

R.-F. Power Generation

4-1 Transmitter Requirements

General Requirements — To minimize interference when a large number of stations must work in one frequency band, the power output of a transmitter must be as stable in frequency and as free from spurious radiations as the state of the art permits. The steady r.f. output, called the *carrier* (§ 5-1), must be free from amplitude variations attributable to ripple from the plate power supply (§ 8-4) or other causes, its frequency should be unaffected by variations in supply voltages or inadvertent changes in circuit constants, and there should be no radiation on other than the intended frequency. The degree to which these requirements can be met depends upon the operating frequency.

Design principles — The design of the transmitter depends on the output frequency, the required power output and the type of operation (c.w. telegraphy or 'phone). For c.w. operation at low power on medium-high frequencies (up to 7 Mc. or so), a simple crystal oscillator circuit can meet the requirements satisfactorily. However, the stable power output which can be taken from an oscillator is limited, so that for higher power the oscillator is used simply as a frequency-controlling element, the power being raised to the desired level by means of amplifiers. The requisite frequency stability can be obtained only when the oscillator is operated on relatively low frequencies, so that for output frequencies up to about 60 Mc. it is necessary to increase the oscillator frequency by multiplication (harmonic generation — § 3-3), which usually is done at fairly low power levels and before the final amplification. An amplifier which delivers power on the frequency applied to its grid circuit is known as a *straight amplifier*; one which gives harmonic output is known as a *frequency multiplier*. An amplifier used principally to isolate the frequency-controlling oscillator from the effects of changes in load or other variations in following amplifier stages is called a *buffer amplifier*. A complete transmitter therefore may consist of an oscillator followed by one or more buffer amplifiers, frequency multipliers and straight amplifiers, the number being determined by the output frequency and power in relation to the oscillator frequency and power. The last amplifier is called the *final amplifier*, and the stages up to the last comprise the *exciter*. Transmitters usually are designed to work in a number of frequency bands so that means for changing frequency har-

monic steps usually is provided, generally by means of plug-in inductances.

The general method of designing a transmitter is to decide upon the power output and the highest output frequency required, and also the number of bands in which the transmitter is to operate. The latter usually will determine the oscillator frequency, since it is general practice to set the oscillator on the lowest frequency band to be used. The oscillator frequency seldom is higher than 7 Mc. except in some portable installations where tubes and power must be conserved. A suitable tube (or pair of tubes) should be selected for the final amplifier, and the required grid driving power determined from the tube manufacturer's data. This sets the power required from the preceding stage. From this point the same process is followed back to the oscillator, including frequency multiplication wherever necessary. The selection of a suitable tube complement requires a knowledge of the operating characteristics of the various types of amplifiers and oscillators. These are discussed in the following sections.

At 112 Mc. and higher frequencies these methods of transmitter design tend to become rather cumbersome, because of the necessity for a large number of frequency multiplier stages. However, in this frequency region less severe stability requirements are imposed because the transmission range is limited (§ 9-5) and the possibility of interference to other communication is reduced. Simple oscillator transmitters, without frequency multiplication or buffer amplifiers, are widely used at 112 Mc. and above.

Vacuum tubes — The type of tube used in the transmitter has an important effect on the circuit design. Tubes of high power sensitivity (§ 3-3) such as pentodes and beam tetrodes give larger power amplification ratios per stage than do triodes, hence fewer tubes and stages may be used to obtain the same output power. On the other hand triodes have certain operating advantages, such as simpler power supply circuits and relatively simpler adjustment for modulation (§ 5-3), and in addition are considerably less expensive for the same power output rating. Consequently it is usually more economical to use triodes as output amplifiers, even though an extra low-power amplifier stage may be necessary.

At frequencies in the region of 56 Mc. and above it is necessary to select tubes designed particularly for operation at very-high frequencies, since tubes built primarily for lower frequencies may work poorly or not at all.

4-2 Self-Controlled Oscillators

Advantages and disadvantages — The chief advantage of a self-controlled oscillator is that the frequency of oscillation is determined by the constants of the tuned circuit, and hence readily can be set to any desired value. However, extreme care in design and adjustment are essential to secure satisfactory frequency stability (§ 3-7). Since frequency stability is generally poorer as the load on the oscillator is increased, the self-controlled oscillator should be used purely to control frequency and not for the purpose of obtaining appreciable power output in transmitters intended for working below 60 Mc.

Oscillator circuits — The inherent stability of all of the oscillator circuits described in § 3-7 is about the same, since stability is more a function of choice of proper circuit values and of adjustment than of the method by which feed-back is obtained. However, some circuits are more convenient to use than others, particularly from the standpoint of feed-back adjustment, mechanical considerations (whether the tuning condenser rotor plates can be grounded or not, etc.), and uniform output over a considerable frequency range. All simple circuits suffer from the fact that the power output must be taken from the frequency-determining tank circuit, so that, aside from the effect of loading on frequency stability, the following amplifier stage also can react on the oscillator in such a way as to cause a change in the frequency.

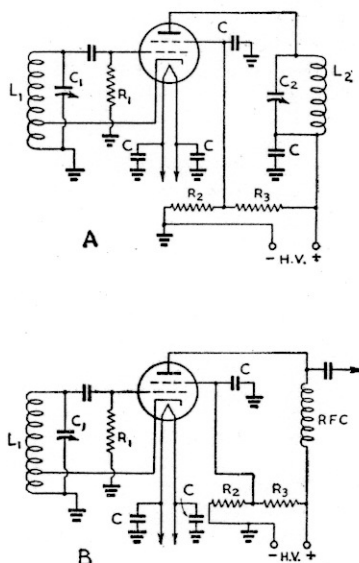


Fig. 401 — Electron-coupled oscillator circuits. For maximum stability the grid leak, R_1 , should be 100,000 ohms or more. The grid condenser should be of the order of 100 $\mu\text{fd.}$ and the other fixed condensers from 0.002 $\mu\text{fd.}$ to 0.1 $\mu\text{fd.}$ Proper values for R_2 and R_3 may be determined from § 8-10. For maximum isolation between oscillator and output circuits the tube should be well shielded and have extremely low grid-plate capacity.

The electron-coupled oscillator — The effects of loading and coupling to the next stage can be greatly reduced by use of the *electron-coupled* circuit, in which a screen-grid tube (§ 3-5) is so connected that its screen grid is used as a plate, in conjunction with the control grid and cathode, in an ordinary triode oscillator circuit. The screen is operated at ground r.f. potential (§ 2-13) to act as a shield between the actual plate and the cathode and control grid; the latter two elements therefore must be above ground potential. The output is taken from the plate circuit. Under these conditions the capacity coupling (§ 2-11) between the plate and other ungrounded tube elements is quite small, hence the output power is secured almost entirely by variations in the plate current caused by the varying potentials on the grid and cathode. Since in a screen-grid tube the plate voltage has a relatively small effect on the plate current, the reaction on the oscillator frequency for different conditions of loading is small.

It is generally most convenient to use a Hartley (§ 3-7) circuit in the frequency-determining part of the oscillator. This is shown in Fig. 401, where L_1C_1 is the oscillator tank circuit. The screen is grounded for r.f. through a by-pass condenser (§ 2-13), but has the usual d.c. potential. The cathode connection is made to a tap on the tank coil to provide feed-back. In the plate circuit, a resonant circuit, L_2C_2 , can be connected as shown at A; it may be tuned either to the oscillation frequency or to one of its harmonics. Untuned output coupling is shown at B; with this method the output voltage and power are considerably lower than with a tuned plate circuit, but better isolation between oscillator and amplifier is secured.

If the oscillator tube is a pentode having an external suppressor connection the suppressor grid should be grounded. This provides additional internal shielding and further isolates the plate from the frequency-determining circuit.

Factors influencing stability — The causes of frequency instability and the necessary remedial steps have been discussed in § 3-7. These apply to all oscillators. In addition, in the electron-coupled oscillator the ratio of plate to screen voltage has marked effect on the stability with changes in supply voltage; the optimum ratio is generally of the order of 3:1, but should be determined experimentally for each case. Since the cathode is above ground potential, means should be taken to reduce the effects of heater-to-cathode capacitance or leakage which, by allowing a small a.c. voltage from the heater supply to develop between cathode and ground, may cause modulation (§ 5-1) at the supply frequency. This effect, which is usually appreciable only at 14 Mc. and higher, may be reduced by by-passing the heater as in Fig. 401 or by operating the heater at the same r.f. potential as the cathode. The latter may be accomplished by the wiring arrangement shown in Fig. 402.

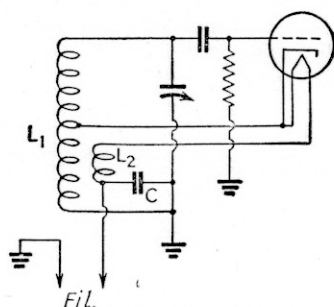


Fig. 402 — Method of operating the heater at cathode r.f. potential in an electron-coupled oscillator. The feed-back coil, L_2 , should have the same number of turns as the part of L_1 between ground and the cathode tap, and should be closely coupled to L_1 (preferably interwound). The by-pass condenser, C , should be 0.01 to 0.1 μfd .

Tank-circuit Q —The most important single factor in determining frequency stability is the Q of the oscillator tank circuit. The effective Q must be as high as possible for best stability. Since oscillation is accompanied by grid-current flow the grid-cathode circuit constitutes a resistance load of appreciable proportions, the effective resistance being low enough to be the determining factor in establishing the effective parallel impedance of the tank circuit. Consequently, if the ends of the tank are connected to plate and grid, as is usual, a high effective Q can be obtained only by decreasing the L/C ratio and making the inherent resistance in the tank as low as possible. The tank resistance can be decreased by using low-loss insulation on condensers and coils, and by winding the coil with large wire. With ordinary construction, the optimum tank capacity is of the order of 500 to 1000 μfd . at a frequency of 3.5 Mc.

The effective circuit Q can be raised by increasing the resistance of the grid circuit and thus decreasing the loading. This can be accomplished through reducing the oscillator grid current, by using minimum feed-back to maintain stable oscillation and by using a high value of grid-leak resistance.

A high- Q tank circuit can also be obtained with a higher L/C ratio by "tapping down" the tube connections on the tank (§ 2-10). This is advantageous in that a coil with higher inherent Q can be used; also, the circulating r.f. current in the tank circuit is reduced so that drift from coil heating is decreased. However, the circuit is complicated to some extent and under some conditions parasitic oscillations may be set up (§ 4-10).

Plate supply—Since the oscillator frequency will be affected to some extent by changes in plate-supply voltage, it is necessary that the latter be free from ripple (§ 8-4) which would cause frequency variations at the ripple-frequency rate (*frequency modulation*). It is advantageous to use a voltage-stabilized power supply (§ 8-8). Since the oscillator usually is operated at low voltage and current, VR-type gaseous regulator tubes are quite suitable.

Power level—The self-controlled oscillator should be designed purely for frequency control and not to give appreciable power output, hence small tubes of the receiving type may be used. The power input ordinarily is not more than a watt or two, subsequent buffer amplifiers being used to increase the power to the desired level. The use of receiving tubes is advantageous mechanically, since the small elements are less susceptible to vibration and usually are securely braced to the envelope.

Oscillator adjustment—The adjustment of an oscillator consists principally in observing the design principles outlined in the preceding paragraphs. Frequency stability should be checked with the aid of a stable receiver. An auxiliary crystal oscillator may be used as a standard for checking dynamic stability and drift, the self-controlled oscillator being adjusted to approximately the same frequency so that an audio-frequency beat (§ 2-13) can be obtained. If it is possible to vary the oscillator plate voltage (an adjustable resistor of 50,000 or 100,000 ohms in series with the plate supply lead will give considerable variation), the change in frequency with change in plate voltage may be observed and the operating conditions varied until minimum frequency shift results. The principal factors affecting dynamic stability will be the tank circuit L/C ratio, the grid-leak resistance, and the amount of feed-back. In the electron-coupled circuit the latter may be adjusted by changing the cathode tap on the tank coil; critical adjustment is required for optimum stability.

Drift may be checked by allowing the oscillator to operate continuously from a cold start, the frequency change being observed at regular intervals. Drift may be minimized by using less than the rated power input to the plate of the tube, by construction which prevents tube heat from reaching the tank circuit elements, and by use of large wire in the tank coil to reduce temperature rise from internal heating.

In the electron-coupled oscillator having a tuned plate circuit (Fig. 401-A), resonance at the fundamental and harmonic frequencies of the oscillator portion of the tube will be indicated by a decrease in plate current as the plate tank condenser is varied. This "dip" should be rather marked at the fundamental, but will be less so on harmonic frequencies.

4-3 Piezoelectric Crystals

Characteristics—Piezoelectric crystals (§ 2-10) are universally used for controlling the frequency of transmitting oscillators, because the extremely high Q of the crystal and the necessarily loose coupling between it and the oscillator tube make the frequency stability of a crystal-controlled oscillator very high. Active plates may be cut from a raw crystal at various angles to its electrical, mechanical and optical axes, resulting in differing characteristics as to thickness, frequency-temperature coefficient, power-handling capabilities, etc.

The commonly used cuts are designated as X, Y, AT, V, and LD.

