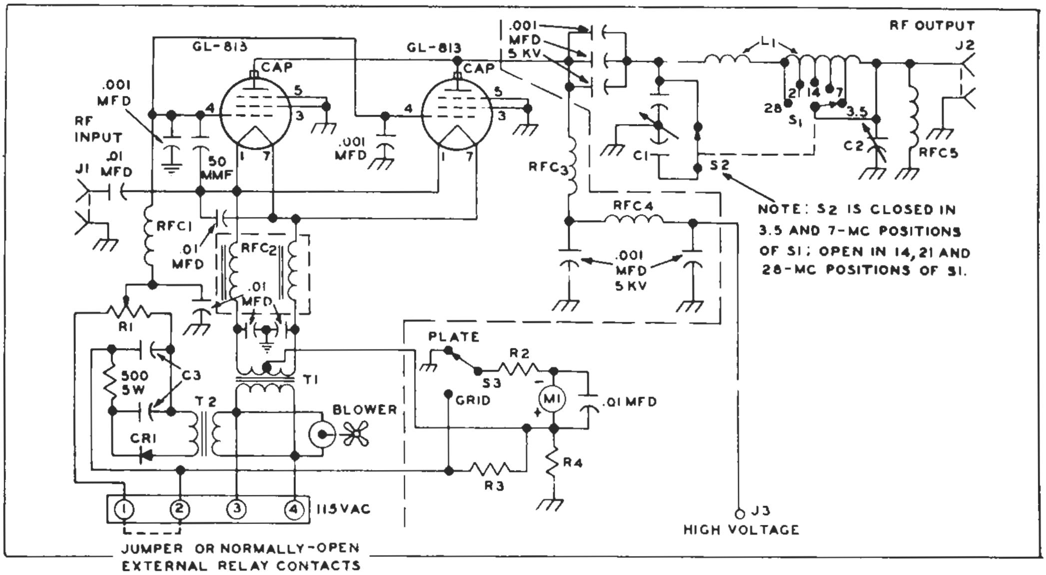


FIG. 1. SCHEMATIC DIAGRAM of the GL-813 grounded-grid linear amplifier. The five .001-mfd, 5KV fixed capacitors are of the cylindrical ceramic type with screw terminals (Centralab 8508-1000, or equivalent). All other bypass capacitances are disc ceramic, 500 volts working. Resistances are in ohms, with wattage ratings as specified. Resistances in the metering circuit are listed in **TABLE I.** No switch is shown in the 115-volt AC circuit, since it is controlled by external power switching circuits. All components to the left of the dashed line running down through the diagram are on the sub-chassis.

TABLE I — PARTS LIST

C_1	Split-Stator variable capacitor; front section, 28—160 mmf; rear section, 7-50 mmf; 0.125-inch air gap (Cardwell P-8359, or equivalent).
C_2	50—1500 mmf variable capacitor, 0.030-inch air gap (Cardwell P-8013, or equivalent).
C_3	2-section electrolytic capacitor, 40-mfd. 150 volts per section (Sprague TVL-2428).
CR_1	130-volt, 75 ma. selenium rectifier.
J_1, J_2	Chassis type coaxial cable connectors (Amphenol 83-1H hood on J_2).
J_3	1½ inch high standoff insulator.
L_1	10 uh pi-network band switching inductor (B & W 851 for up to 600 watts; B & W 850A for over 600 watts).
M_1	DC milliameter, 0-1 ma., full scale.
R_1	500-ohm, 25 watt potentiometer.
R_2	Series resistance for M_1; 1200 ohms, 1 watt.
R_3	12 ohms, 1 watt, for 100-ma grid reading.
R_4	2.4 ohms, 1 watt, for 500-ma plate reading.
RFC_1	0.5-mh, 300-ma r.f. choke (National R-300).
RFC_2	15-ampere dual choke (B & W No. FC-15).
RFC_3	200 uh, 500-ma r.f. choke (National R-175A, or B & W No. 800).
RFC_4, RFC_5	1 mh, 300-ma r.f. chokes (Nat. R-300).
S_1	5 position single section tap switch; part of L_1 pi-network coil.
S_2	Special 2-position, single section switch; see FIGS. 4 and 5 for details.
S_3	2 position, single section tap switch.
T_1	10-volt, 10-ampere filament transformer.
T_2	115-volt, 200-ma power transformer.
V_1, V_2	GL-813 power beam pentode tubes.

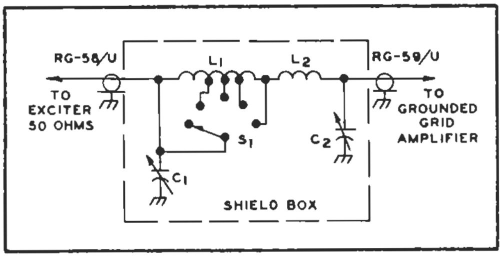


FIG. 2. SCHEMATIC DIAGRAM of an optional pi-network matching circuit. It will match the cathode circuit of the GL-813 amplifier to the 50-ohm output circuit of those exciters which otherwise might not be loaded heavy enough to fully drive the linear amplifier.

TABLE II
PARTS LIST, CATHODE COUPLER

C_1	45—1260 mmf variable (3-section broadcast receiver variable, 15—420-mmf per section, all sections in parallel).
C_2	12 — 325-mmf variable, 0.024-inch air gap (Hammarlund MC-325-M).
L_1	4.2 uh, 17 turns, No. 16 tinned wire, 1¼ inches in diameter, 2⅛ inches long, spacewound 8 turns per inch, tapped 2 (21 MC, 4 (14 MC), and 10 (7 MC) turns from L_2 end of coil. (B & W No. 3018).
L_2	0.44 uh, 5 turns, No. 12 tinned wire, 1 inch in diameter, 1 inch long, spacewound 5 turns per inch, self-supporting.
S_1	1 pole, 5 position tap switch, ceramic insulation (Centralab No. 2500, or equivalent).
Shield Box	4 x 5 x 6-inch Minibox (Bud CU-3007), or 3 x 5 x 7-inch Minibox (Bud CU-3008).

on the setting of R_1. When no connection is made between terminals 1 and 2 on the terminal strip, the tubes are biased to cut off plate current flow. Jumpering these terminals reduces the bias to the value selected by R_1. Leads should be run from these terminals to a switch, or relay contacts which close while transmitting.

Separate metering of current in the grid and plate circuits is accomplished by switching a single meter (M_1) across shunting resistors, R_3 and R_4, respectively.

Only plate current is read in the PLATE position of S_2, since the grid circuit is returned directly to the center tap on the filament transformer (T_1).

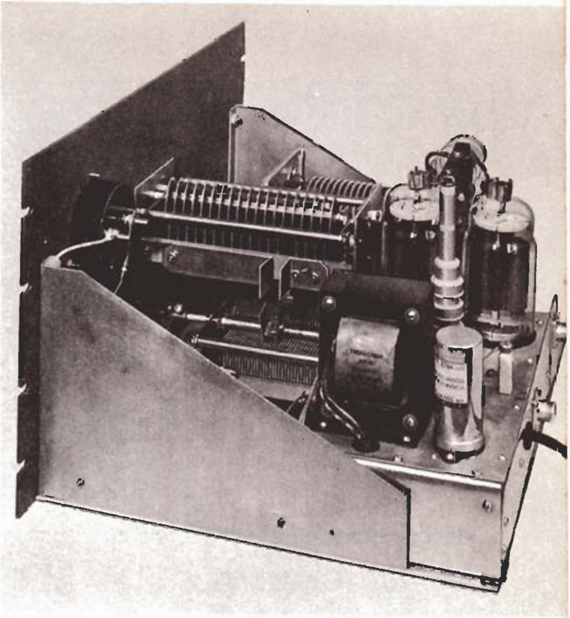
MOST EXCITERS will have a wide enough range in output impedance to match to the cathode circuit of the GL-813's (about 150 to 200 ohms, depending upon frequency). In case the exciter will only match into a 50- to 70-ohm load and will not drive the grounded grid amplifier hard enough, a pi-network matching circuit can be inserted between the exciter and amplifier.

The suggested circuit for this network is shown in Fig. 2. The parts values shown should have sufficient flexibility for most matching requirements. All components. for the matching network were housed in a 4 x 5 x 6-inch Minibox (Bud CU-3007). Lengths of coaxial cable for the input and output were cut to the proper dimensions to run to the exciter and final amplifier.

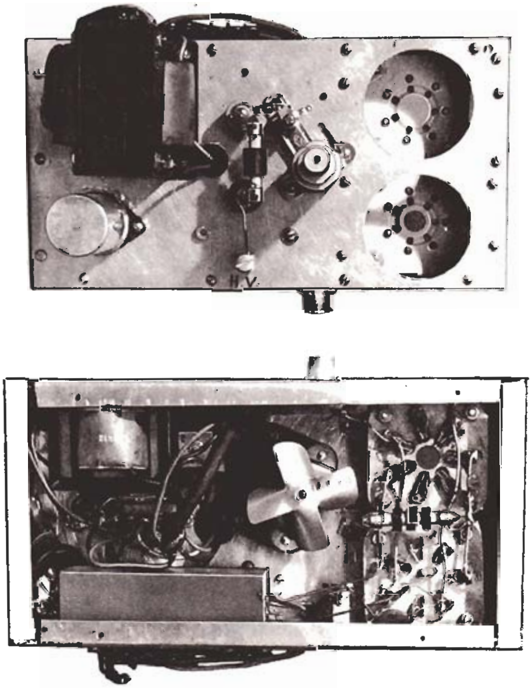
CONSTRUCTION is quite simple, due to the utilization of standard, readily available components throughout the amplifier. The main chassis is a 14½ x 17 x ⅛-inch thick sheet of aluminum fastened with its bottom surface ⅛ of an inch above the lower edge of a 10½ x 19-inch aluminum relay rack panel. Only the pi-network components, meter and meter switch are on the main chassis, the remaining components being assembled on the 6 x 11 x 2½-inch sub-chassis.

The photographs and drawings illustrate the placement of the major components (Figs. 3 and 4). Either a 3½ or 2½-inch meter may be used for M_1.

The front and back plates of C_1 and C_2 are fastened to ⅛-inch thick sheet aluminum brackets 7 inches high and 4 inches wide. The shaft on which the linkage for switch S_2 is supported also runs between these plates. The parts in this linkage, and assembly details, are shown in Fig. 5. A U-shaped clip, made from spring brass or phosphor bronze, completes the connection between copper angle brackets fastened to



RIGHT REAR VIEW of the linear amplifier. Note how C_1 and C_2 are mounted on vertical brackets made from ⅛-inch thick sheet aluminum. The copper angle brackets and U-shaped angle bracket on C_1 is S_2 (See FIG. 5 for details). A 6 x 11 x 2½-inch aluminum chassis houses most of the smaller components in the amplifier.



TOP AND BOTTOM VIEWS of the amplifier sub-chassis. The copper strip plate circuit connections have been removed from RFC_3 in the top view. Under-chassis wiring is insulated hookup wire, except for the filament leads, which are No. 12 tinned wire.

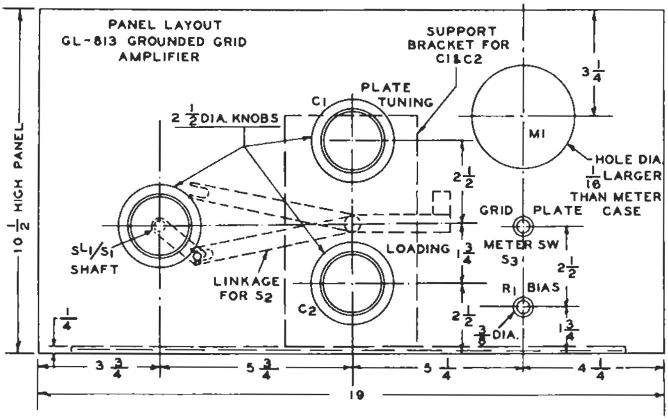


FIG. 4. PANEL LAYOUT DIAGRAM for the GL-813 linear amplifier. The linkage for S_2 pivots on the shaft located between C_1 and C_2. Drill 3/8-inch diameter panel holes for this shaft, and the shafts on C_1, C_2, L_1 and the meter switch, S_3. The aluminum chassis deck is positioned 1/8 of an inch above the bottom edge of the panel.

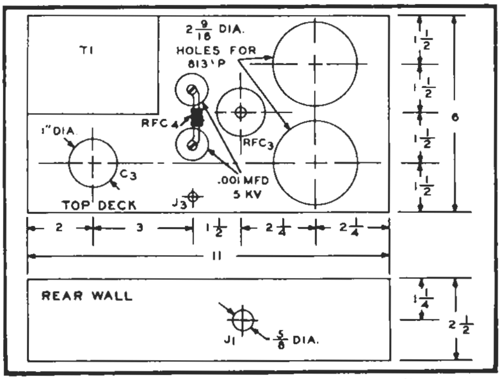


FIG. 3. LAYOUT DIAGRAM for the amplifier subchassis. Holes for the machine screws which secure the components in place are located from the holes on those components.

the two stator sections on C_1, when L_1/S_1 is in the 3.5 and 7-megacycle positions. The arm on the L_1/C_1 shaft is adjusted so that it engages the forked arm, as shown in solid lines on the sketch, when S_1 is in the 7-megacycle position. Both arms should then move up so that the forked arm is in the position indicated by dotted lines when S_1 is in the 14-megacycle position.

Under-chassis wiring, except for the No. 12 tinned wire filament leads, is run with No. 18 insulated wire. The plate circuit connections were made with 1/16 x ½-inch copper strip, as shown in the photos. A small 115-volt phonograph motor with a 3-inch diameter, 4-blade fan draws air up through holes in the aluminum base plate and out through the holes in the subchassis for the 813 tubes.

Once construction is finished, check the filament and bias voltage circuits before connecting the high voltage power supply to J_3. A power supply with provision for reducing the output voltage to about one-half or two-thirds of full voltage is recommended, especially if the full output is 2,000 volts or higher. Connect an antenna or dummy load to J_2.

