SECTION 2

ADVANCED PRACTICAL RADIO ENGINEERING

TECHNICAL ASSIGNMENT

DESIGN FEATURES AND ADJUSTMENTS OF TRANSMITTER CIRCUITS

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DESIGN FEATURES AND ADJUSTMENTS OF TRANSMITTER CIRCUITS

SCOPE OF ASSIGNMENT

This assignment will continue the discussion of Class B and C amplifiers with a study of tank circuits and associated equipment. The Q of the tank circuit is important in determining the "flywheel" effect and hence how pure the output wave is, but it cannot be too large for otherwise the side bands may be unduly attenuated. These matters are therefore discussed at length in this assignment.

Next comes a description of the practical adjustments that have to be made in putting a transmitter into operation. These include the tuning and loading of the tank circuit and neutralizing of the stage; such adjustments check the soundness of the Class-C stage design.

The third item to be discussed is harmonic suppression. The filtering effect of the tank circuit itself is analyzed, and it is shown that the higher the loaded Q of the circuit, the greater is the harmonic suppression. The use of a pi network is analyzed with regard to its filtering action and its impedance matching properties. Then the use of special trap circuits is studied.

The next section has to do with practical examples of tank circuits, in which the application of the foregoing principles are illustrated. No attempt is made to develop the methods by which the various elements of an array are fed, but the components used to feed a single antenna are discussed in detail.

The final section has to do with the design and application of impedance matching units, such as Tee sections. In conjunction with this, practical data on antenna characteristics are presented to enable representative problems to be solved.

TANK CIRCUIT DESIGN

GENERAL CONSIDERATIONS.—The preceding design assumed a tank circuit as shown in Fig. 1. Here Z_T represents the load resistance presented to the tube. This has been designated in other assignments, such as on Audio Amplifiers, by the symbol R_L.

The parallel with Z_T is the tank inductance L_T and the tank capacitance C_T, tuned to the frequency of the incoming signal. Since these are shown as having no losses, they presumably draw no line current, and hence the need for their presence may be questioned by the student.

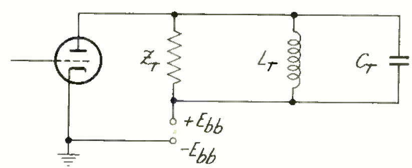


Fig. 1.—Equivalent tank circuit.

However, it must be remembered that they act as a filter, and convert the plate current pulses into sinusoids. More specifically, they act to produce a sine-wave *voltage* of fundamental frequency across Z_T, so that the latter has a sine-wave *current* of fundamental frequency flowing through it instead of a pulse-shaped current.

The actual tank circuit is ordinarily quite different, even though its action is quite similar to the one shown in Fig. 1; indeed, the latter is essentially equivalent to any tank circuit normally employed. However, actual tank circuits perform two important functions not indicated in Fig. 1:

1. They match the impedance and phase angle of the antenna, or the transmission line feeding it, to the load impedance Z_T required by the tube, and

2. They serve to attenuate harmonic components in the current that would otherwise be radiated by the antenna. The circuit in Fig. 1 accomplishes a good deal of attenuation of harmonics by virtue of the filtering action of L_T and C_T; indeed, this is the main reason for their presence in the circuit, but many Class C amplifier circuits use additional components to increase the filtering action.

Often additional circuit elements are employed, such as phasing units. This is the case where several elements of an antenna array have to be fed currents of different magnitudes and phase in order to obtain the desired directional pattern. These elements, however, will not be discussed here, as they will be treated in a later assignment.

HARMONIC DISTORTION.—Suppose a broadcast fundamental frequency of 550 KC is to be radiated. Then the second harmonic is 2 × 550 = 1100 KC, and the third harmonic is 3 × 550 = 1650 KC, or both are in the same broadcast range, and would cause interference with some other broadcast station. (Of course, such harmonics could cause interference with other services even if they were not in the broadcast range, since all parts of the spectrum are being utilized).

Similar considerations apply to the television services. The third harmonic of Channel 2, for example, is 3 × 61.25 mc = 183.75 mc, and is in the middle of the band occupied by Channel 8, which is from 180 to 186 mc. As another example, the second harmonic of Channel 6, (82 - 88 mc), is from 164 - 176 mc, and infringes on the band of Channel 7, which is from 174 to 180 mc. Finally, the second harmonic of Channel 2 is in the range 108 to 120 mc and is just on the fringe of the f-m band, and the second harmonics of f-m stations (88 to 108 mc) are from 176 to 216 mc and can cause trouble in the television channels 7 to 11, inclusive. All this clearly demonstrates the importance of suppressing the radiation of harmonics of the generated wave.

EXAMPLES OF TANK CIRCUITS.—The tank inductance and capacitance, it has been pointed out, act to convert the pulse output of the Class C tube into a sinusoidal current and voltage, and thus in themselves tend to suppress harmonics, as was stated previously. The action is sometimes referred to as a flywheel effect, in that the flywheel of a gas engine, for example, converts the abrupt taps on the pistons from the exploding gas mixture into continuous rotation.

However, the action in the tank circuit can perhaps better be compared to that of the pendulum of a clock, which converts the taps from the escapement wheel into swings to and fro. In this case energy is first stored as kinetic energy in the moving pendulum, then as potential energy at the extremes of the swing. Similarly, the tank capacitor stores the r-f energy during one part of the cycle in electrostatic or potential form, and then this energy is converted into kinetic form ($1/2\ LI^2$) as the capacitor discharges through the tank inductance. The action is exactly analogous to that of a pendulum.

First, however, is to be noted that two methods of d-c feed are employed for tank circuits. Fig. 2 (A) and (B) illustrate what are known as series and shunt feed, respectively. In (A) the d.c. current is fed through a radio-frequency choke coil (RFC) and the tank inductance L_T to the plate of the tube. A by-pass capacitor C_b serves, in conjunction with RFC, to "bottle up" the r-f currents in the stage and to keep them out of the power supply.

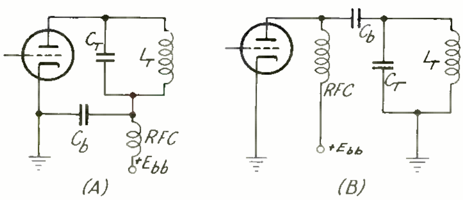


Fig. 2.—Series and shunt feed as employed in Class C tank circuits.

In (B), the r-f choke RFC acts as an r-f shunt across the tank circuit and feeds d.c. directly to the plate, and C_b now acts as a blocking capacitor to keep the d.c. out of the tank circuit, but permit the r-f energy to pass through. Although the series-feed arrangement provides perhaps better filtering of the r-f current from the power supply, the shunt-feed arrangement of (B) in conjunction with C_b keeps the d-c potential off C_T and L_T, so that a cheaper and more compact tank capacitor and inductance can be employed. Moreover, there is no appreciable charge collected on C_T after the equipment is turned off, and this facilitates the servicing of the stage.

TANK CIRCUIT Q AND EFFICIENCY.—In order to provide adequate filtering and Class C performance, the energy stored in L_T and C_T should be several times that expended in Z_T. This is best expressed in terms of the tank circuit Q, as this is a measure of the energy stored to the energy dissipated.

The energy dissipated, however, consists of two parts: that dissipated in the tank circuit losses, and that expended usefully in the load, whether that be an antenna, a dielectric material to be heated, or perhaps the grid driving power of a following stage.

Thus, as is shown in Fig. 3(A), the actual load impedance r_L is coupled into the tank circuit by virtue of the mutual inductance M existing between L_T and the coupling coil L_R. Instead of a load r_L connected to L_R, there may actually be a transmission line connected to L_R and terminated in one way or another by an antenna in its characteristic impedance, which then becomes the resistance r_L seen at the coupling coil end.

However that may be, r_L and the inductance L_R of the coupling coil in series can be reflected as an equivalent reactance in SERIES with L_T. The formula is

$$Z_L = \frac{\omega^2 M^2}{r_L + j\omega L_R} = \frac{\omega^2 M^2 r_L}{r_L^2 + \omega^2 L_R} - j\frac{\omega L_R}{r_L^2 + \omega^2 L_R^2} \qquad (1)$$

after multiplying numerator and denominator by the conjugate $(r_L - j\omega L_R)$ of the denominator. The second form of Z_L shows that Z_L consists of a resistor and *capacitive* reactance in series with L_T. (This was also brought out in an earlier assignment on inductive coupling.) Let the resistive part be denoted by R_L; it is the reflected value of r_L. The capacitive reactance can be regarded as cancelling part of the inductive reactance of the tank coil L_T, thereby throwing the tank coil somewhat out of resonance. This effect is normally small, and easily compensated for by a corresponding small change in C_T. Alternatively a capacitor in the coupling circuit can be used to tune out L_R.

other resistance R_T represents the losses in the tank coil. These are ohmic resistance losses modified by skin effect at the operating frequency. Normally these represent the total losses in the tank circuit; the losses in the tank capacitor C_T are usually negligible, at least at broadcast frequencies.

In passing it is to be noted that $R_L + R_T$ in series with L_T can be replaced with an equivalent resistor paralleling L_T and C_T, as was shown in Fig. 2 by Z_T. At this point in the analysis the circuit shown in Fig. 3(B) is better suited to bring out the two values of tank Q involved.

If no load is coupled into the tank circuit, r_L is infinite, and R_L consequently zero. This leaves only R_T in series with L_T, and the circuit Q is given by

$$Q = \frac{\omega L_T}{R_T} \qquad (2)$$

On the other hand, when the tank circuit is loaded down with R_L, the circuit Q is given by

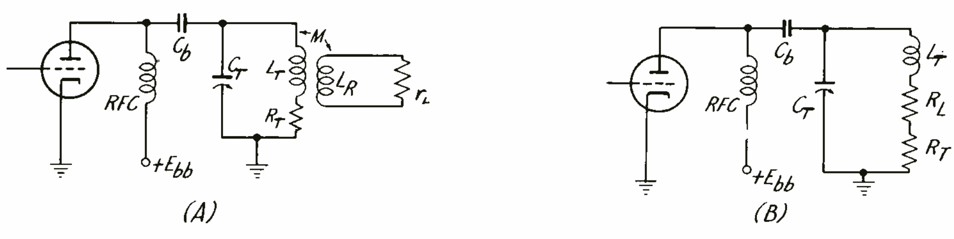


Fig. 3.—Tank circuit coupling and equivalent loaded circuit.

Hence, as shown in Fig. 3(B), the coupled load r_L appears as a resistance R_L in series with L_T, and the coupled-in reactance is absorbed by L_T and C_T and is not shown. The

$$Q_L = \frac{\omega L_T}{R_T + R_L} \qquad (3)$$

and is lower than before. It is quite apparent that the greater R_L

is compared to R_T (or the smaller R_T is compared to R_L), the smaller are the tank losses compared to the useful power delivered to the load, and the more efficient the tank circuit is.

The efficiency of the tank circuit is given by

$$\mathrm{Eff}_T = \frac{Q_T - Q_L}{Q_T} \times 100 \text{ per cent} \quad (4)$$

As an example, suppose L_T = 253.3 μhenries, f = 1000 KC, R_T = 11 ohms, R_L = 100 ohms. Then, from Eqs. (2), (3), and (4),

$$Q_T = \frac{2\pi \times 1000000 \times 253.3 \times 10^{-6}}{11}$$

$$= 144.6$$

$$Q_L = \frac{2\pi \times 1000000 \times 253.3 \times 10^{-6}}{11 \cdot 100}$$

$$= 14.44$$

$$\mathrm{Eff}_T = \frac{144.6 - 14.44}{144.6} \quad 90\%$$

To obtain maximum efficiency, Q_T should be as high as possible (R_T as low as possible), and Q_L should be as low as possible (R_L as high as possible). However, there are economic limits to the magnitude of Q_T, for R_T cannot be reduced indefinitely without the coil becoming inordinately large and expensive. In fact, there is an upper limit to the size of a coil for a given inductance.

There is a lower limit to Q_L. This is that the filtering action for harmonics will be reduced; the impedance to the harmonic current components will be too high. On the other hand, if Q_L is low, it means that the ratio of reactive to active or wattage energy is low. This in turn means that the volt-ampere rating of L_T and C_T will be less, and that these items will be cheaper.

Since a large transmitter is an expensive item, any saving in L_T and C_T is particularly welcome here, and so for very large push-pull Class C amplifiers,* Q_L may be as low as 2 or 3, whereas for ordinary size amplifiers, Q_L is in the neighborhood of 8 or 10.

In designing a Class-C amplifier, Prince and Vodges determined in a paper entitled "Vacuum Tubes as Oscillation Generators," in the General Electric Review in 1929 (pages 35-44), that the ratio of stored to dissipated energy per cycle in a self-controlled oscillator should be 2 in order to obtain stability and a minimum of harmonic output.

They showed that the ratio of stored to dissipated energy per cycle is $E_T I_c / 2\pi P_o$, where E_r is the tank voltage, $[= (E_b - e_{bmin})/\sqrt{2}]$, I_c is the circulating capacitor or tank current, and P_o is the power output (assumed to include the small tank-circuit losses). It can also be readily shown that the Q of the tank circuit when loaded (Q_L) is equal to the ratio of the stored to the dissipated energy, or $Q_L = E_T I_c / P_o$.

