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A Push-Pull Class B-Linear

A 1 kW push-pull grounded-grid linear amplifier using 3-400Z's.

It is one of those minor ironies that during the past ten or fifteen years, while the single-ended audio amplifier has almost completely given way to push-pull, exactly the reverse has occurred in respect to rf amplifiers. This is even more surprising when one remarks that rf amplifiers nowadays are seldom called upon to perform a modulating function and so are, like their audio counterparts, devices for raising the power level.

The faculty of even harmonic distortion cancellation attributed to push-pull circuits depends upon tight coupling between the two halves of the output circuit—this is very much more easily realized at audio than at radio frequencies. Nevertheless, there is a basic symmetry in the push-pull circuit that can hardly do anything but help to produce a symmetrical output which in turn is likely to possess fewer spurious components.

The case for the grounded-grid amplifier has been competently and extensively made and does not need elaboration here. It seems then that a push-pull grounded-grid amplifier would be an especially attractive proposition. Before launching into a description of one such amplifier, I should like to identify some of the other assumptions (perhaps they should be called prejudices) that underlay the project:

1. Bandswitching is not necessary or even desirable if it must be bought at the price of tapped coils or huge voltages across unused coil segments.

2. The desired frequency range is 3.5-29.7 MHz, CW and SSB, and power input capability up to the legal limit. Both plate voltage and current must be continuously monitored at such power levels to satisfy Canadian government regulations.

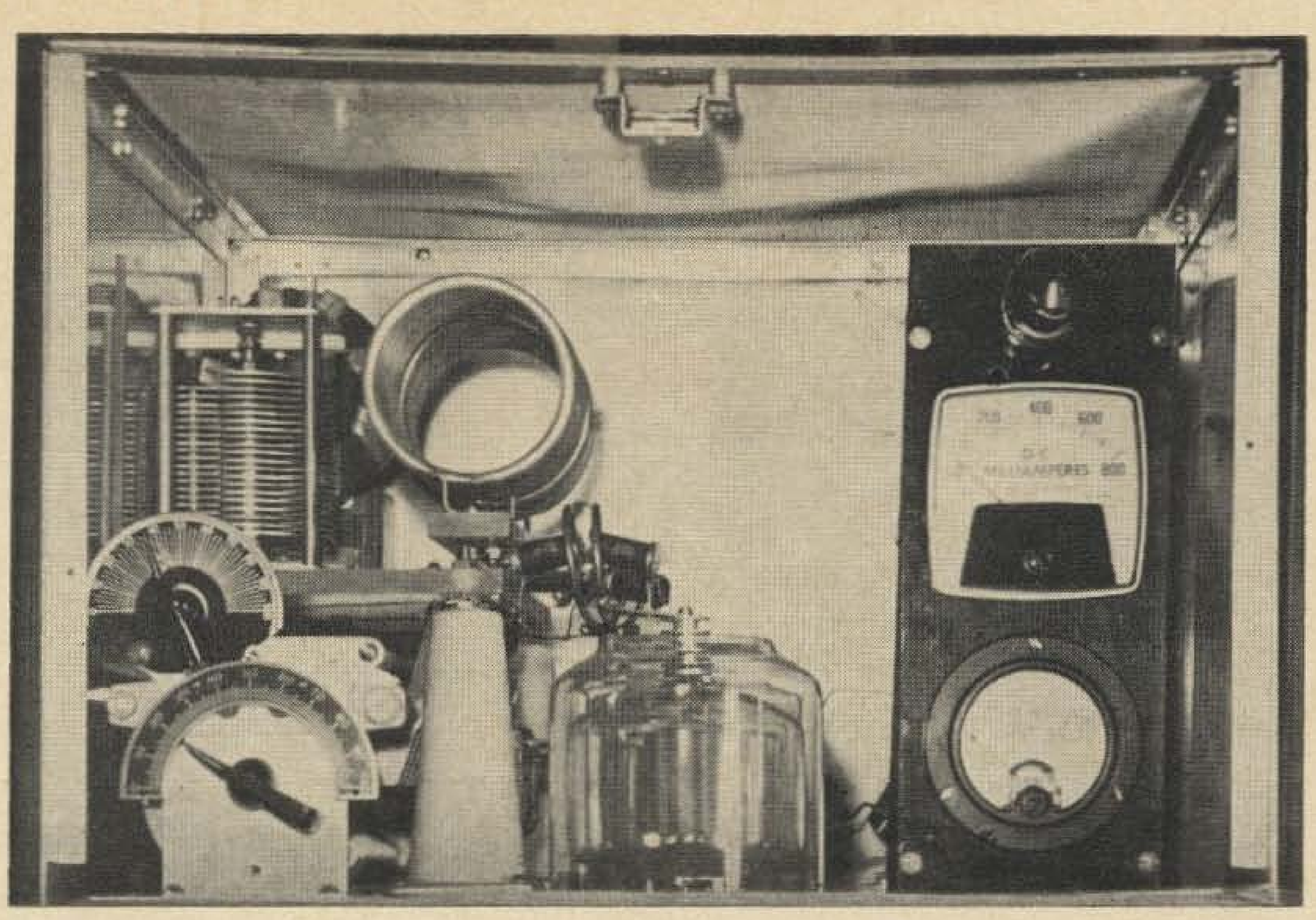
3. Shunt feed is only acceptable as a last resort.

