HAM TIPS
RCA
A PUBLICATION OF THE RCA TUBE DIVISION

Vol. XV, No. 3 October, 1955

Single-Ended Class-C Amplifier Design

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The July-August, 1954 HAM TIPS gave a simplified procedure for the design of pi-coupled amplifiers. Now, W2IYG steps forward to discuss simplified design for single-ended Class-C amplifiers using balanced plate tank circuits.

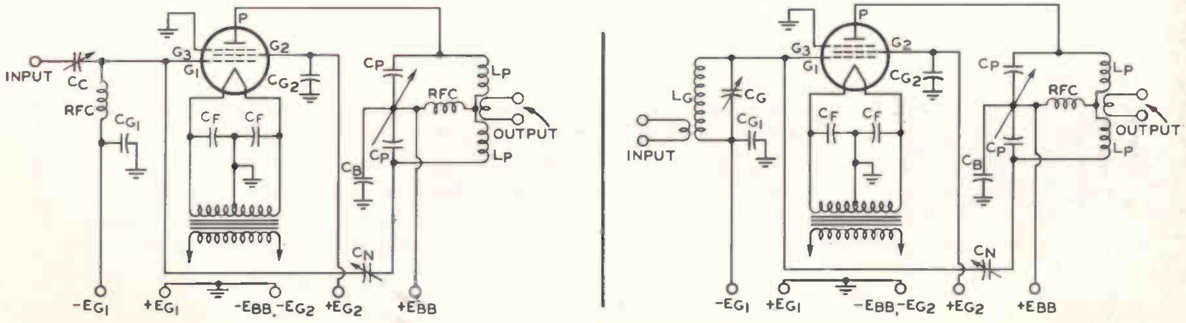
Although much of the material presented here has been published piecemeal in one form or another, W2IYG has gathered the important considerations into this one article and boiled them down into simple, practical form.

The basic circuit for single-ended Class-C amplifiers is essentially the same regardless of the tube type used; the chief problem confronting the designer is the selection of the proper component values for this circuit. The tuned circuits present the greatest difficulty, especially for those who plan to make their own coils and select capacitors suitable for use with these coils. The selection of other circuit components may also pose problems.

This article presents a "rule-of-thumb" approach to the selection of components for use in the circuits shown in Figures 1A and 1B. This approach, which eliminates the use of formulas and equations, provides workable circuits having adequate efficiency for most "ham" uses. A nomograph and a series of charts and curves enable the designer to determine quickly the value and rating of all circuit components including the physical constants of the coils. The step-by-step design procedure is as follows:

1. Select a suitable tube type.
2. Select a circuit, Figure 1A or 1B.
3. Select tube power output from tube data.
4. Determine peak plate voltage by multiplying dc plate voltage by 0.85.
5. On Nomograph, Figure 2, place straightedge on these values of power output and peak plate voltage. Read "Plate Load" value.
6. Place straightedge from this plate load value to the "Amateur Band" desired. Read

Figure 1. Basic Circuits. (When triodes are used, omit Grid-No. 2 and Grid-No. 3 circuitry.)


1A. Capacitance coupling from driver.
1B. Link coupling from driver.

"Reactance X_C and X_L" value.

7. In Figures 3 and 4, *Reactance vs Capacitance and Inductance Curves*, read the values of tank capacitance and tank inductance required.

8. Determine minimum capacitor spacing, from Figure 8.

9. From Figure 5, *Coil Curves*, determine diameter, length, number of turns, and wire size required.

10. From Figure 6, *Miscellaneous Circuit Components Chart*, select values of other circuit components.

Before we run through a typical example, it is worth while to consider the important factors which influence tube selection.

Tube Selection

The selection of a tube to be used in the circuits covered by this article should not be made on the basis of tube power output alone. Equally important factors are: (1) tube output capacitance; (2) plate load; (3) driving power.

Tube output capacitance. This capacitance is added to the tank-circuit capacitance—thus changing the tank circuit's resonant frequency. At the lower frequencies this increase in tank capacitance is not serious, because the ratio of the tuning capacitance to the tube output capacitance is reasonably high. Thus, the tuning capacitor may be adjusted slightly to compensate for the tube output capacitance. At the higher frequencies, however, this capacitance ratio decreases and it may not be possible to reduce tuning capacitance sufficiently to obtain resonance within the band.