TUNEUP FOR SSB operation consists simply of applying full plate voltage and, with terminals 1 and 2 on the power strip shorted, setting R_1 for 40 milliamperes of plate current with S_3 in the PLATE position. Turn S_1 to the same band on which the driving exciter is operating and apply driving power to the amplifier by injecting carrier on the SSB exciter. Adjust the exciter loading for a full-scale reading on M_1 with S_3 in the GRID position.

Turn C_2 to maximum capacitance, S_3 to the PLATE position and adjust C_1 for minimum plate current. Turn on partial high voltage and decrease the capacitance of C_2 for a plate current reading of 200 milliamperes, readjusting C_1 for minimum plate current, as necessary. Apply full plate voltage and adjust C_2 for about 400 milliamperes plate current. The grid current should read 100 milliamperes.

Switch the exciter to deliver SSB output and adjust its operation for the audio gain for normal r.f. power output. With speech, the 813 linear amplifier should swing up to about 150 milliamperes plate current; while with a steady whistle the plate current should reach 400 milliamperes. The amplifier is now tuned up.

TUNEUP FOR CW operation is similar, except that the bias voltage is adjusted initially for almost zero plate current. The exciter is adjusted to deliver 100 milliamperes of grid current in the amplifier without plate voltage. After applying partial plate voltage, load the amplifier to about 180 milliamperes plate current. With full plate voltage, the plate current should be about 350 milliamperes.

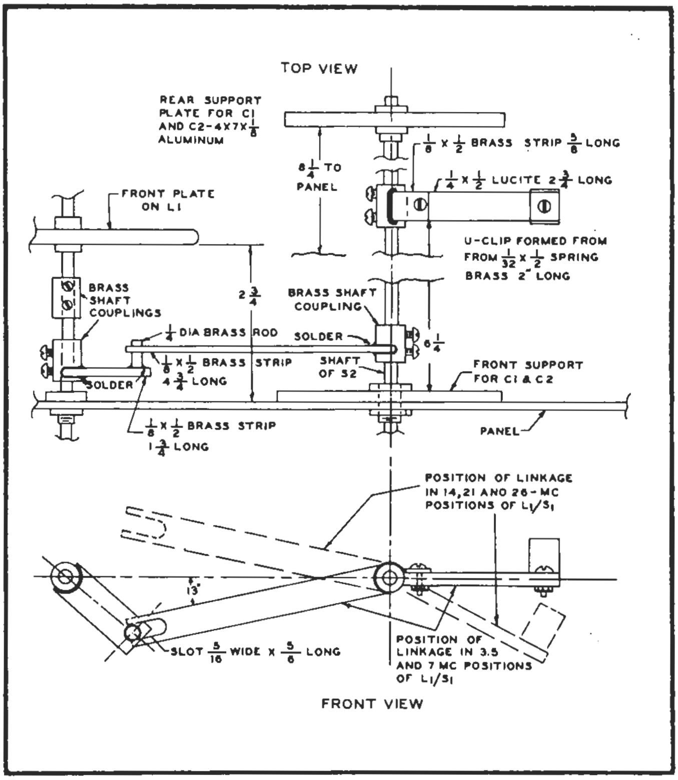
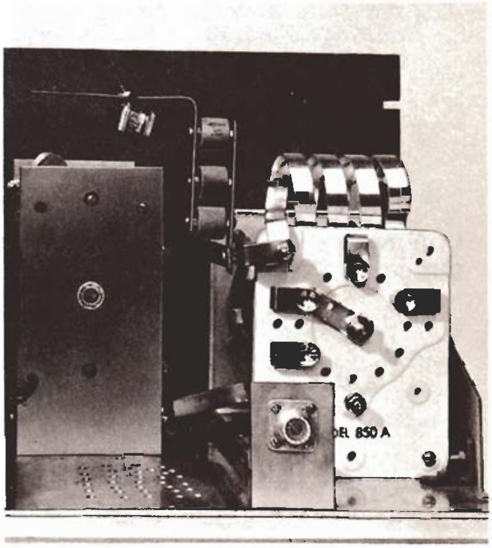


FIG. 5. DETAIL DRAWING of the linkage which actuates S_2 from the shaft driving the bandswitch (S_1) on L_1. Three 1/8 x 1/2-inch brass strips, soldered to brass shaft couplings, are the linkage arms. U-shaped clip-on plastic arm closes circuit between copper angle brackets on C_1 in the 3.5 and 7-megacycle positions of L_1.

This amplifier also may be driven by a conventional amplitude modulated transmitter. The plate current is adjusted to 40 milliamperes at full plate voltage, the same as for SSB operation. Adjust the exciter for 90 to 100 milliamperes of amplifier grid current. Apply partial plate voltage and load the amplifier to about 150 milliamperes plate current. Next, apply full plate voltage and adjust for 300 milliamperes plate current.

Now, reduce the driving power from the exciter until the amplifier plate current reads 150 milliamperes. When the exciter is amplitude modulated 100 percent, the 813 amplifier plate current should rise not more than 5 percent, otherwise distortion of the output signal will result.

It's a good idea to check the operation of this amplifier with an oscilloscope during initial adjustment; and also periodically to ensure linearity of the output signal. The model amplifier constructed for this article has been operated on all bands for over a year at W2GFH without a failure for any reason. It is stable, easy to adjust and provides a really potent signal.



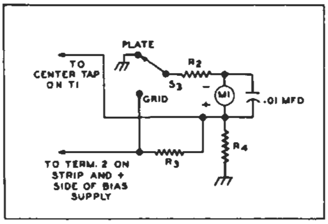
REAR VIEW of the amplifier plate circuit. Sub-chassis has been removed to show the holes in the aluminum plate through which cooling air is drawn into the chassis by the fan, and exhausted up through the chassis holes for the GL-813 tubes.

Additional Information on G-G Linear

All changes listed below have been made in this reprint, but persons who have the original printing of the November-December, 1959 (Vol. 14, No. 6) issue of G-E HAM NEWS should note these changes if they wish to construct this amplifier.

CORRECTIONS:

1. There is an error in the plate current metering circuit in the schematic diagram, Fig., 1, on page 4. The contact on the meter switch, S_3, labeled "PLATE", should be connected to ground, and not connected to the center tap of the filament transformer, T_1. The corrected circuit is shown in Fig. 1 on the reverse side of this bulletin. The circuit as originally shown shorts out the meter in the "PLATE" position, resulting in practically no meter reading.



2. The plate spacing of C_1, the 15--300-mmf variable capacitor in the pi-network cathode input coupler diagram, Fig. 2, on page 4, should be 0.0245 inches, not 0.224 inches, as given in TABLE II - PARTS LIST, CATHODE COUPLER.
3. WATTAGE RATING FOR POTENTIOMETER R_1 - This rating, given as 2 watts, actually should be 25 watts. The low resistance of this potentiometer across the bias voltage supply stabilizes the bias, thus a high-wattage potentiometer is required at this point.
4. CAPACITANCES IN PI-NETWORK CATHODE COUPLER - The listings for capacitors C_1 and C_2 in the pi-network cathode coupler (Fig. 2 on page 4) were reversed. C_1 should be the 3-section broadcast receiver capacitor; and, C_2 should be the 12--325-mmf capacitor to match into the cathodes of the 813 tubes.
5. The size of the main chassis plate, given as 13 inches deep x 17 inches wide, should be 14 1/2 inches deep, in order to accommodate both the capacitor mounting, which occupies 8 1/2 inches of depth, and the 6-inch depth of the subchassis on which the tubes are mounted. This dimension was given in the Left Rear View on page 3, and in the text on page 5.

COMMENTS ON COMPONENTS AND SUGGESTED SUBSTITUTIONS

Here is additional information on components used in the original model, and suggested substitutions for those components which are suitable both mechanically and electrically.

COMMENTS ON COMPONENTS:

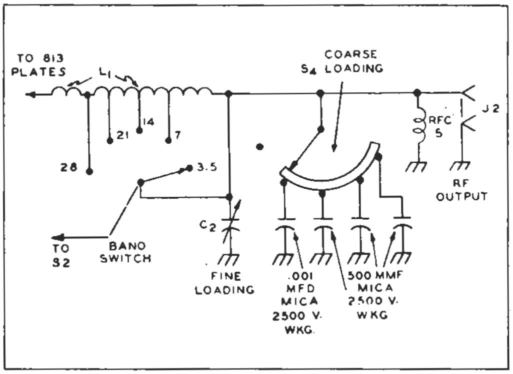
1. THE BARKER & WILLIAMSON components used in the amplifier (L_1/S_1, RFC_2, and the plate RF choke, RFC_3) can be obtained from those radio parts distributors which specialize in amateur type components and equipment. These distributors will order these parts from B & W if they do not have them in stock.
2. CONTROL KNOBS - B & W type 901 turned aluminum knobs (1-7/8 inches in diameter) were used on the bandswitch, plate tuning and plate loading controls. B & W type 903 knobs (11/16 inches in diameter) were used on the meter switch and bias control.
3. PLATE CIRCUIT RF CHOKE - A B & W type 800 RF choke is recommended for RFC_3, rather than the National R-175A choke shown in the model amplifier. The R-175A choke may have VHF resonances which could cause the choke to burn out.

4. CAPACITOR C_1 - This capacitor is a Cardwell type P-8359, no P-8060, as specified in TABLE I PARTS LIST of the original printing of this issue.

5. AVAILABILITY OF CARDWELL CAPACITORS - Some persons have reported difficulty in obtaining the Cardwell type P-8359 (C_1 about \$33.00 amateur net) and P-8013 (C_2 - \$19.50 amateur net) variable capacitors. We have been advised that these capacitors are currently available through electronic parts distributors. If these capacitors are not in stock, the distributor can order from the Cardwell Condenser Corporation, 80 East Montauk Highway, Lindenhurst, Long Island, New York.

6. SUBSTITUTE FOR C_1 - A conventional split-stator variable capacitor of suitable capacitance and voltage rating can be substituted for the Cardwell unit. The Johnson type 100ED45, Cat. No. 154-3, having 15--100-mmf per section, and a 0.125-inch air gap, is recommended. Install the switch between the stators of C_1 on the studs supporting the stator plates at the middle of the capacitor. Change the linkage running from S_1 to the shorting bracket on S_2 to suit the parts layout of your particular amplifier.

7. SUBSTITUTE FOR C_2 - Although the high maximum capacitance range of the Cardwell P-8013 capacitor (150-1500-mmf) makes it ideal for pi-network output circuits, a smaller variable capacitor and a tap switch to add fixed mica capacitors across the pi-network output, can be substituted. The circuit shown in the COMPACT TRIODE KILOWATT (See G-E HAM NEWS, September-October, 1959; Fig. 1, page 4, for details) is suitable. This circuit is repeated at right for your convenience.



8. POWER RATING OF TANK CIRCUIT - If 2,000 volts or less will be run on the plates of the GL-813's, a capacitor for C_1 with 0.100-inch air gap will be suitable. The 0.125-inch air gap specified is suitable for up 3,500 plate volts. The B & W model 851 pi-network circuit is actually suitable for average power inputs of 800 watts in SSB service, as tests on the model amplifier have indicated.

9. RATING OF RFC_4 - Although the rating of the r.f. choke in the plate voltage lead is only 300 milliamperes, the amplifier plate current swings up to 400 milliamperes only on peaks, thus the 300-milliampere r.f. choke is sufficient for the AVERAGE plate current drain.

10. OTHER PI-NETWORK INDUCTORS - The air-dux type 195-1 (500 watts) and 195-2 (1000 watts) inductors also may be used in this amplifier. A number of readers have inquired about this. A well-insulated tap switch capable of carrying 10 amperes of r.f. current is needed for the bandswitch, which is not a part of the air-dux inductors. Home-wound coils, and pi-network coils made up from ready-wound inductor stock, with a 28-megacycle coil wound from copper strip, also can be used for L_1. The same inductance values shown in TABLE 3 - PI-NETWORK CHART FOR 813 AMPLIFIER, should be used to design home-wound coils, or to prune ready-wound inductor stock.

11. PLATE TANK CIRCUIT CONSTANTS - The plate circuit pi-network in the GL-813 grounded-grid amplifier was designed for a 2,500-ohm plate load, working into a 50-ohm antenna load. A tabulation of the inductance and capacitance values required in the circuit for bands from 3.5 to 28 megacycles is given in TABLE 3 Note that the number of active turns in the circuit on each band is given for air-dux type 195-1 and 195-2 coils. The turns figures do not include the strip-wound 28-megacycle coils, and are given from where the strip coil joins the coil wound with wire. The inductance values DO include the strip inductor, which is 0.4 microhenries.

TABLE 3

TABLE 3 - PI-NETWORK CHART FOR 813 AMPLIFIER

LOAD IMPEDANCE (ohms)	BAND (MC)	C_1 (mmf)	L_1 (uh)	ACTIVE TURNS (see text)	C_2 (mmf)
2,500	3.5	210	10.5	15	1,500
2,500	7	105	5.2	8.5	760
2,500	14	52	2.6	5	380
2,500	21	35	2.6	3	250
2,500	28	26	1.28	1	190

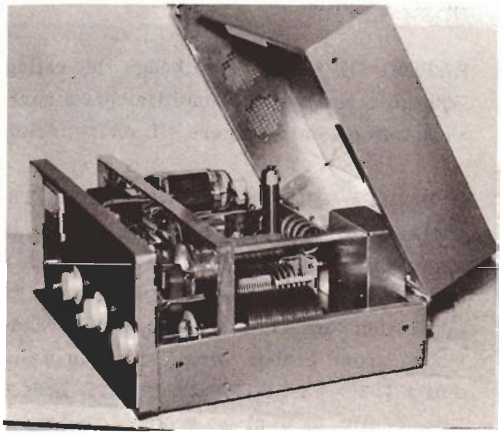
12. HEAVY-DUTY BANDSWITCH REQUIRED FOR S_1 - The G-E HAM NEWS lab has used Ohmite type 111-5 5-position, single section rotary tap switches with air-dux coils in other amplifiers and has found them capable of holding up in r.f. bandswitching service. They are rated at 10 amperes in 115-volt, 60 cycle AC switching service, and have a rotor contact insulated from the shaft for about 600 volts AC. However, we recommend mounting the switch on an insulated bracket, and using an insulated coupling on the shaft for r.f. service, especially in circuits having a plate voltage of 2000 or more.