4. Voltage-doubling circuits, choke-less filters, series-string rectifiers and filter capacitors and such artful dodges are to be avoided.

5. The driver is a B & W 6100 and the load will be a 50 ohm (nominal) unbalanced antenna.

Fig. 1 is the schematic of the completed amplifier. To sum it up, it consists of two Eimac 3-400Z zero bias triodes with 3000 volts on the plate in a push-pull grounded-grid connection. RF drive is series fed to the cathodes (heated by two separate filament transformers—872 type filament transformers have sufficiently low capacitance for this application) from a transformer whose primary is connected to a pi network of reactances affording impedance matching to the driver

The interior of the push-pull grounded-grid amplifier. The 3-400Z's are located in the center, the plate current and voltage meters to the right and the output circuitry to the left. The toroidal rf power transformer is hidden by the vertically mounted variable capacitor to the left.



output. The output circuit is series fed with a split tank coil. The loading of the stage is controlled by the variable capacitor across the output transformer primary. The power supply (full wave 872's; single section L/C filter; 24 μF total capacitance) is of standard design. As for housing the linear, quite conventional construction practices were employed—the underside of the chassis is kept air tight so that a single fan (Ripley SK-4125) can handle both tubes which are mounted in Eimac air system sockets and chimneys.

The rf transformers

The central features of this linear are the *trifilar* input and output transformers pictured in **Fig. 2** and detailed in **Fig. 3.** "Trifilar" means that three conductors are grouped and wound onto the core as a single turn. Ferrite core material is employed because of its admirable magnetic properties at radio frequencies. This mode of winding on this type of core seems to produce the tightest possible coupling consistent with low losses and reasonable distributed capacitance. In both cases the transformers are used with two windings connected in series and one winding by itself. The input transformer is, therefore, 1:2 step up in turns. However, since only one tube is operating at any one instant, it may be viewed as simply 1:1 in terms of impedance. The output transformer has part of the tank circuit circulating current in its primary and sees the antenna as its load, so it is 2:1 step down in turns and 4:1 step down in impedance. The transformers provide good performance on three adjacent ham bands so there is an overlap on 14 MHz.

The pi input network

In spite of the additional coil which requires band switching, this network more than pays its way for several reasons. First,

The trifilar wound rf transformers. Ferrite cores were used in the interest of close coupling, low capacity and high Q.