Plate load. A survey of popular power tubes used by amateurs reveals that most of them have plate load resistances in the range between 2500 and 5000 ohms. The Nomograph can be used for all popular types because it covers resistance values from 1000 to 5000 ohms. If the selected tube has a plate load resistance in excess of 5000 ohms, parallel operation of two or more lower-power tubes should be considered. The plate load resistance may also be reduced by operating the tube at a lower plate voltage and a higher plate current.

Driving power. The power output from the driver stage should be at least twice the grid driving power required by the driven tube. When sufficient driving power is available, the selection of a triode greatly simplifies circuit design because triodes in general have low output capacitances, are easy to neutralize, and have a plate load resistance of approximately 3500 ohms. In addition, grid-No. 2 and grid-No. 3 considerations are eliminated.

Typical Design Problem

The following sample design problem can easily be solved with the aid of the Nomograph, charts, and curves.

Problem: To design a 500-watt input class-C amplifier for CW telegraphy service, having a single-ended, balanced, plate tank circuit and a tuned grid-input circuit, for operation on 40 meters. Power output from an available driver stage is about 10 watts.

Procedure: Refer to a technical booklet such as the "RCA Headliners for Hams" (Form No. HAM 103B), which lists popular RCA types for amateur use. With the aid of such a publication, we find that a beam power tube or a pentode (for example, type 813) fits the driving-power requirements for the plate input involved.

Having selected an RCA-813 as the desired tube (step 1), we next choose our circuit (step 2). Because the driver stage is on a separate chassis, link coupling is desirable. Consequently, the circuit of Figure 1B is chosen.

3. The power input is 500 watts under the following typical ICAS conditions given in the tube data:

DC Plate Voltage	2250	volts
DC Grid-No. 3 Voltage	0	volts
DC Grid-No. 2 Voltage	400	volts
DC Grid-No. 1 Voltage	–155	volts
Peak RF Grid-No. 1 Voltage	275	volts
DC Plate Current	220	ma
DC Grid-No. 2 Current	40	ma
DC Grid-No. 1 Current (Approx.)	15	ma
Driving Power (Approx.)	4.0	watts
Power Output (Approx.)	375	watts

4. The peak plate voltage is 1910 volts (2250 x 0.85).

5. The plate load resistance, obtained from the Nomograph, is about 4900 ohms.

6. Also from the Nomograph, the reactances X_C and X_L required for a plate load of 4900 ohms at 40 meters are 800 ohms for each section of the plate tank, and 400 ohms for the grid tank.

7a. Figure 3 shows that: (1) The capacitance of *each section* (C_P) of the split-stator plate-tank capacitor is 27 μμf at the mid-frequency. A capacitor of 50 μμf (each section) should be used to provide adequate band coverage. (2) The inductance of *each section* of the plate-tank inductor is 17 μh.

7b. Figure 4 shows that: (1) The capacitance of the grid-tank capacitor is 55 μμf at the mid-frequency. A capacitor of 100 $\mu\mu$f should be used to provide band coverage. (2) The inductance of the grid-tank inductor is 8.9 μh.