The ability to adhere closely to a known frequency is the outstanding characteristic of a crystal oscillator. This also is a disadvantage, in that a different crystal is required for each frequency on which the transmitter is to operate.

Frequency-thickness ratio — Crystals used for transmitting purposes are so cut that the thickness of the crystal is the frequency-determining factor, the length and width of the plate being of relatively minor importance. For a given crystal cut, the thickness and frequency are related by a constant, k ; that is,

$$F = \frac{k}{t}$$

where F is the frequency in megacycles and t is the thickness of the crystal in thousandths of an inch. For the X-cut, $k = 112.6$; for the Y-cut, $k = 77.0$; for the AT-cut, $k = 66.2$.

At frequencies above the 7-Mc. region the crystal becomes very thin and correspondingly fragile, so that crystals seldom are manufactured for operation much above this frequency. Direct crystal control on 14 and 28 Mc. is secured by use of "harmonic" crystals, which are ground to be active oscillators when excited at the third harmonic of the frequency represented by their thickness.

Temperature coefficient of frequency — The resonant frequency of a crystal will vary with its temperature, to an extent depending upon the type of cut. The frequency-temperature coefficient is usually expressed in the number of cycles frequency change per megacycle per degree Centigrade temperature change, and may be either positive (increasing frequency with increasing temperature) or negative (decreasing frequency with increasing temperature). X-cut crystals have a negative coefficient of 15 to 25 cycles/megacycle/degree C. The coefficient of Y-cut crystals may vary from -20 cycles/megacycle/degree C. to $+100$ cycles/megacycle/degree C. The AT, V and LD cuts have very low coefficients. Y-cut crystals frequently "jump" to another frequency when the temperature is changed rather than gradually changing frequency as the nominal coefficient might indicate, and hence are rather unreliable under temperature variations.

The temperature of a crystal depends not only on the temperature of its surroundings but also on the power it must dissipate while oscillating, since power dissipation causes heating (§ 2-6, 2-8). Consequently, the crystal temperature in operation may be considerably above that of the surrounding air. To minimize heating and frequency drift (§ 3-7), the power dissipated must be kept to a minimum.

Power limitations — If the crystal is made to oscillate too strongly, as when it is used in an oscillator circuit with high plate voltage and excessive feed-back, the amplitude of the mechanical vibration will become great enough

to crack or puncture the quartz. An indication of the vibration amplitude can be obtained by connecting an r.f. current-indicating device of suitable range in series with the crystal. Safe r.f. crystal currents range from 50 to 200 milliamperes, depending upon the type of cut. A flashlight bulb or dial light of equivalent current rating makes a good current indicator. By choosing a bulb of lower rating than the current specified by the manufacturer as safe for the particular type of crystal used, the bulb will serve as a fuse, burning out before a current dangerous to the crystal is reached. The 60-ma. and 100-ma. bulbs frequently are used for this purpose. High crystal current is accompanied by increased power dissipation and heating, so that the frequency change also is greatest when the crystal is overloaded.

Crystal mountings — To make use of the crystal, it must be mounted between two metal electrodes. There are two types of mountings, one having a small air-gap between the top plate and the crystal and the other maintaining both plates in contact with the crystal. It is essential that the surfaces of the metal plates in contact with the crystal be perfectly flat. In the air-gap type of holder, the frequency of oscillation depends to some extent upon the size of the gap. By using a holder having a top plate with closely adjustable spacing, a controllable frequency variation can be obtained. A 3.5-Mc. crystal will oscillate without very great variation in power output over a range of about 5 kc. X- and Y-cut crystals are not generally suitable for this type of operation, because they have a tendency to "jump" in frequency with different air gaps.

A holder having a heavy metal bottom plate with a large surface exposed to the air is advantageous in that it radiates quickly the heat generated in the crystal, thereby reducing temperature effects. Different plate sizes, pressures, etc., will cause slight changes in frequency, so that if a crystal is being ground to an exact frequency it should be tested in the same holder and in the same oscillator circuit with which it will be used in the transmitter.

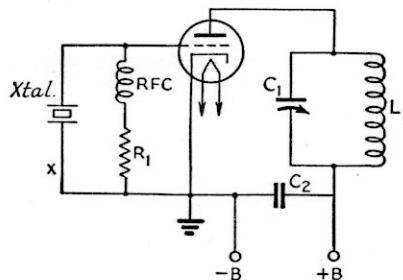


Fig. 403 — Triode crystal oscillator. The tank condenser, C_1 , may be a 100- μ fd. variable, with L_1 proportioned so that the tank will tune to the crystal frequency. C_2 should be 0.001 μ fd. or larger. The grid leak, R_1 , will vary with the type of tube; high- μ tubes take values of 2500 to 10,000 ohms, while medium and low- μ types take values of 10,000 to 25,000 ohms. A small flashlight bulb or r.f. milliammeter (§ 4-3) may be inserted at X.

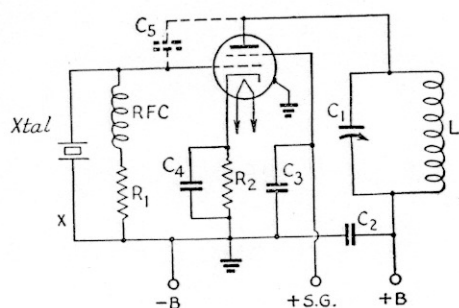


Fig. 404 — Tetrode or pentode crystal oscillator. Typical values: C_1 , 100 $\mu\text{fd.}$, with L wound to suit frequency; C_2 , C_3 , 0.001 $\mu\text{fd.}$ or larger; C_4 , 0.01 $\mu\text{fd.}$; R_1 , 10,000 to 50,000 ohms, best value being determined by trial for the plate voltage and operating conditions chosen; R_2 , 250 to 400 ohms. R_2 and C_4 may be omitted, connecting cathode directly to ground, if plate voltage is limited to 250 volts. C_5 (if needed) may be formed by two metal plates $\frac{1}{2}$ -inch square spaced $\frac{1}{4}$ inch. If the tube has a suppressor grid, it should be grounded. X indicates where a flashlight bulb may be inserted (§ 4-3).

4-4 Crystal Oscillators

Triode oscillators — The triode crystal oscillator circuit (§ 3-7) is shown in Fig. 403. The limit of plate voltage that can be used without endangering the crystal is about 250 volts. With the r.f. crystal current limited to a safe value of about 100 ma., the power output obtainable is about 5 watts. The oscillation frequency is dependent to some extent on the plate tank tuning, because of the change in input capacity with changes in effective amplification (§ 3-3).

Tetrode and pentode oscillators — Since the power output of a crystal oscillator is limited by the permissible r.f. crystal current (§ 4-3), it is advantageous to use an oscillator tube of high power sensitivity (§ 3-3) such as a pentode or beam tetrode (§ 3-5). Thus for a given crystal voltage or current more power output may be obtained than with the triode oscillator, or for a given output the crystal voltage will be lower, thereby reducing crystal heating. In addition, tank-circuit tuning and loading react less on the crystal frequency because of the lower grid-plate capacity (§ 3-3).

Fig. 404 shows a typical pentode or tetrode oscillator circuit. The pentode and tetrode tubes designed for audio power work are excellent crystal-oscillator tubes. The screen voltage is generally of the order of half the plate voltage for optimum operation. Small tubes rated at 250 volts for audio work may be operated with 300 volts on the plate and 100–125 on the screen as crystal oscillators. The screen is at ground potential for r.f. and has no part in the operation of the circuit other than to set the operating characteristics of the tube. The larger beam tubes may be operated at 400 to 500 volts on the plate and 250 on the screen for maximum output.

Pentode oscillators operating at 250 to 300 volts will give 4 or 5 watts output under normal conditions. Beam-type tubes such as the

6L6 and 807 will give 15 watts or more at maximum plate voltage.

The grid-plate capacity may be too low to give sufficient feed-back, particularly at the lower frequencies, in which case a feed-back condenser, C_5 , may be required. Its capacity should be the lowest value which will give stable oscillation; 1 or 2 $\mu\text{fd.}$ is generally sufficient.

Circuit constants — Typical values for grid-leak resistances and by-pass condensers are given in Figs. 403 and 404. Since the crystal is the frequency-determining element, the Q of the plate tank circuit has a relatively minor effect on the oscillator frequency. A Q of 12 (§ 4-8) is satisfactory for average conditions, but some departure from this figure will not greatly affect the performance of the oscillator.

Adjustment of crystal oscillators — The tuning characteristics and procedure to be followed in tuning are essentially the same for triode, tetrode or pentode crystal oscillators. Using a plate milliammeter as an indicator of oscillation (a 0–100 ma. d.c. meter will have ample range for all low-power oscillators), the plate current will be found to be steady when the circuit is in the non-oscillating state, but will dip when the plate condenser is tuned through resonance at the crystal frequency. Fig. 405 is typical of the behavior of plate current as the tank condenser capacity is varied. An r.f. indicator, such as a small neon bulb touched to the plate end of the tank coil, will show a maximum indication at point A. However, when the oscillator is delivering power to a load it is best to operate in the region B-C since the oscillator will be more stable and there is less likelihood that a slight change in loading will throw the circuit out of oscillation, which is likely to happen when operation is too near the critical point, A. The crystal current also is lower in the B-C region.

When power is taken from the oscillator the dip in plate current is less pronounced, as indicated by the dotted curve. The greater the power output, the smaller the dip in plate current. If the load is made too great, oscillations will not start. Loading is adjusted by varying the coupling to the load circuit (§ 2-11).

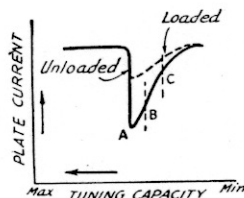


Fig. 405 — Curves showing d.c. plate current vs. plate tuning capacity in a crystal oscillator, both with and without load. These curves apply equally to the triode, tetrode or pentode crystal oscillator.

The greater the loading, the smaller the voltage fed back to the grid circuit for excitation purposes. This means that the r.f. voltage across the crystal also will be reduced, hence there is less crystal heating when the oscillator is delivering power than when it is unloaded.

Failure of a crystal circuit to oscillate may be caused by any of the following:

- 1) Dirty, chipped or fractured crystal.
- 2) Imperfect or unclean holder surfaces.
- 3) Too tight coupling to load.
- 4) Plate tank circuit not tuning correctly.
- 5) Insufficient feed-back capacity.

Pierce oscillator — This circuit is shown in Fig. 406. It is equivalent to the ultraudion cir-

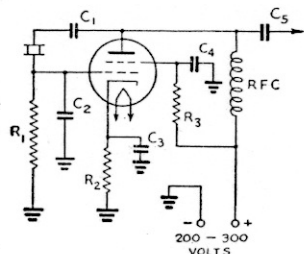


Fig. 406 — Pierce oscillator circuit. Tubes such as the 6C5 and 6F6 are suitable, operating at plate voltages not exceeding 300 to prevent crystal fracture. When a triode is used, R_3 and C_4 are omitted. R_1 should be 25,000 to 50,000 ohms. 1000 ohms is recommended for R_2 . R_3 is the screen voltage dropping resistance (75,000 ohms for the 6F6). C_1 may have any value between 0.001 and 0.01 μfd . C_3 and C_4 should be 0.01 μfd . C_2 , the regeneration capacity, must be determined by experiment; usual values are between 50 and 150 μfd . The capacity of C_5 should be adjusted so that the oscillator is not overloaded; usually 100 μfd is satisfactory.

cuit (§ 3-7), with the crystal replacing the tuned circuit. Although the output of the Pierce oscillator is relatively small, it has the advantage that no tuning controls are required. The circuit requires capacitive coupling to a following stage. The amount of feed-back is determined by the condenser, C_2 . To sustain oscillation, the net reactance (§ 2-8) of the plate-cathode circuit must be capacitive; this condition is met so long as the inductance of the r.f. choke, together with the inductance of any coils associated with the input circuit of the following stage and the tube and stray capacities, forms a circuit tuned to a lower frequency than that of the crystal.

4-5 Harmonic-Generating Crystal Oscillators

Tri-tet oscillator — The Tri-tet oscillator circuit is shown in Fig. 407. In this circuit the screen grid is operated at ground potential and the cathode at an r.f. potential above ground. The screen-grid acts as the anode of a triode crystal oscillator, while the plate or output circuit is tuned to the oscillator frequency or, for harmonic output, to a multiple of it.

Besides giving harmonic output, the Tri-tet circuit has the "buffering" feature of electron-coupling between crystal and output circuits (§ 4-2). This makes the crystal frequency less susceptible to changes in loading or tuning, and hence improves the stability.

If the output circuit is to be tuned to the same frequency as the crystal, a tube having

low grid-plate capacity (§ 3-2, 3-5) must be used. Otherwise, there may be excessive feedback and danger of fracturing the crystal.

The cathode tank circuit, L_1C_1 , is not tuned to the frequency of the crystal, but to a considerably higher frequency. Recommended values for L_1 are given under the diagram. C_1 should be set to as near minimum capacity as is consistent with good output. This reduces the crystal voltage.