13. INSTABILITY AT 28 MEGACYCLES - If instability is encountered in this amplifier at 28 megacycles, try connecting a 50-mmf mica capacitor between the control grid and one side of the filament (pin 4 to pin 1) on one 813 tube socket. This should help stabilize the amplifier at this frequency.

14. OTHER TUBE TYPES IN THE GL-813 GROUNDED-GRID CIRCUIT - Other tetrode and pentode transmitting tubes also may be used in this circuit. Of course, the cathode input impedance and plate load impedance will differ from the values given for this amplifier. The pi-network cathode coupler circuit, shown on page 4 (Fig. 2) of the November-December, 1959 issue, usually will provide a close impedance match between the exciter and the linear amplifier. For tubes operating at higher plate voltages and lower currents (higher plate load impedance) than the 813, less capacitance is needed in C_1 and C_2, and L1 will have higher inductance. For tubes operating at lower plate voltages and higher currents (lower plate load impedance), more capacitance will be needed in C_1 and C_2, and less inductance needed in L_1. Excellent pi-network data can be found on Tele-Hints sheet No. 8 for air-dux coils. This sheet is published by Illumitronic Engineering, Sunnyvale, California.

A PREVIEW OF '63 MODEL --

PHOTO AT RIGHT shows preliminary model of repackaged parallel-GL-813 amplifier being readied for publication in G-E HAM NEWS late in 1962. Design is suited for either grounded-cathode pentode, or grounded-grid triode operation of GL-813's. Cabinet is made from a 13 x 17 x 3-inch, and a 13 x 17 x 4-inch chassis, for total height of only 7 inches.



Operation of GL-813 as SSB Linear Amplifier

	Single Tube			Two Tubes (Parallel)			
	AB_1		AB_2	AB_1		AB_1	AB_2
Plate voltage	1250 v	1500 v	2500 v	1250 v	1500 v	2000 v	2500 v
Control grid voltage	-80 v	-90 v	-95 v	-80 v	-90 v	-90 v	-95 v
Screen grid voltage[1]	750 v	750 v	750 v	750 v	750 v	750 v	750 v
Peak grid to grid ac voltage	80 v	95 v	117 v	160 v	190 v	212 v	234 v
Static plate current	45 ma	40 ma	18 ma	90 ma	80 ma	90 ma	36 ma
Max. Sig. Plate current (sine wave input)	165 ma	158 ma	180 ma	330 ma	315 ma	330 ma	360 ma
Static #2 grid current	3 ma	1.5 ma	0.6 ma	6 ma	3 ma	4 ma	1.2 ma
Max. Sig. #2 grid current (sine wave input)	25 ma	29 ma	28 ma	50 ma	58 ma	60 ma	56 ma
Max. Sig. driving power[2]	0 w	0.1 w	0.18 w	0 w	0.2 w	0.2 w	0.36 w
Control grid current[2]	0 ma	0 ma	0.2 ma	0 ma	0 ma	0 ma	0.4 ma
RMS power output	110 w	160 w	325 w	220 w	320 w	430 w	650 w
RMS power input	206 w	254 w	420 w	412 w	508 w	660 w	840 w
Load impedance, ohms	3300	5000	7000	1900	2300	3000	3400 ohms

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[1] In pentode-connected grounded cathode circuits. In grounded-grid No. 1 service, screen grids should be operated at 0 volts DC.

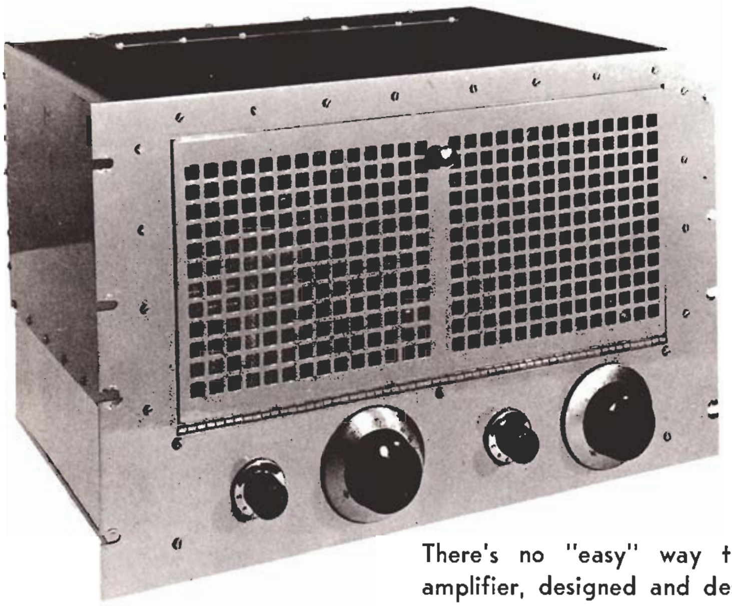
[2] In pentode-connected grounded cathode circuits. In grounded-grid No. 1 service, driving power will run from 50 to 90 watts, and grid current from 70 to 100 milliamperes, depending on plate voltage and operating frequency.

Regulation of control grid and screen voltages should be within 5 percent or better for best linearity. A string of five OD3/VR-150 voltage regulator tubes in series will provide a suitable source of regulated screen voltage. A good power supply also may be used. Never apply screen voltage without plate voltage.

600-WATT ALL-BAND AMPLIFIER
FOR CW, AM OR SSB LINEAR SERVICE

Featuring — Push-Pull GL-813's to Ease Your Steps to High Power

From November-December, 1954



There's no "easy" way to power — but this amplifier, designed and described by W2GYV, employs tested techniques and standard components to make the road to power as smooth as possible.

—Lighthouse Larry

GENERAL DESCRIPTION

Here's a husky all-band final that does not utilize any new or trick circuits or any substantially different mechanical layout. It will be recognized from the circuit diagram and photographs as a conventional push-pull tetrode amplifier constructed in a straightforward manner. It illustrates the use of modern components and practical design.

In this complicated age, there is much to be said for an occasional attempt at simplification; and those seeking a respectable amount of power may find this amplifier fills their needs without emptying their pocketbooks or fraying their nerves during construction and testing.

The amplifier employs a pair of GL-813 tubes in a neutralized push-pull circuit. A multiband grid tank allows the input circuits to be permanently shielded and simplifies band-changing. The plate circuit uses standard plug-in coils which are easily accessible for band changing through the shielded and RF weather-stripped panel door.

No metering is provided in the amplifier itself. The incorporation of meters would make shielding and circuit isolation more difficult. It is much simpler and forthright to install grid, screen and plate current meters in a standard three-hole panel mounted elsewhere in the rack and connected in the power leads going from the amplifier after all RF has been filtered from them.

A regulated bias supply is included in the unit since with the low grid currents encountered it can be a simple affair and is something that would probably have to be built up in any event.

All controls, including input and output coupling, are conveniently located on the front panel. Coaxial connectors are used for the RF input and output and HV plug connectors for plate and screen leads. The grid meter and interlock circuit connections are made with two-contact microphone plugs mounted under a small shield on the rear of the chassis—thus making it a short and easy operation to disconnect all leads and remove the amplifier from its rack. The AC input—for bias and filament power—is through a cord and plug leading to the control unit shown in G-E HAM NEWS of March-April, 1954. (Volume 9, No. 2).

CIRCUIT DETAILS

The only part of the circuit which may be out of the ordinary is the use of a four-section variable capacitor, C_{12}, in the plate tank. This capacitor is adapted from a standard unit as explained under the constructional details and allows optimum L/C ratio to be achieved on all bands. It also makes tuning less critical on the three highest bands. The proper sections of the capacitor are selected automatically by jumpers on the coils between pins 1 and 2 and 7 and 8.

The plate coils are standard 500-watt units and although the amplifier has been run for extended periods at inputs of over 600 watts no undue heating of the coils was experienced. Jacks 3 and 6 on the coil socket were not used in this design.

The output is through a shielded link as specified. These links are available in 1, 2, and 3 turns. Generally, a 1-turn link is considered satisfactory at 10 meters, a 2-turn link at 15 and 20 meters, and a 3-turn link for 40 and 80. However, during tests, a 2-turn link was found satisfactory for all bands when working into a 52-ohm coaxial line. Experimentation is recommended here as each antenna system may be slightly different. What works at one installation may not work well at another, even though the same general system is used, since one line may have a different standing wave ratio than the other. At any rate, link coupling of this sort is probably the easiest of all coupling devices to adjust.

The vacuum capacitors C_6 and C_{11} are for the purpose of providing a short low impedance path for the higher harmonics which might cause TVI. It should be pointed out that they are not necessary to the normal satisfactory operation of the amplifier and may be omitted if TVI is not a problem.

Don't be misled, however, into thinking that these capacitors themselves will be a complete cure for all TVI. They are an aid in stubborn cases and you may well want to try the amplifier before installing them. However, the vacuum capacitors are part of the total plate tank capacitance and the coil modifications given in the coil table are based on their use. Leaving them out may not necessitate the coil modifications listed under "Coil Data."

The neutralizing capacitors, C_2 and C_5, were found necessary to completely stabilize the amplifier. All normal checks failed to reveal the need for neutralizing; but on checking the amplifier for stability by operating it at zero bias, no RF drive, and with plate and screen voltages adjusted to give rated static plate and screen dissipation, it was found that a weak oscillation would occur when both grid and plate were tuned to the same frequency. The neutralizing wires were then adjusted until this did not occur. This should be done with the 10 meter coils in place and will then hold for all-band operation. The neutralizing wires are made from No. 14 copper wire and are brought through the chassis approximately one inch from the tubes. Small ceramic feed-through insulators were used for this purpose. Start off with wires reaching to the tops of the tube anodes and adjust them by clipping off ½ inch at a time until a length is found which will give complete neutralization. Fine adjustment is made by changing the spacing between wires and tubes by means of an insulated rod through the ¼-inch holes in the back of the shield.

The bias supply is conventional. It utilizes a GL-OA3/VR75 tube for regulation and so furnishes 75 volts of fixed bias. The remaining bias is developed across R_1 by the flow of grid current. This resistor may be seen in the photographs on top of the bias supply sub-chassis. The remaining resistors and selenium rectifier are mounted under this sub-chassis. The 75 volts is more than sufficient for plate current cutoff, allowing the driver to be keyed for CW work provided the screen is supplied from a fixed supply or from a voltage divider from the HV plate supply. Do not attempt CW operation if the screen is supplied through a dropping resistor.

Liberal use has been made of by-pass capacitors and RF chokes. All of these precautions make for stable, trouble-free operation and are well worth their cost..

An interlock switch S_1, is provided to protect the absent-minded when changing coils. It should be connected in the power supply in such a manner that the primary voltage to the plate supply is removed when the door is opened. The micro-switch used is a SPDT switch and should be connected so that the switch opens the circuit when the door is open. In addition, provision should be made for shorting the high voltage lead to discharge the filter capacitors before changing coils. Make up a shorting stick NOW. AND USE IT! A fellow isn't even allowed one mistake at these voltages!

MECHANICAL DETAILS

Much thought and time was given trying to evolve some novel and suitable mechanical layout—something that would be eye-catching and efficient. In fact, the whole project was delayed several months because of this. Several unique ideas were dreamed up but discarded because they were too expensive, too difficult to construct without metal-working facilities or else they just shouted over-design.

The old standby of chassis and panel construction proved to be not only the easiest to handle with the usual facilities but also promised to fit into most modern station layouts.

The biggest problem (and it was small compared to some of the layouts that were considered) was that of getting the plate tank capacitor and link controls out to the front panel. The solution was found with standard components. The capacitor is driven with a right-angle drive unit, two universal joints, and some ¼-inch diameter shaft. Panel bushings are used wherever the shaft goes through the chassis or panel. The link control required only two flexible shafts. The arrangement should be evident by inspecting the photographs.

The parts layout is also clearly shown and no detailed drawings are given. The multiband tank is mounted on spacers so the tuning and link shafts are centered on the lower section of the front panel.

The bias supply is built on a separate sub-chassis easily shaped and mounted as shown and there is nothing critical about the placement of parts. The sub-chassis is fastened to the side of the main chassis by two screws in front and by the feed-through capacitors, C_{20} and C_{22} on the rear apron of the main chassis. The AC line filter capacitors, C_{25} and C_{27} are mounted on the bias chassis and project through the main chassis in close-fitting holes.

Ventilation is provided through the panel door and the vent holes over each tube. Natural draft provides sufficient air to prevent overheating of the tubes.