Hence, from the rule for oscillators that $E_T I_c / 2\pi P_o = 2$, or $E_T I_c / P_o = Q_L = 4\pi$, we have the simple rule that the loaded Q should be 4π or about 12. For a driven Class C amplifier, a value of 1.5 rather than 2 can be used, so that $Q_L = 3\pi$ or about 9 to 10. This is because the coupling system and even the antenna

*A push-pull amplifier does not have any second-harmonic power in the output, hence less filtering is necessary since the second harmonic is the strongest and lowest frequency harmonic present; hence Q_L can be less.

load has a certain amount of reactance and therefore energy storage, and moreover, harmonic filters can be incorporated without upsetting the behavior of the driven stage at the fundamental frequency, as might happen to a self-oscillator.

There is a further objection to the use of a higher Q_L than 3π besides that of cost, and that is that the tank may become too selective and the side bands may be "clipped" or attenuated. In the case of a-m broadcasting, a $Q_L = 3\pi$ will in practically all cases afford sufficient bandwidth, particularly if the additional damping of the source (tube) is taken into account. In f-m broadcasting a greater sideband width is required, but fortunately the carrier frequency is higher—88 to 108 mc, and hence there is little difficulty in maintaining the necessary Q_L for harmonic attenuation and "flywheel" effect.

It is in television, particularly in the lowest channel (#2) that side band clipping may occur because of the relatively low carrier frequency (61.25 mc) and the large bandwidth of close to 6 mc. It is here that a push-pull stage is of advantage, because as mentioned previously it eliminates the second harmonic and therefore permits a lower Q_L for bandwidth purposes without compromising the attenuation of the third and higher odd harmonics. This assignment, however, will be concerned with audio broadcast transmitters.

COUPLING CIRCUITS.—A large number of coupling circuits have been developed for transferring the energy from the tank circuit to the load (usually an antenna). Fig. 3 showed a very common method, that of inductive coupling. If the reactance, such as L_R, of the coupling circuit be tuned out or else absorbed in the tank circuit, then the value of the mutual inductance M necessary to reflect r_L clear back to the tube as Z_T, the resonant tank-circuit impedance, is given by

$$M = \frac{(L_T - R_T C_T Z_T)\, r_L}{\omega^2 C_T Z_T} \qquad (5)$$

where L_T and C_T are the tank inductance and capacitance, respectively, R_T is the resistance of the tank coil, and ω of course the angular frequency. Note that M is given in terms of the resistance r_L in the coupling circuit and the resistance Z_T presented to the tube rather than the resistance R_L reflected in series with L_T. This is illustrated in Fig. 4.

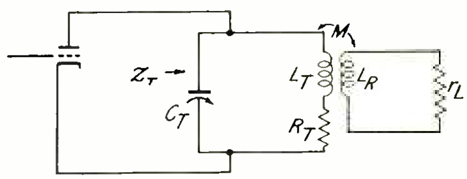


Fig. 4.—Load r_L, in conjunction with coil loss R_T, reflects as a resistance Z_T to the tube.

As an example, take the tank circuit whose efficiency was calculated previously. We had $L_T = 253.3$ μhenries, f = 1000 kc, and $R_T = 11$ ohms. Let $Z_T = 5000$ ohms, and $r_L = 25$ ohms. The value of C_T can be found with sufficient accuracy from the ordinary resonance formula:

$$C_T = \frac{1}{\omega^2 L_T} = \frac{1}{(2\pi\, 10^6)^2\ 253.3 \times 10^{-6}} = 100\ \mu\mu f.$$

Then, from Eq. (5)

$$M = \sqrt{\frac{(253.3\times10^{-6} - 11\times100\times10^{-12}\times5000)\,25}{(2\pi\times10^{6})^{2}\times100\times10^{-12}\times5000}}$$

$$= \sqrt{\frac{(253.3 - 5.5)\times10^{-6}\times25}{4\pi^{2}\times5\times10^{5}}}$$

$$= 17.72\ \mu\text{henries}$$

For design purposes it is not particularly important to include the tank coil losses R_T, so that Eq. (5) can be simplified to

$$M \cong \sqrt{\frac{L_T r_L}{\omega^2 C_T Z_T}} \qquad (6)$$

The value of M calculated from this simpler formula is

$$M = \sqrt{\frac{253.3\times10^{-6}\times25}{(2\pi10^{6})^{2}\ 100\times10^{-12}\times5000}}$$

$$= 17.9\ \mu\text{henries}$$

which is close enough to 17.72 μhenries.

Fig. 5 shows a direct or impedance coupling method that can be employed instead of the inductive coupling method. Actually the coupling is inductive, too, but is an auto-transformer arrangement as compared to the two-winding arrangement shown in Fig. 4.

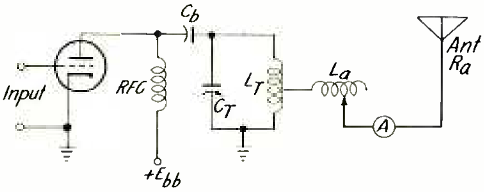


Fig. 5.—Direct (impedance) coupling of an antenna to a tank circuit.

The tapped coil L_a constitutes an adjustable inductance used to tune out any capacitive reactance inherent in the antenna. Particularly in the early days of radio, when the frequency of operation was low, antennas were considerably below one-quarter wave length in height and hence presented a capacitive reactance to the transmitter.

The coupling arrangement shown here is satisfactory so long as the load impedance R_a is not too low. If R_a is very small, M must be small, and this in turn means that the tank coil L_T must be tapped down practically at the bottom turn; lower than this the coupling cannot be decreased. However, very low values for R_a present a particularly difficult problem in any event, mainly because R_a is associated usually with a large amount of capacitive reactance, which in turn requires a large coil L_a whose resistance inherently will tend to exceed R_a.

Fig. 6 shows the direct coupling method employed in conjunction with a push-pull amplifier. Direct d-c feed through the tank coil is shown.

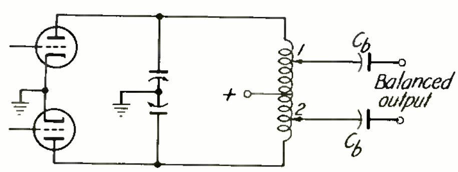


Fig. 6.—Direct coupling to a push-pull stage.

hence the coupling taps 1-2 are connected to the output through capacitors C_b to block the d-c potential.

Although tap 1 or 2 could be moved up to the center point (r-f ground) of the coil, thereby furnishing an unbalanced-to-ground output, it is perhaps preferable to have both taps the same distance on either side of the center point so as to couple equally to both halves of the coil. In this case the output is inherently balanced to ground and therefore suitable for feeding a two-wire line to a load.

TRANSMITTER ADJUSTMENTS

GENERAL CONSIDERATIONS.—Adjusting a transmitter presents problems because the various waveforms cannot be readily observed with an oscilloscope, particularly at f-m and T-V frequencies, and it is not easy to measure, or at any rate to determine quickly how much load impedance is coupled into the tank circuit and thence presented to the tube, and whether or not it is resistive in nature.

Furthermore, as was seen in the discussion of Class C amplifier design, there are many variables involved, such as grid bias, grid swing, plate voltage, etc., and these all have profound effects upon the operation of the stage. Hence care must be exercised in adjusting a transmitter, and a thorough knowledge of its operation is indispensible in enabling the operator to interpret from the meter readings just what is going on in the circuits.

TUNING PROCEDURE.—If the Class C stage is very much out of adjustment, then dangerously high currents will flow and considerable damage to the tube and other components can occur, or else the circuit breakers will open and shut down the stage. In the process of setting the stage into operation, therefore, it is necessary to start with a low value of r-f grid excitation, say about 50% of normal, in order that a moderate amount of both grid and plate currents flow even if the stage is grossly out of adjustment. Also, for safety purposes, the plate supply voltage should be reduced to about 25% of its normal value.

Furthermore, no load should be initially coupled into the tank circuit. This has two advantages:

1. The tank impedance will be much higher, and hence the plate-current pulses will be smaller. This means less d-c current drawn by the stage, and hence indirectly less plate dissipation.

2. The unloaded tank has the higher Q denoted previously by Q_T, on the order of 100-150, instead of the loaded value of Q_L, on the order of 10 or thereabouts. This means that resonance will be sharper and therefore more precise, although resonance is admittedly sharp for a Q of 10. On the other hand, the grid current is higher for the unloaded tank than it is for the loaded tank.

If the tank circuit is initially out of tune, then its impedance will be low and either predominantly inductive or capacitive, depending upon in which direction it is mistuned. Such a tank circuit will draw a large fundamental component, and hence a large peak current, and this also means that it will draw a large d-c component from the plate power supply. The latter fact will be noted very readily by the d-c ammeter in series with the plate supply.

As the tank is tuned to resonance at the grid excitation frequency, the plate current will drop, and it will be at a minimum at resonance. Hence minimum I_b indicates resonance, and the d-c plate meter is a simple and satisfactory device to be used for tuning the tank circuit.

The grid circuit can also be adjusted for resonance. Here, as the tuned driver circuit is brought into resonance, the voltage E_g applied to the grid increases, (see Fig. 7), and the grid draws more current from the cathode. This in turn is reflected in an increased reading of the d-c grid meter, indicating a higher d-c grid current. In order that the latter be not excessive, it is desirable to have plate voltage applied, as stated previously, so that the plate will divert space current to itself and thus keep the grid current down.

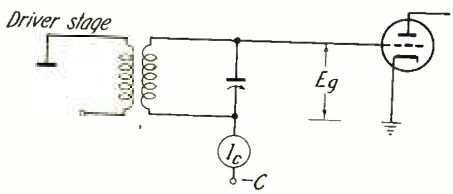


Fig. 7.—Conditions in the tuned grid circuit.

In connection with this, note that the d-c grid meter can also be used indirectly as a check on resonance of the tank circuit. When the tank circuit is resonant, I_b is a minimum, and also $e_{b\,min}$ has its smallest value because of the increased r-f voltage drop in the tank circuit. When $e_{b\,min}$ is low, more of the space current is diverted to the grid, as can be checked from the positive grid curves for any tube in the Tube Manual.

As a result of this, I_c increases somewhat as resonance is approached, so that tank circuit resonance is indicated both by an increase in the d-c grid meter reading as well as a decrease in the d-c plate meter reading. However, if the stage is not properly neutralized, the maximum and minimum readings may not coincide; this will be discussed subsequently.

LOADING THE TRANSMITTER.—Load can now be applied to the transmitter stage. First, since the tank circuit has been resonated, E_{bb} can be increased to its normal value. I_b should increase, and I_c should decrease, since the plate is diverting more of the space current to itself.

Loading is accomplished by increasing the coupling of the load circuit to the tank circuit. Where a two-winding transformer is involved, as in Fig. 3(A), the coupling (and M) are increased by rotating L_R so as to enable it to link more of the flux of L_T. Where taps are employed, as in Figs. 5 and 6, loading is accomplished by moving the taps closer to the plate end of the tank coil.

In the case of Fig. 6, the two taps should be moved *equally* toward the respective plate ends of the tank coil in order to maintain balanced loading. This will be further indicated, if separate plate meters are used in the push-pull stage, by equal d-c current readings. Another check can be obtained by inserting an r-f meter in series with each tap to see if equal readings are obtained.

If the stage under adjustment is a driver stage feeding the grid or grids of a succeeding stage, then the proper amount of loading can also be told by the d-c grid-current reading of the following stage. Where push-pull grids are involved, the adjustment must aim for equal grid-current readings.

Where the actual load is an antenna, which exhibits marked reactance characteristics, it is advisable to employ a dummy load as indicated by dotted lines in Fig. 8. However, the final full power adjustments will probably have to be made using the antenna, especially in a large installation, since a dummy load of sufficient power dissipation may not be available.

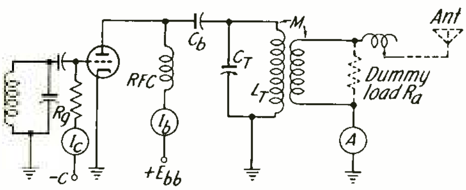


Fig. 8.—Test set up for adjusting a Class-C stage, showing connection of a dummy load, or alternatively, the antenna.

As load is coupled in, the impedance Z_T presented to the plate of the tube decreases from a very high value (owing solely to the tank coil losses) down to the value specified by the manufacturer or calculated on paper. The d-c plate current I_b rises and the d-c grid current I_c drops. If the grid excitation is still maintained at a low value as during the tuning procedure, the two currents should be less than the rated values.

As load is coupled into the tank circuit, the tank coil reactance may be reduced in accordance with Eq. (1), and hence detuning may occur. A slight adjustment of the tank capacitor C_T may therefore be necessary to bring the circuit back to resonance, and this can be told as before by I_b being a minimum and I_c a maximum while C_T is varied and the coupling adjustment temporarily held fixed.

If the loaded tank Q is very low, maximum impedance does not occur at unity power factor. In this case the tank circuit is tuned for maximum power into the load (as indicated by a maximum reading on r-f ammeter A), rather than by minimum I_b and I_c.

The grid excitation is now increased, and I_c, I_b, and I_L, (the load current as measured on the r-f ammeter, A, of Fig. 8), all go up. Loading now consists in juggling the excitation voltage and coupling of the load into the tank circuit until the r-f meter indicates that the power output $I_L^2R_a$, the d-c plate current I_b, and the d-c grid current I_c are at approximately their rated values.

Slight adjustments of the tuning control may also be necessary from time to time. The main object is to get the rated power output with the rated d-c plate current I_b, hence the rated power input, plate efficiency, and plate dissipation, without the d-c grid current I_c being excessive.