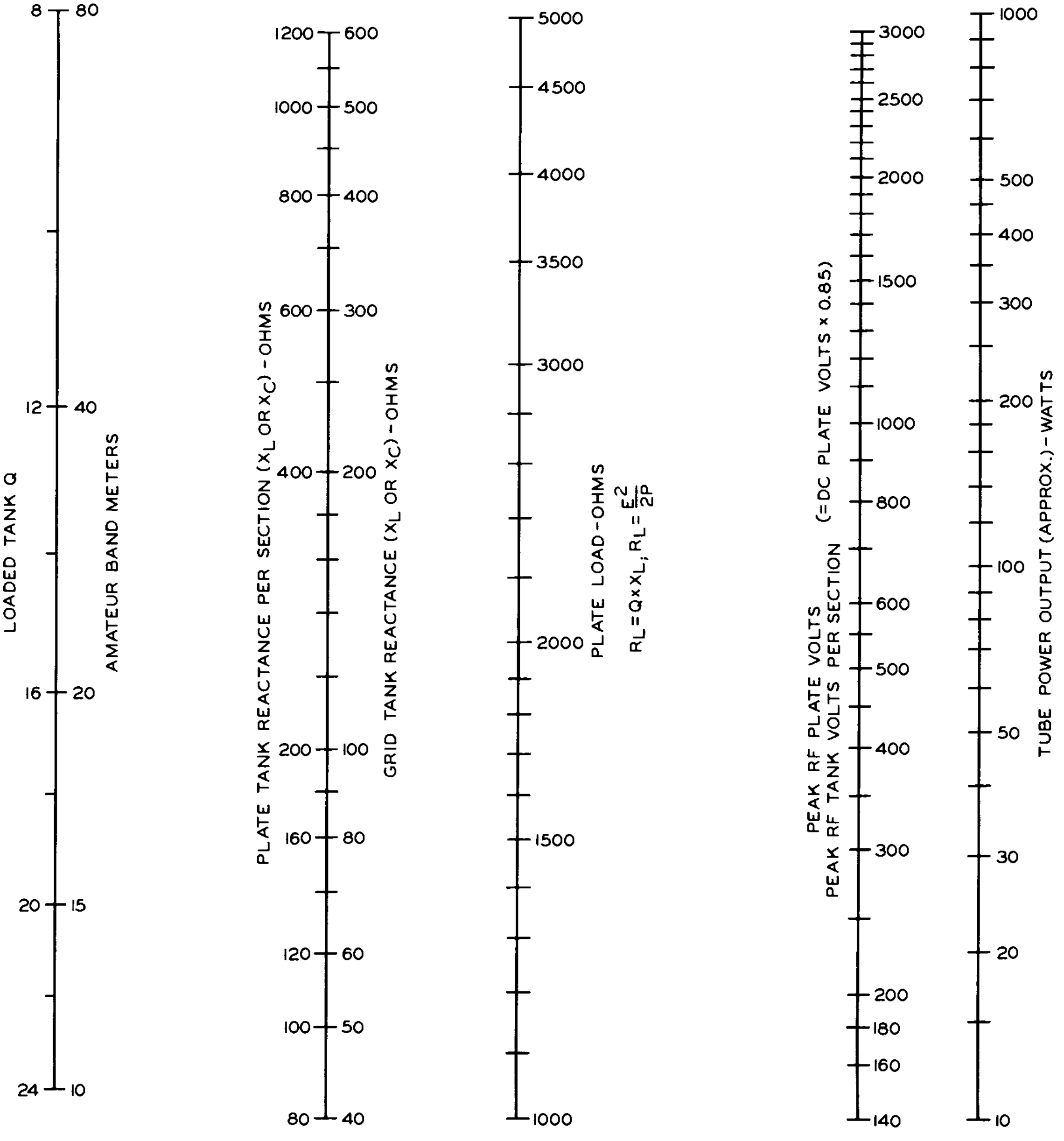
8 a. Figure 8 shows that rotor-to-stator spacing for each section (C_P) of plate-tank capacitor for a peak rf plate voltage of 1910 v = 0.06″, minimum. (For telephony service, the peak rf plate voltage is 2 x 1910 v = 3820 v, and the spacing would be increased to 2 x 0.06″ = 0.12″, minimum.)

8 b. Figure 8 also shows that rotor-to-stator spacing of grid-tank capacitor (C_G) for a peak rf grid voltage of 275 v = 0.01″, minimum distance (approximately).

9a. Step 7a showed that the plate tank inductance required is 17μh for each section, or a total inductance of 34 μh. Referring to Figure 5, we find curves for 1-inch, 2-inch, and 3-inch diameter coils. The table of wire-sizes shows that No. 10 wire is suitable for a tank coil used in conjunction with a tube having a 375-watt power output.

The Wire Table in Figure 5 shows that the maximum number of turns per inch for No. 10 wire is 9 turns. Referring next to the curves in Figure 5 (for three representative coil-form dimensions), we find that an inductance of

Figure 2. Nomograph.



34 μh requires 56 turns on a form having a 1″ diameter and a 2″ length, 41 turns on a form of 2″ diameter and 4″ length, and 32 turns on a form 3″ in diameter and 6″ in length. However, we have already noted that no more than 9 turns per inch can be wound with No. 10 wire, so it is clear that the coil form of 3″ diameter and 6″ length is the only one of the three which allows the necessary number of turns of No. 10 wire for an inductance of 34 μh. (For the experimenter willing to design coils using coil forms other than those used for the curves in Figure 5, the equation shown with the curves will be of value.)