With pentode-type tubes having separate suppressor connections, the suppressor may be either connected directly to ground or operated at about 50 volts positive. The latter method will give somewhat higher output than with the suppressor connected to ground.

With transmitting pentodes or beam tubes operated at 500 volts on the plate an output of 15 watts can be obtained on the fundamental and very nearly as much on the second harmonic, or enough to drive directly an amplifier of moderate power.

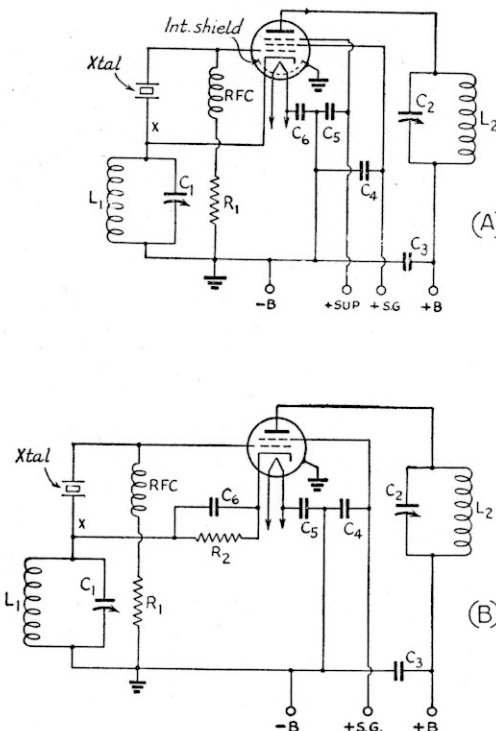


Fig. 407 — Tri-tet oscillator circuit, using pentodes (A) or beam tetrodes (B). C_1 and C_2 are 200- μfd . variable condensers. C_3 , C_4 , C_5 , C_6 , may be 0.001 to 0.01 μfd ; their values are not critical. R_1 , 20,000 to 100,000 ohms. R_2 should be 400 ohms for 400- or 500-volt operation. The following specifications for the cathode coils, L_1 , are based on a diameter of $1\frac{1}{2}$ inches and a length of 1 inch; turns should be spaced evenly to fill the required length: for 1.75-Mc. crystal, 32 turns; 3.5 Mc., 10 turns; 7 Mc., 6 turns. The screen should be operated at 250 volts or less. Audio beam tetrodes such as the 6L6 and 6L6G should be used only for second-harmonic output. A flash-light bulb may be inserted at the point marked X (§ 4-3). The L/C ratio in the plate tank, L_2C_2 , should be such that the capacity in use is 75 to 100 μfd . for fundamental output and about 25 μfd . for second harmonic output.

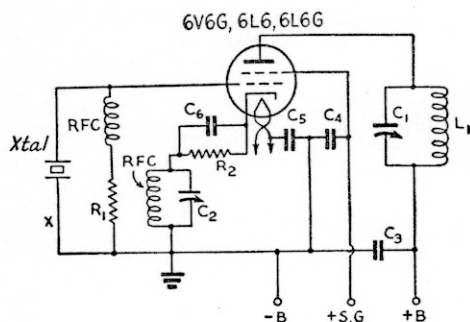


Fig. 408 — Grid-plate crystal oscillator circuit. In the cathode circuit, RFC is a 2.5-mh. r.f. choke. Other constants are the same as in Fig. 407. A crystal-current indicator may be inserted at the point marked X (§ 4-3).

Grid-plate oscillator — In the grid-plate oscillator, Fig. 408, the crystal is connected between grid and ground and the cathode tuned circuit, C_2RFC , is tuned to a frequency lower than that of the crystal. This circuit gives high output on the fundamental crystal frequency with low crystal current. The output on even harmonics (2nd, 4th, etc.) is not as great as that obtainable with the Tri-tet, but on odd harmonics (3rd, 5th, etc.) the output is appreciably better.

If harmonic output is not needed, C_2 may be a fixed capacity of 100 μfd . The cathode coil, RFC , may be a 2.5-mh. choke, since the inductance is not critical.

Output power of 15 to 20 watts at the crystal fundamental may be obtained with a tube such as the 6L6G at plate and screen voltages of 400 and 250, respectively.

Tuning and adjustment — The tuning procedure for the Tri-tet oscillator is as follows: With the cathode tank condenser at about three-quarters scale turn the plate tank condenser until there is a sharp dip in plate current, indicating that the plate circuit is in resonance. The crystal should be oscillating continuously, regardless of the setting of the plate condenser. Set the plate condenser so that plate current is minimum. The load circuit may then be coupled and adjusted so that the oscillator delivers power. The minimum plate current will rise; it may be necessary to retune the plate condenser when the load is coupled to bring the plate current to a new minimum. Fig. 409 shows the typical behavior of plate current with plate-condenser tuning.

After the plate circuit is adjusted and the oscillator is delivering power, the cathode condenser should be readjusted to obtain optimum power output. The setting should be as far toward the low-capacity end of the scale as is consistent with good output; it may, in fact, be desirable to sacrifice a little output if so doing lowers the current through the crystal and thus reduces heating.

For harmonic output the plate tank circuit is tuned to the harmonic instead of the fundamental of the crystal frequency. A plate-current dip will occur at the harmonic. If the

cathode condenser is adjusted for maximum output at the harmonic, this adjustment will usually serve for the fundamental as well. The crystal should be checked for excessive heating, the most effective remedy being to lower plate and/or screen voltage or to reduce the loading. Maximum r.f. voltage across the crystal is developed at maximum load, so heating should be checked with the load coupled.

When a fixed cathode condenser is used in the grid-plate oscillator the plate tank circuit is simply resonated, as indicated by the plate-current dip, to the fundamental or a harmonic of the output frequency, loading being adjusted to give optimum power output. If the variable cathode condenser is used, it should be set to give, by observation, the maximum power output consistent with safe crystal current. The variable condenser is useful chiefly in increasing the output on the third and higher harmonics; for fundamental operation, the cathode capacity is not critical and the fixed condenser may be used.

4-6 Interstage Coupling

Requirements — The purpose of the interstage coupling system is to transfer, with as little energy loss as possible, the power developed in the plate circuit of one tube (the *driver*) to the grid circuit of the following amplifier tube or frequency multiplier. The circuits in practical use are based on the fundamental coupling arrangements described in § 2-11. In the process of power transfer, impedance transformation (§ 2-9) frequently is necessary so that the proper exciting voltage and current will be available at the grid of the driven tube.

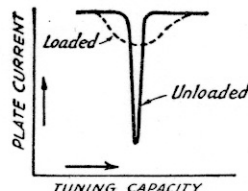


Fig. 409 — Curves showing d.c. plate current vs. plate tuning capacity, both with and without load, for the Tri-tet oscillator. The setting for minimum plate current may shift with loading.

Capacity coupling — Fig. 410 shows several types of capacitive coupling. In each case, C is the coupling condenser. The coupling condenser serves also as a blocking condenser (§ 2-13) to isolate the d.c. plate voltage of the driver from the grid of the amplifier. The circuits of C and D are preferable when a balanced circuit is used in the output of the driver; instead of both tubes being in parallel across one side, the output capacity of the driver tube and the input capacity of the amplifier are across opposite sides of the tank circuit, thereby preserving a better circuit balance. The circuits of E and F are designed for coupling to a push-pull stage.

In A, B, E and F, excitation is adjusted by moving the tap on the coil to provide an optimum impedance match. In E and F, the two grid taps should be maintained equidistant from the center-tap on the coil.

While capacitive coupling is simplest from the viewpoint of construction, it has certain disadvantages. The input capacity of the amplifier is shunted across at least a portion of the driver tank coil. When added to the output capacity of the driver tube, this additional capacity may be sufficient, in many cases, to prevent use of a desirable L/C ratio in circuits for frequencies above about 7 Mc.

Link coupling — At the higher frequencies it is advantageous in reducing the effects of tube capacities on the L/C ratio to use separate tank circuits for the driver plate and amplifier grid, coupling the two circuits by means of a link (§ 2-11). This method of coupling also has some constructional advantages, in that separate parts of the transmitter may be constructed as separate units without the necessity for running long leads at high r.f. potential.

Circuits for link coupling are shown in Fig. 411. The coupling ordinarily is by a turn or two of wire closely coupled to the tank inductance at a point of low r.f. potential, such as the center of the coil of a balanced tank circuit or the "ground" end of the coil in a single-ended

circuit. The link line usually consists of two closely spaced parallel wires; occasionally the wires are twisted together, but this usually causes undue losses at high frequencies.

It is advisable to have some means of varying the coupling between link and tank coils. The link coil may be arranged to be swung in relation to the tank coil or, when it consists of a large turn around the outside of the tank coil, split into two parts which can be pulled apart or closed somewhat in the fashion of a pair of calipers. If the tank coils are wound on forms, the link may be wound close to the main coil.

With fixed coils, some adjustment of coupling usually can be obtained by varying the number of turns on the link. In general, the proper number of turns for the link must be found by experiment.

4-7 R.F. Power Amplifier Circuits

Tetrode and pentode amplifiers — When the input and output circuits of an r.f. amplifier tube are tuned to the same frequency it will oscillate as a tuned-grid tuned-plate oscil-

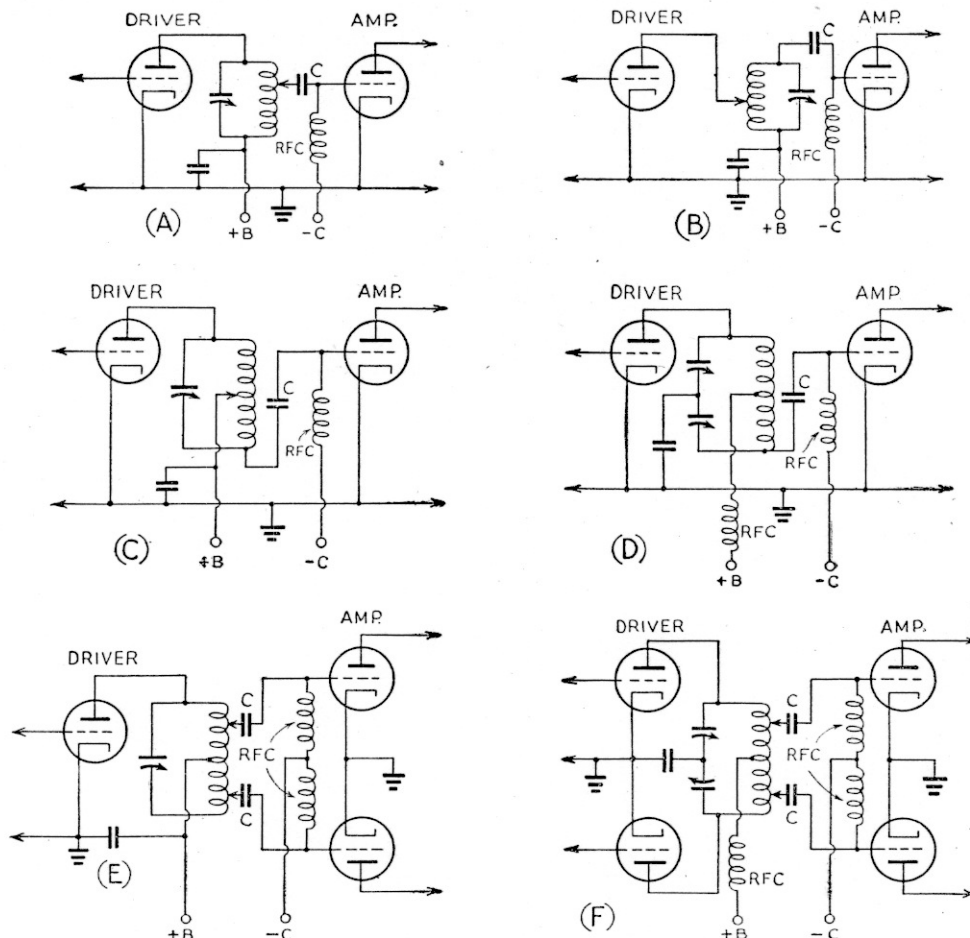


Fig. 410 — Direct- or capacity-coupled driver and amplifier stages. The coupling capacity may be from 50 $\mu\text{fd.}$ to 0.002 $\mu\text{fd.}$; it is not critical except where tapping the coils for control of excitation is not possible. Parallel plate feed to the driver and series grid feed to the amplifier may be substituted in any of the circuits (§ 3-7).