Suppose the power output is calculated to be the rated value, but the plate current is low and the grid current is too high. This indicates that the tank impedance Z_T is still too high, but that by excessive grid excitation sufficient plate current flows to furnish enough fundamental component to yield the desired power output. Yet the plate current is not up to the rated value since if Z_T is high, I_p and also I_b can be less and still furnish rated output.

The remedy is to increase the coupling of the load to the tank circuit, and thereby lower Z_T. Now I_b and I_L will increase and I_c will decrease. An increase in I_L means more than rated power output, hence the excitation should now be decreased. This will reduce I_b, I_L, and I_c; by proper adjustment of the coupling and excitation or grid drive, the rated values for all three can be obtained. In connection with this the plate dissipation should be watched as well as I_c, to see that neither is excessive so that neither the grid nor plate electrodes are damaged.

Where bias is obtained solely or in large part from a grid-leak resistance, the procedure begins with the calculated value of grid-leak resistance, and the preceding sequence followed. There is now another variable to take into account, namely the grid bias. This is calculated from the known d-c grid current I_c and grid-leak resistance R_g ($E_c = I_c R_g$), and if it is not the specified or calculated value, R_g is altered correspondingly and the adjustments repeated. Ultimately after a series of trials the proper values for I_b, I_c, I_L, and plate and grid dissipations can be obtained.

NEUTRALIZATION.—The theory of neutralization has been covered elsewhere, hence only the procedure for neutralizing a Class-C stage will be described here. Assume for convenience a specific form of stage, such as that shown in Fig. 9. A neutralizing coil L_N is closely coupled to the tank coil L_T, so that at least over a narrow range of frequencies about resonance, the voltage induced in L is practically 180° out of phase with that in L_T.

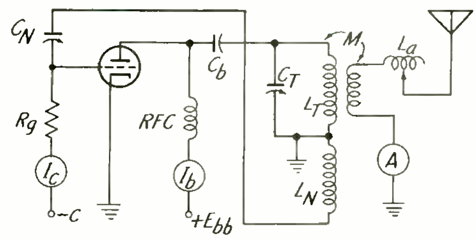


Fig. 9.—Class-C stage showing neutralizing circuit components.

The voltage induced in L_N is applied through the neutralizing capacitor C_N to the grid of the tube. It acts to oppose the r-f feedback voltage applied to the grid from the plate via the plate-to-grid capacity (not shown). By adjusting C_N to the proper value, neutralization is accomplished, and the stage is free of feedback. As a result it is stable and not prone to oscillate in spite of the presence of tuned circuits both in the grid and plate circuits.

To neutralize this stage, first tune it as described above and then disconnect the plate supply, thus removing E_b. The filament, however, is energized. Normal grid excitation is then applied, and a neutralizing indicator is coupled to the tank circuit. The neutralizing capacitor C_N is adjusted for zero indication of the neutralizing indicator.

The latter can be of various forms: a neon bulb, a single-turn loop connected to a flashlight or dial lamp, or a low-reading r-f galvanometer, which may be temporarily substituted for the normal r-f ammeter A in Fig. 9. Still more sensitive indicators that may be used are a communications receiver, or a tuned signal tracer of the type commonly employed in radio and television servicing.

If the neutralization is correct, no variation in I_c will be noted when C_T is tuned through resonance. If this is attained, E_{bb} may then be applied, and I_b and I_c noted carefully as C_T is again tuned through resonance by a small amount. If maximum I_c occurs at exactly the same point as minimum I_b, the circuit is satisfactorily neutralized.

SUMMARY OF TUNING PROCEDURE.—Refer to Fig. 9. It is assumed that the filament is on, all stages including the one under consideration are neutralized, and the preceding stages have been tuned. Proceed as follows:

1. With no E_{bb}, apply about half normal excitation.
2. Apply about 25 per cent E_{bb}, and tune C_T for maximum dip of the plate current meter.
3. Increase E_{bb} to about three-quarters normal value, and retune C_T if necessary.
4. Increase M by whatever form of adjustment is provided for this purpose, and simultaneously adjust L_a for maximum antenna current as indicated on the r-f ammeter A.
5. Increase E_{bb}, E_g (the excitation), M, and adjust L_a until I_c, I_b, and the power output are as calculated or specified by the manufacturer.

SIDE BAND DISTORTION.—It was brought out previously that the tuned behavior of a tank circuit tended to discriminate against the sidebands produced by the higher modulation frequencies because these side bands were farther away from the carrier in frequency. This is minimized by keeping the tank circuit Q down to 10 or less; in this range of Q there is little if any sideband "cutting" or attenuation even at 10 kc audio frequencies or higher in the standard broadcast band. In large transmitters, where the Q may be as low as 2, sideband cutting is particularly slight.

There is a rule usually employed for band width which relates the Q of the circuit to the fractional bandwidth $\Delta f/f$ as follows:

$$\Delta f/f_c = 1/Q \qquad (7)$$

where, as illustrated in Fig. 10, f_c is the resonant frequency at which, say, maximum tank voltage E_T occurs, and f_L and f_h are the extreme lower and upper sideband frequencies at which the tank voltage drops to $1/\sqrt{2} = 0.707E_T$, and $f_h - f_L = \Delta f$ is the bandwidth by arbitrary definition. At f_h and f_L the power drops to one-half its value at f_c (half-power points).

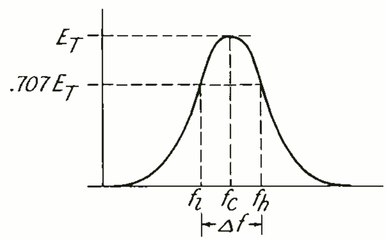


Fig. 10.—Relation between bandwidth, center frequency, and half-power points.

From Eq. (7) it follows that as Q is increased, Δf decreases for a given value of f_c. Hence it would appear relatively simple to determine the value of Q required to cause the power to drop to any small fraction of its carrier value at the extremes of the given audio bandwidth when the value of Q for a 50 percent power drop is given by Eq. (7).

There is, however, one hitch to this, and that is that the Q of Eq. (7) refers to the ratio of the reactance of either C_T or L_T relative to the TOTAL shunt resistance. The total shunt resistance involves not only the load resistance, reflected to the tube as Z_T, BUT ALSO THE TUBE RESISTANCE R_b IN SHUNT WITH Z_T.

In other words, the source or generator internal resistance as well as the load resistance are involved, and therein lies the complication. The tube resistance R_b is not the ordinary plate resistance R_p, but involves R_p and also the angle of flow θ_p. This is because the tube conducts for only a portion of the r-f cycle, and is an open circuit for the remainder of the cycle. The average resistance is therefore higher than R_p, which is the plate resistance for Class A operation, when the tube conducts over the entire cycle.

Everitt* gives the following relationship between R_b and R_p:

$$R_b = \beta R_p = \frac{\pi R_p}{\theta_p - \sin\theta_p \cos\theta_p} \qquad (8)$$

Note that R_p refers to the value for positive or peak grid voltages, where it is usually much lower than for negative grid biases used in Class A operation. This tends to compensate for the factor β, but the point is that R_b is not readily determined, and is a function of θ_p and hence of the tube potentials and load impedance.

For this reason no attempt will be made to determine the optimum value of Q so far as sideband cutting is concerned, so long as such cutting is not appreciable. This is generally the case, and the values of Q recommended previously are generally satisfactory so far as bandwidth is concerned.

As a matter of interest, the circuit shown in Fig. 11 was set up in the CREI laboratory. A type 801 tube, operating at 2 mc, was employed, and the applied frequency was varied from 200 kc below to 200 kc above the resonant frequency of 2 mc in 25 kc steps.

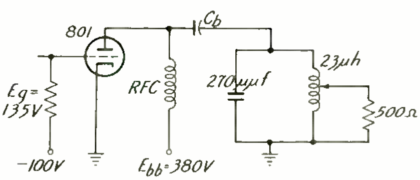


Fig. 11.—Experimental Class-C amplifier setup to measure sideband cutting.

A Boonton Q meter was used to measure the tank Q under unloaded conditions; its value was found to be 170. The tank impedance Z_T was found to be 2500 ohms. This was determined by inserting a resistance of 767 ohms (measured on a General Radio r-f bridge) in series with the tank and measuring the voltage across the tank alone and across it and the resistor. The ratio of the voltage gave the value of Z_T, and the loaded tank, exclusive of the tube, was found to be 8.62 when a dummy load

*Communication Engineering, p. 568.

resistor of 500 ohms was connected as shown.

As the grid excitation was varied, the tank voltage E_T varied as shown in Fig. 12. From the bandwidth determined by the half-power points, namely 384 kc, the Q was found to be 5.2 (= Q_{Lb}) or with the tube in the circuit as compared to 8.62 for the loaded tank (= Q_L). This reduction is due to R_b, which can then be calculated, since Z_T = 2500 ohms, and the two Q's are known. Thus,

$$R_b = \frac{Q_{Lb}\ Z_T}{Q_L - Q_{Lb}} \qquad (9)$$

or

$$R_b = \frac{5.2 \times 2500}{8.62 - 5.2} = 3,810 \text{ ohms}$$

This compares with the value of 4300 ohms for Class-A operation as given by the manufacturer, but it must be remembered that a much lower R_p for positive grid potentials is involved in determining R_b.

An important thing to note from Fig. 12 is that for a range of frequencies ± 50 kc from the 2-mc carrier value, the tank voltage does not appreciably vary, and over the normal +10 kc audio range, the variation is insignificant. Since the operating values for the 801 tube were typical, one may conclude that normally no concern need be felt concerning sideband cutting.

In connection with this it may be pointed out that the Q encountered in actual practice involves that of the antenna, which is not a pure resistance, and the associated transmission line. The reactances in these components, as well as phasing and matching networks, represent additional energy storage and hence an increase in the Q of the tank circuit as compared to a load resistance Z_T connected directly across the tank circuit.

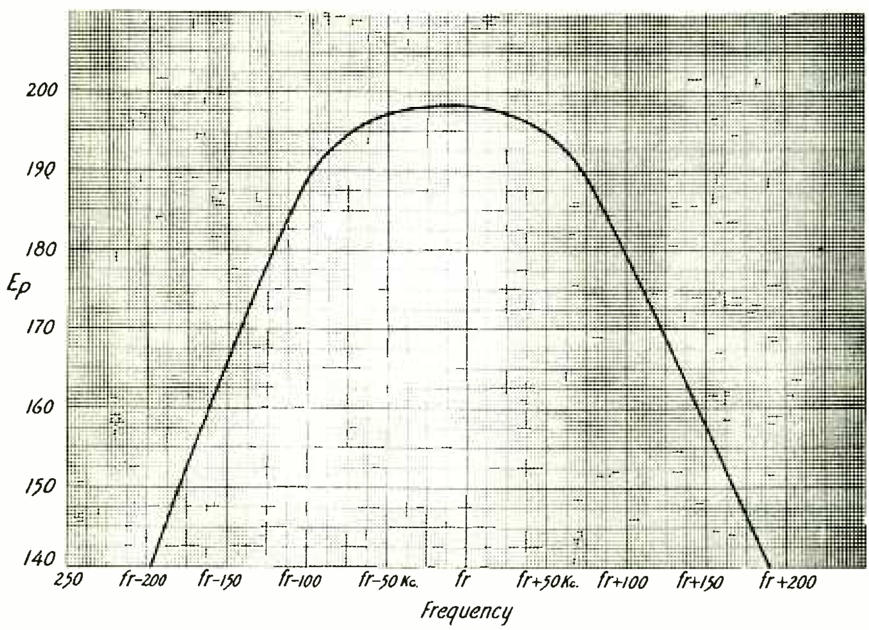


Fig. 12.—The overall selectivity curve of the test circuit of Fig. 31.

However, even in this case no serious sideband cutting over the audio band is encountered. The antenna itself has a Q of 6 or less, although this depends upon its radiation resistance and hence upon its height. For all except perhaps the shortest antennas, such as those used in mobile installations at relatively low frequencies, the Q is sufficiently low so that even in conjunction with a moderate length of transmission line, it does not raise the overall Q to too high a figure. Since the calculation of such an overall Q would be very involved, it is fortunate that this factor is not an appreciable limitation to the operation of the system.

TANK CIRCUIT DESIGN.—In designing a tank circuit, one must first assume or have given certain initial values. From the Class-C amplifier design, Z_T, the resistance presented to the plate of the tube by the tank circuit, has been calculated. Also, from the same design, the tank voltage $E_T = (E_b - e_{bmin})$ is known, as is also the frequency f.

One then chooses Q_L, the loaded tank Q, in accordance with the considerations presented previously. This information is sufficient, although a further point is to determine the tank losses. This will then give Q_T, the unloaded Q, and then the tank-circuit efficiency can be calculated. Or alternatively, the tank-circuit efficiency can be chosen, Q_T then calculated, and the tank coil losses (resistance) then determined.

The following formulas give the values of the tank circuit constants in terms of the factors assumed above (see Fig. 13).

The tank capacity:

$$C_T = Q_L/(2\pi f Z_T) \qquad (10)$$

The tank coil inductance:

$$L_T = Z_T/(2\pi f Q_L) \qquad (11)$$

The total resistance in series with L_T:

$$R = R_T + R_L = L_T/C_T Z_T \qquad (12)$$

Reflected load resistance:

$$R_L = L_T\left(\frac{1}{C_T Z_T} - \frac{\omega}{Q_T}\right) \qquad (13)$$

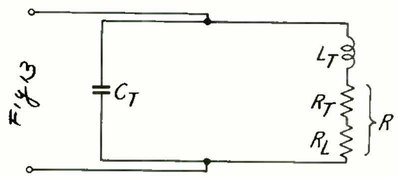


Fig. 13.—Factors involved in tank circuit.