9b. Step 7b showed that the grid-tank inductance required is 8.9 μh. Referring to Figure 5 again, with a tank inductance of 8.9 μh, and with #18 wire (suitable for power levels below 75 watts), we find that 30 turns on a 1-inch coil diameter and a 2-inch winding length provide the inductance required.

10. From the circuit shown in Figure 1B and from the "Miscellaneous Circuit Components Chart," Figure 6, we find that the following additional components, with indicated ratings, are required:

CAPACITORS

Capacitance	Working Voltage Volts (Minimum)	Type
Bypass:		
Filament, C_F		
0.001 to 0.01 μf	200	Disc Ceramic
Grid-No. 1, C_{G1}		
0.001 μf	200	Disc Ceramic
Grid-No. 2, C_{G2}		
0.001 to 0.005 μf	400	Disc Ceramic
Plate, C_B		
0.001 μf	2250	Mica
Neutralizing, C_N:		
0.5 μμf max.	4500	Variable-Air

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Inductance mh	Current Rating Ma (Minimum)	Type
Plate:		
2.5	220	Any
Grid No. 1:		
2.5	15	Any

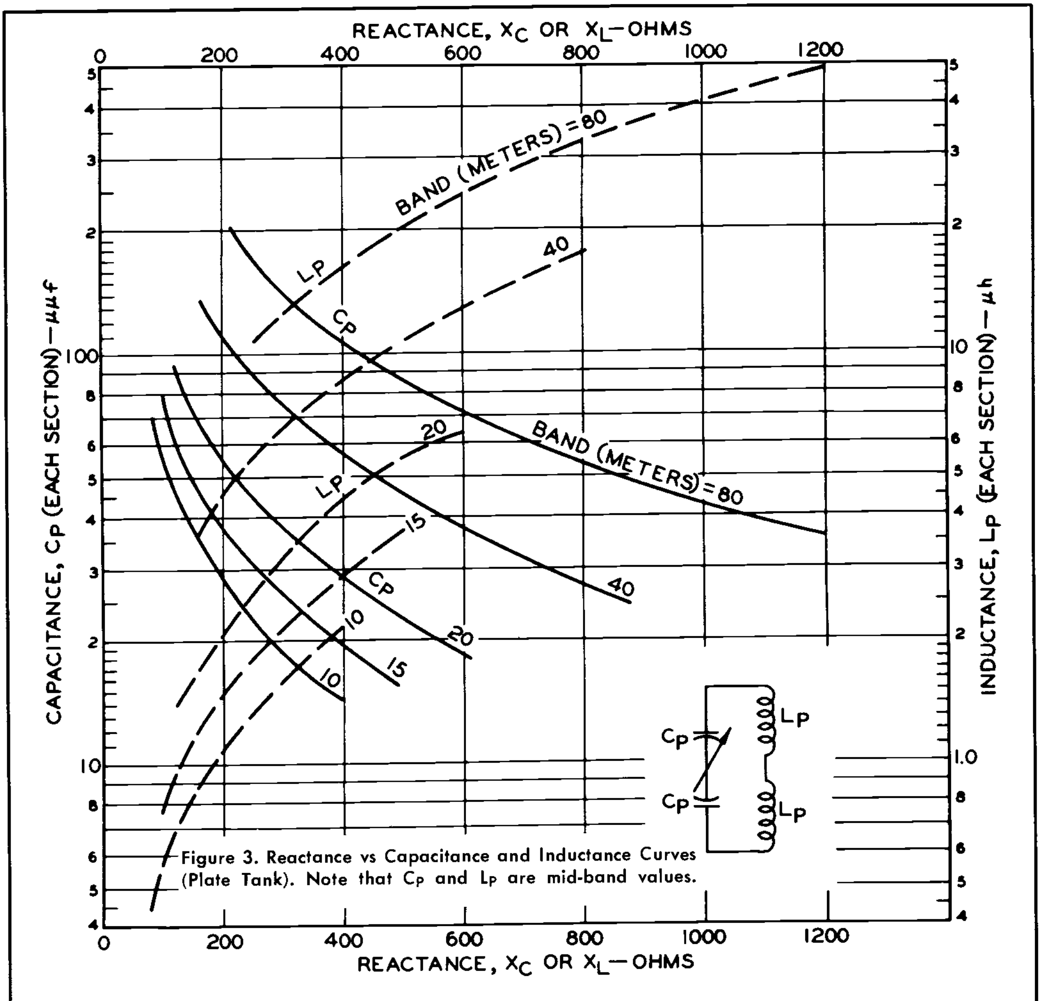


Figure 3. Reactance vs Capacitance and Inductance Curves (Plate Tank). Note that C_P and L_P are mid-band values.

That's all there is to it. You've designed a complete final stage, to the required specifications. If you're in a rush to get "on the air," you can stop reading right now and plug in your soldering iron. The balance of this article is a discussion of the various charts and tables, with some thoughts on plate tank circuits in general.

Basic Circuits

The circuits discussed in this article were selected for the following reasons:

1. They are very popular.
2. They are easily adjusted and require no special balancing. Neutralization is simple and straightforward.
3. All components can be easily obtained, and are available in great variety at relatively low cost.
4. There is less likelihood of TVI from single-ended balanced tank circuits than there is from the average push-pull amplifier.
5. A balanced tank circuit with link coupling allows easy installation of a low-pass filter designed to work on 50- or 75-ohm lines.

The Nomograph

The Nomograph (Figure 2) provides a simple method for solving a set of equations with reasonable accuracy. It indicates the proper plate load for any tube operating at a power level between 10 and 1000 watts and at dc plate voltage between 165 and 3500 volts. The Nomograph also relates "plate load" and "operating frequency" to the proper value of capacitive and inductive reactance required in the tank circuit. (It is important that the reactances X_C and X_L, along with loaded Q, be the specified values, to ensure proper plate loading and good circuit efficiency.) The Nomograph, used in conjunction with the single-ended balanced tank circuits shown in Figures 1A and 1B, also aids in the selection of a tube suitable for use with these circuits, as discussed under "Tube Selection."

To permit the use of practical values of tank C and L over the amateur bands from 80 through 10 meters, the Nomograph has been designed so that suggested values of loaded tank Q vary with the amateur band being used (Q increases with frequency).