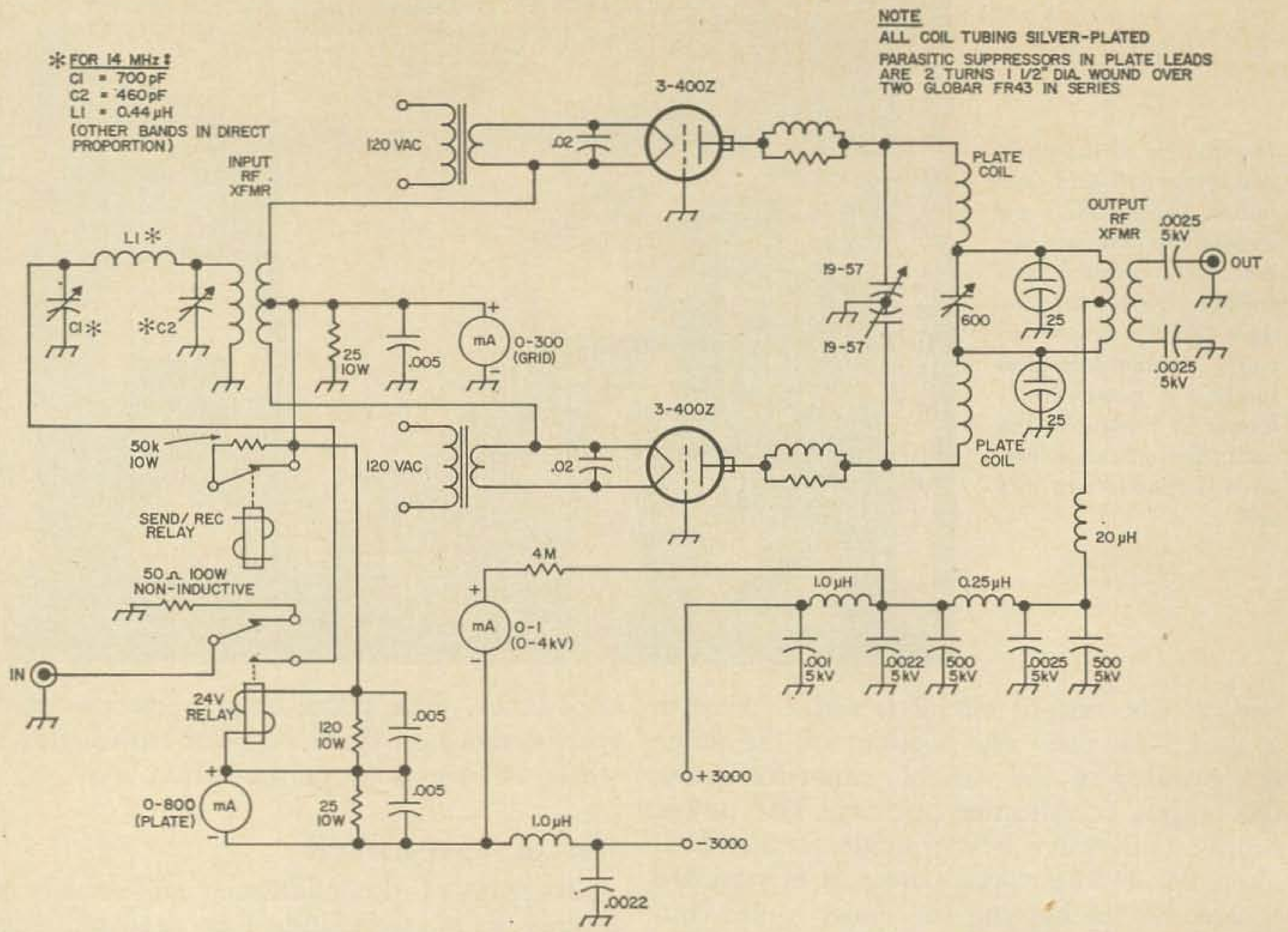


Fig. 1. Schematic of the push-pull grounded-grid class-B linear amplifier. The dual 19-57 pF capacitor in the plate circuit was made from a surplus unit, 0.25 spacing, by removing all but four stator plates per section.

it serves as a reservoir of stored energy whose flywheel action serves both to couple the tubes together and to stabilize their waveform. Secondly, it provides almost complete isolation betwen the linear and its driver, thus making it possible to make the SWR presented to the driver very close to 1:1.

Since the definitive article on *all* phases of grounded-grid power amplifier operation apparently has yet to be written, it is, perhaps, appropriate to summarize the problem of driving such an amplifier. Four impedances are of concern:

1. The impedance looking toward the amplifier—analytically, this represents the *fed-through* power plus the grid losses.

2. The impedance seen by the cathodes of the linear stage looking back toward the driver. Theoretically this may be zero—practically it must be finite. Furthermore, if there is to be any stored energy, reactances must be involved and resonance must be achieved so that the cathode-ground voltage will be in phase with the plate current.

3. The desired impedance seen looking forward from the exciter. This is almost always 50-52 ohms (unbalanced).

4. The impedance seen looking back into the exciter output terminals. This may be nearly any small resistance, often accompanied by a larger reactive component.