As an example of the application of these formulas, suppose f = 1.5 mc, and a Type 826 tube is employed. Let E_b = 1250 volts, E_c = -125 volts, and Z_T = 2540 ohms. Assume Q_L = 10, and an efficiency of 90%.

From Eq. (4), Q_T may be solved in terms of the efficiency and Q_L:

$$Q_T = Q_L/(1 - \text{Eff.}) \qquad (14)$$

Then

$$Q_T = 10(1 - .90) = 10/0.1 = 100$$

From Eqs. (10), (11), (12), and (13):

$$C_T = 10/2\pi \times 1.5 \times 10^6 \times 2540$$

$$= 417\ \mu\mu f.$$

$$L_T = 2540/2 \times 1.5 \times 10^6 \times 10$$

$$= 27\ \mu h.$$

$$R = 27 \times 10^{-6}/417 \times 10^{-12} \times 2540$$

$$= 25.9 \text{ ohms.}$$

$$R_L = 27 \times 10^{-6} \left(\frac{1}{417 \times 10^{-12} \times 2540} - \frac{2\pi \times 1.5 \times 10^6}{100} \right) = 23.4 \text{ ohms.}$$

In the case of a push-pull circuit, the two tubes may be regarded as essentially in series, and the value of Z_T calculated for Class-C operation of either tube alone must be doubled. This in turn means that for the same loaded tank Q, namely Q_L, the tank coil inductance L_T must be doubled, and the tank capacitance C_T must be *halved*. (Note that $2L_T$ and $C_T/2$ resonate to the same frequency as L_T and C_T.)

The reader may question this on the basis that each tube, looking into half of the tank coil, sees $1/4\ L_T$ instead of $1/2\ L_T$, as it should in order to operate under the same conditions as when it is operating by itself. The answer to this is that owing to the presence of the other tube, it sees $1/2\ L_T$ and not $1/4\ L_T$, because the other tube helps furnish half of the inductive volt-amperes. Thus, although normally half the turns gives one-quarter the inductance, in the presence of another generator (tube) connected across the other half of the coil, half the turns gives half the inductance.

As a result, each tube of the push-pull pair faces a load and tank Q exactly the same as if it were operating by itself. The power output is doubled; corresponding to this one requires twice as great an inductance, and half the capacitance, BUT ITS R-F VOLTAGE RATING MUST BE DOUBLED. This can be obtained by using TWO tank capacitors and connecting them in SERIES.

It is thus apparent that the tank circuit requirements, so far as volt-ampere ratings are concerned, are equal to those for two tubes in parallel (and double those for one tube alone). The only difference between push-pull and parallel operation is that in parallel operation C_T must be doubled (two C_T's in parallel), Z_T must be halved, and L_T must be halved, BUT MUST THEN BE CAPABLE OF CARRYING TWICE AS MUCH CIRCULATING CURRENT.

HARMONIC SUPPRESSION

PRELIMINARY CONSIDERATIONS.—At the International Telecommunications Conference in Atlantic City in 1947, it was agreed that between 10 and 30,000 kc the power of a harmonic or a parasitic emission supplied to an antenna must be at least 40 db below the power of the fundamental. In no case shall it exceed 200 milliwatts, mean power. This, of course, was to prevent a high-powered station from producing noticeable interference to a weak station operating at say twice the frequency.

Fundamentally, the harmonic problem begins with the Class-C amplifier. The distorted plate-current pulse is the source of the harmonic current; hence the amplitude of the latter depends upon the distortion and therefore the angle of flow θ_p.

Ordinarily the second and third harmonics are the only ones having appreciable amplitude and therefore requiring attention. For that reason, the ratio of either to the fundamental current, or I_{pn}/I_p (where n is the order of the harmonic and equals either 2 or 3 in the figure) has been plotted versus the angle of flow θ_p in Fig. 14.

Note that these ratios represent their values in the plate-current pulse. The tank circuit thereupon filters out the harmonics, so that their ratios to the fundamental in the antenna circuit are much less. It will be of interest to calculate this filtering action.

In Fig. 15 are shown the tank circuit impedances and the tank currents. In (A) the fundamental current I_p is shown. The capacitive reactance is X_{CT}, and a leading current I_c flows through it. The inductive reactance is X_{LT}, and a lagging current I_L flows through it. For tuned conditions, $I_c = I_L$, since $X_{CT} = X_{LT} = X$, their common value at resonance.

In (B) are shown the relations for the n^{th} harmonic. The capacitive reactance is $1/n^{th}$ of X_{CT}, or X_{CT}/n.

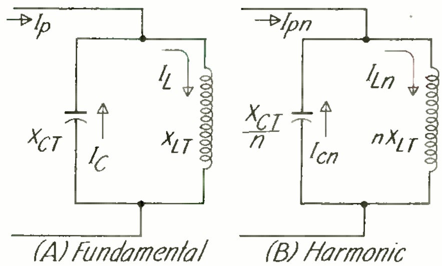


Fig. 15.—Impedance and current relations in a tank circuit for the fundamental and the n^{th} harmonic.

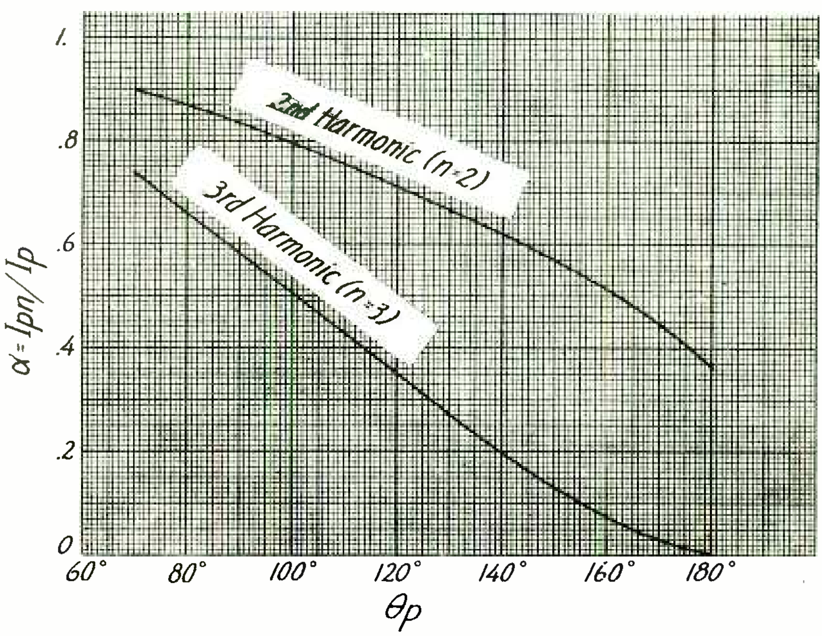


Fig. 14.—The relative amplitude of the 2nd and 3rd harmonic components pulse as a function of θ_p.

If n = 2 (second harmonic), then the capacitive reactance is one-half of its value at the fundamental frequency, since the capacitive reactance varies inversely as the frequency. On the other hand, the inductive reactance goes up to nX_{LT} or n times its fundamental value.

This means that I_{cn} is not equal to I_{Ln}, as is the case for the fundamental components; instead I_{cn} is increased to n times the value it would have if the tank were tuned to n times the fundamental frequency, and I_{Ln} is reduced to $1/n^{th}$ the value it would have at resonance, so that $I_{cn} = n^2 I_{Ln}$.

At harmonic frequencies the tank circuit (tuned to the fundamental) is so far away from resonance that its reactances predominate, and its resistances can be ignored. Hence the impedance Z_{Tn} of the tank circuit is X_{CT}/n and nX_{LT} in parallel, or

$$Z_{Tn} = \frac{(-jX_{CT}/n)(jnX_{LT})}{-jX_{CT}/n + jnX_{LT}} = \frac{nX}{n^2-1} \qquad (15)$$

We can now find the relation between the harmonic amplitude of the line current, I_{pn}, and the amplitude of the inductive component I_{Ln}, which current is assumed to flow in the reflected load. The ratio of these will indicate the attenuation produced by the tank to the n^{th} component.

The ratio of a branch to a main or line current is in INVERSE proportion to the impedances they face. From Eq. (15), the harmonic line current I_{pn} faces the impedance $nX/(n^2-1)$. The harmonic component in the inductive branch faces the impedance nX. Hence

$$\frac{I_{Ln}}{I_{pn}} = \frac{nX}{n^2 - 1} \cdot \frac{1}{nX} = \frac{1}{n^2 - 1} \qquad (16)$$

Thus, for the second harmonic (n = 2), $I_{Ln}/I_{pn} = 1/(2^2 - 1) = 1/3$. Suppose the angle of flow is 130°. Then from Fig. 13 $I_{pn}/I_p = 0.668$, and in the inductive branch this is further cut down so that $I_{Ln} = 1/3 \times 0.668\ I_p = 0.223\ I_p$. In words, the second-harmonic current through the inductive branch is 0.223 of the fundamental line current I_p if the angle of flow is 130°.

However, there is still a further effect that must be taken into account, and that is the Q of the tank circuit at the fundamental frequency. This in effect multiplies the fundamental line current I_p to Q times that value of I_L, that is $I_L = Q_L I_p$, where Q_L as before is the loaded Q of the tank circuit.

Since the inductive currents should be compared, we have

$$\frac{I_{Ln}}{I_L} = \frac{\alpha}{Q(n^2-1)} \qquad (17)$$

where α is the ratio of I_{pn} to I_p as obtained from Fig. 14. If Q = 10, the ratio of harmonic to fundamental load current for $\theta_p = 130°$ becomes 0.223/10 = 0.0223. The power ratio is the square of this, and in db. Eq. (17) becomes

$$DB = 20 \log \frac{I_{Ln}}{I_L} = -20 \log I_L/I_{Ln}$$

$$= -20 \log Q(n^2-1)/\alpha \qquad (18)$$

In the example just given,

$$DB = -20 \log 1/.0223 = -20 \log 44.8$$

$$= (-20)(1.6513) = 33.0 \text{ db.}$$

Note that this is 7db short of meeting the standards set by the 1947 conference, so that further filtering is necessary.

For the third harmonic,

$$\frac{I_{L3}}{I_L} = \frac{.28}{10(9-1)} = 0.0035$$

$$DB = -20 \log 1/.0035 = -20 \log 286$$

$$= -20(2.4564) = -49.1 \text{ db}$$

which is clearly greater than the 40 db limit. Normally harmonics above the third have negligible output and may be disregarded.

It should also be noted in passing that the amplitude of any harmonic becomes greater, the smaller the angle of flow, since the plate current pulse becomes more distorted. For example, Fig. 14 shows that if $\theta_p = 70°$ (a value admittedly too low) $\alpha = 0.9$, or the amplitude of the second harmonic is initially 90% of that of the fundamental.

PUSH-PULL OPERATION.—The push-pull amplifier has a very important advantage as regards harmonic suppression. Since it inherently balances out all even order harmonics, it inherently reduces the worst offender, the second harmonic, to a very low value without any need for high-Q tank circuits or other filters.

The disadvantage, of course, is that two tubes are required for a given power output instead of a single larger tube, but where the power output requirements fall squarely on the combined ratings of two tubes, and an available single tube might be of such design as to require a much higher plate-supply voltage, the use of two tubes is justified.

So far as the amount of suppression produced by a push-pull stage is concerned, this is a difficult matter to determine. If the tubes were perfectly matched, and the circuit components (each half) were matched as well, the even-harmonic outputs would be all zero. However, owing to unavoidable unbalances in the tubes and circuit, some second harmonic current is found to be present.

In audio work, the output transformer is designed to operate satisfactorily if the tubes are unbalanced no more than 5%. In Class C work, individual grid bias adjustments permit the unbalance to be kept perhaps within the same limits. This means that the net fundamental component responsible for the unbalance is 5% or 1/20 of the fundamental current of either tube, and that the unbalanced power is $(1/20)^2 = 1/400$ of the power output of either tube, or 1/800 of the power output of the stage.

This corresponds to an initial suppression of -10 log 800 = 29 db, which approaches the 40 db limit. Since this is further increased by the factors involved in Eq.(18), it can be seen that second harmonic disturbances should normally be of no concern, and only the third harmonic need probably be checked in the design of the stage.

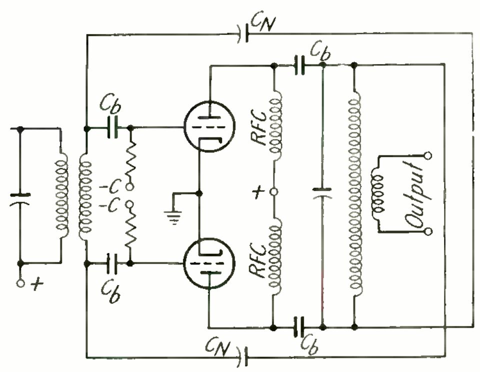


Fig. 16.—Push-pull Class-C amplifier stage, showing use of two neutralizing capacitors.

One further advantage of push-pull operation is its ease of neutralization. This is illustrated in Fig. 16. Since each a-c plate voltage is 180° out of phase with that of the other, each serves as a source of neutralizing voltage for the other tube's grid. Hence no additional coil is required to couple to the tank coil; by cross-connecting the neutralizing capacitors C_N as shown, neutralization is obtained.