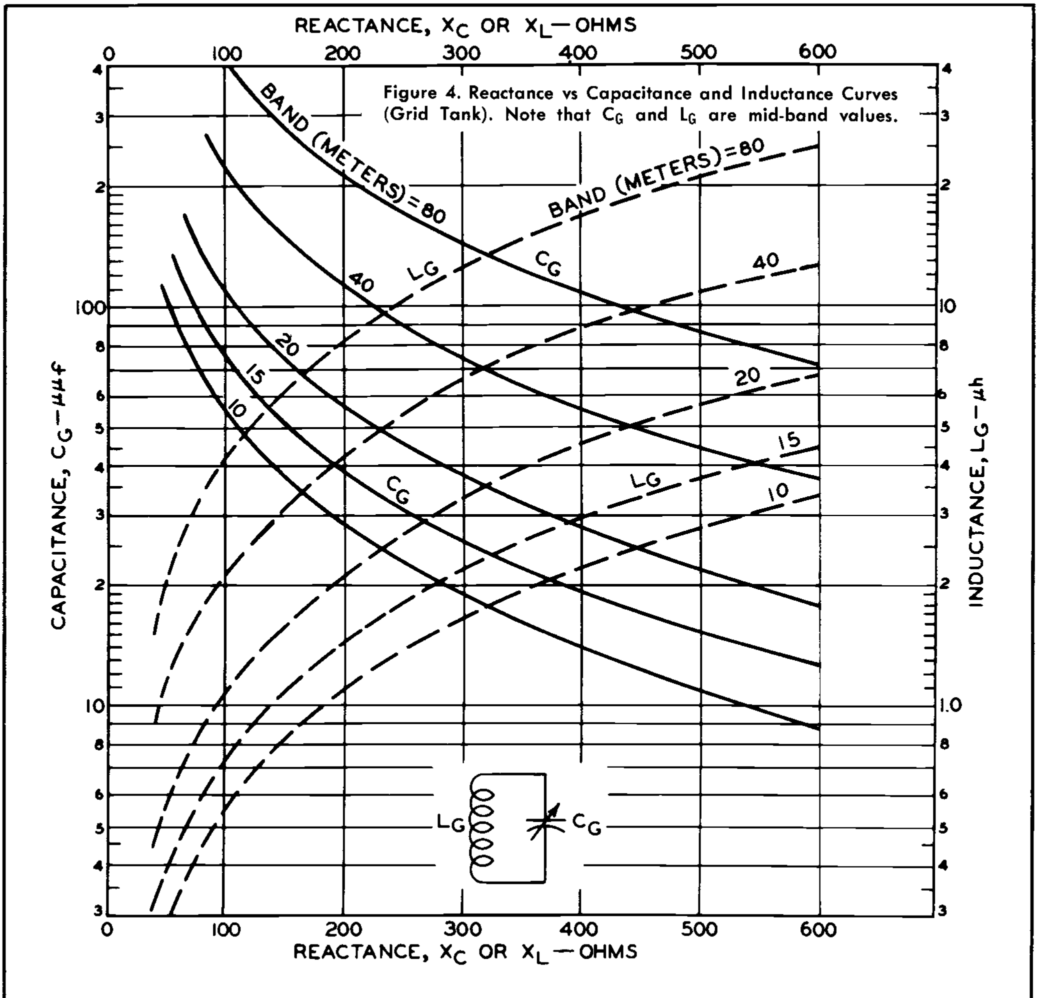


Figure 4. Reactance vs Capacitance and Inductance Curves (Grid Tank). Note that C_G and L_G are mid-band values.

Plate Tank Circuit Considerations

As mentioned in "Tube Selection," the minimum value of the tuning capacitor is an important consideration for operation at the higher frequencies. It is good engineering practice to select a capacitor having the lowest possible minimum capacitance because, whenever circuit constants are such that the tube output capacitance becomes a major consideration, a capacitor of low minimum value will allow more flexibility in the choice of the amplifier tube.

Regarding tuning-capacitor range, calculations show that, for tuning the amateur bands, the maximum percentage change in capacitance from the value at mid-frequency is approximately ±15%. As a safety factor, a tuning capacitor having a minimum tuning range of ±30% should be adequate. Before testing a new amplifier, it is advisable to use a grid-dip oscillator to check the tuning range of each tank circuit with tubes in their sockets but no voltage applied.

Neutralization

Most class-C amplifiers must be neutralized in order to prevent self-oscillation. Triodes always require neutralization when used in the circuits shown in this article, whereas beam power tubes or pentode tube types may