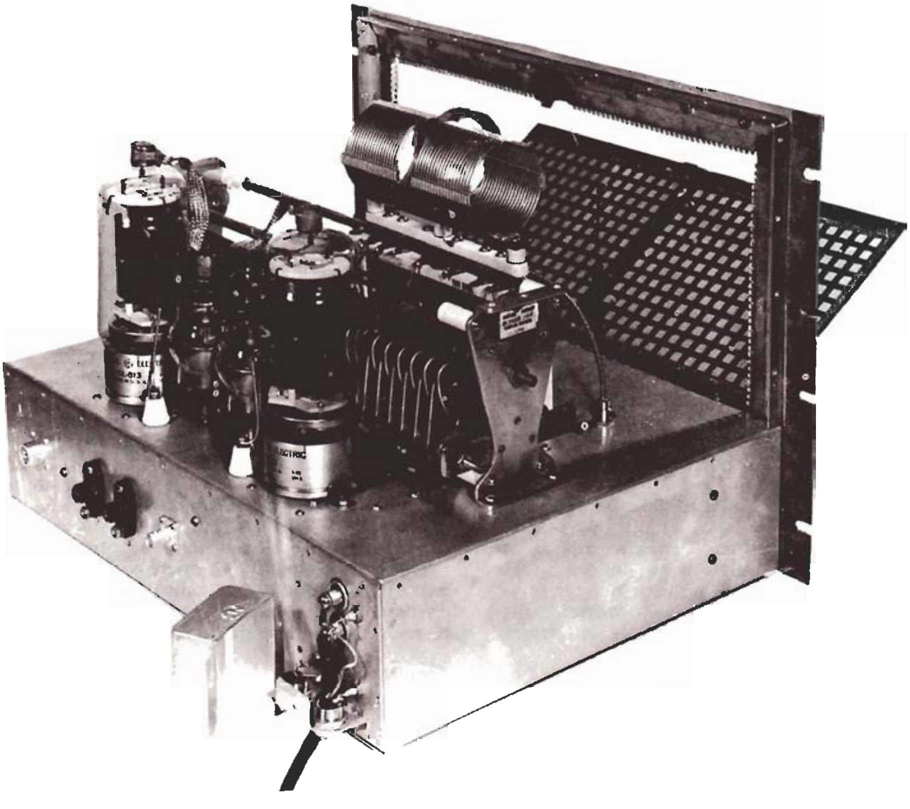
CONSTRUCTIONAL DETAILS

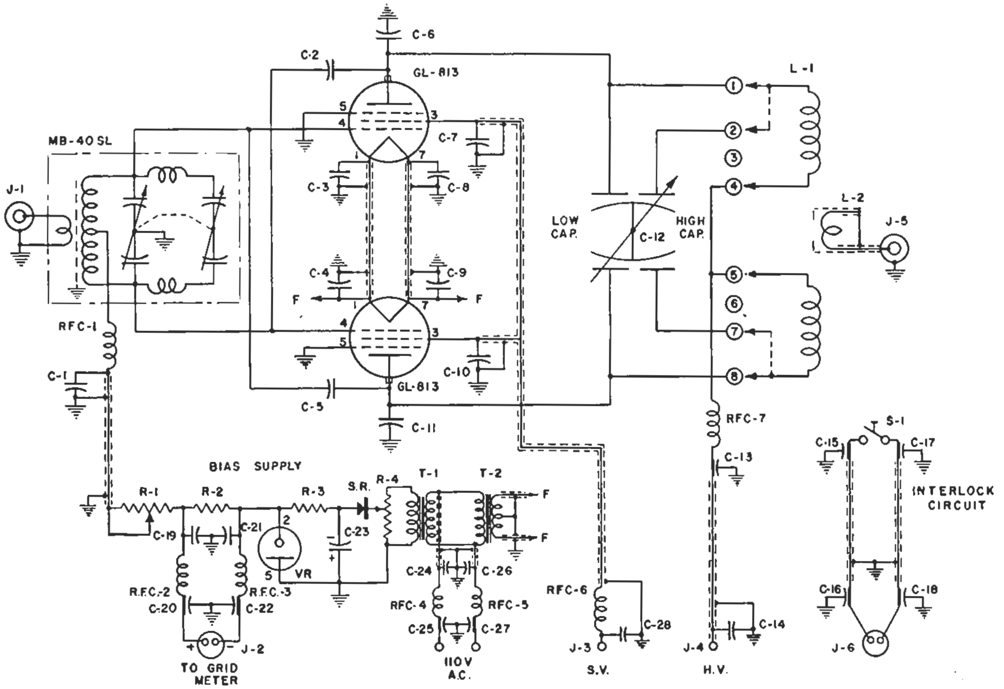
All components are mounted as shown in the photographs on a 13 x 17 x 4-inch aluminum chassis. Aluminum is recommended rather than steel as it is both easier to work and will not rust in damp locations. Even a plated steel chassis will rust around the drilled holes. No special precautions are necessary in the layout that cannot be observed in the illustrations.

The front panel calls for special attention if satisfactory shielding is to be achieved. The panel used is a 12¼-inch Par-Metal Grille Door Panel (Cat. No. G-682). In making the panel RF-tight, the paint was removed by soaking the entire panel in paint remover and then rinsing well. After this was done, the panel was copper-plated. While plating is not absolutely essential it will result in a more permanent shielding job.

After plating, a piece of standard bronze insect screen was carefully soldered to the inside of the grill door.

The next operation was to install the RF weather stripping. The particular material used was made by Instrument Specialties Co., Little Falls, N. J. (Cat. No. 97-112-H). This material is ⅞-inch-wide beryllium copper strip with ⅛-inch wide fingers, 5½ fingers per inch. Similar stripping of other manufacture could also be used satisfactorily. This strip is held to the panel by a ½ x ½-inch aluminum angle running completely around the sides and top of the door opening and secured to the panel with brass machine screws.



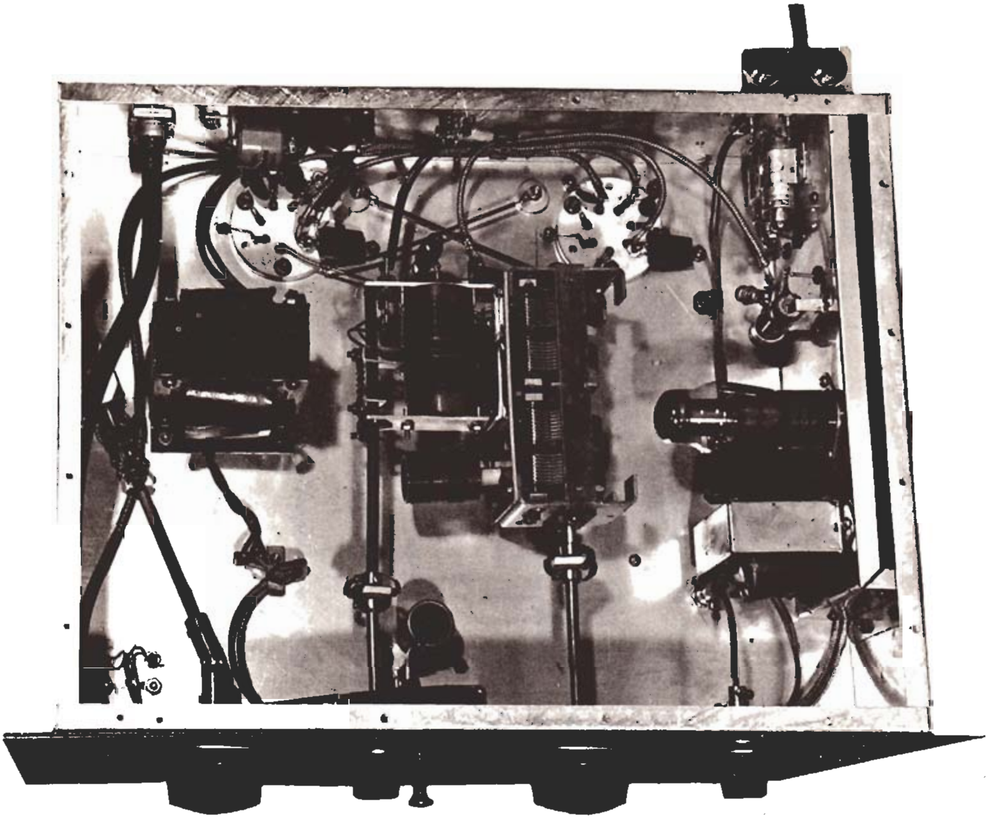


Parts List and Coil Winding Table

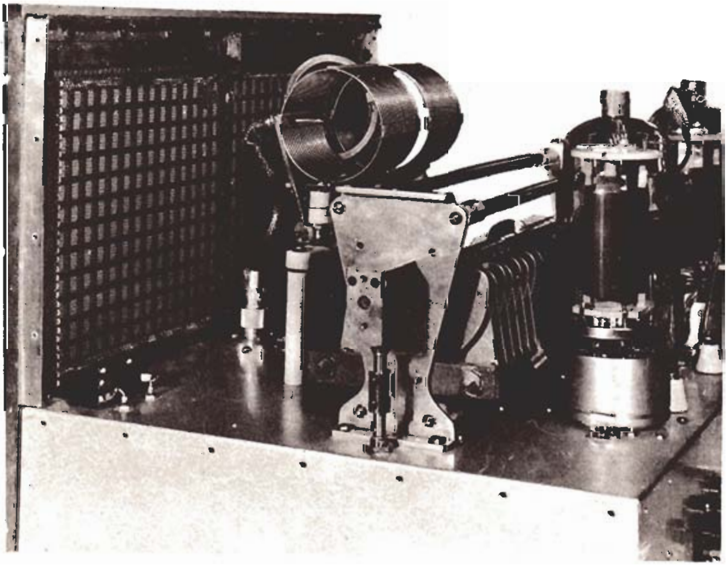
C_1, C_3, C_4, C_8, C_9—.002 mfd. disc ceramic (Centralab DD-202)
C_2, C_5—Neutralizing wires (see text)
C_6, C_{11}—12 mmf. vacuum capacitor (GL-1L21 or 1L25)
C_{12}—100 mmf. per section, split stator. (Bud 1633A modified as described in text.)
C_7, C_{10}, C_{28}—.0005 mfd., 1000-volt mica (Sprague 3CFM-35)
C_{13}—.002 mfd., 5 KV (Sprague Hypass 47P16)
C_{14}—500 mmf., 20 KV ceramic (Sprague 20DK-T5)
C_{15}, C_{16}, C_{17}, C_{18}, C_{20}, C_{22}—.001 mfd., 500-volt ceramic feed-thru (Centralab No. FT-1000)
C_{19}, C_{21}, C_{24}, C_{26}—.001 mfd., disc ceramic (Centralab DD-102)
C_{23}—10 mfd., 450 VDC electrolytic (Sprague EL-1)
C_{25}, C_{27}—0.1 mfd., 250 VAC (Sprague Hypass 48P9)
R_1—5000-ohm, 25-watt, adjustable wire-wound
R_2—100-ohm, 2-watt
R_3—10,000-ohm, 5-watt, wire-wound
R_4—25,000-ohm, 25-watt, adjustable, wire-wound
T_1—Thordarson T-22R12, 117/120, 6.3-volt, selenium rectifier power transformer. (6.3-volt winding not used.)
T_2—Thordarson T-21F19, 10-volt, 12-amp. filament transformer
SR—100 ma., 135-volt selenium rectifier (GE-6RS5GH1A)
MB-40SL—National multiband tank unit
L_1—B & W type TVH, 500-watt coils.
L_2—B & W shielded link No. 3282.
J_1—UG—90/U, BNC connector
J_2, J_6—Amphenol 80-PC2F locknut receptacles.
J_3, J_4—Millen 37001 HV connector
J_5—SO-239, UHF connector
S_1—Microswitch (BZ-RQ1)
RFC_1—2.5 mh RF choke
RFC_2, RFC_3, RFC_6—Ohmite Z-50
RFC_4, RFC_5—25 turns, ¼″ diameter, No. 16 en., close wound, self-supporting.
RFC_7—4 mh, 750 ma. (Miller No. 4336)
VR—GL-OA3/VR75 voltage regulator tube

PLATE TANK COIL DATA

All coils B & W TVH, 2½-inch inside diameter
80—38 t. No. 14 spaced to 5¼-inch length with ¾-inch separation in center. (Jumpers between pins 1 & 2 and 7 & 8.)
40—24 t.; other specifications same as 80-meter coil, including jumpers.
20—12 t. No. 12 spaced to 4¾-inch length with ¾-inch separation in center. (TVH with one turn removed from each end.)
15—8 t. of ⅛-inch d. wire or tubing spaced to 6-inch length with ¾-inch separation in center. (TVH with one turn removed from each end.)
10—4 t. of ⅛-inch d. wire or tubing spaced to 3-inch length with ¾-inch separation in center. (TVH with two turns removed from each end.)



Bottom view clearly shows placement of components. Note RG-8/U output link runs from output connector at top right of picture around upper edge and down to similar connector at left center. Bias supply components mounted on sub-chassis. In close-up picture (below) note RFC_7, mounted underneath final tank coil. This view also shows lugs added to tank tuning capacitor when modified as described in text.



This angle serves the dual purpose of providing a support for the cover as well as holding down the RF weather strip.

The chassis cover is made of 1/16-inch soft aluminum, bent by clamping it over the edge of a work bench using a piece of angle iron and two "C" clamps. Lips should be bent on the edges of the back to be bolted to the sides after all bending is completed. Self-tapping screws are used to hold things together here. The ventilation holes over the tubes should be drilled before the cover is bent. (Those who notice the photographs show a plate with vent holes bolted over two large holes in the top of the shield are asked to excuse a mistake made during construction. It was intended to drill a fancy design in the top for vent purposes but the drill unfortunately slipped. Again, we recommend simplicity!)

The chassis for the bias supply was conveniently formed over a short length of 2 x 4-inch lumber. This made it exactly the right width and also furnished a back-up block for drilling operations.

Do not skimp on the number of screws used in holding the shielding together. Any gaps in the joints provide a chance for RF to leak out. The bottom plate should be fastened with several self-tapping screws along each edge rather than with the screws in each corner as provided by the manufacturer.

Two ¼-inch diameter holes should be drilled in the back opposite the neutralizing wires for later use in adjusting the neutralization.

After the construction and wiring is complete, the outside of the panel and the cover can be painted with a hard machinery enamel.

After all mechanical details are complete, the amplifier may be wired. Shielded wire was used exclusively —RG-58/U coax for the high voltage leads and ordinary single-conductor shielded wire for the low voltage wiring. The filament leads should be No. 14 shielded wire. Ground the shielding at both ends of the leads and wherever else it may be convenient.

Lead lengths on all by-pass condensers should be kept as short as possible.

The Sprague Hy-Pass capacitor used for C_{13} was considered desirable as it allowed the return to be made to the under side of the chassis, providing a short and direct path to the cathode. If it were made to the top of the chassis, the RF would have to find its way through the chassis in order to complete the circuit to the cathodes and could well result in instability due to incomplete plate by-passing. This capacitor is mounted through a snug-fitting hole and held in place by a small brass angle on the underside of the chassis. This angle also provides the ground connection for the capacitor.