PI TANK CIRCUIT.—A simple modification of the ordinary L-C network provides increased harmonic suppression, as well as a measure of impedance matching. Reference is made to the pi-type tank circuit, also known as the Collins coupler. This is illustrated in Fig. 17. In (A) is shown the pi network as normally drawn: C_T, L_T, and C_π form the three impedances arranged in the form of the Greek letter pi (π).

Normally R_L is a low resistance, such as the 50 ohms characteristic impedance of a coaxial transmission line, and Z_T is desired to be on the order of several thousand ohms to "match" the tube. Hence C_π is relatively large, and its effect on the resonance of the circuit is therefore relatively small.

This is better seen from the alternative representation of Fig. 17(B). Here it is evident that if C_π is large and its capacitive reactance therefore low, it will subtract very little from the inductive reactance of L_T. This means that approximately L_T and C_T resonate by themselves to the driver frequency.

It is also clear from this figure that since R_L appears in series with L_T, the circuit is very much like the ordinary tank circuit, the only modification being that C_π is present here to shunt R_L.

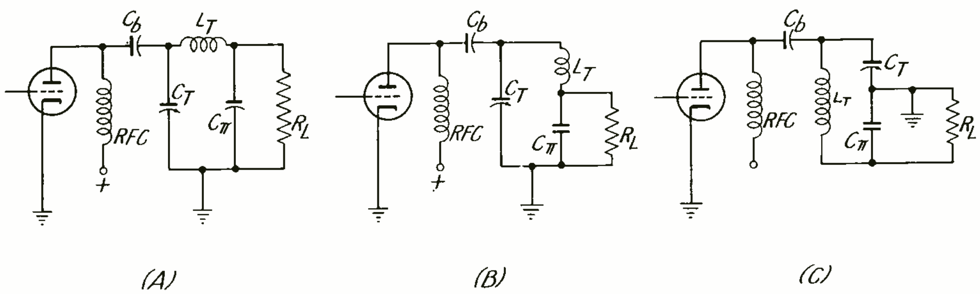


Fig. 17.—Pi tank circuit, drawn in three different forms.

By suitable choice of C_T, L_T, and C_π, an impedance, such as resistance R_L, can be made to appear as a higher impedance Z_T presented to the tube (shunting C_T). The appropriate formulas will be given farther on, but it may be noted here that C_π must be greater than C_T to make a lower resistance R_L appear as a higher resistance Z_T.

It is also clear from this figure (B), how harmonic suppression is improved. In the previous analysis for the ordinary tank circuit, the suppression came about from the fact that the harmonics encountered a low impedance to ground in the path containing C_T, and a high impedance in the path containing L_T and R_L, so that much less harmonic current flowed in R_L compared to fundamental current.

In the pi tank circuit, further suppression comes about in that any harmonic current that forces its way through L_T, is bypassed by C_π around R_L, so that even less gets into R_L than in the case of the ordinary tank circuit not having C_π.

The representation in Fig. 17(C) is a third way of drawing the pi network, and is shown so that the reader will recognize it as such if he sees it elsewhere. However, it does not reveal the action of the circuit as clearly as (A) and (B) do.

PI-TANK FORMULAS.—The following formulas apply to the pi tank circuit, but curves will be furnished to facilitate the actual design of

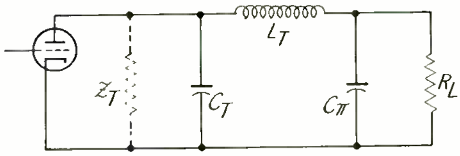


Fig. 18.—Pi tank circuit. R_L is the actual load resistance, which is reflected by the pi network to the tube as Z_T.

this type of circuit. The values of reactance rather than the actual inductance or capacity are given, but the latter can readily be calculated since the frequency is known.

$$X_{CT} = Z_T/Q_L \qquad (19)$$

$$X_{C\pi} = R_L \sqrt{\frac{Z_T/R_L}{Q_L^2 + 1 - \frac{R_L}{Z_T}}} \qquad (20)$$

$$X_{LT} = \frac{Q_L Z_T + \frac{Z_T R_L}{X_{C\pi}}}{Q_L^2 + 1} \qquad (21)$$

where $X_{LT} = 2\pi f L_T$, $X_{CT} = 1/2\pi f C_T$, and $X_{C\pi} = 1/2\pi f C_\pi$. As before, Q_L, the loaded Q of the tank circuit, is chosen anywhere from 2 (for very large push-pull stages), to 10 or perhaps even 20, in the case of an oscillator.

Figs. 19, 20, and 21 represent suitable plots of Eqs. (19), (20), and (21), and Fig. 22 enables the suppression of the second harmonic to be determined. As an example of its use, suppose Z_T = 2540 ohms, f = 1.5 mc, and Q_L = 10. Also let R_L = 50 ohms. In Fig. 19, follow the ordinate representing 2540 ohms up to the line designated by Q = 10, then go across to the left, and read off the X_{CT} ordinate the value 255 ohms. Then

$$C_T = \frac{1}{2\pi f X_{T1}} = \frac{1}{2\pi \times 1.5 \times 10^6 \times 255}$$

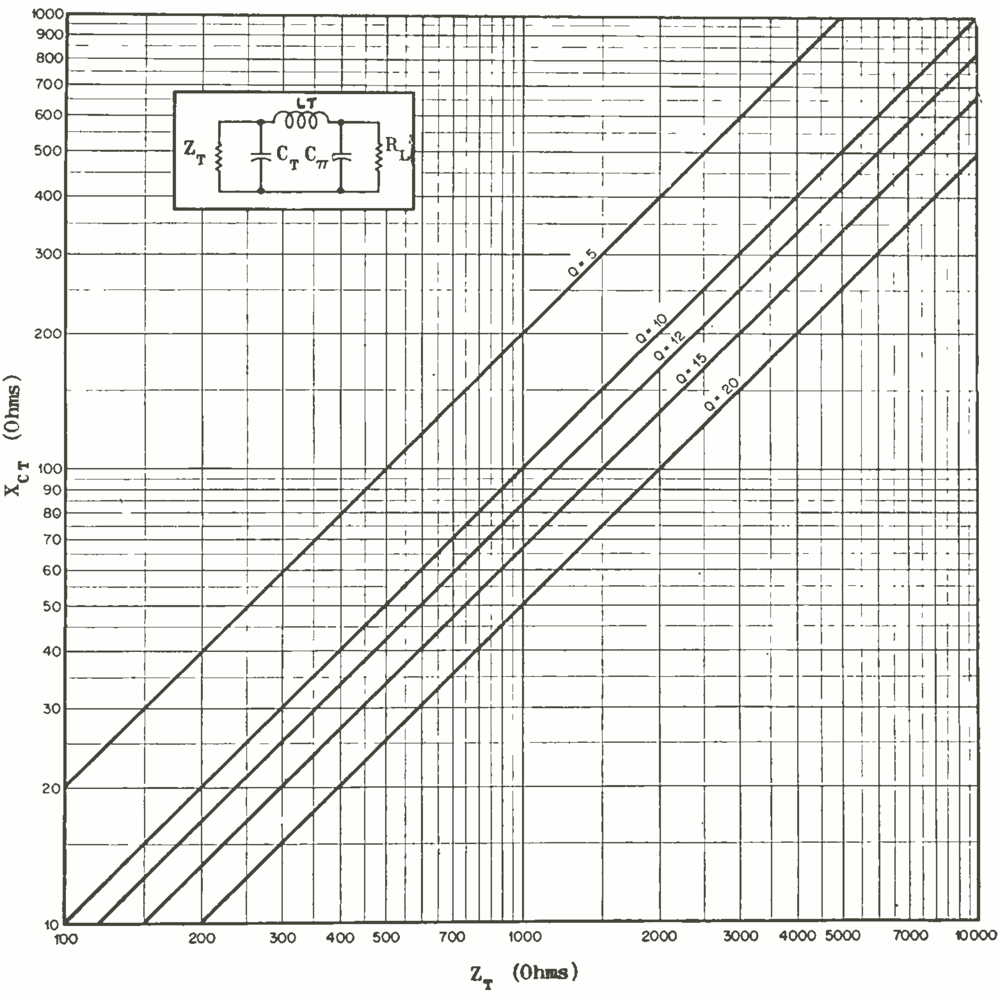
$$= 417\ \mu\mu f.$$

Next calculate the ratio R_L/Z_T. This is 50/2540 = 0.01969. Now refer to Fig. 20. Proceed up the ordinate corresponding to 0.01969 (practically 0.02) until the Q = 10 curve is reached. Now go across to the left, and obtain X_{LT}/Z_T = 0.109. Hence X_{LT} = 2540 ×.109 = 277 ohms, from which

$$L_T = 277/2\pi \times 1.5 \times 10^6$$

$$= 29.4\ \mu\text{henries}$$

To find $X_{C\pi}$, use Fig. 21. Follow the ordinate corresponding to 0.01969 up to the Q = 10 curve, then across to $X_{C\pi}/Z_T$ = .02. Hence $X_{C\pi}$ = 2540 × .02 = 50.8 ohms, from which C_π = 1/2π × 1.5 × 10^6 × 50.8 = 2100 μμf.

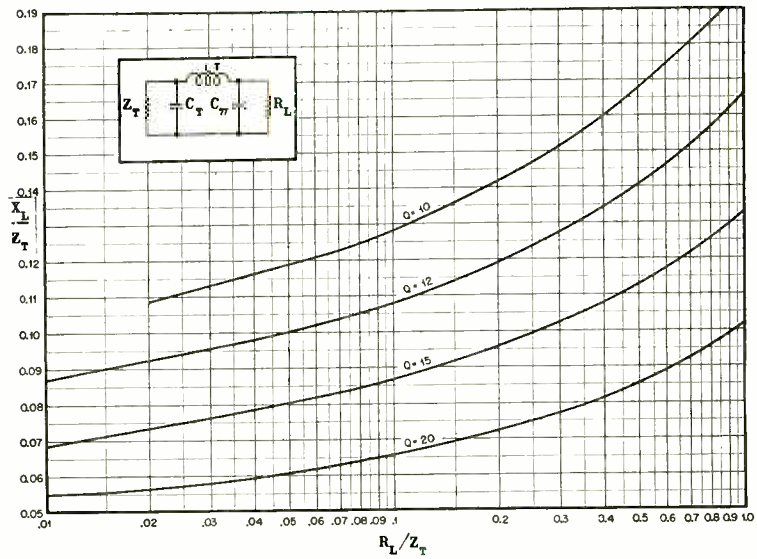


(Courtesy CQ)

Fig. 19.—Relation between input impedance and near-end shunt capacitance for a pi tank circuit.

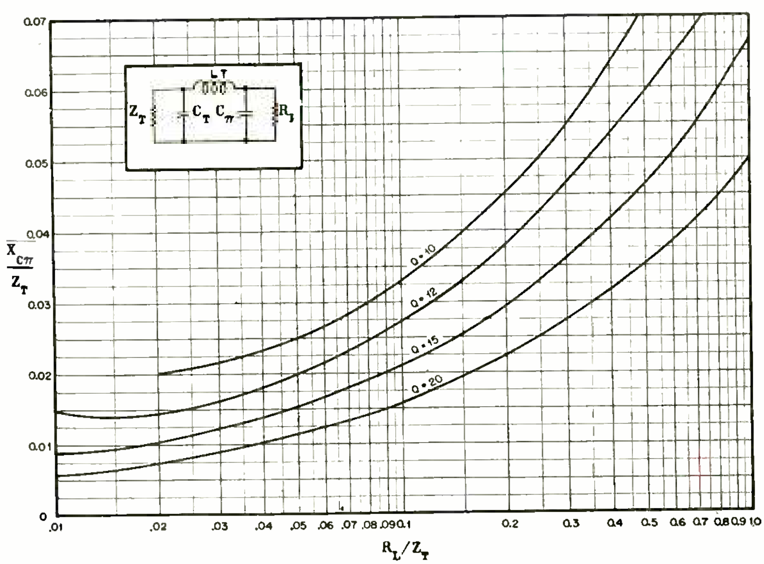
Now find the second harmonic distortion from Fig. 22. Use the same value of R_L/Z_T as before, namely 0.01969, and locate the corresponding ordinate. Proceed up to the Q = 10 curve, then go across and find that the second harmonic distortion is 34 db. down or below its level at the input. To this is to be added the amount by which the second harmonic is below the fundamental at the plate of the tube, for a given θ_p. This, it will be recalled, is found from Fig. 14. The value of α and Q_L gives the db attenuation as

$$db = -20 \log \frac{Q_L}{\alpha} \qquad (22)$$



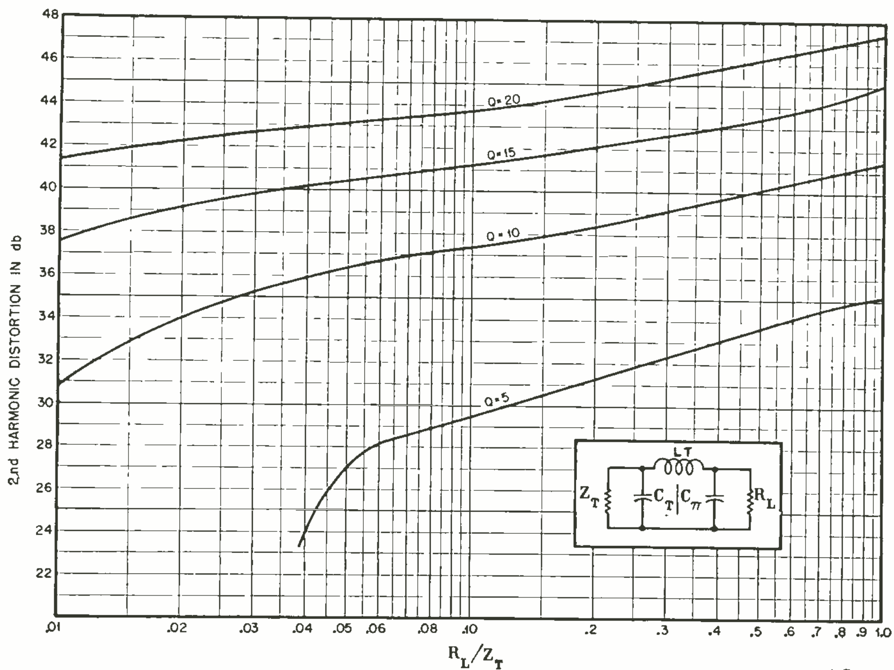
(Courtesy CQ)

Fig. 20.—Relation between impedance ratio R_L/X_T and ratio X_{LT}/X_T for a pi-tank network.