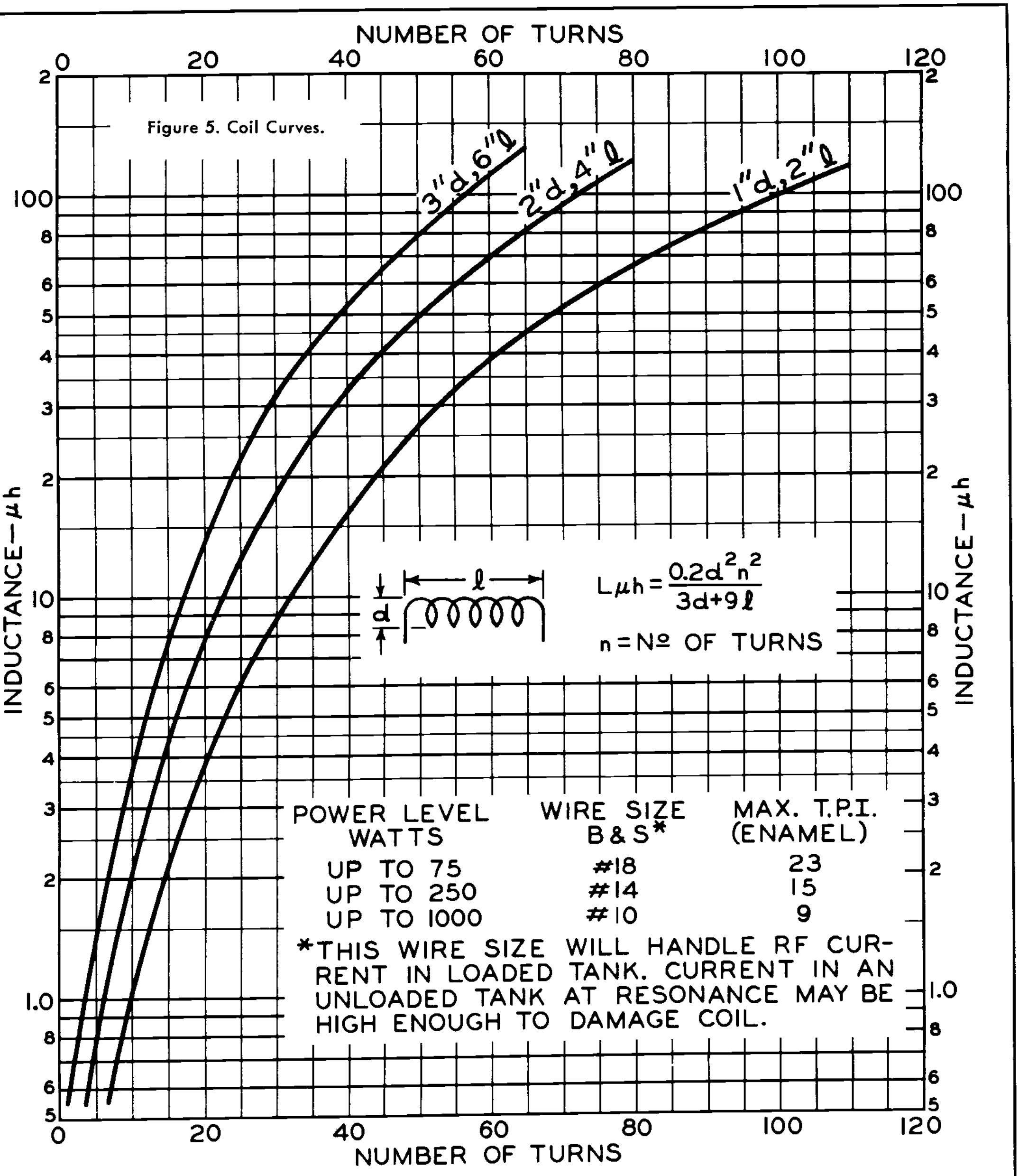


Figure 5. Coil Curves.

$$L_{\mu h} = \frac{0.2d^2n^2}{3d+9\ell}$$

n = № OF TURNS

POWER LEVEL WATTS	WIRE SIZE B&S*	MAX. T.P.I. (ENAMEL)
UP TO 75	#18	23
UP TO 250	#14	15
UP TO 1000	#10	9

*THIS WIRE SIZE WILL HANDLE RF CURRENT IN LOADED TANK. CURRENT IN AN UNLOADED TANK AT RESONANCE MAY BE HIGH ENOUGH TO DAMAGE COIL.

require neutralization or may not.

When input and output circuits of beam power tubes or pentode tube types are effectively isolated and good bypassing is employed, it is generally not necessary to provide for neutralization. However, it is difficult to build such an amplifier and, therefore, many amateurs are confronted with the problem of a self-oscillating amplifier when a new final is tested. Because the inclusion of a small neutralizing capacitor during the building of a new amplifier is a comparatively simple task, the capacitor is a worthwhile addition in view of its contribution to stable operation.

Neutralizing capacitors required for beam power tubes and pentode tube types are usually on the order of ¼ µµf. If it should prove difficult to obtain a neutralizing capacitor of this low value, it is a simple matter to construct your own. The capacitor shown in Figure 7 is variable from about 1 µµf to 0.06 µµf, and will be adequate for most beam power tubes or pentodes. For those wishing to design their own neutralizing capacitor, the equation $A = 4.5\,Cd$ is suitable, where A is the area of one plate in square inches; C is in µµf (approximately twice the grid-No. 1-to-plate capacitance is an appropriate value); and d is the distance between plates in inches (see Figure 8 for minimum spacing).

Figure 6. Miscellaneous circuit-components chart.