The interlock circuit and grid current meter terminals are protected by an aluminum cover cut from a coil shield can.

MODIFYING THE PLATE CAPACITOR

The modification of the plate tuning capacitor requires some careful workmanship. The capacitor, before modification, consisted of two sections—each with ten stator plates. The seventh stator plate from each end was removed by sawing through the support rods ¼-inch from each side of the plates. Next, four pieces of ½-inch diameter insulating rod (mycalex was used) were cut to fit exactly the gaps left between the sixth to eighth plates. The ends of these insulating spacers were drilled and tapped to take the threads of the stator support rods. No changes were made in the rotor assembly. This left a capacitor having four separate stator sections—the two inside sections consisting of three plates each, and the two outside sections six plates each. Suitable heavy solder lugs, visible in the photographs, are inserted between both ends of the insulated rod and adjacent plates to allow connections to be made to the stators.

The shielded link is plugged into an SO-239 coaxial connector mounted on top of the chassis, to allow the link line to feed through the chassis and connect to the output connector on the rear apron. Both connectors are shielded where the coaxial jumper connects by means of standard receptacle hoods designed for this purpose. The shielded link is supplied with a pair of shielded leads. To use the link with coaxial circuitry, it is necessary to connect one inner conductor to the shielding braid right at the link, leaving a single shielded lead for connection (see circuit diagram).

The bases of the GL-813's are grounded to the chassis by small metal clips from a socket for a GL-4-250A. Since these may not be readily available, a suitable clip can be made from spring brass or bronze.

TUNING UP

The first step in getting the amplifier into operation is to set the bias voltage. This can best be done before the supply is fastened in place. After checking to be sure all wiring is correct, apply power and adjust R_4 for a current of 5 milliamperes through the VR tube. The easiest way to check this is to measure the voltage drop across the 10,000-ohm series resistor, R_3, using a VTVM or high resistance DC voltmeter. This will be 50 volts DC for 5 milliamperes of current. Bias resistor R_1 should be set at 3500 ohms for a plate supply voltage of 1600 volts and 3000 ohms for 2000 volts. If only CW operation is contemplated, set R_1 at 2500 ohms. The higher values will be satisfactory for both phone and CW work but it is recommended that slightly lower grid drive be used on CW, approximately 7 milliamperes per tube. It is good practice to use the minimum amount of drive for full output under all conditions as an aid to keeping down harmonic generation.

Neutralizing should be accomplished as explained under "Circuit Details" *only* if fully adjustable plate and screen voltages are available. Otherwise it should be done in the conventional manner by coupling a sensitive RF indicator to the plate tank and adjusting the neutralizing wires for minimum output.

It is recommended that all wiring to the power supplies and meters be shielded and the shields grounded at both ends.

Several methods of obtaining screen voltage are possible. A series dropping resistor from the plate supply may be used for phone work only or a voltage divider across the plate suppply could be used for CW. The method used with this final was a fixed supply of 350 to 400 volts with choke output consisting of a standard 10-henry filter choke. This method allows the screens to modulate themselves and has the added advantage of not requiring any changes for CW work. When going from phone to CW it is only necessary to turn off the modulator supply and short the secondary of the modulation transformer.

This amplifier has proved itself in all respects. It is easy to build; provides a good quality signal; and offers sufficient power to compete with the best.

CONSTRUCTION NOTES FOR THE 600-WATT ALL-BAND AMPLIFIER

Additional construction information has been compiled about this amplifier, and to suggest alternate plate tank capacitors for the Bud No. 163A originally specified.

The National MB-40 grid tank circuit was mounted on small tubular metal spacers slipped over the machine screws that run between the underside of the chassis and the side bracket on the MB-40 capacitor. The other side bracket appears in the bottom view photograph.

RFC_4 and RFC_5 are located underneath the small sub-chassis and do not show in the pictures. One end of each of these chokes attaches to the ends of the feed-through capacitors which you can see clamped on top of this sub-chassis. The other ends of these chokes run to short standoff insulators underneath the sub-chassis. Also attached to these insulators are C_{24}, C_{26} and the leads from T_1 and T_2.

RFC_7 is a Miller No. 4536, not 4336, as the parts list specified. Other RF chokes with similar ratings, such as the National R-152 and R-154; Bud CH-569; Johnson 102-754; or ICA 267 and 278, may be substitutued, since the RF choke does not work very hard in this particular circuit. The choke is mounted directly beneath the amplifier plate tank coil, L_1. Incidentally, the jack bar for the tank coil is mounted on 3/4-inch diameter x 2-inch long steatite pillar insulators.

Two Millen right angle drive units, No. 10012, and a universal joint, Millen No. 39005, are required to drive the plate tank capacitor shaft from the front panel. The drive is attached onto the capacitor shaft by taking off the cover, loosening the set screw that holds the gear on one extension shaft, and removing this shaft. The capacitor shaft is then inserted into this gear, the set screw is again tightened, and the cover is replaced. The body of the right-angle drive is then fastened to the capacitor frame.

A short extension shaft is coupled to the right-angle drive, then run through a panel bearing to the second right-angle drive, located beneath the chassis between the filament transformer and the chassis side wall. This drive is fastened to the chassis at an angle, as shown in the bottom view, and another extension shaft runs to the universal joint near the panel. A shaft and panel bearing assembly mounted on the panel runs to the universal joint. This assembly work should be carefully done to insure a smooth running drive with no backlash.

Since the Mycalex insulation specified for the insulating bushings that must be added to the Bud plate tank capacitor, C_{12}, may not be readily available, 3/4-inch diameter polystyrene rod may be substituted. The overall length of this insulating spacer should be 0.953 inches. The holes for the stator plate rods should be carefully drilled and tapped, because the polystyrene is easily overheated and may clog the drill or even crack. A 10-32 tap size is required for the rods on the Bud 1633A capacitor.

Another good insulated spacer for the Bud capacitor may be made from a Centralab No. X-21 steatite pillar insulator. This pillar is 3/4 of an inch in diameter, 1 inch long and has 10-32 threaded holes at each end. If a small workshop grinder is available, the ends can be ground off to make the overall length 0.953 inches. Care should be taken to make the ends square with the sides of the pillar.

If the 1-inch long pillar cannot easily be shortened, a Centralab No. X-20 steatite pillar, 3/4 of an inch in diameter, 3/4 of an inch long, also with a 10-32 threaded holes, can be used with spacer washers. These washers should total 0.203 inches in thickness within a few thousandths of an inch. Otherwise, the both stator sections cannot be properly centered with respect to the rotor plates.

A Johnson Cat. 153-510, 150DD70 2-section variable capacitor can be substituted for the Bud capacitor. It had 10 stator plates per section, each of which was split to form two stators of three and six plates. One plate in each stator is eliminated when the insulator is inserted. The Johnson capacitor has 11 stator plates per section, and should be split between the third and fourth stator plates from the center of the capacitor. This leaves small stator sections having three and seven plates, respectively.

Since this capacitor also has 10-32 threaded rods holding the stator plates together, the same type of home-made bushing, or a Centralab No. X-21 bushing ground down to 0.853 inches long, will serve as the insulated spacer. Or, a Centralab No. X-20 3/4-inch long spacer can be used, along with 0.103-inch thick spacer washer.

The Allen D. Cardwell Co. has made a special 4-section split-stator variable capacitor, Cat. No. PL-8081, that also may be used for C_{12} in this amplifier. Since this capacitor has an air gap of only 0.100 inches, the rotor must be insulated from ground. This may be done with small angle brackets fastened to the end plates, mounted in turn on suitable ceramic insulators about 1 1/2 inches high.

An insulated shaft coupling also must be inserted in the shaft drive. The best place for this seems to be in the shaft which runs down from the right-angle drive to the shaft bushing that passes through the chassis.

Since this capacitor has higher maximum capacity than the original, lower inductance tank coils may be used at L_1 on 80 and 40 meters. Both the original coils and the suggested substitute coils for the PL-8081 capacitor have been tabulated separately.

Meters were not included in this amplifier because of the complex shielding required around them. Instead, they may be mounted on a separate meter panel near the amplifier, or else the meters and power wiring used on another final amplifier in the transmitter may be switched to this amplifier. The following sketch suggests meter and switching connections for power wiring running to this amplifier.

Technical Tidbits

CAUTION—Screen Grid at Work

The screen grid is probably the most critical single element in modern high-gain tubes and yet it is undoubtedly the most abused element. The average ham looks upon the screen grid as an element which is ***supposed to be*** fixed in potential, and because the screen seems to go no place in particular in the circuit he completely neglects it. He feels that once he has connected the screen voltage lead that he is through with that part of the circuit until the rig wears out. (The latest census lists 1,269,321 cases of parasitics due to improperly bypassed and stabilized screen circuits. The adding machine broke down before the number of resultant key clicks was totalized.—Editor's note.)

If the screen is important, let us see why. The best way to do this is to compare triodes and screen-grid tubes. A comparison on this basis brings out the following points.

(a) In a triode there is a large capacitance between grid and plate. If this capacitance is not taken care of by neutralization, the resultant feedback voltage may cause oscillation. In a screen-grid tube, the screen, ***if suitably bypassed,*** acts as an electrostatic shield between grid and plate and therefore materially reduces the feedback.

(b) The plate voltage (and grid voltage) in a triode determines the amount of cathode current that flows. In a screen-grid tube the plate voltage has a negligible effect in determining the amount of cathode current because the screen acts as a shield between plate and cathode. It is the screen voltage (and grid voltage) which controls electron flow in a screen-grid tube, just as the plate voltage controls the electron flow in a triode. Obviously then, if the current flow is to be held constant, then the screen voltage must necessarily be held absolutely constant.

Thinking now of an actual circuit using a screen-grid tube, what do the above two points mean? Let us assume a screen-grid tube in the final of our rig. With the antenna tightly coupled to the final tank coil, we find that the plate current isn't high enough to suit us. The link is therefore coupled tighter and tighter in an endeavour to get more input. However, the plate current does not increase appreciably. At this point the average ham decides that his antenna won't load up properly. Actually all that happened was to be expected. In point "b" we stated that the current depended upon the screen voltage. Inasmuch as the screen voltage was not affected by increased loading, we found it difficult to change the plate current. All that was accomplished by the increased loading was a decrease in power output, because the plate voltage swing was decreased as the loading was increased and the plate dissipation went up.

Taking the other extreme of loading—too little load—we come to the exception in rule "b." That is, too little loading will bring on a condition where the plate voltage will affect the cathode current. Practically this means that if the final is lightly loaded, the screen current will be high (even over rating), the plate current low, efficiency poor, and output low. This is true because a lightly loaded final (using screen-grid tubes) will have a large voltage swing, and the minimum voltage on the plate will occur when maximum current should flow. With a low enough plate voltage, the electrons in the tube will not be attracted to the plate as strongly as usual. These electrons will therefore tend to collect on the screen-grid. This large increase in screen current may harm the screen, as it is a flimsy element in comparison to the plate, and is not capable of dissipating too much energy.

Many amateurs have found from first-hand experience that this last point is true. When an ECO is lightly loaded so that this effect takes place, a slight change in loading will change the frequency quite a good deal, whereas the same ECO, when heavily loaded, will be less affected frequency-wise by a load change.

Adding up the information above gives us data by which we may formulate four rules for operating screen-grid tubes to make them do the fine job they were designed to do.

1. Carefully bypass and install the screen circuit so that it acts as a good shielding device. This means that the bypass condenser leads should be short and properly placed. Also, external shielding should be used on the tube if such is recommended.

2. Make certain that the screen voltage is accurately held to the design value. If the circuit is keyed this may require a separate, stable source of voltage. It is also important that an accurate voltmeter be used. The voltmeter part of volt-ohmmeters, especially home-made units, may easily be off 20—30% if the volt-ohmmeter is an old instrument.

3. Make all loading adjustments carefully for maximum power output and maximum circuit efficiency. Loading an amplifier or final too lightly or too heavily will cause poor circuit and tube efficiency. Maximum power output will be obtained when the loading is neither too light or too heavy.

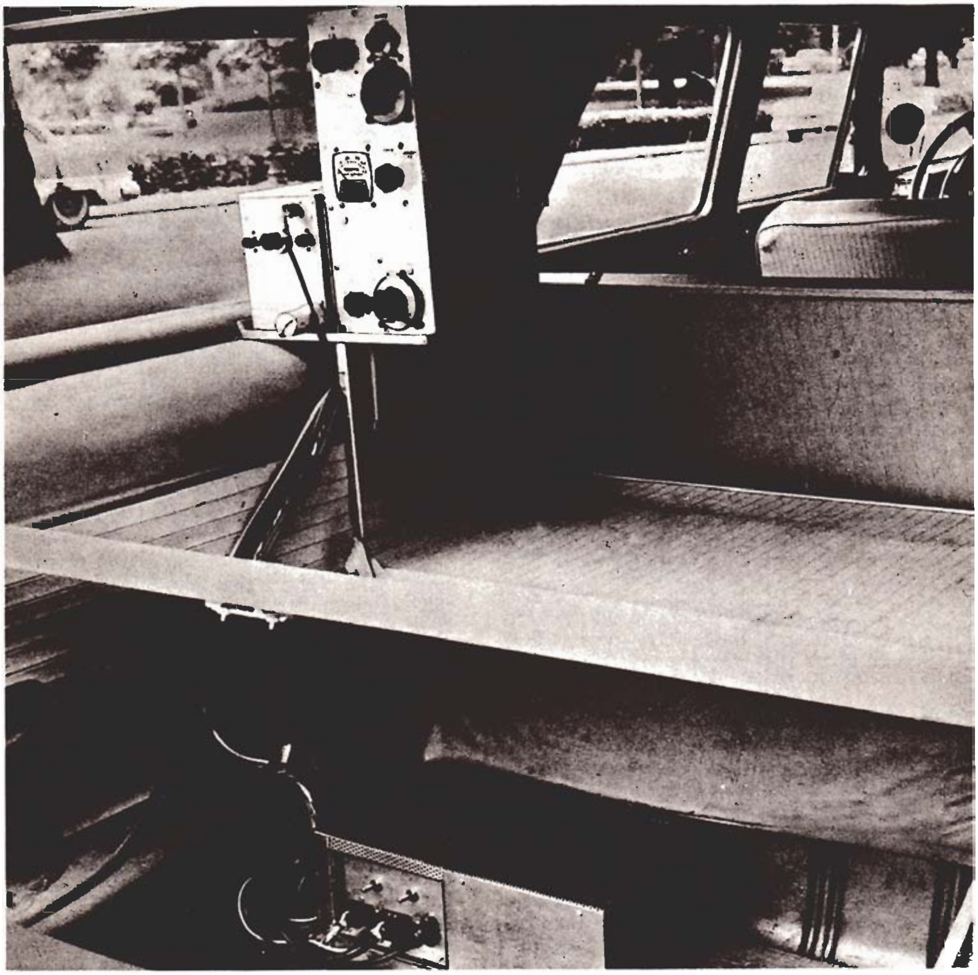
4. Install a screen current monitoring position. A screen current meter, connected in the circuit at all times is to be preferred. This will help to avoid accidental damage to the screen due to overload. Also, a screen current meter is an invaluable aid in the tuning-up process, as this meter is much more sensitive as a tuning indicator than the plate current meter.