(Courtesy CQ)

Fig. 21.—Relation between impedance ratio R_L/Z_T and ratio $X_{C\pi}/Z_T$ for a pi-tank network.



(Courtesy CQ)

Fig. 22.—Db second harmonic distortion plotted against impedance ratio R_L/Z_T for a pi tank network.

The total attenuation is then this plus that found from Fig. 22. For example, if $\theta_p = 130°$, $\alpha = 0.223$, and if $Q_L = 10$, $Q_L/\alpha = 10/0.223 = 44.8$, and from Eq. (22)

$$\text{db} = -20 \log 448 = -(20)(1.6513)$$

$$= -33 \text{ db}.$$

The total attenuation is therefore -33 - 34 = -67 db, which is more than sufficient.

The third harmonic will be 12 db down on the second, or 79 db down on the fundamental, and the fourth harmonic will be found to be 20 db down on the second, or 87 db down on the fundamental. As stated previously, if the second-harmonic attenuation is sufficiently great, the attenuation of the higher harmonics will be more than ample.

PI TANK ADJUSTMENTS.—The pi tank is quite easy to adjust. To tune, C_π is turned to a maximum (minimum reactance), and then C_T is turned until resonance is obtained, as is indicated by a minimum value for I_b. With C_π at a maximum, the load R_L is shunted out by it to a maximum degree, so that the loading on the tube is at a minimum (Z_T very high).

To make the tube take on load, C_π is now decreased. R_L now reflects as a lower value of Z_T to the tube, and the latter starts to draw current (I_b increases). Some further small readjustment will have to be made to C_T to maintain resonance.

There is a limit to the ratio of R_L/Z_T that the pi network can match. The minimum value of R_L that the pi tank can possibly transform to give a desired value of Z_T is slightly greater than Z_T/Q_L^2. For example, if Z_T = 2540 ohms, and Q_L = 10, the minimum R that can be matched is 2540/100 = 25.4 ohms.

If it is attempted to use a smaller value of R_L, it will be found that to increase the load on the tube, C_π must be INCREASED rather than decreased. Nevertheless, the pi tank affords a sufficient impedance range for most practical applications, and employs the fewest number of circuit elements for a maximum of harmonic attenuation.

It is not, however, as satisfactory as an ordinary tank circuit for the suppression of sub-harmonics; i.e., frequencies equal to one-half, or one-third, etc., of the driver frequency. For that reason it is not suitable to be driven by a doubler stage, since the subharmonic frequency that has been doubled by such a stage is still present in appreciable amounts in the output, and would be further accentuated by the pi network stage.

HARMONIC TRAPS.—Where harmonic suppression has to be very great, as in a high-power low-Q installation, or where occasionally a given harmonic of a transmitter causes interference with another station operating at or close to that harmonic frequency, special means must be taken to reduce this harmonic to the required degree. Often this is a "custom" problem to be handled by the consulting engineer for the station.

This is usually a cut-and-try process, because the trap circuit or circuits employed for the purpose may resonate with the antenna load at the harmonic frequency and enhance rather than decrease the interference. Fig. 23 shows some of the schemes employed.

In (A) a parallel resonant filter circuit composed of L_F and C_F are in series with the Class-C tube and its pi tank circuit. L_F and C_F are resonant at the harmonic frequency, whereas they act as a low

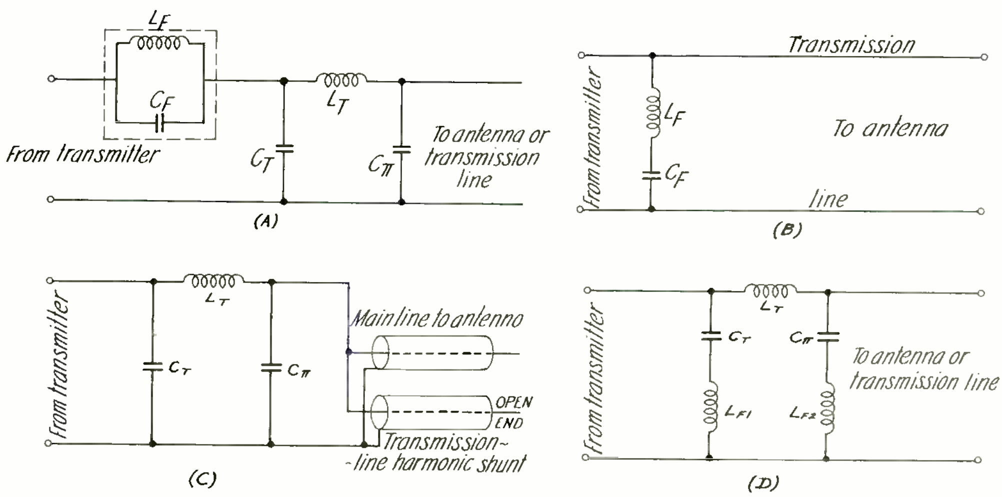


Fig. 23.—Four different kinds of harmonic traps used for suppression purposes.

impedance at the fundamental frequency. The harmonic is thus blocked from entering the tank circuit; then C_π of the tank circuit produces further filtering.

In (B), a series circuit $L_F C_F$ resonant at the harmonic frequency is shunted across the line and acts as a short circuit to the harmonic and thus prevents it from entering the antenna. A similar series resonant shunt is employed in (C), but here the resonant circuit is a transmission-line section that is a quarter wave in length at the harmonic frequency. Such a section, when open-circuited at the far end, acts like a short circuit at its near end, and thus short circuits the main line to the antenna at the harmonic frequency. Note that it also shorts-circuits the supply line at ODD multiples of the given harmonic frequencies; that is, at frequencies where its wave length is $3\lambda/4$, $5\lambda/4$, etc. For example, if it is cut to be $\lambda/4$ at the second-harmonic frequency and therefore to act as a short circuit at this frequency, it will also act as a short circuit at the $3 \times 2 = 6^{th}$ harmonic, tenth harmonic, 14^{th} harmonic, etc. Usually, however, the attenuation is ample at these higher frequencies without the use of this filter.

A quarter-wave section is rather bulky at low frequencies, but has a relatively high Q and therefore makes a very effective shunt at the harmonic frequency. It is particularly useful at high frequencies where lumped inductances and capacitances are difficult to build in the small values required. The Q is also much higher than that of a lumped circuit.

In (D) are shown modifications to a pi tank circuit that make it more effective as a harmonic filter. The capacitive reactances X_{CT} and $X_{C\pi}$ required in Eqs. (19) and (20) need not be just capacitances; instead they can be a series combination of L_{F1} and C_T and C_π and L_{F2} such that for each pair the *net* reactance at the fundamental frequency is the value required by the tank.

At the same time, values can be found for these such that each pair SIMULTANEOUSLY resonates at the harmonic frequency. The two pairs therefore act as the short-circuiting elements shown in (B) and (C). Note, however, that there is no saving in circuit elements; in (A) and (B) an extra capacitance and inductance are required; in (D) two extra inductances are required.

In passing, it may be noted that the values for L_{F1} (or L_{F2}) and C_T and C_π are given in terms of the angular fundamental and harmonic frequencies ω_f and ω_h, respectively, and the reactances X_{CT} or $X_{C\pi}$, respectively, as follows:

$$\left.\begin{aligned} L_{F1} &= X_{CT}\left(\frac{\omega_f}{\omega_h^2 - \omega_f^2}\right) \\ C_T &= \left(\frac{1}{X_{CT}}\right)\left(\frac{\omega_h^2 - \omega_f^2}{\omega_f \omega_h^2}\right) \\ L_{F2} &= X_{C\pi}\left(\frac{\omega_f}{\omega_h^2 - \omega_f^2}\right) \\ C_\pi &= \left(\frac{1}{X_{C\pi}}\right)\left(\frac{\omega_h^2 - \omega_f^2}{\omega_f \omega_h^2}\right) \end{aligned}\right\} \quad (21)$$

PRACTICAL EXAMPLES OF CLASS-C AMPLIFIERS

THE GE BT-22-A TRANSMITTER.— Fig. 24 shows a photograph of a

General Electric Type BT-22-A transmitter. Its modern styling conceals the many circuits and components required in such a unit. It consists of three main sections which contain respectively the exciter modulator, power amplifier, and rectifier-control units, all forming a unified assembly mounted within a cabinet finished in two-tone blue smooth-surfaced baked enamel with an opalescent pattern effect. The trim is brushed stainless steel.

Air cooling is used throughout. It is supplied from a central blower system and directed to the modulator and power amplifier tubes by means of ducts. Filters of the cleanable metallic type are provided for removal of dust from the cooling air, and in cold weather the exhaust air can be used to heat the transmitter building.

Tubes are visible through windows in the front panel, and centralized supervisory lights indicate the status of the control circuits, as well as the exact circuit in which an overload or other trouble arises. Each audio and r-f tube is individually metered, and all necessary tuning, neutralizing, and bias controls are brought out to the front panel for convenient adjustment with power supplied.

High-speed overload relays protect all high-power circuits; other circuits are protected by circuit-breaker-type automatic-trip switches, so that there is no need for fuses. Instantaneous change from 5 kw to 1 kw output is obtained by operating a switch on the front panel. On the other hand, by adding a second power amplifier in a space provided, and installing larger modulation and

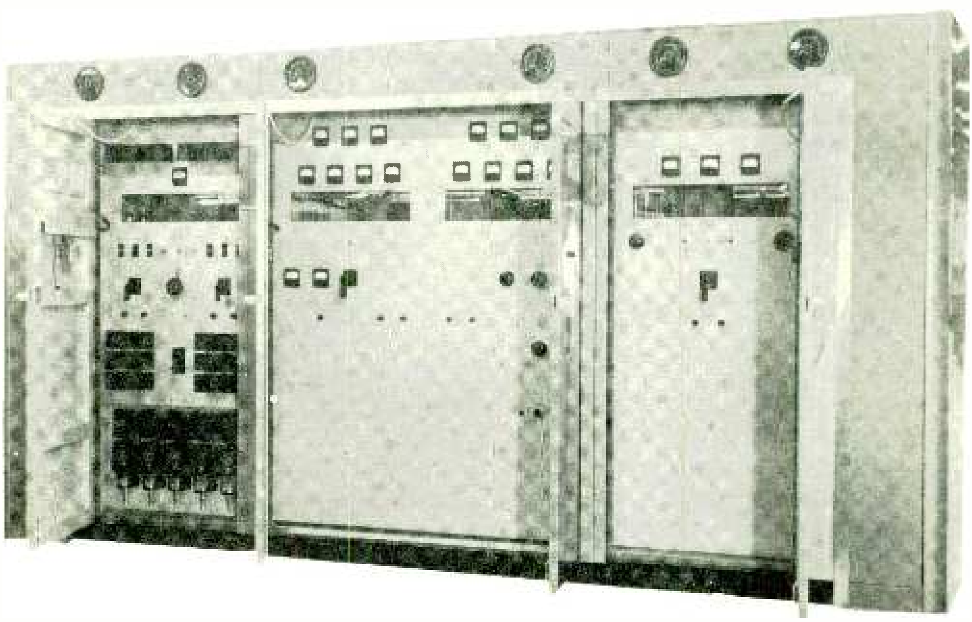


Fig. 24.—The GE Type BT-22-A 5 KW AM broadcast transmitter.

rectifier plate transformers, conversion to 10-kw operation is easily obtained.

A very important and new feature for transmitters of this size is the arrangement whereby the high-power tubes may be simply and quickly switched in or out of the operating circuits in the event of tube failure. Thus, spare tubes may be quickly switched into the circuit and normal operation continued, saving valuable program time. Yet the filaments of the spare tubes do not have to be on all the time because high-reactance current-limiting transformers allow the filaments to reach operating temperature quickly and safely when switched into the circuit.

Fig. 25 shows the circuit employed in the final amplifier stage. It will be observed that a pi tank circuit is used, in which L_T is fixed, and C_T and C_π are variable for tuning and loading the transmitter. The pi tank feeds an antenna or transmission line through the adjustable inductance L_A.

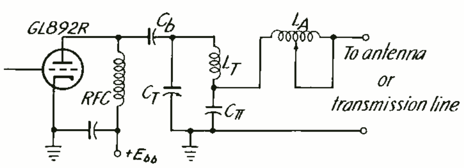


Fig. 25.—Circuit diagram of the final stage, showing the pi tank circuit and the antenna reactor.