CAPACITORS

Value	Minimum DC Working Voltage — Volts		Type
	Telegraphy	AM Telephony	
COUPLING, C_C 0.0001 µf	E_{bb} of driver $+E_{g1}$ of driven stage	E_{bb} of driver $+E_{g1}$ of driven stage	Variable, air; or fixed mica
BYPASS:			
Filament, C_F 0.001—0.01 µf	200	200	Disc ceramic
Grid No. 1, C_{G1} 0.001 µf	E_{g1}	E_{g1}	Disc ceramic
Grid No. 2, C_{G2} 0.001—0.005 µf	E_{g2}	2 x E_{g2}	Disc ceramic
Plate, C_B 0.001 µf	E_{bb}	2 x E_{bb}	Disc ceramic
NEUTRALIZING, C_N 2 x Grid No. 1—plate capacitance (Max.)	2 x E_{bb}	4 x E_{bb}	Variable, air

RF CHOKES

Value	Current-carrying Capacity	Type
GRID 2.5 mh (Approx.)	At least I_{g1}	Any
PLATE 2.5 mh (Approx.)	At least I_p	Any

Figure 7. Small neutralizing capacitor.

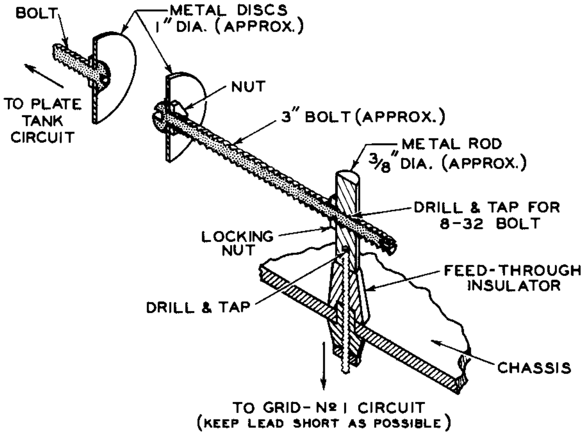
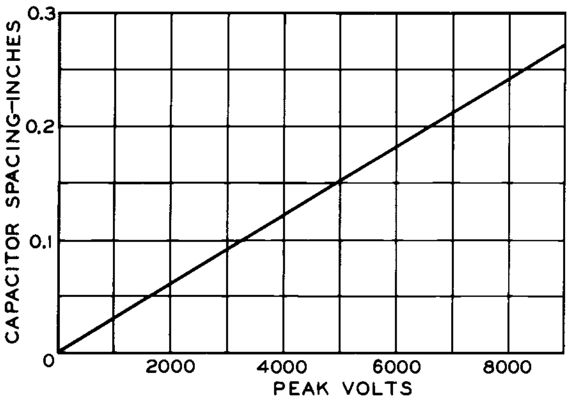


Figure 8. Capacitor-spacing Graph.



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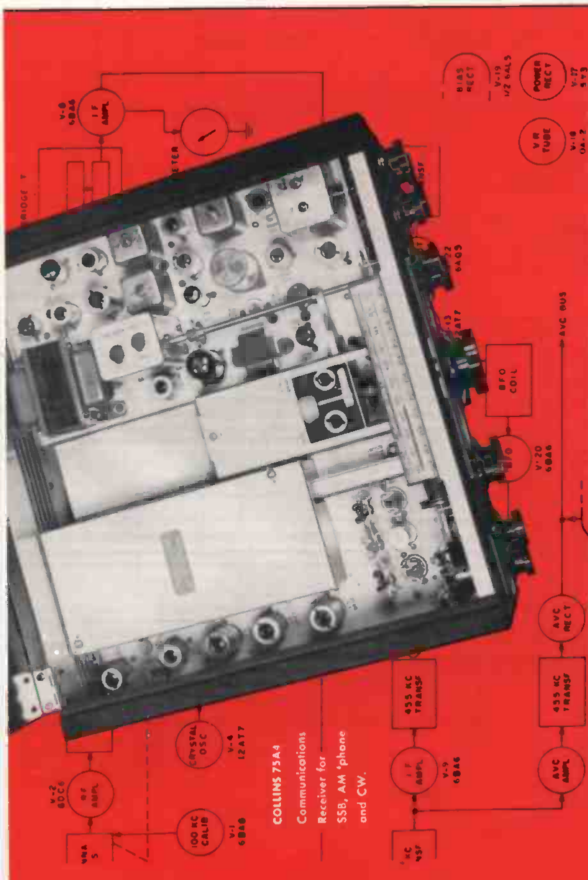

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