When a screen-grid circuit is unloaded, plate current will be very low and the screen-grid current will be high. As the loading is increased the screen current will drop off as the plate current rises. A point will be reached where further loading does not affect the screen current. This is the approximate point of proper loading. A further refinement would be to check power output as the loading was changed, and adjust the loading for maximum output.—Lighthouse Larry.

BANDSWITCHING MOBILE LINEAR AMPLIFIER

WITH GL-4D21/4-125-A's

By W. C. Louden, W8WFH



KILOWATT MOBILE LINEAR AMPLIFIER installed in W8WFH's station wagon over the left rear wheel housing. Power supplies delivering 2,500 volts DC for the GL-4D21/4-125A amplifier tube plates, and 600 volts DC for the screen grids, are in the metal box under the floor. The metal box next to the amplifier contains a motor-driven, remote-tuned oscillator, hetrodyning and driver stages for the amplifier. The SSB generator, and audio and VOX circuits are under the front seat.

STABILITY AND RELIABILITY are of prime importance in mobile radio equipment. This well-shielded linear amplifier meets these requirements and has components rated for a full kilowatt DC input in class AB_1 or AB_2 operation. It is also well-suited for home-station installations.

The high power sensitivity of modern tetrode and beam pentode transmitting tubes simplifies the construction of an amateur transmitter since they require only low driving power, and thus, a simple exciter. Two GL-4D21/4-125A tetrodes were connected in parallel in this amplifier in a tuned-grid, tuned-plate circuit, as shown in the schematic diagram, Fig. 1.

COMMERCIALLY MADE GRID AND PLATE tank circuits, as specified in TABLE I — PARTS LIST, were found to have the correct inductances for the grid and plate circuits over the range of 3.5 to 30 megacycles. The plate pi-network loading capacitor C_4, is a standard 3-gang broadcast type variable.

TABLE I — PARTS LIST MOBILE LINEAR AMPLIFIER

C_1.....10 — 200-mmf vorioble (Part of Horrington GP-50 tuned circuit).

C_2.....1-11-mmf neutralizing capacitor.

C_3.....15-250-mmf variable, 3,000 volt spacing.

C_4.....30 — 1140-mmf variable (3-section broadcast receiver capacitor with 10 — 380-mmf per section).

J_1, J_2 ....chassis coaxial cable connectors.

L_1.....grid coil assembly (part of GP-50).

L_2......10-microhenry coil with taps and switch S_2 (Barker & Williamson Model 851 pi-network tank circuit).

L_3, L_4, L_5, L_6, L_7.parasitic suppressor chokes made fram 6 turns af No. 16 enameled wire on 2 watt, 47-ohm compositian resistors.

M_1....0 — 50-milliompere DC milliometer (G.E. Model DW-91, or equivalent).

R_1, R_2 ....0.667 ohms, 2 wotts; resistance wire wound on 2-watt resistors.

RFC_1, RFC_3........2.5-milihenry, 4 pi r.f. choke, 125-milliampere rating.

RFC_2..200-microhenry solenoid wound r.f. choke (National R-175A, or Barker & Williamson No. 800).

S_1.....2-pole, 5-position ceramic rotary tap switch (Part of GP-50).

S_2.....1 pole, 5-position tap switch (Part of B & W 851 coil).

S_3.....2-pole, 5-positian rotary tap switch.

T_1, T_2 ....5-volt, 6.5-ampere filament transformers, 12 ar 115-volt primaries.

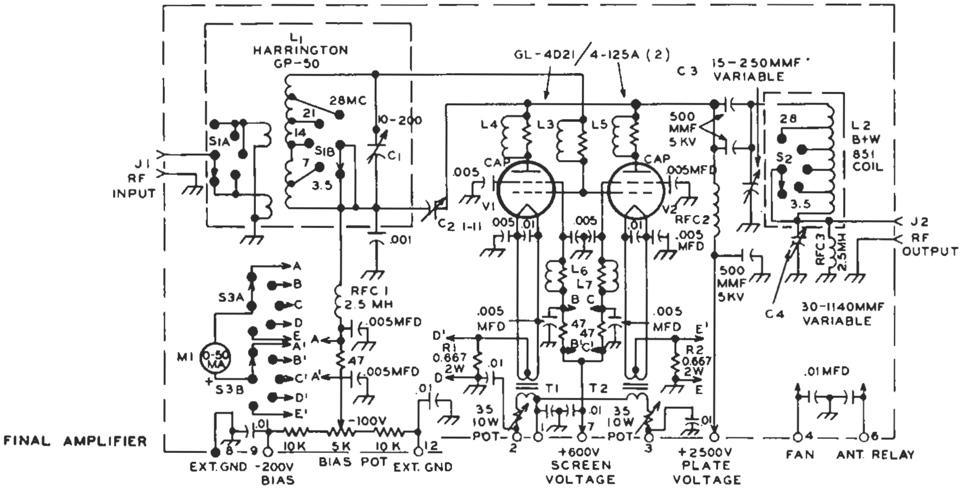


FIG. 1. SCHEMATIC DIAGRAM of the GL-4D21/4-125-A mobile linear amplifier. The 0.001, 0.005 and 0.01-mfd capacitances shown as bypasses in various circuits are disc ceramic capacitors, with DC valtage ratings at least double the operating valtage of each circuit. Resistances are in ohms, ½ watt rating unless otherwise specified. Components C_1 L_1 and S_1 are included in the Harrington GP-50 grid tank circuit; L_2 and S_2 are included in the B & W 851 pi-network plate tank circuit.

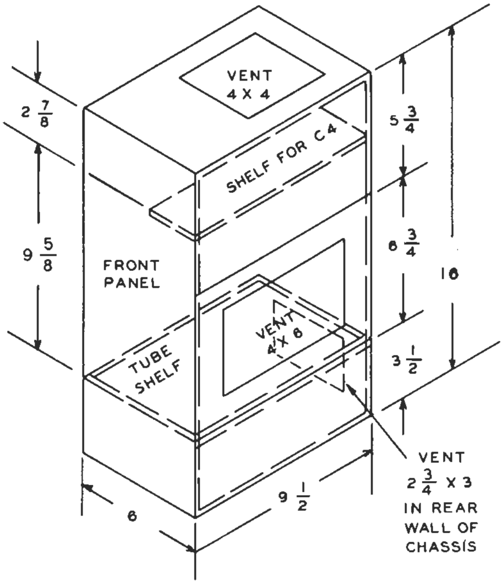


FIG. 2. CABINET DRAWING for the mobile linear amplifier. This cabinet was fabricated from $\frac{1}{16}$-inch thick sheet aluminum, with flanges for side shields.

Capacitive bridge neutralization was included in the circuit to ensure stabilty on all bands. Ths bridge is formed by the tube capacitances, plus C_2 and the 0.001-mfd capacitor from C_1 to ground.

Separate current metering was provided for the screen grid and cathode circuits of each tube to check on the balance of power between them. A 0 to 50-milliampere DC current meter is switched across resistors in the control grid (A) and screen grid (B & C) metering positions of S_3. In the cathode circuits (D & E), 0.667-ohm shunts multiply the meter reading by 4 times for a full scale reading of 200 milliamperes in each circuit. If the separate metering of cathode currents is not necessary, a single filament transformer may be used.

If GL-4-250A/5D22 or GL-4-400A tetrodes are used in this amplifier, larger filament transformers are needed. Also, if these tubes will be operated near maximum power, a heavier plate tank coil, the **B & W** Model 850A, which requires more space, should be substituted for the Model 851 coil. Type GL-813 pentodes also may be used in this amplifier by installing the proper sockets and filament transformers.

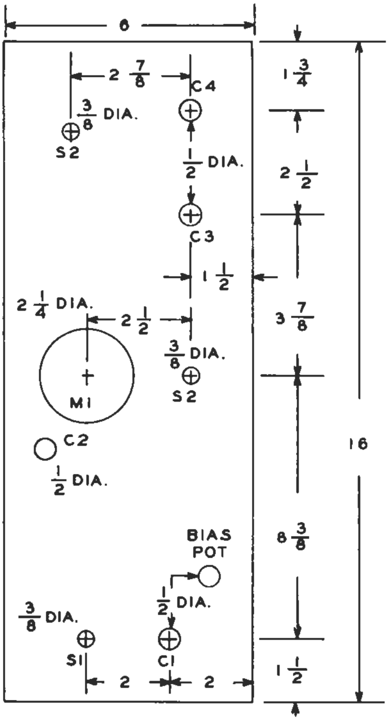
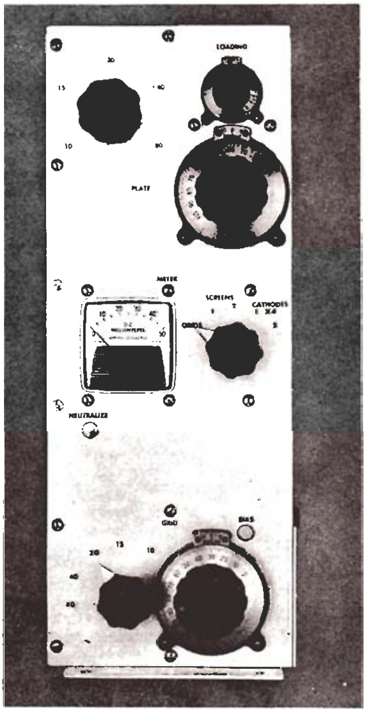


FIG. 3. PANEL LAYOUT DIAGRAM for the amplifier. Only major hole locations are shown. Locations of small holes for hardware should be located from the part being mounted. Cut meter hole to a diameter slightly larger than case of meter.



PANEL VIEW of the linear amplifier. Note that grid and plate bandswitches have separate knobs, and are not ganged. Snap-in buttons cover the holes through which the neutralizing capacitor (C_2) and bias potentiometer are adjusted.

THE SHIELDED ENCLOSURE for the amplifier, shown in Fig 2, was fabricated from 1/16-inch thick sheet aluminum. All sides were made as separate pieces with flanges on them for assembly to adjacent pieces with machine screws and nuts, or self-tapping screws. The shelves and vent holes should be added before holes are cut for mounting the components. Vent holes may be covered with aluminum screening or perforated sheet.

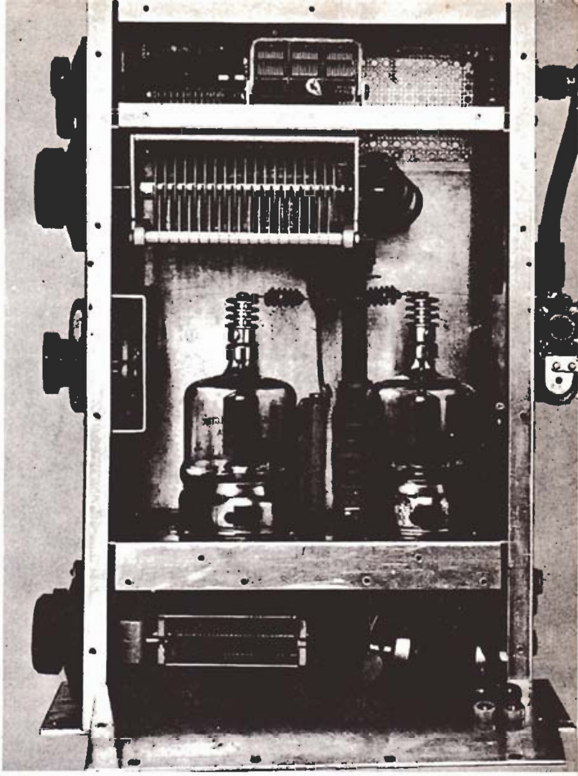
The front panel layout, Fig. 3, and the sub-chassis shelf layout, Fig. 4, are correct for the components specified in the PARTS LIST. Holes should be relocated to suit other brands of components as necessary. Locations for small parts can be determined from the pictures.

Although no commercially made enclosure of similar dimensions is available, a 6 x 10 x 3-inch aluminum chassis or Minibox (**Bud** CU-3010) could be used as a chassis base and fitted with the 6 x 16-inch front panel. A frame of aluminum angle covered with perforated sheet aluminum would make a good r.f. shield and support the upper shelf.

COMPONENT SUBSTITUTIONS may be made, as long as their electrical and mechanical characteristics are similar. The neutralizing capacitor, C_2, may be a **Bud** NC-853, **Millen** 15011, or **Johnson** 159-125. Or, a suitable capacitor may be made by mounting two aluminum plates about 1 x 4 inches spaced about ½ inch apart on standoff insulators.

The upper shelf may be dropped about an inch if necessary to allow room for a larger B & W Model 850A plate tank circuit which should be used with the larger tubes. The vernier tuning dials for the grid and plate circuits are Lafayette type F-346, 3 inches in diameter. **National** type AM dials also are suitable.