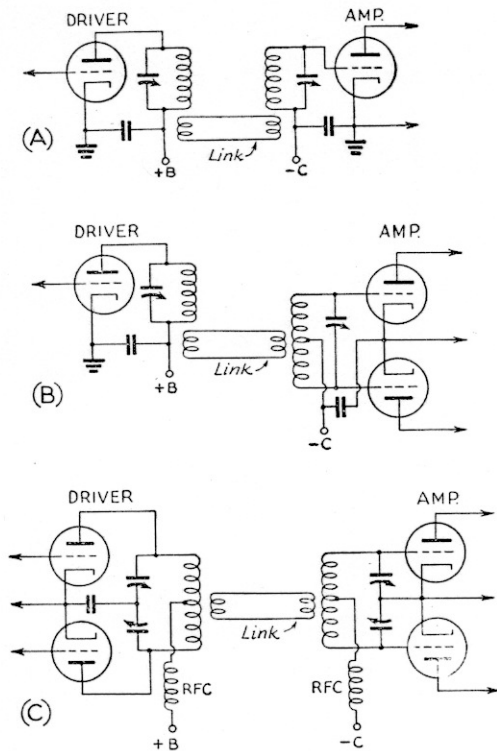


Fig. 411 — Link coupling between driver and amplifier.

lator, unless some means is provided to eliminate the effects of feed-back through the plate-to-grid capacity of the tube (§ 3-5). In all transmitting r.f. tetrodes and pentodes, this capacity is reduced to a satisfactory degree by the internal shielding between grid and plate provided by the screen. Tetrodes and pentodes designed for audio use (such as the 6L6, 6V6, 6F6, etc.) are not sufficiently well screened for use as r.f. amplifiers without employing suitable means for nullifying the effect of the grid-plate capacity.

Typical circuits of tetrode and pentode r.f. amplifiers are shown in Fig. 412. The high power sensitivity (§ 3-3) of pentodes and tetrodes, makes them prone to self-oscillate with very small values of feed-back voltage, however, so that particular care must be used to prevent feed-back by means external to the tube itself. This calls for adequate isolation of plate and grid tank circuits to prevent undesired magnetic or capacity coupling between them. The requisite isolation can be secured by keeping the circuits well separated and mounting the coils so that magnetic coupling is minimized, or by shielding (§ 2-11).

Triode amplifiers — The feed-back through the grid-plate capacity of a triode cannot be eliminated, and therefore special circuit means called *neutralization* must be used to prevent oscillation. A properly neutralized triode amplifier then behaves as though it were operating at very low frequencies, where the grid-plate capacity feed-back is negligible (§ 3-3).

Neutralization — Neutralization amounts to taking some of the radio-frequency current from the output or input circuit of the amplifier and introducing it into the other circuit in such a way that it effectively cancels the current flowing through the grid-plate capacity of the tube, thus rendering it impossible for the tube to supply its own excitation. For complete neutralization, the two currents must be opposite in phase (§ 2-7) and equal in amplitude.

The out-of-phase current (or voltage) can be obtained quite readily by using a balanced tank circuit for either grid or plate, taking the neutralizing voltage from the end of the tank opposite that to which the grid or plate is connected. The amplitude of the neutralizing voltage can be regulated by means of a small condenser, the *neutralizing condenser*, having the same order of capacity as the grid-plate capacity of the tube. Circuits in which the neutralizing voltage is obtained from a balanced grid tank and fed to the plate through the neutralizing condenser are termed *grid-neutralized* circuits, while if the neutralizing voltage is obtained from a balanced plate tank and fed to the grid of the tube the circuit is *plate-neutralized*.

Plate-neutralized circuits — The circuits for plate neutralization are shown in Fig. 413

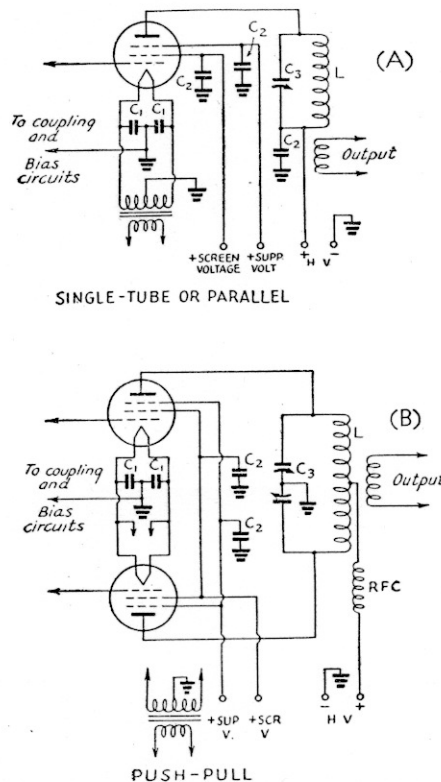


Fig. 412 — Typical tetrode-pentode r.f. amplifier circuits. C_1 — 0.01 μ fd. C_2 — 0.001 μ fd. C_3 -L — see § 4-8. In circuits for tetrodes, the suppressor-grid connection and its associated by-pass condenser are omitted.

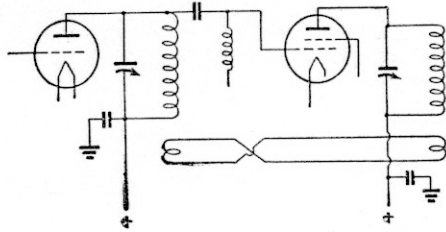


Fig. 415 — Inductive neutralizing circuit. The link coils are of one or two turns coupled to the grounded ends of the tank coils. Neutralization is adjusted by moving the link coils in relation to the tank coils. Reversal of connections to one coil may be required for proper phasing.

Inductive neutralization — With this type of neutralization, inductive coupling between the grid and plate circuits is provided in such a way that the voltage induced in the grid coil by magnetic coupling from the plate coil opposes the voltage fed back through the grid-plate capacity of the tube. A representative circuit arrangement, using a coupling link to provide the mutual inductance (§ 2-11), is shown in Fig. 415. Ordinary inductive coupling between the two coils also could be used, but it is less convenient. Inductive neutralization is complete only at one frequency since the effective mutual inductance changes to some extent with tuning, but is useful in cases where the grid-plate capacity of the tube being neutralized is very small and suitable circuit balance cannot be obtained with circuits using neutralizing condensers.

Push-pull neutralization — With push-pull circuits two neutralizing condensers are used, as shown in Fig. 416. In these circuits, the grid-plate capacities of the tubes and the neutralizing capacities form a capacity bridge (§ 2-11) which is independent of the grid and plate tank circuits. The neutralizing capacities are approximately the same as the tube grid-plate capacities. With electrically similar tubes and symmetrical construction (stray capacities to ground equal on both sides of the circuit), the neutralization is complete and independent of frequency. A circuit using a balanced condenser, as at B, is preferred, since it is an aid in obtaining good circuit balance.

Frequency effects — The effects of slight dissymmetry in a neutralized circuit become more important as the frequency is raised, and may be sufficient at the very-high frequencies (or even lower) to prevent good neutralization. At these frequencies the inductances and stray capacities of even short leads become important elements in the circuit, while input loading effects (§ 7-6) may make it impossible to get proper phasing, particularly in single-tube circuits. In such cases the use of a push-pull amplifier, with its general freedom from the effects of dissymmetry, is not only much to be preferred but may be the only type of circuit which can be satisfactorily neutralized.

Neutralizing condensers — In most cases the neutralizing voltage will be equal to the r.f. voltage between the plate and grid of the

tube, so that for perfect balance the capacity required in the neutralizing condenser theoretically will be equal to the grid-plate capacity. If, in the circuits having tapped tank coils, the tap is more than half the total number of turns from the plate end of the coil, the required neutralizing capacity will increase approximately in proportion to the relative number of turns in the two sections of the coil.

With tubes having grid and plate connections brought out through the bulb, a condenser having at about half-scale or less a capacity equal to the grid-plate capacity of the tube should be chosen. If the grid and plate leads are brought through a common base the capacity needed is greater, because the tube socket and its associated wiring adds some capacity to the actual interelement capacities. When two or more tubes are connected in parallel, the neutralizing capacity required will be in proportion to the number of tubes.

The voltage rating of neutralizing condensers must at least equal the r.f. voltage across the condenser plus the sum of the d.c. plate voltage and the grid-bias voltage.

Neutralizing procedure — The procedure in neutralizing is essentially the same for all tubes and circuits. The filament of the tube should be lighted and excitation from the pre-

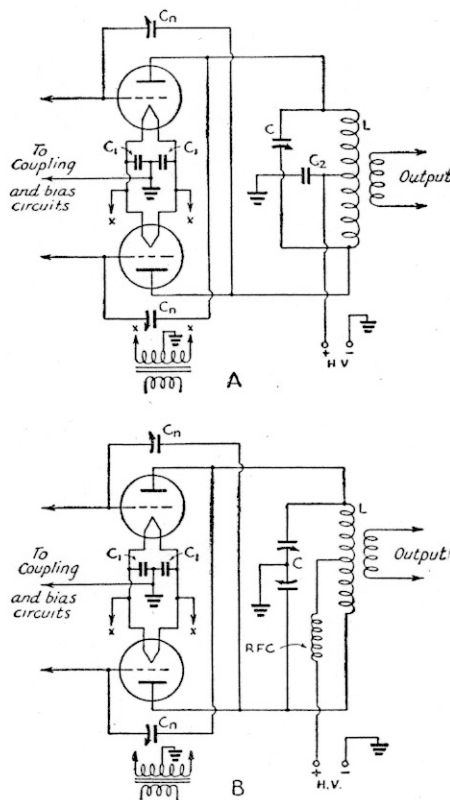


Fig. 416 — "Cross-neutralized" push-pull r.f. amplifier circuits. Either capacitive or link coupling may be used. C-L — See § 4-8. C_n — Neutralizing condensers. C₁ — 0.01 μ fd. C₂ — 0.001 μ fd. or larger.

ceding stage fed to the grid circuit. There should be no plate voltage on the amplifier.

The grid-circuit milliammeter makes a good neutralizing indicator. If the circuit is not completely neutralized, tuning of the plate tank circuit through resonance will change the tuning of the grid circuit and affect its loading, causing a change in the rectified d.c. grid current. The setting of the neutralizing condenser which leaves the grid current unaffected as the plate tank is tuned through resonance is the correct one. If the circuit is out of neutralization, the grid current will drop perceptibly as the plate tank is tuned through resonance. As the point of neutralization is approached, by adjusting the neutralizing capacity in small steps the dip in grid current as the plate condenser is swung through resonance will become less and less pronounced, until, at exact neutralization, there will be no dip at all. Further change of the neutralizing capacity in the same direction will bring the grid-current dip back. The neutralizing condenser should always be adjusted with a screwdriver of insulating material to avoid hand-capacity effects.

Adjustment of the neutralizing condenser may affect the tuning of the grid tank or driver plate tank, so both circuits should be retuned each time a change is made in neutralizing capacity. In neutralizing a push-pull amplifier the neutralizing condensers should be adjusted together, step by step, keeping their capacities as equal as possible.

With single-ended circuits having split-stator neutralizing, the behavior of the grid meter will depend somewhat upon the type of tube used. If the tube output capacity is not great enough to upset the balance, the action of the meter will be the same as in other circuits. With high-capacity tubes, however, the meter usually will show a gradual rise and fall as the plate tank is tuned through resonance, reaching a maximum right at resonance when the circuit is properly neutralized.

When an amplifier is not neutralized a neon bulb touched to the plate of the amplifier tube or to the plate side of the tuning condenser will glow when the tank circuit is tuned through resonance, providing the driver has sufficient power. The glow will disappear when the amplifier is neutralized. However, touching the

neon bulb to such an ungrounded point in the circuit may introduce enough stray capacity to unbalance the circuit slightly, thus upsetting the neutralizing.

A flashlight bulb connected in series with a single-turn loop of wire $2\frac{1}{2}$ or 3 inches in diameter, with the loop coupled to the tank coil, also will serve as a neutralizing indicator. Capacitive unbalance can be avoided by coupling the loop to the low-potential part of the tank coil.

Incomplete neutralization — If a setting of the neutralizing condenser can be found which gives minimum r.f. current in the plate tank circuit without completely eliminating it, there may be magnetic or capacity coupling between the input and output circuits external to the tube itself. Short leads in neutralizing circuits are highly desirable, and the input and output inductances should be so placed with respect to each other that magnetic coupling is minimized. Usually this requires that the axes of the coils must be at right angles to each other. In some cases it may be necessary to shield the input and output circuits from each other. Magnetic coupling can be detected by disconnecting the plate tank from the remainder of the circuit and testing for r.f. in it (by means of the flashlight lamp and loop) as the tank condenser is tuned through resonance. The driver stage must be operating while this is done, of course.

With single-ended amplifiers there are many stray capacities left uncompensated for in the neutralizing process. With large tubes, especially those having relatively high interelectrode capacities, these commonly neglected stray capacities can prevent perfect neutralization. Symmetrical arrangement of a push-pull stage is about the only way to obtain practically perfect balance throughout the amplifier.

The neutralization of tubes with extremely low grid-plate capacity, such as the 6L6, is often difficult, since it frequently happens that the wiring itself will introduce sufficient capacity between the right points to "over-neutralize" the grid-plate capacity. The use of a neutralizing condenser only aggravates the condition. Inductive or link neutralization, as shown in Fig. 415, has been used successfully with such tubes.