The specific function of L_A is to tune out any net capacitive reactance of the antenna or transmission line. It is true that the transmission line should be terminated in its characteristic impedance to eliminate standing-wave losses, and therefore should appear as a pure resistance at its input end. In case, however, the impedance is somewhat capacitive, L_A can be used to tune it out.

If the transmission line presents an inductive reactance to the tank, then it in conjunction with the proper amount of L_A and part of C_π will act as an "L" network to produce a pure resistance of different magnitude to the rest of C_π. The latter than, in conjunction with L_T and C_T, transforms it into the desired value of Z_T to present to the tube.

THE RCA BTA5F TRANSMITTER.—In Fig. 26 is shown the RCA BTA5F 5 kw A-M transmitter final output stage. Here C_T and C_π are fixed in the pi-tank network, and L_T is adjustable. As can be seen from the figure, it is made up of three adjustable inductors in order to provide sufficient fineness of control in tuning.

Observe also L_a, the inductance employed either to tune out antenna capacitive reactance, or more usually to tune out any net capacitive reactance of the transmission line owing to inability to match it perfectly at its far end. An additional element is the Tee matching network preceding the antenna. It is for the purpose of matching the antenna to the characteristic impedance of the line and also cancelling out any reactance of the antenna.

The circuit detail designated "For open-wire line" is for the purpose of enabling a balanced-to-ground open-wire line to be connected into this inherently unbalanced-to-ground system. Since it involves transmission-line theory, it will not be further discussed at this point. In the case of a coaxial cable, which is inherently unbalanced to ground, the inner conductor is connected in series between L_a and L_1, and the sheath is simply grounded.

and other components are accessible from the front.

The transmitter, composed of four main sections can have cabinet extensions added to either or both ends for phasing, monitoring, test, and audio equipment. A desk-type

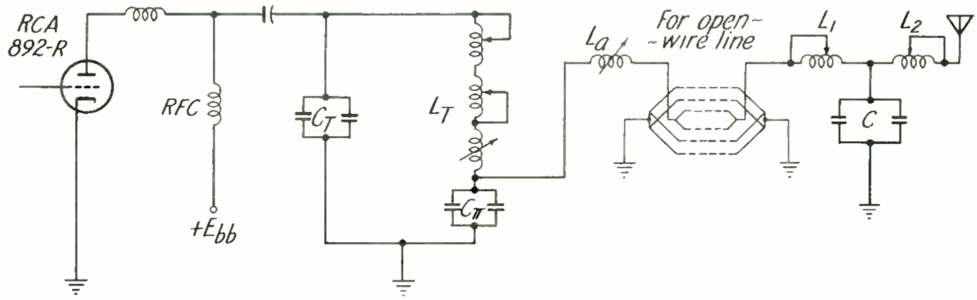


Fig. 26.—Circuit diagram of the Class C output stage of an RCA BTA5F 5 kw A-M transmitter.

As is clear from the diagram, it is composed of the fixed shunt element C (two capacitors in parallel), and the two variable series inductors, L_1 and L_2. By varying these in the manner to be described in the next section, the antenna impedance can be made resistive and matched to the characteristic impedance of the line. It is to be appreciated that this network can also be used with the G.E. or other transmitter.

Fig. 27 shows an inside view of the transmitter. The bottom compartments have solid metal covers, but the upper compartments have doors that are composed of vertical aluminum slats that slide to the left much in the same manner as the wooden slats of a roll-top desk. Similar doors are used in the rear, and thus no clearance is required as for swinging doors. All controls, tubes,

control console is also provided with the transmitter and provides all mixing and switching facilities for normal operation.

The output stage uses a single RCA 892-R tube operated Class C, as is indicated in Fig. 26, but the latter diagram does not indicate (for the sake of clarity) the fact that the stage is plate-modulated by two 892-R audio tubes operating Class B. The use of the same tube in the modulator and r-f stages makes for tube economy; only 24 tubes total are used, and these consist of but six different types.

The use of variable inductors throughout instead of variable capacitors is claimed to result in more trouble-free operation in that there are no air capacitors to collect dust, bugs, lint and other foreign particles that may cause a flashover. Motor-driven tuning of

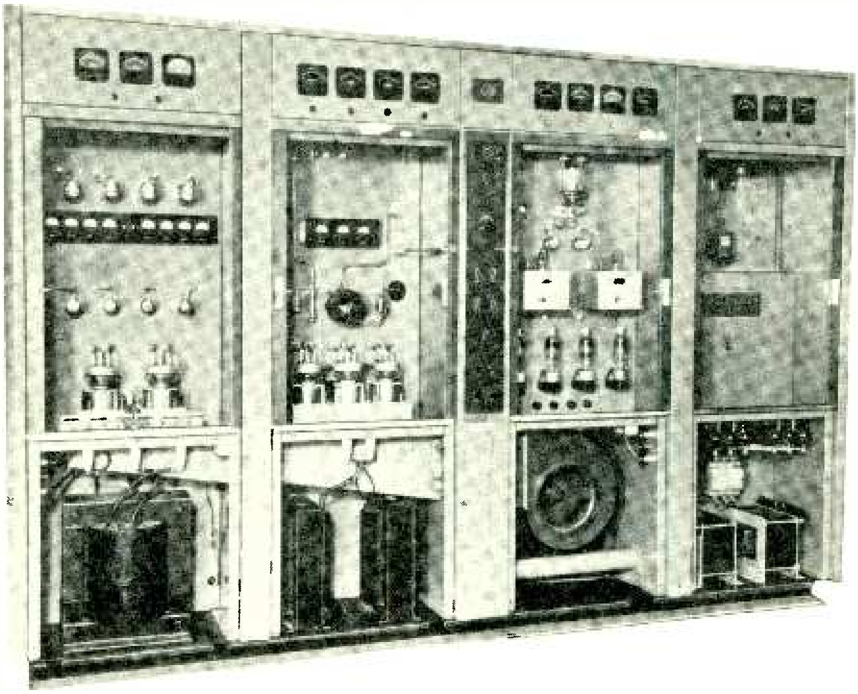


Fig. 27.—The RCA BTA-5F 5 kw A-M transmitter, showing the components comprising the transmitter.

the driver plate tank and output tank inductances is controlled by push button switches on the front panel, and variable adjustment of the load coupling is also provided.

Two crystal oscillators employing 807 tubes are used, and these can be instantly switched by a selector relay operated by a push button located on the transmitter front panel. They are followed by an 828 tube in a buffer stage, which then feeds two 810 tubes in parallel acting as a driver stage.

AUXILIARY EQUIPMENT

ANTENNA MATCHING NETWORKS.—These networks can be of the L, Tee, or Pi configuration, and can serve for three purposes:

1. To cancel out any reactance in the load (antenna) circuit and thus make it appear to be a pure resistance at the operating frequency,

2. To transform this load resistance to the value Z_T required to face the Class-C tube, and

3. To produce a phase shift in the transmitter wave. This latter role is mainly employed when several antenna elements of an array are to be fed currents of certain desired amplitudes and phase for proper operation of the array. Phase shifts between 0° and 180° can occur.

Consider the Tee network shown in Fig. 28. It is of the low-pass-filter type, but is here employed for impedance matching. The series inductance of reactance X_2 can be used in part to cancel the reactance of the antenna as well as to act with X_1 and X_3 to effect an impedance match from the antenna resistance R_a to the characteristic line resistance R_o.

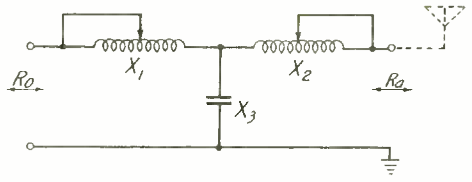


Fig. 28.—Tee matching network.

Thus, suppose the antenna has an impedance which can be expressed as a capacitive reactance X_{ca} in series with a resistance R_a representing its radiation resistance. Then part of X_2 can be used to cancel X_{ca}, and thus leave a pure resistance R_a to be matched by the rest of X_2 in conjunction with X_1 and X_3.

On the other hand, suppose the antenna has an impedance which can be expressed as an inductive reactance X_{La} in series with R_a. Then, providing X_{La} is not excessive, it can be used to supply part of the inductive reactance required by the right-hand series arm of the tee; i.e., X_2 itself is reduced to a value where it plus X_{La} furnishes precisely the amount of reactance required. Thus in this case too there remains a pure resistance R_a to be matched to R_o.

Let β be the phase shift through the network. This can be chosen arbitrarily, values from -180° (cut-off) to 0° are possible. The reactance values to provide an impedance match depend upon the value of β chosen. The magnitudes of X_1, X_2, and X_3 are then given by:

$$\left.\begin{aligned} X_1 &= -\frac{\sqrt{R_a R_o}(1 - \cos\beta)\sqrt{R_o/R_a}}{\sin\beta} \\ X_2 &= -\frac{\sqrt{R_a R_o}(1 - \cos\beta)\sqrt{R_a/R_o}}{\sin\beta} \\ X_3 &= +\sqrt{R_a R_o}/\sin\beta \end{aligned}\right\} \quad (22)$$

If β = -180° or 0°, sin β=0, and X_1, X_2 and X_3 become infinite. If β is close to these values, these reactances become very high, and this is particularly undesirable in the case of X_1 and X_2, since it means coils of high inductance are required.

Hence, unless some special value of β is desired, it is best to operate with β = -90°, in which case sin β = -1, and Eq. (22) simplifies down to:

$$\left.\begin{aligned} X_1 &= +\sqrt{R_o R_a} \\ X_2 &= +\sqrt{R_o R_a} \\ X_3 &= -\sqrt{R_o R_a} \end{aligned}\right\} \quad (23)$$

Note the negative sign for X_3 is capacitive. Should these lead to inconvenient values of X_1, X_2, or X_3, a different value of β can be chosen.

Two examples will now be worked out using a value of β = -90°. Assume first that the transmission line has a characteristic impedance of 52 ohms, and that the antenna has a length of 0.22λ (wavelength) and is of the guyed-mast type. Refer to Fig. 29, where are shown the reactance and resistance of both self-supporting and guyed-mast types of antennas for various electrical heights from 50° to 200°.

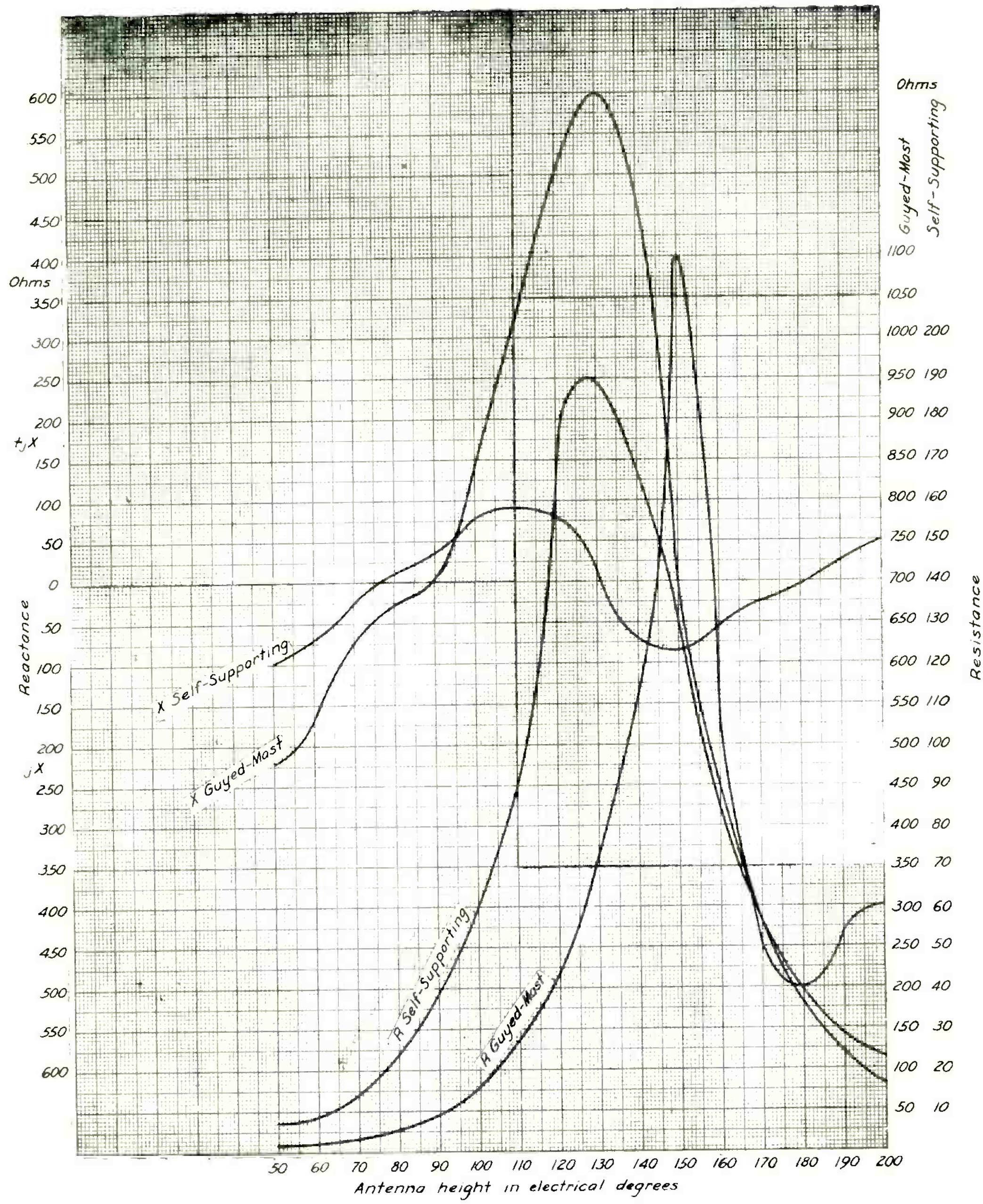


Fig. 29.—The resistance and reactance of a self-supporting and a guyed-mast antenna as a function of electrical height.