Power wiring was run with insulated wire of sufficient size to carry the voltages and currents in the various circuits. Leads carrying the grid and plate r.f. currents should be of 1/32 x ½-inch copper strip. In the plate tank circuit, use joints fastened with brass machine screws instead of solder when possible.



SIDE VIEW of the amplifier. A "U" shaped bracket (Bud CB-1628 miniature chassis) behind the panel shields the meter (M_1) and meter switch (S_2) from strong r.f. field present around the plate tank circuit.

The fan shown is simply a small 12-volt DC motor with a fan blade. It pulls cool air into the chassis through the 2¾ x 3-inch vent in the chassis, forces it up through the holes in the tube sockets, and out through the upper vents in the box.

The antenna changeover relay was mounted on the outside of the cabinet where it would be easily accessible. Power for the

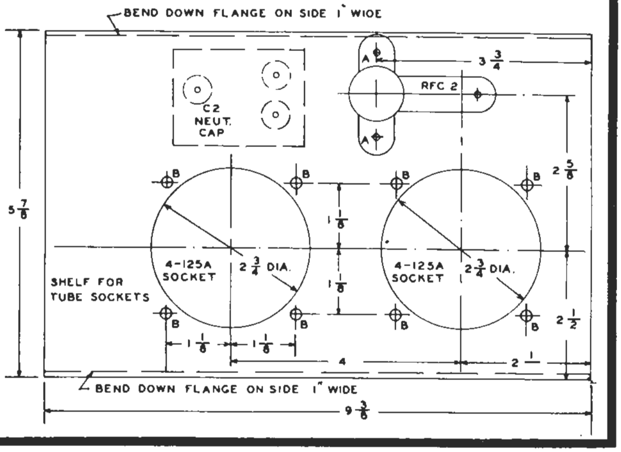
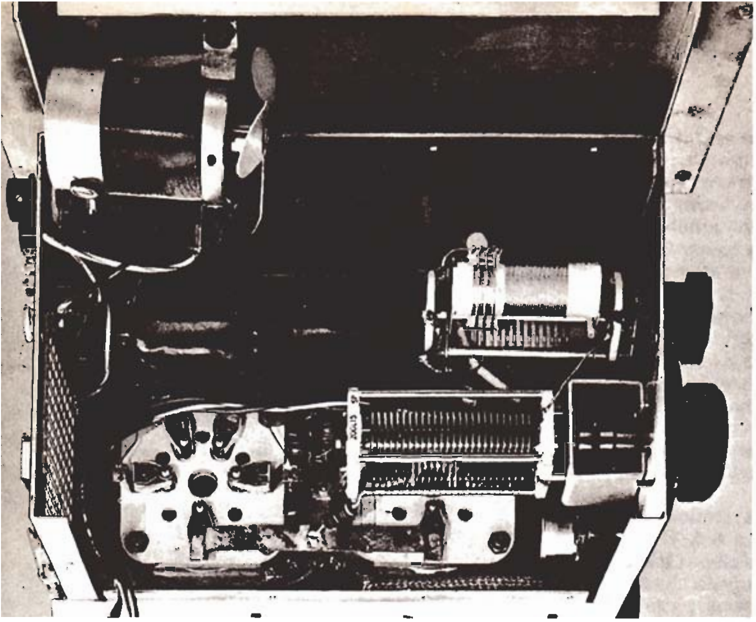


FIG. 4. SUB-CHASSIS LAYOUT diagram. Socket hole diameter (2¾ inches) is for Johnson 122-275-1 sockets, and may be different for other brands of giant 5-pin wafer sockets designed for GL-4D21/4-125-A and similar tubes. Socket hole spacing is sufficient to permit using the higher plate dissipation GL-4-250A/5D22 and GL-4-400A tetrodes in the amplifier if desired.



BOTTOM VIEW of the linear amplifier. Note 3/8-inch wide copper strip connection between the control grid terminals on the tube sockets. Fan under the chassis forces air up through holes in the tube sockets, due to tight construction of lower part of box. Air cools seals in bases of tubes, then passes out through holes in bases and up along glass envelopes.

BIBLIOGRAPHY OF INFORMATION ON LINEAR AMPLIFIER TESTING

"Adjustment of Class B Linear Amplifiers," *RADIO HANDBOOK*, 14th Edition, by Editors and Engineers, page 278.

"Two Tone Tests and Their Meaning," by Don Stoner, W6TNS, *NEW SIDEBAND HANDBOOK*, page 151.

'How to Test and Align a Linear Amplifier," by Robert W. Ehrlich, W0JSM, *SINGLE SIDEBAND FOR THE RADIO AMATEUR*, page 134; also in QST, May, 1952, page 39; and the RADIO AMATEUR'S HANDBOOK, page 314.

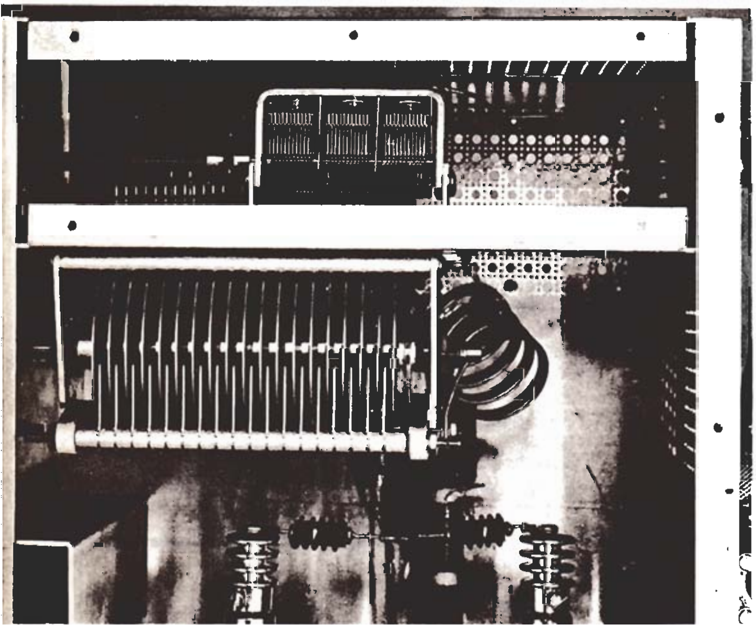


PLATE TANK CIRCUIT of the linear amplifier. Plate tuning capacitor, C_3, is suspended from shelf, with pi-network loading capacitor C_4 mounted on shelf. The 28-megacycle coil was removed from the B & W Model 851 pi-network tank circuit frame and mounted between C_3 and the other section of coil. L_2 is mounted upside down from the top of the cabinet.

relay coil was brought into the amplifier through the 12-pin plug **(Jones P-312-AB)** along with the other low and medium voltage circuits. Bypass capacitors were connected to each pin on this plug, as well as used liberally throughout the amplifier, to keep r.f. currents off the power wiring.

INITIAL TESTING should preferably be done in a home station where checks and adjustments can be made more easily than in a vehicle. The test setup should preferably have a dummy antenna load, and have provision for reducing and turning off plate and screen voltages. First apply filament power, bias voltage and r.f. excitation to the amplifier so that the neutralizing adjustment can be made. About 5 watts of r.f. excitation at 14 megacycles or higher is necessary. This will give a grid current reading of 10 to 15 milliamperes.

Set S_3 in position "A" and tune the grid circuit for maximum current, making sure that the grid and plate bandswitches are in the proper position. Then, with loading capacitor C_4 near maximum capacitance, "rock" the plate tuning capacitor, C_3, back and forth, watching for a quick fluctuation in grid current at one point on the dial for C_3. Adjust the neutralizing capacitor, C_2, until the grid current is constant.

As a final check for neutralization, remove the r.f. drive, apply about half of normal plate and screen voltages, and reduce the grid bias so that the plate current increases to near maximum plate dissipation for the tubes used. Rotate both the grid and plate tuning capacitors to see if the amplifier will break into oscillation at any combination of settings. This test should be tried on all bands. If an oscillation is noticed, readjust C_2 slightly until the oscillation disappears.

After turning off power, connect the amplifier to a suitable dummy antenna load having a 50-ohm impedance and power capability of at least 500 watts. Insert a standing wave ratio bridge in the coaxial cable between the amplifier and dummy antenna. Apply r.f. drive, and about half of normal plate and screen voltages, and tune the amplifier for maximum output.

If the amplifier appears to function normally, apply full plate and screen voltages. Adjust C_4 so that each tube draws about 150 milliamperes plate current (for GL-4D21/4-125A tubes). Check to see if maximum power output on the SWR indicator occurs at the same setting of C_3 as the minimum plate current dip. Any major differences in plate or screen currents drawn by each tube indicates that one tube may be better.

Preferably, a SSB exciter should be used to drive the amplifier, so that linearity tests can be run on the amplifier before installation in the vehicle. If excess driving power is available from the exciter, a 5,000-ohm, 25-watt non-inductive resistor (Sprague 25NIT-5000 or equivalent) can be connected across C_1 to swamp the excess drive. Complete descriptions of linearity tests are given in the amateur radio handbooks, as listed in the bibliography on page 6.

INSTALLATION IN THE VEHICLE is simply a matter of mounting the amplifier securely so that it will not shake or vibrate excessively while the vehicle is in motion. Connect each filament transformer primary across a different phase of the 3-phase AC power source in the vehicle. Heater power for the exciter should be obtained from the third phase to balance the heater load.

In W8WFH's installation, bias voltage is obtained from a small 200-volt negative single-phase AC supply, while 600 volts for the GL-4D21/4-125A screen grids is delivered by a 300/600-volt 3-phase star bridge rectifier supply which also powers the exciter from the 300-volt tap (Fig. 9 on page 7 of the July-August, 1960 issue). A 2500-volt 3-phase plate supply is used, but plate voltages up to 3000 are suitable.

W8WFH does not recommend regulating the bias and screen grid voltages for the amplifier. Plate voltage may fluctuate more than 10 percent due to variations in the alternator output voltage with engine speed — from 100 volts at idle, to 120 volts at road speeds — and plate current peaks during modulation. By allowing the bias and screen grid voltages to fluctuate in accordance with the plate voltage, a fairly *constant ratio* is maintained among these three voltages, and amplifier linearity is improved.

A husky mobile antenna is required for this amplifier. W8DLD and W8WFH have constructed their own antennas with separate center-loading coils for each band. Details will be published in a forthcoming issue. Check with the manufacturer of the mobile antenna you may be considering, to ensure that it will withstand the several hundred watts of power output delivered by this amplifier.

If you want real performance in your mobile amateur radio installation, follow the proven recommendations published in this 3-part series in *G-E HAM NEWS.*

TECHNICAL TIDBITS

Proper Tank Circuit Padding

There comes a time when practically every ham wants to take a high-frequency rig and by hook or crook, make it work on a lower frequency. This involves wiring around frequency multiplier stages and winding new coils. It also involves worrying about the fact that the tuning condensers are of too low a capacitance to meet the requirements for a proper Q. The usual reaction to this problem is to parallel the old condensers with fixed capacitance of some sort, vacuum capacitors, discarded tuning condensers or anything which will add the proper capacitance.

Unless proper procedures are followed in this padding stunt, it is very likely that a nice case of TVI will be developed, or perhaps a polite note from the FCC regarding harmonic emission. There is a right and a wrong way to add padding capacitance across a tuned circuit.

If the circuit considered is a single tube circuit with a single-ended plate tank, that is, one which has a single-section tuning condenser and a coil where the B plus voltage feeds in at the bottom, then no further worrying need be done. Padding capacitance may be added directly across the tuning condenser and the circuit will not be changed effectively by the added capacitance.

However, if the circuit is a single tube circuit with a double-ended plate tank, which is needed if the tube is neutralized, or if the circuit is a push-pull circuit, where again a double-ended plate tank is used, then we must watch out for gremlins. These gremlins take the shape of undesired harmonic signal output. Second harmonic, third harmonic and other harmonic signals will be present in the plate tank coil and thus be radiated if we allow these various harmonic currents to flow through the coil and induce their own voltages in the coil. To minimize the possibility of radiating these harmonics, it is necessary only to keep these harmonic currents from flowing through the final tank coil.

With reference to Fig. 7A, this circuit is one which is commonly used with either a single tube or a push-pull stage. C_1 is the tuning condenser and C_X the usual bypass condenser. When this circuit is tuned to resonance, it will have a very high impedance to current which comes from the tube and which is an r-f current at the fundamental frequency. However, current is also coming from the tube at radio frequencies which are harmonics of the fundamental frequency. These harmonic currents do not see the tank circuit as a resonant tank, but they merely see the tank circuit as a combination of inductance and capacitance, the inductance acting as a choke and the capacitance acting as a bypass condenser. These harmonic currents, like the fundamental current, are trying to find a path to ground. Naturally they will take the lowest impedance path. In Fig. 7A the only path for these harmonic currents is the path through the coil proper, through condenser C_X, and thence to ground.

If one tube is considered, then the path is through the top of the coil, whereas with a push-pull circuit, one tube sends its currents through the top of the coil and the other tube through the bottom of the coil. In any case, these harmonic currents are passing through the coil, and therefore they induce a harmonic voltage in the coil. Further, as higher and higher harmonics are considered the coil becomes a better and better choke, therefore the higher and higher a harmonic voltage will be induced. This means that the antenna link will pick up these voltages, send them on to the antenna, which will radiate these harmonics. Of course, many stunts are used in order to prevent the harmonic voltage from being coupled to the antenna, but we are interested here in preventing the harmonic voltage from existing.

How is this done? Refer to Fig. 7B. This is identical to Fig. 7A except that C_1 has been replaced with a split-stator condenser C_2. Now, when harmonic currents come from the tube, they are faced with the problem of whether to go through the coil (with its increasingly high impedance to higher and higher frequency harmonics), or whether to go through the split-stator condenser, C_2, (whose impedance is decreasing with frequency and which is becoming more and more effective as a bypass condenser as higher order harmonics are considered). Because of the difference in the impedance of these two paths, most of the harmonic current will take the path through C_2.