The inverted amplifier — The circuit of Fig. 417 avoids the necessity for neutralization by operating the control grid of the tube at ground potential, thus making it serve as a shield between the input and output circuits. It is particularly useful with tubes of low grid-plate capacity, which are difficult to neutralize by ordinary methods. Excitation is applied between grid and cathode through the coupling coil, L ; since this coil is common to both the plate and grid circuits the amplifier is degenerative with the circuit constants normally used, hence more excitation voltage and power are required for a given output than is the case with a neutralized amplifier. The

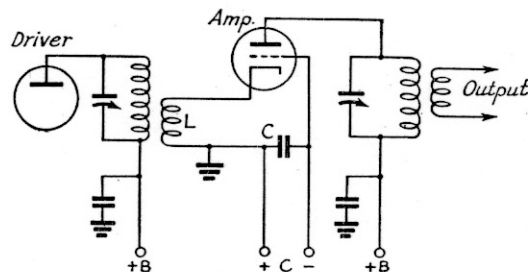


Fig. 417 — Inverted amplifier. The number of turns at L should be adjusted by experiment to give optimum grid excitation. By-pass condenser C is 0.001 μ fd. or larger.

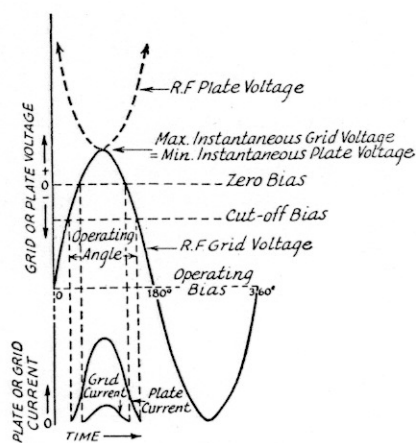


Fig. 418 — Instantaneous voltages and currents in a Class-C amplifier operating under optimum conditions.

tube used must have low plate-cathode capacity (of the order of 1 $\mu\text{u.f.}$ or less) since larger values will give sufficient feed-back to permit it to oscillate, the circuit then becoming the ultraudion (§ 3-7). Tubes having sufficiently low plate-cathode capacity (audio pentodes, for example) can be used without danger of oscillation at frequencies up to 30 Mc. or so.

4-8 Power Amplifier Operation

Efficiency—An r.f. power amplifier is usually operated Class-C (§ 3-4) to obtain a reasonably high value of plate efficiency (§ 3-3). The higher the plate efficiency the higher the power input that can be applied to the tube without exceeding the plate dissipation rating (§ 3-2), up to the limits of other tube ratings (plate voltage and plate current). Plate efficiencies of the order of 75 per cent are readily obtainable at frequencies up to the 30-60-Mc. region. The *overall* efficiency of the amplifier will be lower by the power lost in the tank and coupling circuits, so that the actual efficiency is less than the plate efficiency.

Operating angle — The operating angle is the proportionate part of the exciting grid voltage cycle (§ 2-7) during which plate current flows, as shown in Fig. 418. For Class-C operation, it is usually in the vicinity of 120–150 degrees. With other operating considerations, this angle results in an optimum relationship between plate efficiency and grid driving power.

Load impedance—The load impedance (§ 3-3) for an r.f. power amplifier is adjusted, by tuning the plate tank circuit to resonance, to represent a pure resistance at the operating frequency (§ 2-10). Its value, which usually is in the neighborhood of a few thousand ohms, is adjusted by varying the loading on the tank circuit, closer coupling to the load giving lower values of load resistance and vice versa (§ 2-11). The load may be either the grid circuit of a following stage or the antenna circuit.

For highest efficiency the value of load resistance should be relatively high, but if only

limited excitation voltage is available greater power output will be secured by using a lower value of load resistance. The latter adjustment is accompanied by a decrease in plate efficiency. The optimum load resistance is that which, for the maximum permissible peak plate current, causes the minimum instantaneous plate voltage (Fig. 418) to be equal to the maximum instantaneous grid voltage required to cause the peak plate current to flow; this gives the optimum ratio of plate efficiency to required grid driving power.

R.f. grid voltage and grid bias — For most tubes optimum operating conditions result when the minimum instantaneous plate voltage is 10 to 20 per cent of the d.c. plate voltage, so that the maximum instantaneous positive grid voltage must be approximately the same figure. Since plate current starts flowing when the instantaneous voltage reaches the cut-off value (§ 3-2), the d.c. grid voltage must be considerably higher than cut-off to confine the operating angle to 150 degrees or less (with grid bias at cut-off, the angle would be 180 degrees). For an angle of 120 degrees, the r.f. grid voltage must reach 50 per cent of its peak value (§ 2-7) at the cut-off point. The corresponding figure for an angle of 150 degrees is 25 per cent. Hence, the operating bias required is the cut-off value plus 25 to 50 per cent of the peak r.f. grid voltage. These relations are shown in Fig. 418. The grid bias should be at least twice cut-off if the amplifier is to be plate modulated, so that the operating angle will be not less than 180 degrees when the plate voltage rises to twice the steady d.c. value (§ 5-3). Because of their relatively high amplification factors, with most modern tubes Class-C operation requires considerably more than twice cut-off bias to make the operating angle fall in the region mentioned above. Suitable operating conditions are usually found in the data accompanying the type of tube used.

Grid bias may be secured either from a bias source (*fixed bias*), a grid leak (§ 3-6) of suitable value, or from a combination of both. When a bias supply is used, its voltage regulation should be taken into consideration (§ 8-9).

Driving power—As indicated in Fig. 418, grid current flows only during a small portion of the peak of the r.f. grid voltage cycle. The power consumed in the grid circuit therefore is approximately equal to the peak r.f. grid voltage multiplied by the average rectified grid current as read by a d.c. milliammeter. The peak r.f. grid voltage, if not included in the tube manufacturer's operating data, can be estimated roughly by adding 10 to 20 per cent of the plate voltage to the operating grid bias, assuming the operating conditions are as described above.

At frequencies up to 30 Mc. or so, the grid losses are practically entirely those resulting from grid-current flow. At the very-high frequencies, however, dielectric losses in the glass envelope and base materials become appreciable.

ciable, together with losses caused by transit-time effects (§ 7-6), and may necessitate supplying several times the driving power indicated above. At any frequency, the driving stage should be capable of a power output two to three times the power it is expected the grid circuit of the amplifier will consume. This is necessary because losses in the tank and coupling circuits must also be supplied, and also to provide reasonably good regulation of the r.f. grid voltage. Good voltage regulation (see § 8-1 for general definition) insures that the waveform of the excitation voltage will not be distorted because of the changing load on the driver during the r.f. cycle.

Grid impedance—During most of the r.f. grid-voltage cycle no grid current is flowing, as indicated in Fig. 418, hence the grid impedance is infinite. During the peak of the cycle, however, the impedance may drop to very low values (of the order of 1000 ohms), depending upon the type of tube. Both the minimum and average values of grid impedance depend to a considerable extent on the amplification factor

of the tube, being lower with tubes having large amplification factors.

The average grid impedance is equal to E^2/P , where E is the r.m.s. (§ 2-7) value of r.f. grid voltage and P is the grid driving power. Under optimum operating conditions, values of average grid impedance ranging from 2000 ohms for high- μ tubes to four or five times as much for low- μ types are representative. Values in the vicinity of 4000 to 5000 ohms are typical of modern triodes with amplification factors of 20 to 30.

Because of the large change in impedance during the cycle it is necessary that the tank circuit associated with the amplifier grid have fairly high Q , so that the voltage regulation over the cycle will be good. The requisite Q may be obtained by adjusting the L/C ratio or by tapping the grid circuit across only part of the tank (§ 4-6).

Tank-circuit Q —Besides serving as a means for transforming the actual load resistance to the required value of plate load impedance for the tube, the plate tank circuit also should suppress the harmonics present in the tube output as a result of the non-sinusoidal plate current (§ 2-7, 3-3). For satisfactory harmonic suppression, a Q of 12 or more (with the circuit fully loaded) is desirable. A Q of this order also is helpful from the standpoint of securing adequate coupling to the load or antenna circuit (§ 2-11). The proper Q can be obtained by suitable selection of L/C ratio in relation to the optimum plate load resistance for the tube (§ 2-10).

For a Class-C amplifier operated under optimum conditions as described above, the plate load impedance is approximately proportional to the ratio of d.c. plate voltage to d.c. plate current. For a given effective Q the tank capacity required at a given frequency will be inversely proportional to the parallel resistance (§ 2-10), so that it will also be inversely proportional to the plate-voltage/plate-current ratio. The capacity required on various amateur bands for a Q of 12 is shown in Fig. 419 as a function of this ratio. The capacity given is for single-ended tank circuits, as shown in Fig. 420 at A and B. When a balanced tank circuit is used the total tank capacity required is reduced to one-fourth this value, because the tube is connected across only half the circuit (§ 2-9). Thus, if the plate-voltage/plate-current ratio calls for a capacity of 200 $\mu\text{fd.}$ in a single-ended circuit at the desired frequency, only 50 $\mu\text{fd.}$ would be needed in a balanced circuit. If a split-stator or balanced tank condenser is used each section should have a capacity of 100 $\mu\text{fd.}$, the total capacity of the two in series being 50 $\mu\text{fd.}$ These are "in use" capacities, not simply the rated maximum capacity of the condenser. Larger values may be used with an increase in the effective Q .

To reduce energy loss in the tank circuit, the inherent Q of the coil and condenser should be high. Since transmitting coils usually have Q s

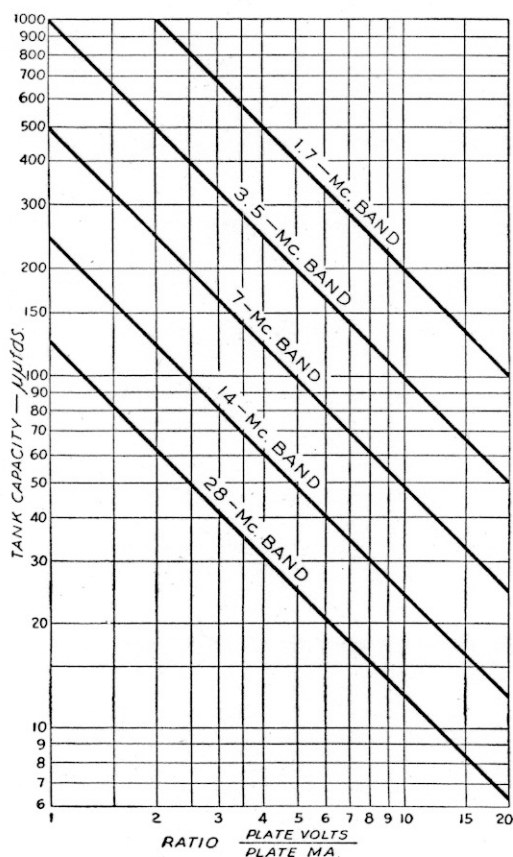


Fig. 419—Chart showing tank capacities required for a Q of 12 with various ratios of plate voltage to plate current, for various frequencies. In circuits F, G, H (Fig. 420), the capacities shown in the graph may be divided by four. In circuits C, D, E, I, J and K, the capacity of each section of the split-stator condenser may be one-half that shown by the graph. The values given by the graph should be used for circuits A and B.

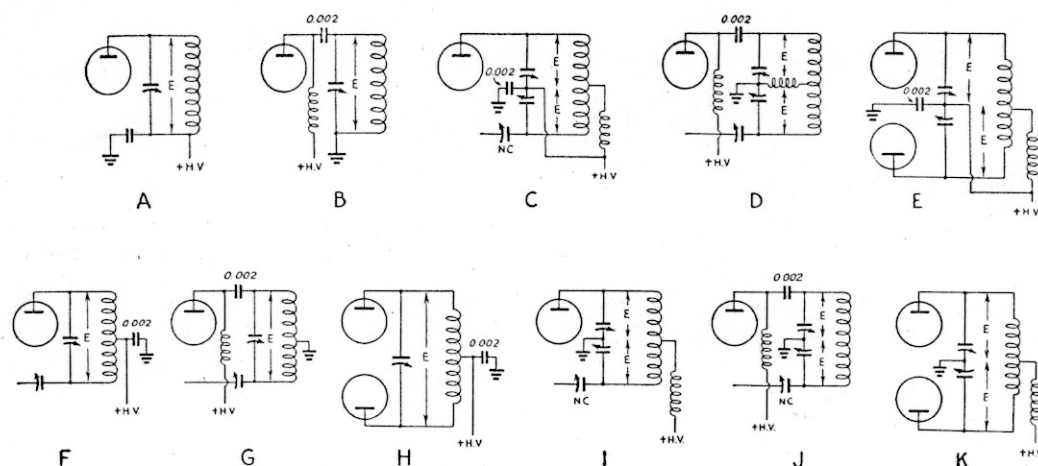


Fig. 420 — In circuits A, B, C, D and E, the peak voltage E will be approximately equal to the d.c. plate voltage applied for c.w. or twice this value for 'phone. In circuits F, G, H, I, J and K, E will be twice the d.c. plate voltage for c.w. or four times the plate voltage for 'phone. The circuit is assumed to be fully loaded. Tubes in parallel in any of the circuits will not affect the peak voltage. Circuits A, C, E, F, G and H require that the tank condenser be insulated from chassis or ground and that it be provided with a suitably insulated shaft coupling for tuning.

ranging from 100 to several hundred, the tank transfer efficiency generally is 90 per cent or more. An unduly large C/L ratio is not advisable since it will result in large circulating r.f. tank current and hence relatively large losses in the tank, with a consequent reduction in the power available for the load.