The antenna height is given in wavelengths; it can be converted to degrees by the following formula:

$$H = h \times 360° \qquad (24)$$

where h is the height in wavelengths. Here h = .22, hence H = .22 × 360 = 79.2°. From Fig. 29 it is found that for H = 79.2°, R_a = 28 ohms and X_a = -28 ohms or 28 ohms capacitive reactance. This will have to be cancelled out by a corresponding portion of X_2 and X_1 will have a value:

$$X_1 = \sqrt{R_o R_a} = \sqrt{52 \times 28} = 38.1 \text{ ohms,}$$

This means that the total reactance of X_2 will have to be

$$X_2 = 38.1 + 28 = 66.1 \text{ ohms.}$$

Reactance X_3 will have the value -X, or -38.1 ohms, - that is, 38.1 ohms capacitive.

The second example is that of a self-supporting antenna λ/4 long. Here H = (360)(1/4) = 90°, and for this type antenna R_a = 40 ohms, and X_a = + 35 ohms or inductive. Let R_o = 52 ohms as before. Then

$$X_1 = \sqrt{52 \times 40} = 45.6 \text{ ohms}$$

X_2 = 45.6 - 35 = 10.6 ohms net inductive reactance. In other words, the antenna supplies 35 ohms of the required 45.6 ohms inductive reactance, so that the right-hand series coil of the tee network need supply only the remaining 10.6 ohms inductive reactance. Then finally X_3 = 45.6 ohms of capacitive reactance. It is then, of course, a simple matter to find the values of L and C, once the frequency is specified.

ADJUSTMENTS OF TEE NETWORK.—An r-f bridge will facilitate the tuning procedure very much, and is therefore recommended. The object is to adjust the inductances to tune out the antenna reactance and match the antenna resistance to the line. Note that the inductances are the variable elements; the shunt capacitance is chosen in accordance with the preceding calculations.

The tuning unit is normally housed in a weatherproof metal box, and is designed to be mounted either below or adjacent to the antenna base. Often a small house is provided (so-called "dog-house"), particularly if an array is involved which requires several tuning and phasing units. Otherwise the unit may be mounted on wooden posts or upon a wooden platform or steel cradle.

The antenna wire is brought out through a ceramic bowl insulator, for the r-f field is intense and the dielectric stress high. An opening in the bottom is also provided for a coaxial cable, and in the event of a two-wire line, a second ceramic bowl insulator is used.

A thermocouple for a remote r-f ammeter is provided, together with an r-f meter and a S.P.D.T. make-before-break type knife switch to disconnect the meter when readings are not being taken, (see Fig. 30). This feature protects the meter against lightning surges, and in addition further protection is afforded by the horn gap on the outside of the tuner housing near the antenna bowl insulator.

To adjust the network with an r-f bridge, the circuit arrangement shown in Fig. 31 is employed. After the necessary calculations have been

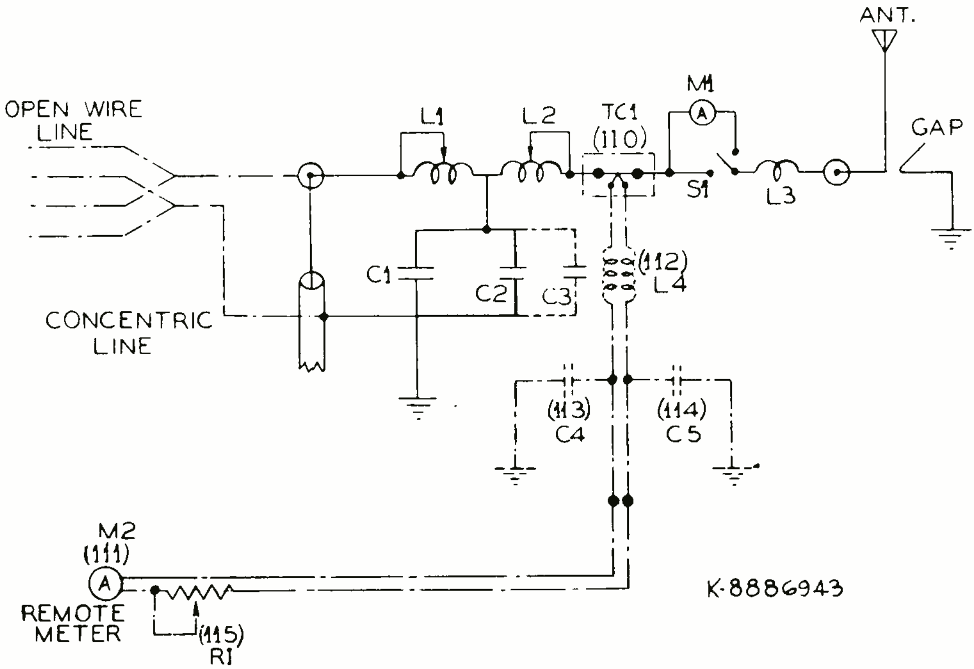


Fig. 30.—Tuning Unit Schematic diagram.

made, the inductance taps are chosen to give the approximately correct value of inductance required.

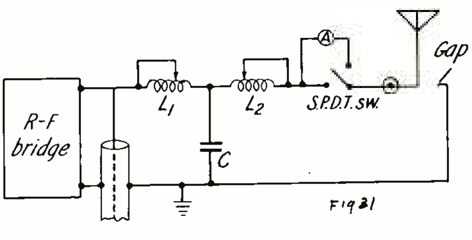


Fig. 31.—Test setup for adjusting a tuning unit with the aid of an r-f bridge.

Then the transmission line is disconnected, and the r-f bridge used to measure the input impedance of the tuning unit with the antenna connected. (If desired, the bridge can also be used to measure the antenna impedance, as well.) The input impedance should equal the characteristic impedance of the line, such as 52 ohms or whatever it may be.

If not, L_1 and L_2 have to be readjusted by a process of trial-and-error until the correct impedance is obtained. The line is then reconnected and the r-f bridge removed from the circuit, and operation begun at a low power level. If everything is all right, full power can then be applied.

A calculation of the current in the capacitor C should be made to insure that the rating of the capacitor, both in voltage and current, is not exceeded. The company provides capacitors on the basis of information received with the order; this calculation acts as a check on the information furnished.

TUNING PROCEDURE WITHOUT R-F BRIDGE.—If an r-f bridge is not available, a simple substitution method may be employed. The circuit is shown in Fig. 32. Here a small carbon resistor is employed in place of the tuning unit and antenna, depending upon which way the switch is thrown. Since the resistor has a rating of but a few watts, reduced power should be applied, such as from a low-level stage. The test coupler and series tuning capacitor are for this purpose.

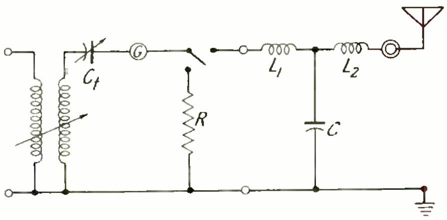


Fig. 32.—Test setup for adjusting a tuning unit when an r-f bridge is not available.

With the switch set first in one position and then in the other, the line current is observed on meter G. If it is the same in either position, the tuner is in proper adjustment.

Suppose the switch is set in the resistor position. Capacitor C_T is then tuned for maximum current reading. The switch is then shifted to the tuner input. Suppose C_T now has to be increased to obtain a maximum current. This indicates that the tuner load has capacitive reactance as well as resistance, and C_T had to be increased in order to decrease its reactance by the amount present in the tuner. Appropriate changes must then be made in the tuner components.

On the other hand, suppose C_T has to be reduced. In this case the tuner impedance is inductive, and again the appropriate changes must be made in the tuner components. Finally, C_T may not have to be readjusted, but the current may increase as the switch is shifted from R to the tuner load. This indicates the latter is resistive in nature, but of a lower magnitude than the desired value R.

If the current decreases on shifting the switch, it of course indicates that the tuner load is a resistance higher than R. In either case appropriate corrections must be made to the tuner adjustments, but note that this substitution method enables one not only to determine when the adjustments are correct, but also when incorrect, which way the error is and hence how to correct for it. In fact, this method may in general be used to determine unknown resistances and reactances in terms of a calibrated resistor and capacitor.

RESUME'

This concludes the assignment on the design features and adjustments of transmitter circuits. It covered not only the conventional tank circuit design and adjustments, but also push-pull considerations for the same type of tank circuit. Following this the pi type of tank was analyzed, and its ability to match impedances as well as to suppress harmonics was demonstrated.

The practical adjustments of a Class C amplifier are important, and a considerable portion of the assignment is devoted to this topic, both as regards the ordinary tank, the pi tank, and the tuning units. The readings of the various meters afford an indirect clue as to the tuning and loading of a unit, and hence as to whether or not the stage is being operated in accordance with the calculated design or the manufacturer's specifications. Along with this the subject of neutralization was covered, showing how this is accomplished in practice.

Harmonic suppression was further explored in this assignment, and various types of trap circuits, as well as a modification to the pi tank, were illustrated and discussed. In the case of the pi tank itself, a graph shows the amount of second-harmonic suppression obtained for various tank Q's.

Two practical examples of transmitter Class-C stages were presented, and the assignment concluded with a discussion of the design and adjustment of Tee matching or tuning units.

EXAMINATION

1. A 50 kw transmitter is two miles away from a receiver, and on a frequency of 550 kc. It radiates second-harmonic power that is 40 db below the fundamental in power. A small station of 250 watts capacity is operating on 1100 kc. It is 20 miles distant from the receiver. Assume that its signal strength varies inversely as the distance (power varies inversely as the square of the distance), rather than at a more rapid rate, as is the case if the earth does not have 100 per cent conductivity.

   (A) How much second-harmonic power does the 50 kw station radiate?

   (B) What is the ratio of second-harmonic power to the power of the 250-watt station at the receiver terminals?

2. A tank circuit has an inductance L_T = 200 μhenries, and a resistance of 18 ohms. The load resistance reflected in series with L_T is 140 ohms. The frequency of operation is 1500 kc.

   (A) What is the unloaded Q of the tank coil?

   (B) What is the loaded Q of the tank coil?

   (C) What is the efficiency of the tank circuit?

3. (A) In the above example, what is the value of the tank capacitor C_T that is required?

(B) It is desired to present a resistance to the plate of the tube of Z_T = 2500 ohms. The actual load r_L coupled to L_T is the characteristic impedance of the antenna transmission line Z_o = 52 ohms. What value of mutual inductance M is required between the transmission-line coupling coil and L_T?

(C) What is the more approximate value of M, neglecting the tank-coil losses?

4. Discuss briefly but in detail the procedure in tuning, neutralizing, and loading a transmitter.

4. *(Continued)*

5. An ordinary type of L-C tank circuit is to be designed to operate at 1000 kc. The load resistance to be presented to the plate of the tube is 3500 ohms, and the loaded Q is to be 8. The tank efficiency is to be 95%.

(A) Find the value of the tank capacitor C_T.

(B) Find the value of the tank inductance L_T.

(C) Calculate the reflected load resistance R_L in series with L_T.

(D) Calculate the resistance R_T of the tank coil.

6. (A) Suppose in the above problem that two tubes of the same type as the one used there were employed in push-pull, and under the same Class-C conditions.

(a) What value of L_T would be required?

(b) What value of C_T would be required?

(c) What value of Z_T is required?

(d) What value of Q_L is required?

(e) How does the power output compare with that of the single tube?

(B) Suppose instead of push-pull, two of the same tubes were used in parallel. Answer the same questions (a) to (e) as in (A) above.

(a)

(b)

(c)

(d)

(e)

7. An ordinary L-C tank circuit is used in a Class-C amplifier stage. The angle of flow is $\theta_p = 140°$, and $Q_L = 10$. The fundamental power output is 1 kw.

(A) Calculate the amount of db the second-harmonic power is down on the fundamental power. Is this within the limits permitted?

(B) Calculate the actual amount of second-harmonic power radiated. Is this numerical value within the limits permitted?

8. Design a pi tank circuit to match 3,000 ohms to 50 ohms at 1250 kc. A loaded Q of 12 is desired. Find C_T, L_T, and C_π, also the amount of second-harmonic suppression.

9. It is desired to build a tank circuit of the form shown in Fig. 23(D) of the text. The tank capacitive reactance X_{CT} is 250 ohms; the pi capacitive reactance $X_{C\pi}$ is 42 ohms, and the fundamental frequency is 1250 kc. Find the values of L_{F1}, C_T, L_{F2}, and C_π that will give the required suppression at the second-harmonic frequency.

10. Given an antenna that has the following impedance at 1.5×10^6 mc: $R_a + jX_a = 40 + j35$. Calculate the *inductances* and *capacitances* required in a Tee network that is to match it to a 52-ohm transmission line and is to have a -90° phase shift.