Before we start praising this circuit too greatly, however, let us examine it more closely. The two halves of the coil are coupled together and the center-tap is rather firmly tied to ground through condenser C_Y. If these two halves of the coil are overcoupled, as is usually the case, then the resonant curve for the entire coil may turn out to have a double hump. This is a nasty situation because it is then impossible to tune C_2 properly. If C_2 is set for the resonant frequency, then the impedance of the coil is not what it should be, and if C_2 is tuned so that the impedance is correct, then the circuit is not exactly at resonance.

This situation may be avoided by a few quick twists of a soldering iron, so that the circuit resembles that in Fig 7C. Another equally correct circuit would be with C_Z omitted and the center of C_3 grounded, with the r-f choke disconnected from the center of C_3, or any combination of the above. The important thing is to omit the bypass condenser which you occasionally find tied to the center of the tank coil. The introduction of the r-f choke in the center-tap lead of the coil in Fig. 7C and the omission of the bypass condenser at the center-tap point practically guarantees that all of the harmonic current will flow through C_3 to ground.

Now what about this padding that we started to discuss early in this article? In Fig. 7A, a padding condenser (C_A) would normally be added directly across C_1. Inasmuch as this circuit is already beyond hope, we are adding the last coffin nail by so doing. Ergo, don't add C_A as shown. If you insist on using that circuit, the least that can be done is to add two padding condensers in series across C_1. Then, if the junction of these two padding condensers is tied directly to ground, or bypassed to ground, we have minimized harmonic radiation by providing a low impedance path to ground. Also, with these series padders in place, we can remove C_X and store it in the junk box. Now that that has been done, note that this circuit is now a brother of the circuit in Fig. 7C.

Fig. 7B is a circuit that it is best to stay away from, but if it were to be used, two padding condensers should be used, at C_B, one each across the two sections of the tuning condenser C_2. If at this point you can talk yourself into removing the bypass condenser, C_Y, you will have made this circuit into another brother of the one in Fig. 7C. Referring to this latter circuit, padding capacitance should be added as indicated at C_C. If a single padding condenser were added directly across the whole tank coil then the harmonic currents could get to ground only through the original split-stator condenser C_3, which is now extremely small in capacitance compared to the rest of the circuit, and hence rather ineffectual. The current would divide, some going through this condenser, and the rest through the coil. This division of current would depend on the exact values of the capacitance and the inductance, but the point is that much current would be passing through the tank coil, and therefore producing harmonic voltages, which need not pass through if the padding capacitance were also made up in a split-stator arrangement.

Summing up all of the above, make sure that you have the proper circuit to start with. Then, when you add padding capacitance to this circuit to reach a lower frequency, make sure that you parallel both sections of the split-stator condenser with individual padding condensers. Your reward will be an improvement in tube efficiency and a silent muttered prayer from your neighbors.—Lighthouse Larry.

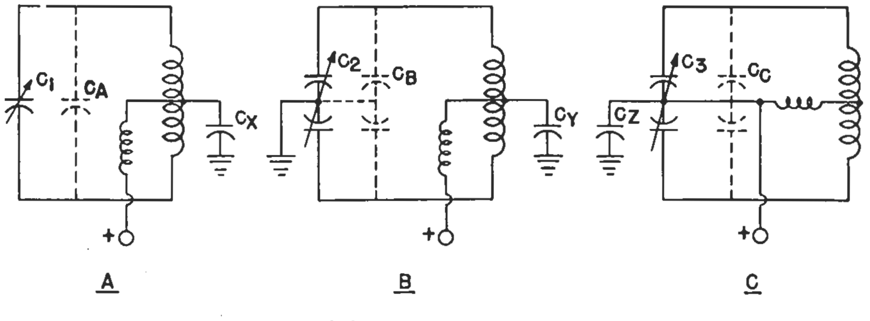


Fig. 7. Double-Ended Output Tank Circuits Discussed Above.

Proper Tank Circuit "Q" and Loading

From March-April, 1948

We have mentioned at several places in the article on the Power Peaker something about tank circuit Q's, which possibly might have left some of our readers wondering what significance it all has in the design and operation of radio gear. The fact is that operating Q's have a very profound effect on the performance of most of the equipment we have, so a little working knowledge of the subject might serve as a useful guide in the selection of components and operating conditions in equipment we hams use every day. Do not blame us if you are moved to check into some of your gear after reading this discussion and make changes which improve the operation (more output, less TVI, cooler tubes, and the like) of equipment at your station.

The term "Q" is applied to the ratio of reactive power (wattless power) in a circuit to real power. From this basic definition of Q follows many interesting corollary relations in electrical circuits, although the concept is not in the least limited to the field of electricity. Immediately one can say that the Q of resistance is zero, and that the Q of a perfect coil or condenser is infinite. These are the absolute limits of Q's, but they are broad enough to provide plenty of room for error—or design, whichever way you may look at it.

What can a person do about Q if he buys a coil that has a Q of 250, and the designer of a circuit says such and so circuit should have a Q of 25? Are the manufacturers kidding; are they soaking us for a lot of Q we do not need; or does the designer of the circuit think that any old coil will do if it will fit into the coil socket? No, the manufacturer is talking about his *product* when he says its Q is 250; the designer is talking about his *circuit* which generally involves more than the coil alone, and he should know enough about it to pick components which are the right ones for the job. One of the fundamental properties of a coil of wire is its inductance. Disregarding distributed capacity (which can become a headache sometimes), the reactance of a coil is proportional to the product of its inductance and the frequency at which it is operated. Pure reactances are nice to talk about, but coils are not actually 100% pure reactances by the time you buy or make one—the wire has resistance! This resistance is generally distributed throughout the coil, as is the reactance, but let us think of it as being all drained down to the bottom of the coil in one chunk of pure resistance, leaving pure reactance at the top. If the reactance portion of this *series* circuit of pure reactance and pure resistance has a value of 250 ohms, and the resistance is one ohm, the Q of the coil is 250; or, concisely,

$$\text{Q coil} = \frac{\text{Reactance (X)}}{\text{Resistance (R)}} = \frac{250}{1} = 250.$$

This is consistent with the basic definition given earlier. What we have said about coils is equally true of capacitors, but it turns out that condensers can be made with much higher Q's than coils generally have, so we worry about coils a little more than capacitors when speaking about Q's of the circuit elements we use.

Well, if we apply 1000 volts RMS to this coil having a reactance of 250 ohms and a resistance of one ohm (the impedance is very, very nearly 250 ohms, not 251 ohms), 4 amperes of current will flow through both reactance and resistance, and the *real* power in the coil is 16 watts (which shows up as heat) and the reactive power is 4000 volt-amperes, so called to distinguish wattless power from real power. The heat generated in this transaction represents energy lost—or at least energy converted from electrical form (that can be used conveniently) into heat that warms the coil and does not ever show up as energy in the antenna. What of it? Why worry about 16 watts lost when we have 4000 volt-amperes reactive power in the coil? If volt-amperes were what we were after, this would be fine. Think of it—4000 volt-amperes that cost only 16 watts! A good bargain? Not bad if we know our P's (powers) and Q's, but that is the rest of the story. The circuit designer can now take over where the coil builder left off.

As we all know, a capacitor in parallel with a coil makes a tuned circuit. It turns out that at the resonant frequency of this circuit the reactance of the capacitor is equal to the reactance of the coil. If we tune our coil with a capacitor having a Q of 5000 (not unusual) we can truly neglect the 8/10 of a watt lost in the equivalent resistance of the capacitor compared with the 4000 volt-amperes of reactive power (not lost—yet) in the coil and capacitor, and the 16 watts loss in the coil. Now let us add a fourth circuit element to the reactance and resistance of the coil and the reactance of the capacitor comprising the tuned (tank) circuit we are talking about. Let us make this one a resistance, and let us put it across the condenser of the tank circuit. If 1000 volts is still supplied across the coil, it now appears across the resistance and the capacitor as well. A little over 16 watts has already been accounted for in the coil and condenser so what about the new resistor? Well, a current of E/R flows in it, and power *is* consumed in the resistance—no doubt about it. It is already pretty hot!

How much power goes into this resistor? That is an easy one. The power is

$\text{P (watts)} = E^2/R = \frac{1{,}000{,}000}{\text{R (Ohms)}}$, since the voltage E is 1000 volts, RMS, by hypothesis. If R is 5000 ohms, the power is 200 watts and the circuit Q is now $\text{Q (circuit)} = \frac{\text{Reactive Power}}{\text{Real Power}} = \frac{4000}{216} = 18.5$ according to our basic definition of Q stated at the outset.

Let us not be quite so crude about it. Suppose the *equivalent* of this resistance is put across the capacitor by *coupling* a load to the coil and adjusting the coupling until the power delivered to the load is 200 watts. If the coupling job did not disturb the tuning, the circuit Q is still 18.5, and the generator feeding this circuit is unable to detect the difference. It still has to supply 216 real watts as before and 4000 volt-amperes to the coil and the capacitor of the tank circuit. In fact, the generator does not even feel the 4000 VA in the coil because the 4000 VA in the capacitor happens to cancel the reactive power of the coil! That is co-operation on a pretty big scale, but nobody should be surprised about it—this is what happens at resonance. Has the bargain evaporated? Not entirely, although the 4000 VA has slipped through our fingers somehow. Pfoof! That was wattless power anyway. We did get 200 watts of good output from our circuit that loaded the generator to 216 watts, so the circuit efficiency is

$\eta\ \text{(circuit)} = \frac{200}{216} \times 100 = 92.6\%$, a pretty fair bargain at that. Had we loaded the circuit to extract only 100 watts, the circuit efficiency would have been $100/116 \times 100 = 86.3\%$, not quite so good. The circuit Q in this case would have been 34.5. If the circuit were not loaded at all, the circuit efficiency would have been zero, with a Q of almost 250, about the same as that of the coil. Loading the circuit so that 400 watts is delivered would give a circuit efficiency of $100 \times \frac{400}{416} = 96.2\%$ with a circuit Q of 9.62. Which loading would you choose? To answer that we must consider the characteristics of the generator and the signal it generates.

If the generator had sinusoidal waveform (no harmonics) the tank circuit would not be needed at all, and so the load circuit efficiency would be very close to 100% at any power level. But the generators we are interested in are vacuum tubes running as class B or C amplifiers, generally. A class B amplifier delivers a signal that is only half of a sine wave, and a class C amplifier does even less. The tank circuit helps the tube, which delivers only half of a sine wave (or less), to deliver a whole sine wave to the load. The degree to which this is done is almost directly proportional to the operating Q of the circuit. Thus, the tank circuit serves as a much needed coupling device between the tube and the load, and by various adjustments of coupling, we can make a fixed value of load resistance present a chosen value of load into which the tube (generator) actually delivers power. A little power loss in the tank circuit is justifiable, since we have limited control over the actual load resistance and the tube characteristics; i.e., the optimum load for the tube itself. We have seen that the power output of the generator depends on the load resistance presented to it, in this case across the capacitor of the tank circuit. For a given tube and mode of operation (class A, AB, B, or C) there is a definite best loading. Too light a load will not allow a reasonable output power; too heavy a load, on the other hand, wastes power in the tube (generator) and makes it overheat. All of these factors indicate a compromise, with the circuit designer as referee. It has been found that circuit Q's of about 10 or more make the tube happy—accept power for half a cycle or less and deliver power for a whole cycle. The numerical example showed us that the higher circuit Q's had lower efficiencies (with a fixed coil Q) so this tends to push the choice of circuit Q down.

The response of a tuned circuit to harmonics is approximately $\frac{1}{nQ}$, where n is the order of the harmonic (2 for second, 3 for third, etc.), so this consideration makes a choice of high Q desirable. A good all-round choice of operating Q is from 12 to 15, a compromise to be sure. Now we do some juggling. We want to present the optimum load to the tube, but we must keep it happy. We also want to have good discrimination against harmonics present in the output of the tube. In addition, we want to waste as little of the tube's output power as possible; that is, we want good over-all efficiency. Having chosen the operating voltage for the tube, the optimum resonant load resistance is fixed. Taking this and a value of circuit Q around 12 to 15 we can solve for the reactance of the coil and the condenser by substituting values in the following equation:

$$\text{Reactance} = \frac{\text{Load Resistance desired}}{\text{Q (circuit)}}$$

This is the value that must be used to obtain the desired output power at good tube efficiency, at reasonable circuit efficiency, and with reasonable harmonic attenuation. Circuit Q affects all these things. The Q of the coil alone determines the power loss in the coil, once its reactance is established. Doubling the Q of the coil alone will cut the power loss in the coil itself to half—a desirable move for the sake of the coil—but this is not so easy, and the circuit efficiency will be raised only a little bit (from 96%, say, to 98%, a little difficult to detect on the scale of the output power). Doubling the coil Q will not affect ***in the least*** the loss occurring in the tube itself. That loss is determined by the load into which the tube works, and by the mode of operation; i.e., class A, B, or C.

It takes no magician to apply the foregoing information intelligently. In the Power Peaker amplifier, for example, the output circuit Q was chosen at about 15. (This will vary somewhat throughout a given band because of tuning.) The choice of 1500 volts (the highest allowed by the tube manufacturer) was made to get the greatest useable output power, and this sets the value of load resistance and coil reactance at any operating frequency. The numbers used in the foregoing numerical examples are quite close to those actually appearing in the Power Peaker amplifier. That is all there was to it. Easy? You betcha!

One more comment. If a Q of 12 or 15 is so good for the output circuit why was a Q of 25 chosen for the input (grid circuit) of the Power Peaker? Two main considerations guided this choice. The input load of the GL811-A depends somewhat on the loading in the output circuit. In order to have some latitude for error, the Q of the input circuit was made higher than actually necessary so that things would be on the safe side. The other consideration was this: the exciter, when coupled to the amplifier grid circuit, lowers the grid-circuit Q. Thus, it is quite probable that the working Q of the grid tank circuit will be around 15, after all.

Watch your P's and Q's. Keep your tubes happy, get more power out of your rig, lower the harmonic output, and save money in the choice of suitable components.