Tank constants — When the capacity necessary for a Q of 12 has been determined from Fig. 419, the inductance required to resonate at the given frequency can be found by means of the formula in § 2-10. Alternatively, the required number of turns on coils of various construction can be found from the charts of Figs. 421 and 422.

Fig. 421 is for coils wound on receiving-type forms having a diameter of $1\frac{1}{2}$ inches and ceramic forms having a diameter of $1\frac{3}{4}$ inches and winding length of 3 inches. Such coils would be suitable for oscillator and buffer stages where the power is not over 50 watts. In all cases, the number of turns given must be wound to fit the length indicated and the turns should be evenly spaced.

Fig. 422 gives data on coils wound on transmitting-type ceramic forms. In the case of the smallest form, extra curves are given for double spacing (winding turns in alternate grooves). This is sometimes advisable in the case of 14- and 28-Mc. coils when only a few turns are required. In all other cases, the specified number of turns should be wound in the grooves without any additional spacing.

Ratings of components — The peak voltage to be expected between the plates of a tank condenser depends upon the arrangement of the tank circuit as well as the d.c. plate voltage. Peak voltage may be determined from Fig. 420, which shows all of the commonly used tank-circuit arrangements. These estimates assume that the amplifier is fully loaded; the voltage will rise considerably should the amplifier be

operated without load. The figures include a reasonable factor of safety.

The condenser plate spacing required to withstand any particular voltage will vary with the construction. Most manufacturers specify peak-voltage ratings in describing their condensers.

Plate or screen by-pass condensers of $0.001 \mu\text{fd.}$ should be satisfactory for frequencies as low as 1.7 Mc. Cathode-resistor and filament by-passes in r.f. circuits should be not less than $0.01 \mu\text{fd.}$ Fixed condensers used for these purposes should have voltage ratings 25 to 50 per cent greater than the maximum d.c. or a.c. voltage across them.

Interstage coupling condensers should have voltage ratings 50 to 100 per cent greater than the sum of the driver plate and amplifier grid-biasing voltages.

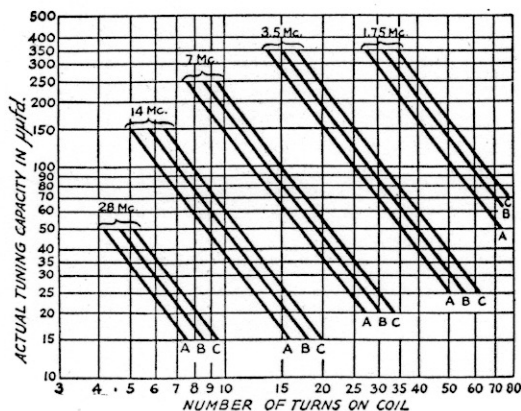


Fig. 421 — Coil-winding data for receiving-type forms, diameter $1\frac{1}{2}$ inches. Curve A — winding length, 1 inch; Curve B — winding length, $1\frac{1}{2}$ inches; Curve C — winding length, 2 inches. Curve C is also suitable for coils wound on $1\frac{3}{4}$ -inch diameter transmitting-type ceramic forms with 3 inches of winding length.

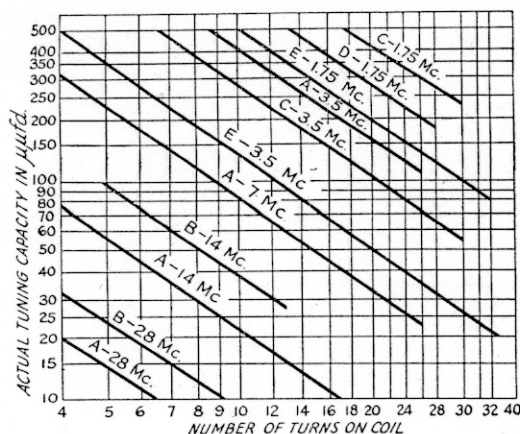


Fig. 422—Coil-winding data for ceramic transmitting-type forms. Curve A—ceramic form 2½-inch effective diameter, 26 grooves, 7 per inch; Curve B—same as A, but with turns wound in alternate grooves; Curve C—ceramic form 2⅞-inch effective diameter, 32 grooves, 7.1 turns per inch, approximately; Curve D—ceramic form 4-inch effective diameter, 28 grooves, 5.85 turns per inch, approximately; Curve E—ceramic form 5-inch effective diameter, 26 grooves, 7 per inch. Coils may be wound with either No. 12 or No. 14 wire.

4-9 Adjustment of Power Amplifiers

Excitation—The effectiveness of adjustments to the coupling between the driver plate and amplifier grid circuits can be gauged by the relative values of amplifier rectified grid current and driver plate current, the object being to obtain maximum grid current with minimum driver loading. The amplifier grid circuit represents the load on the driver, and the average grid impedance must be transformed to the value for optimum driver operation (§ 4-8).

With capacity coupling, either the driver plate or amplifier grid must be tapped down on the driver tank coil, as shown in Fig. 410 at A and B, unless the grid impedance is approximately the right value for the driver plate load, when it will be satisfactory to connect both elements to the end of the tank. If the grid impedance is lower than the required driver plate load, Fig. 410-A is used; if higher, Fig. 410-B. In either case, the coupling which gives the desired grid current with minimum driver loading should be determined experimentally by moving the tap. Should both plate and grid be connected to the end of the circuit it is sometimes possible to control the loading, when the grid impedance is low, by varying the capacity of the coupling condenser, *C*, but this method is not altogether satisfactory since it is simply an expedient to prevent driver overloading without giving suitable impedance matching.

In push-pull circuits the method of adjustment is similar, except that the taps should be kept symmetrically located with respect to the center of the tank circuit.

With link coupling, Fig. 411, the object of adjustment is the same. The two tanks are first tuned to resonance, as indicated by maximum grid current, and the coupling adjusted

by means of the links (§ 4-6) to give maximum grid current with minimum driver plate current. This usually will suffice to load the driver to its rated output, provided the driver plate and amplifier grid tank circuits have reasonable values of *Q*. If the *Q* of one or both of the circuits is too low, it may not be possible to load the driver fully with any adjustment of link turns or coupling at either tank. In such a case, the *Q*s of the tank circuits must be increased to the point where adequate coupling is secured. If the driver plate tank is designed to have a *Q* of 12, the difficulty almost invariably is in the amplifier grid tank. The *Q* can be increased to a suitable value by adjustment of the *L/C* ratio or by tapping the load across part of the coil (§ 2-10).

Whatever the type of coupling, a preliminary adjustment should be made with the proper bias voltage and/or grid leak, but with the amplifier plate voltage off; then the amplifier should be carefully neutralized. After neutralization the driver-amplifier coupling should be readjusted for optimum power transfer, after which plate voltage may be applied and the amplifier plate circuit adjusted to resonance and coupled to its load. Under actual operating conditions the grid current decreases below the value obtained without plate voltage on the amplifier and the effective grid impedance rises, hence the final adjustment is to re-check the coupling to take care of this shift.

With recommended bias, the grid current obtained before plate voltage is applied to the amplifier should be 25 to 30 per cent higher than the value required for operating conditions. If this value is not obtained, and the driver plate input is up to rated value, the reason may be either improper matching of the amplifier grid to the driver plate or simply insufficient power output from the driver to take care of all losses. Driver operating voltages should be checked to assure they are up to rated values. If batteries are used for bias and are not strictly fresh, they should be replaced, since batteries which have been in use for some time often develop high internal resistance which effectively acts as additional grid-leak resistance. If a rectified a.c. bias supply is used, the bleeder or voltage-divider resistances should be checked to make certain that low grid current is not caused by greater grid-circuit resistance than is recommended. In this connection it is helpful to measure the actual bias when grid current is flowing, by means of a high-resistance d.c. voltmeter. There is also the possibility of loss of filament emission of the amplifier tube, either from prolonged service or from operating the filament under or over the rated voltage.

Plate tuning—In preliminary tuning, it is desirable to use low plate voltage to avoid possible damage to the tube. With excitation and plate voltage applied, rotate the plate tank condenser until the plate current dips. Then set the condenser at the minimum plate-current

point (resonance). When the resonance point has been found, the plate voltage may be increased to its normal value.

With adequate excitation, the off-resonance plate current of a triode amplifier may be two or more times the normal operating value. With screen-grid tubes the off-resonance plate current may not be much higher than the normal operating value, since the plate current is principally determined by the screen rather than the plate voltage.

Under reasonably efficient operating conditions the minimum plate current with the amplifier unloaded will be a small fraction of the rated plate current for the tube (usually a fifth or less), since with no load the parallel impedance of the tank circuit is high. If the excitation is low the "dip" will not be very marked, but with adequate excitation the plate current at resonance without loading will be just high enough so that the d.c. plate power input supplies all the losses in the tube and circuit. As an indication of probable efficiency, the minimum plate current value should not be taken too seriously, because

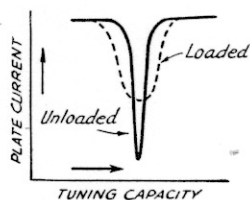


Fig. 423 — Typical behavior of d.c. plate current vs. tuning capacity in the plate circuit of an amplifier.

without load the Q of the circuit is high and the tank current relatively large. When the amplifier is delivering power to a load, the circulating current drops considerably and the tank losses correspondingly decrease. High minimum unloaded plate current is chiefly encountered at 28 Mc. and above, where tank losses are higher and the tank L/C ratio is usually lower than normal because of irreducible tube capacities. The effect is particularly noticeable with screen-grid tubes, which have relatively high output capacity. Because of the decrease in tank r.f. current with loading, however, the actual efficiency under load is reasonably good.

With the load (antenna or following amplifier grid circuit) connected, the coupling between plate tank and load should be adjusted to make the tube take rated plate current, keeping the tank always tuned to resonance. As the output coupling is increased the minimum plate current also will increase, about as shown in Fig. 423. Simultaneously the tuning becomes less sharp, because of the increase in effective resistance of the tank. If the load circuit simulates a resistance, the resonance setting of the tank condenser will be practically unchanged with loading; this is generally the case, since the load circuit usually is also tuned to resonance. A reactive load (such as an antenna or feeder system not tuned exactly to resonance) may cause the tank condenser setting to change with loading, since reactance as well as resistance is coupled into the tank (§ 2-11).

Power output — As a check on the operation of an amplifier, its power output may be measured by the use of a load of known resistance, coupled to the amplifier output as shown in Fig. 424. At A a thermoammeter, M , and a non-inductive (ordinary wire-wound resistors are not satisfactory) resistance, R , are connected across a coil of a few turns coupled to the amplifier tank coil. The higher the resistance of R , the greater the number of turns required in the coupling coil. A resistor used in this way is generally called a "dummy antenna," since its use permits the transmitter to be adjusted without actually radiating power. The loading may readily be adjusted by varying the coupling between the two coils, so that the amplifier draws rated plate current when tuned to resonance. The power output is then calculated from Ohm's Law:

$$P \text{ (watts)} = I^2 R$$

where I is the current indicated by the thermoammeter and R is the resistance of the non-inductive resistor. Special resistance units are available for this purpose, ranging from 73 to 600 ohms (simulating antenna and transmission-line impedances) at power ratings up to 100 watts. For higher powers, the units may be connected in series-parallel. The meter scale required for any expected value of power output may also be determined from Ohm's Law:

$$I = \sqrt{\frac{P}{R}}$$

Incandescent light bulbs can be used to replace the special resistor and thermoammeter. The lamp should be equipped with a pair of leads, preferably soldered to the terminals on the lamp base. The coupling should be varied

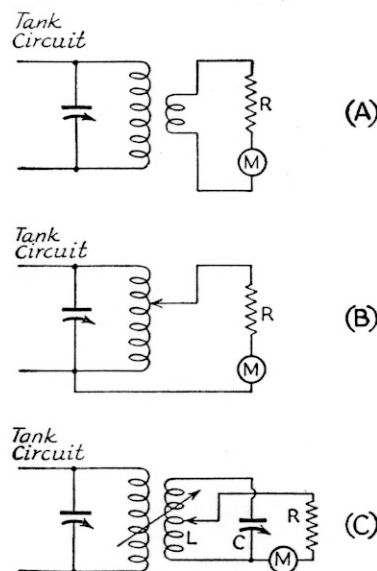


Fig. 424 — "Dummy antenna" circuits for checking power output and making operating adjustments under load without applying power to the actual antenna.

until the greatest brilliance is obtained for a given plate input. In using lamps as dummy antennas a size corresponding to the expected power output should be selected, so that the lamp will operate near its normal brilliancy. Then, when the adjustments have been completed, an approximation of the power output can be obtained by comparing the brightness of the lamp with the brightness of one of similar power rating in a 115-volt socket.

The circuit of Fig. 424-B is for resistors or lamps of relatively high resistance. In using this circuit, care should be taken to avoid accidental contact with the plate tank when the power is on. This danger is avoided by circuit C, in which a separate tank circuit, *LC*, tuned to the operating frequency, is coupled to the plate tank circuit. The loading is adjusted by varying the number of turns across which the dummy antenna is connected on *L* and by changing the coupling between the two coils. With push-pull amplifiers, the dummy antenna should be tapped equally on either side of the center of the tank when the circuit of Fig. 424-B is used.