Suppose that, on the basis of reasonable capacitor sizes and modest Q, we aim to make the cathode to ground impedance (2) equal to the impedance looking toward the amplifier (1). Since impedance is equal to Q times capacitive reactance ($Z = Q X_c$), high Q's call for low X_c's and therefore, large capacitors. The basis of this design was $Q = 5$; therefore, the capacitive reactance (X_c) is about 25 ohms since (1) is approximately 125 ohms for the 3-400Z in this circuit. A nameless but very useful theorem* states that in any circuit containing loss-less elements (L, C, and perfect transformers), if a conjugate impedance match occurs at one junction then it must exist at every other junction and conversely. Such a state of affairs would mean that the conjugate of (4) would be the load to the driver and this is nowhere near the value of (3). To be blunt, there would be a very high SWR on the driver-to-linear transmission line with consequent difficulty in getting power out of the driver. As an additional complication, unless the exciter and linear are bolted together, these various impedances are transformed differently depending on whether one is considering the direction — exciter to linear or linear to exciter. Not only that, these transformations will be different on different bands unless the length of coaxial line is changed when changing bands. The only straightforward way out of this dilemma is to swamp out the impedance irregularities by imposing the greatest power loss that can be tolerated between the exciter and the linear. Consequently a 3 dB pad (see **Fig. 4**) is placed between the linear and the exciter. Since the greater the loss in the pad the greater isolation it affords, and since there is a considerable surplus of drive from the B & W 6100, the pad could have been raised to 4 dB or so in my case to some advantage.

Drive interlock

Most articles on grounded-grid amplifiers view the possibility of drive being present with no plate current with alarm—an eventuality that has been rendered almost impossible by the drive interlock relay whose resistor terminates the driver when the relay is not actuated.

Trials and tribulations

Perhaps a paragraph or so on the unsuccessful experiments and assorted disappointments would be appropriate here. The feasibility of the cathode drive transformer idea was established at the outset in a series of experiments involving 809's and 811's (*not* 811A's). Cross neutralization of these tubes is easily achieved by bringing a lead up through the chassis from a cathode to a copper bracket and facing it toward the opposite plate through the glass envelope—less than 1 pF is required. However, on 21 and 28 MHz the parasitics took over in a spectacular fashion. The only way they could be tamed was by using resistive stoppers between grid and ground. However, a little circuit analysis shows that this makes the neutralizing null and void with resultant operating-frequency instability. No such problem was ever encountered with the 3-400Z's.

**Communications Engineering*, third edition, Everitt and Anner, McGraw-Hill, page 407.

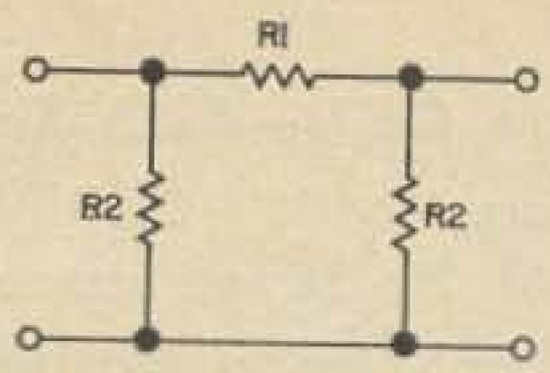


Fig. 2. 3-dB isolating pad. R1 consists of twenty 360-ohm, 1-watt composition resistors in parallel—total resistance 18 ohms. Each of the pad resistors labeled R2 consist of thirteen 3900-ohm, 2-watt resistors in parallel—total resistance 300 ohms.*

Right up until nearly the end of the experiments, it had been hoped that a shielded link coupling could be used between the tank and the antenna. Unfortunately, the coupling obtained with the link proved to be quite insufficient on 21 and 28 MHz and the output transformer had to be introduced. It was also necessary to come to terms with the fact that the load impedance seen by each tube for the target outputs is in the vicinity of 5500 ohms. Using the old rule of thumb that a Q of 6 is adequate with push pull, the capacitance required works out to about 6 pF on 28 MHz, 8 pF on 21 MHz, 12 pF on 14 MHz and so on. Since the output capacitance of the 3-400Z is 4 pF and strays will

*For construction hints, see K. Glanzer, "T-Pads for RF Circuits," *CQ*, July 1964.

VE3AAZ's push-pull grounded-grid linear amplifier. In this view the underside of the chassis is opened up to show the blower. The screen door across the rf compartment permits changing the final plug-in coil.