Harmonic suppression — The most important step in the elimination of harmonic radiation (§ 4-8, 2-12) is to use an output tank circuit having a *Q* of 12 or more. Beyond this it is desirable to avoid any considerable amount of over-excitation of a Class-C amplifier, since excitation in excess of that required for normal Class-C operation further distorts the plate-current pulse and increases the harmonic content in the output of the amplifier even though the proper tank *Q* is used. If the antenna system in use will accept harmonic frequencies they will be radiated when distortion is present, and consequently the antenna coupling system preferably should be selected with harmonic transfer in mind (§ 10-6).

Harmonic content can be reduced to some extent by preventing distortion of the r.f. grid-voltage waveshape. This can be done by using a grid tank circuit with high effective *Q*. Link coupling between the driver and final amplifier are helpful, since the two tank circuits provide more attenuation than one at the harmonic frequencies. However, the advantages of link coupling in this respect may be nullified unless the *Q* of the grid tank is high enough to give good voltage regulation, which minimizes harmonic transfer and thus prevents distortion in the grid circuit.

The stray capacity between the antenna coupling coil and the tank coil may be sufficient to couple harmonic energy into the antenna system. This coupling may be eliminated by the use of electrostatic shielding (*Faraday shield*) between the two coils. Fig. 425 shows the construction of such a shield, while Fig. 426 illustrates the manner in which it is installed. The construction shown in Fig. 425 prevents current flow in the shield, which would occur if the wires formed closed circuits since the shield is in the magnetic field of the tank coil.

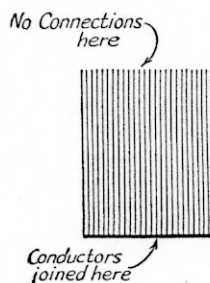


Fig. 425 — The Faraday electrostatic shield for eliminating capacitive transfer of harmonic energy. It is made of parallel conductors, insulated from each other except at one end where all are joined. Stiff wire or small diameter rod may be used, spaced about the diameter of the wire or rod.

Should this occur, there would be magnetic shielding as well as electrostatic; in addition, there would be a power loss in the shield.

Improper operation — Inexact neutralization or stray coupling between plate and grid circuits may result in regeneration. This effect is most evident with low excitation, when the amplifier will show a sudden increase in output when the plate tank circuit is tuned slightly to the high-frequency side of resonance. It is accompanied by a pronounced increase in grid current.

Self-oscillation is apt to occur with tubes of high power sensitivity, such as the r.f. pentodes and tetrodes. In event of either regeneration or oscillation, circuit components should be arranged so that those in the plate circuit are well isolated from those of the grid circuit. Plate and grid leads should be made as short as possible and the screen should be by-passed as close to the socket terminal as possible. A cylindrical shield surrounding the lower portion of the tube up to the lower edge of the plate is sometimes required.

"Double resonance," or two tuning spots on the plate-tank condenser, one giving minimum plate current and the other maximum power output, may occur when the tank circuit *Q* is too low (§ 2-10). A similar effect also occurs at times with screen-grid amplifiers when the screen-voltage regulation (§ 8-1) is poor, as when the screen is supplied through a dropping resistor. The screen voltage decreases with an increase in plate current, because the screen current increases under the same conditions. Thus the minimum plate-current point causes the screen voltage, and hence the power output, to be less than when a slightly higher plate current is drawn.

A phenomenon known as "grid emission" may occur when the amplifier tube is operated at higher than rated power dissipation on either the plate or grid. It is particularly likely to occur with tubes having oxide-coated cathodes, such as the indirectly heated types. It is caused by the grid reaching a temperature high enough to cause electron emission (§ 2-4). The electrons so emitted are attracted to the plate, further increasing the power input and heating, so that grid emission is characterized by gradually increasing plate current and heat which eventually will ruin the tube if the power is not removed. Grid emission can be prevented by operating the tube within its ratings.

4-10 Parasitic Oscillations

Description — If the circuit conditions in an oscillator or amplifier are such that self-oscillation exists at some frequency other than that desired, the spurious oscillation is termed *parasitic*. The energy required to maintain a parasitic oscillation is wasted so far as useful output is concerned, hence an oscillator or amplifier having parasitics will operate at reduced efficiency. In addition, its behavior at the operating frequency often will be erratic. Parasitic oscillations may be either higher or lower in frequency than the operating frequency.

The parasitic oscillation usually starts the instant plate voltage is applied, or, when the amplifier is biased beyond cut-off, at the instant excitation is applied. In the latter case, the oscillation frequently will be self-sustaining after the excitation has been removed. At other times the oscillation may not be self-sustaining, becoming active only in the presence of excitation. It may be apparent only by the production of abnormal key clicks (§ 6-1) over a wide frequency range, or by the presence of spurious side-bands (§ 5-2) with 'phone modulation.

Low-frequency parasitics — Parasitic oscillations at low frequencies (usually 500 kc. or less) are of the tuned-plate tuned-grid type, the tuned circuits being formed by r.f. chokes and associated by-pass and coupling condensers, with the regular tank tuning condensers having only a minor effect on the oscillation. The operating-frequency tank coil has negligible inductance for such low frequencies and may be short-circuited without affecting the oscillations. The oscillations do not occur when no r.f. chokes are used, hence whenever possible in series-fed circuits such chokes should be omitted. With single-ended amplifiers, it is usually possible to arrange the circuit so that either the grid or plate circuit needs no choke. In push-pull stages, where chokes must be used in both plate and grid circuits, it is helpful to connect an unby-passed grid leak from the choke to the bias supply or ground, thus placing the resistance in the parasitic circuit and tending to prevent oscillation. When the driver plate circuit has parallel feed and the amplifier grid circuit series feed (§ 3-7) this type of oscillation cannot occur if no choke is used in the series grid circuit, since the grid is grounded through the tank coil for the parasitic frequency.

Parasitics near operating frequency — In circuits utilizing a tap on the plate tank coil to establish a ground for a balanced neutralizing circuit, such as Fig. 413-B, a parasitic oscillation may be set up if the amplifier grid is tapped down on the grid (or driver plate) tank circuit for adjustment of driver-amplifier

coupling (§ 4-6). In this case the turns between grid and ground and between plate and ground form, with the stray and other capacities present, a t.p.t.g. circuit (§ 3-7) which oscillates at a frequency somewhat higher than the nominal operating frequency. Such an oscillation can be prevented by dispensing with the taps in either the plate or grid circuit. Balancing the plate circuit by means of a split-stator condenser (Fig. 413-C) is recommended.

Very-high-frequency parasitics — Parasitics in the v.h.f. region are likely to occur with any amplifier having a balanced tank circuit, particularly when associated with neutralizing connections. The parasitic circuit, formed by leads connecting the various components, may be either the t.p.t.g. or ultraudion type.

The frequency of such oscillations may be determined by connecting a tuned circuit in series with the grid lead to the tube. A variable condenser (50 or 100 $\mu\text{fd.}$) may be used, in conjunction with three or four self-supporting turns of heavy wire wound into a coil an inch or so in diameter. With the amplifier oscillating at the parasitic frequency, the condenser is slowly tuned through its range until oscillations cease. If this point is not found on the first trial, the turns of the coil may be spread apart or a turn removed and the process repeated. The use of such a tuned circuit as a trap is an almost certain remedy if the frequency can be determined, and introduces little if any loss at the operating frequency.

An alternative cure, which is feasible when the oscillation is of the t.p.t.g. type, is to detune the parasitic circuit in either the plate or grid circuit. Since this type of oscillation occurs most frequently with push-pull amplifiers, it may often be cured by making the grid and plate leads to their respective tank circuits of considerably different length. Similar considerations apply to neutralizing connections in push-pull circuits. The extra wire length may be coiled up in the form of a so-called "choke," which in this case is simply additional inductance for detuning the parasitic circuit.

Testing for parasitic oscillations — An amplifier always should be tested for parasitic oscillations before being considered ready for service. The preferable method is first to neutralize the amplifier, then apply sufficient fixed bias to permit a moderate value of plate current to flow without excitation. (The plate current should not be large enough to cause the power input to exceed the rated plate dissipation of the tube.) If the amplifier is free from self-starting parasitics, the plate current

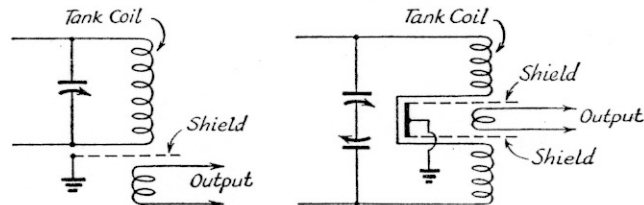


Fig. 426 — Methods of using the Faraday shield. Two are required with a push-pull or balanced tank circuit. The shield should be larger than the diameters of the coupled coils and placed between them so each is isolated from the other.

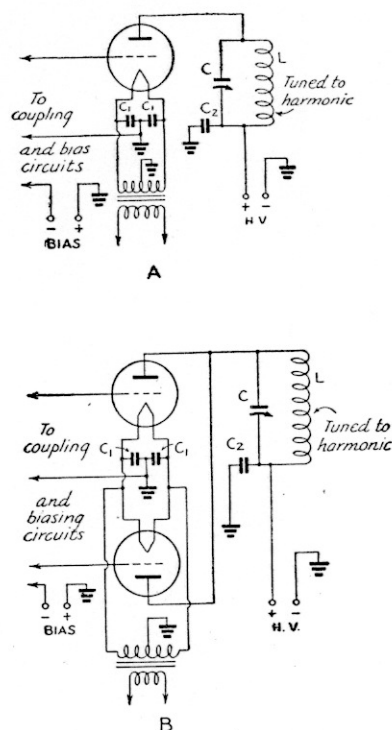


Fig. 427—Frequency-multiplying circuits. A is for triodes, used either singly or in parallel. The push-push doubler is shown at B. Any type of coupling may be used between the grid circuit and the driver. C_1 should be 0.01 μ fd. or larger; C_2 , 0.001 μ fd. or larger

will remain steady as the tank condensers are varied; also, there will be no grid current and a neon bulb touched either to the plate or grid will show no glow. Care must be used not to let the hand come in contact with any metal parts of the transmitter in using the neon bulb.

If any of these effects are present, the frequency of the parasitic must first be determined. If r.f. chokes are used in both the plate and grid circuits, one of them should be short-circuited to determine if the oscillation is at a low frequency; if so, it may be eliminated by the methods outlined above. If the test indicates that the parasitic is not a low-frequency oscillation, the grid trap described above should be tried for the v.h.f. type. The type which occurs near the operating frequency will not exist unless the plate and grid tank coils are both tapped, hence may be eliminated from consideration if this is not the case in the circuit used. When such an oscillation is present its existence can be detected by moving the grid tap to include the whole tank circuit, whereupon the oscillation will cease.

Some indication of the frequency of the parasitic can be obtained from the color of the glow in the neon bulb. Usually it will be yellowish with low-frequency oscillations and violet with v.h.f. oscillations.

If the amplifier is stable under the conditions described above, excitation should be applied and then removed to ascertain if a self-

sustaining oscillation is set up with excitation. If the plate current does not return to the previous value when the excitation is cut off, the same tests should be applied to determine the parasitic frequency.

As a final test, the transmitter should be put on the air and a nearby receiver tuned over as wide a frequency range as possible to locate any off-frequency signals associated with the radiation. Parasitics usually can be recognized by their poor stability as contrasted to the normal harmonics, which will have the same stability as the fundamental signal as well as the usual harmonic relationship. Harmonics should be quite weak compared to the fundamental frequency, whereas parasitic oscillations may have considerable strength.

4-11 Frequency Multiplication

Circuits—A frequency multiplier is an amplifier having its plate tank circuit tuned to a multiple (harmonic) of the frequency applied to its grid. The difference between a straight amplifier (§ 4-1) and a frequency multiplier is in the way in which it is operated, rather than in the circuit. However, since the grid and plate tank circuits are tuned to different frequencies a triode frequency multiplier will not self-oscillate, hence does not need neutralization. A typical circuit arrangement is shown in Fig. 427-A. For screen-grid multipliers, the circuit is the same as in Fig. 412-A. Under usual conditions the plate efficiency of a frequency multiplier drops off rapidly with an increase in the number of times the frequency is multiplied. For this reason most multipliers are used as *frequency doublers*, giving second harmonic output.

A special circuit for frequency doubling ("push-push" doubler) is shown in Fig. 427-B. The grids of the tubes are in push-pull and the plates in parallel, thus the plate tank receives two pulses of plate current for each cycle of excitation frequency. The circuit is similar to the full-wave rectifier (§ 8-3) where the ripple frequency is twice the applied frequency.

Push-pull amplifiers are suitable for frequency multiplication at odd harmonics, but are unsuited to even harmonic multiplication because the even harmonics are largely balanced out in the tank circuit (§ 3-3).