Table I. Coils

	Plate Coils—Both Sides
3.5 MHz	18 turns #14, 2¼" long, 2⅜" ID, shunted by 25 pF vacuum capacitor at high end of band; shunted by 35 pF vacuum capacitor at low end.
7 MHz	12 turns #12, 2¼" long, 2⅜" ID, shunted by 10 pF vacuum capacitor.
14 MHz	8 turns ¼" silver-plated copper tubing, 2¼" long, 2¾" ID.
21 MHz	6 turns ¼" silver-plated copper tubing, 2¼" long, 2⅜" ID.
28 MHz	4 turns ⅜" silver-plated copper tubing, 2¼" long, 2⅝" ID.
	L1—Input Pi Network
3.5 MHz	8 turns #14, 2" long, 1½" ID.
7 MHz	5 turns #14, 1¾" long, 1½" ID.
14 MHz	3 turns ⅛" silver-plated tubing, close wound, 1¼" ID.
21 MHz	2 turns ⅛" silver-plated tubing, close wound, 1½" ID.
28 MHz	2 turns ⅛" silver-plated tubing, close wound, ⅞" ID.

Coil Construction

The input rf transformer is wound on an Indiana General CF-117* toroid ⅜" thick 1⅞" OD., 1⅜" ID. The primary consists of a 0.010 copper strip, 3/16" wide, placed next to the core. The pushpull secondary winding consists of 150-ohm twin lead wound over the primary strip; 14 turns for 80, 40 and 20 meters, 12 turns for 20, 15 and 10.

The output transformer is wound on an Indiana General CF-124 form ½" thick, 2" ID and 3½" OD. The primary consists of a 0.010 copper strip, ¼" wide placed next to the core. The push-pull secondary winding is made from two ⅛" wide 0.010 copper strips; insulated by #9 Teflon tubing and wound over the primary strip; 9 turns for 80, 40 and 20, 7 turns for 20, 15 and 10. Two CF-117 cores are mounted in the center of the larger core as shown in photographs.

These cores from Indiana General are available in two different materials designated Q1 and Q2. Material Q1 has a nominal relative permeability of 125, while Q2 has a nominal relative permeability of 40. In the both the input and output cores used in this linear, Q1 cores were used for 80–20 meters, and Q2 cores were on 20, 15 and 10.

*Indiana General cores may be purchased from Permag Corporation, 88-06 Van Wyck Expressway, Jamaica 18, New York.

account for an additional 10 pF or so, we are just not going to be able to meet our specification. *It is only a slight comfort to know that parallel connection and a Q of 12 would call for 12 pF on 28 MHz–8 pF being contributed by the tubes.* Nor can we evade the issue by dropping the plate voltage and then calling for lower load impedances to give the rated power. When the "C" is too large and the "L" is too small we lose power in the tank circuit; if we drop plate voltages, we sacrifice plate efficiency and lose power at the plate. The only way out seems to be to use as large a coil as possible and keep its losses low–silver plated copper tubing was used here for the coils with jumbo banana plugs and jacks. In any case, be prepared to accept the drop in power as frequency rises with good grace. For these reasons no L/C values are shown in **Fig. 1**–anyone wishing to copy the design will have his own approach to this matter–he might even have a split-stator vacuum variable in the junk box! I didn't.

Power and distortion

It has become fashionable to rate linear amplifiers at so many watts PEP input. Aside from the rather impressive numbers generated, there seems to be little to recommend the practice. It is far more meaningful to quote the CW output and the PEP output consistent with good linearity–and with due respect to legal restrictions on power input.

With a 1 kW dc input, this amplifier yields at least 600 watts output on the 3.5, 7, and 14 MHz bands, shading off to 550 watts on 21 MHz and 500 watts on 28 MHz. The PEP output with good linearity is at least 1 kW on the low bands tapering off to about 800 watts on 28 MHz. The drive powers range from 20-40 watts, but the driver has to deliver twice this power since one-half is lost in the 3 dB pad. The power gain in the linear itself then is at least 20.

Distortion figures must of necessity describe all of the system up to the point of measurement. The published specifications for the B & W 6100 are: harmonics–50 dB or more down; intermodulation products–35 dB or more down. These figures can be met at the output of this linear driven by this exciter. Without becoming involved, therefore, in any attribution of distortion components, this amplifier does not measurably degrade the signal.

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