Operating conditions and circuit constants—To obtain good efficiency the operating angle at the harmonic frequency must be 180 degrees or less, preferably in the vicinity of 150–120 degrees (§ 4-8). In a doubler, this means that plate current should flow during only half this angle of fundamental frequency. Consequently the r.f. grid voltage, operating bias, and grid driving power must be increased considerably beyond the values obtaining for normal Class-C amplification. For comparable plate efficiency the bias will ordinarily be four to five times the normal Class-C bias, and the r.f. grid voltage must be considerably larger to drive the tube to the same peak plate cur-

rent. Since the plate and grid current pulses under these conditions have the same peak amplitudes but only half the time duration as in a straight amplifier, the average d.c. values should be one-half those for normal Class-C operation. That is, a tube operated in this way will have the same plate efficiency as a Class-C amplifier but can be operated at only half the plate input, so that the output power also is halved. The driving power required usually is about twice that for straight-through amplification with the same plate efficiency.

Greater output can be secured by using a larger operating angle (lower grid bias) or lower plate load resistance to increase the plate current, but this is accompanied by a decrease in efficiency. Since operation described in the preceding paragraph is below the maximum plate dissipation rating of the tube, decreased efficiency usually can be tolerated in the interests of securing more power output. In practice, an efficiency of 40 to 50 per cent is average.

The tank circuit should have reasonably high Q (12 is satisfactory) to give good output voltage regulation (§ 4-9), since a plate-current pulse occurs only once every two cycles of output frequency. A low- Q circuit (high L/C ratio) is helpful chiefly when the operating angle is greater than 180 degrees at the second harmonic. Such a tank circuit will have relatively high impedance to the fundamental-frequency component of plate current which is present with large operating angles, and thus aid in reducing the average d.c. plate current.

The grid impedance of a frequency multiplier is considerably higher than that of a straight amplifier, because of the high bias voltage. The average impedance can be calculated as previously described (§ 4-8). The L/C ratio of the grid tank circuit may be higher, therefore, for a given Q . Often it is advantageous to use a fairly high ratio, since a large r.f. voltage must be developed between grid and cathode, so long as it is not made too high (Q too low) to permit adequate coupling between the grid tank circuit and the driver stage. It may be necessary to step up the driver output voltage to obtain sufficient r.f. grid voltage for the doubler; this may be done by tapping the driver plate on its tank circuit, when capacity coupling is used, or by similar tapping or use of a higher C/L ratio in the driver plate tank when the stages are link-coupled (§ 4-6).

Tubes for frequency multiplication — There is no essential difference between tubes of various characteristics in their performance as frequency doublers. Tubes having high amplification factors will require somewhat less bias for equivalent operation but the grid driving power needed is almost independent of the μ , assuming tubes of otherwise similar construction and characteristics. Pentodes and tetrodes will, as in normal amplifier operation, require less driving power than triodes for efficient doubling, although more power will be needed than for straight amplification.

4-12 Very-High-Frequency Oscillators

Linear circuits — At very high frequencies tube interelectrode capacities become of increasing importance, so that eventually the inductance of the shortest possible straight wire connection between elements, in conjunction with internal leads and capacities, represents the highest possible frequency to which the tube can be tuned. The tube usually will not oscillate up to this limit because of dielectric losses in the seals and other loading effects (§ 7-6). With most small tubes of ordinary construction, the upper limit of oscillation is in the region of 150 Mc.; for higher frequencies, special v.h.f. tubes having low interelectrode capacities and low internal lead inductance are used. Only a few types are capable of developing more than a few watts at 300 Mc. and higher.

Although ordinary coil and condenser tank circuits can be used at frequencies as high as 112 Mc., the Q of such circuits is low at very-high frequencies because of increased losses, so that both stability and efficiency are poor. For this reason special tank circuits of the linear type (§ 2-12) are preferable. These may be any multiple of a quarter wave in length, the stability increasing with the number of quarter waves. The quarter-wave line is more generally used, however, because of the considerable space required for longer lines. At 112 Mc. it is also possible to build high- Q tank circuits with lumped constants, not in the form of ordinary coils and condensers but with large conducting surfaces to reduce resistance.

The oscillator circuits used are the same in principle as on the lower frequencies (§ 3-7), although frequently modified considerably to compensate for inherent capacities and inductances which are negligible at lower frequencies.

Two-conductor lines — The quarter-wave two-conductor open line is equivalent to a resonant circuit (§ 2-12) and can be used as the tank circuit (§ 3-7) in an oscillator. It should be used as a balanced circuit to avoid unequal

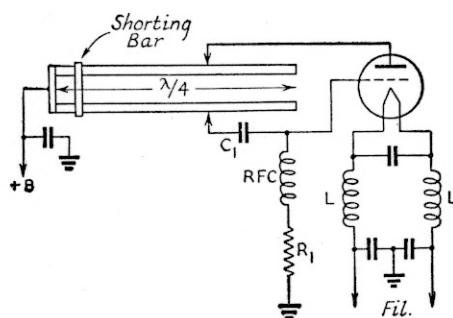


Fig. 428 — Single-tube line oscillator. The grid condenser, C_1 , may be 50 $\mu\text{fd.}$; grid leak, R_1 , 5000 to 50,000 ohms depending upon the type of tube. The choke, RFC , will in general consist of relatively few turns (20 to 50) wound to a diameter of $\frac{1}{4}$ inch, although dimensions will change considerably with the frequency. Bypass condensers should be small in physical size, to reduce lead inductance; 500 $\mu\text{fd.}$ is a satisfactory value.

currents in the two conductors and consequent loss of Q because of radiation.

A typical oscillator circuit of the ultraudion type is shown in Fig. 428. The resonant line is usually constructed of copper tubing to reduce resistance and provide a mechanically stable circuit. The line should be approximately a quarter-wavelength long. Frequency can be changed by moving the shorting bar to change its effective length.

The tube elements preferably should be tapped down on the line, as shown, to reduce the loading effect and thus prevent an undue decrease in Q . These taps should be close to the shorted end of the line, since the frequency stability will be better under these conditions.

The coils in the filament circuit (L) are frequently required at 112 Mc. and higher to compensate for the effects of the inductance of connecting leads, which in many cases are long enough to cause appreciable phase shift (§ 2-7). The effective length of the filament circuit should be approximately $\frac{1}{2}$ wavelength, to bring the filament to the same potential as the shorted ends of the lines. The proper inductance must be determined by experiment, the coils being adjusted for optimum stability and power output.

The oscillation frequency also may be adjusted by connecting a low-capacity variable condenser across the open end of the line. The added capacity makes it necessary to shorten the line considerably for a given frequency, however, and this, together with the additional loss in the condenser, causes a marked decrease in the Q of the line. These effects will be less if the condenser is connected down on the line rather than at the open end. Tapping down also gives greater bandspread effect (§ 7-7).

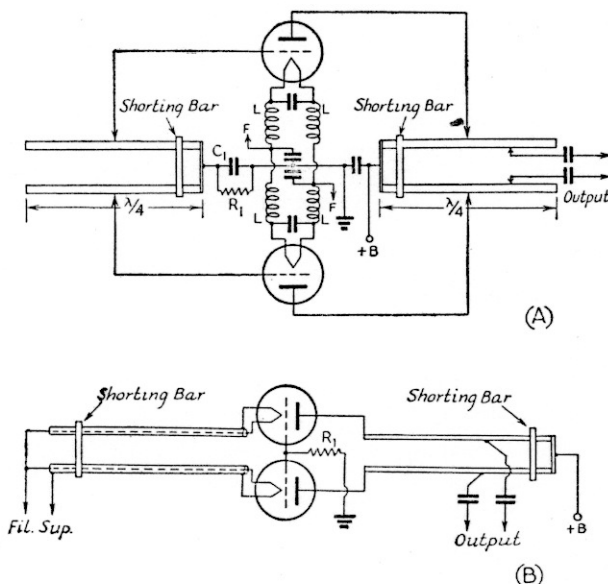


Fig. 429 — Push-pull line oscillators. See Fig. 428 for constants.

Push-pull oscillators — It is often advantageous to use a push-pull oscillator circuit at very-high frequencies, not only as a means to secure more power output than can be obtained from one tube but also because better circuit symmetry is possible with open lines. Fig. 429 shows a typical push-pull circuit of the t.p.t.g. (§ 3-7) type. The grid line is usually operated as the frequency-controlling circuit, since it is not associated with the load and hence its Q can be kept high. The same adjustment considerations apply as in the case of the single-tube oscillator described in the preceding paragraph. The grid taps in particular should be tapped down as far as possible, thus improving the frequency stability.

It is also possible to use a linear tank in the grid circuit for frequency control, in conjunction with a conventional coil-condenser tank in the plate circuit where the lower Q does not have so great an effect on the stability.

Fig. 429-B shows a push-pull oscillator having tuned plate and cathode circuits, using linear tanks for each. The grids are connected together and grounded through the grid leak, R_1 ; ordinarily no by-pass condenser is needed across R_1 . This circuit gives good power output at very-high frequencies, but is not especially stable unless the plates are tapped down on the plate tank circuit to avoid too great a reduction in Q . Tapping on the cathode line is not feasible for mechanical reasons, since one filament lead must be brought through the tubing in order to maintain both sides of the filament at the same r.f. potential.

Concentric-line circuits — At frequencies in the neighborhood of 300 Mc., radiation (§ 2-12) from the open line becomes so serious that the Q is greatly reduced. This is because the conductor spacing represents an appreciable fraction of the wavelength. Consequently, at these frequencies the concentric line must be used. In this type the field is confined inside the line, so that radiation is negligible. There is a further advantage in that the outside of the line is "cold"; that is, no r.f. potentials develop between points on the outer surface. While the concentric line also is advantageous at lower frequencies, because it is more complicated to construct and adjustments are more difficult the open lines are generally favored.

The concentric line usually is constructed of copper pipes arranged concentrically and short-circuited at one end. The optimum ratio of inner diameter of the outer conductor to the outer diameter of the inner conductor is 3.6. Taps may be made on the inner conductor and brought through a hole in the outer conductor to the tube element, as shown in Fig. 430. The tube loads the line in the same way as described in the preceding par-

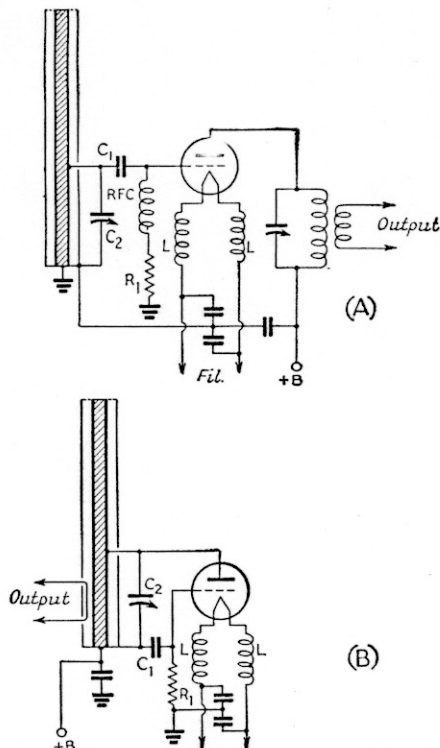


Fig. 430 — Concentric-line oscillator circuits. The line, usually made of tubular conductors, is shown in cross-section. See Fig. 428 and the text for circuit constants.

agraphs, hence the length is generally shorter than an actual quarter wavelength. The length can be adjusted by a sliding short-circuiting disc at the closed end, a close fit and low-resistance contact being necessary to avoid reduction of the Q . It is also possible to make the inner conductor a pair of close-fitting concentric tubes, so that one may be slid in or out of the other to change the effective conductor length.

The circuit of Fig. 430-A is a t.p.t.g. (§ 3-7) oscillator, using the concentric line in the grid circuit for frequency control. An ordinary coil-condenser tank is shown in the plate circuit, but a linear tank may be substituted. The filament inductances have the same function as in the preceding circuits. The ultraudion circuit is shown at B; the same considerations apply. In this case, the output is taken from the line inductively by means of the half-turn "hairpin" shown; coupling can be changed to some extent by varying the position of the hairpin. Both circuits may be tuned by means of the small variable condenser, C_2 , although this condenser may be omitted and the tuning accomplished by changing the line length.

For ease of construction, the concentric line sometimes is modified into a "trough," in which the cross-section of the outer conductor is in the shape of a square U, one side being left open for tapping and adjustment of the inner conductor. Some radiation takes place with this type of construction, although not so much as with open lines.

High- Q circuits with lumped constants —

To obtain reasonably high effective Q when a low resistance is connected across the tank circuit, it is necessary to use a high C/L ratio and a tank of inherently high Q (§ 2-10). At low frequencies the inherent Q of any well-designed circuit will be high enough so that it may be neglected in comparison to the effective Q when loaded, so that no special precautions have to be taken with respect to the resistance of coils and condensers. At the very-high frequencies these internal resistances are too large to be ignored, and a reduction of the L/C ratio will not increase the effective Q unless the internal resistance of the tank can be made very small. The reduction in resistance can be brought about by use of large conducting surfaces and elimination of radiation. In such cases, the inductance and capacity are generally built as a unit; several arrangements are possible, one being shown in Fig. 431. The tank circuit consists of a rod A (the inductance) inside two concentric cylinders, B and C , which form a two-plate condenser, one plate being connected to each end of the inductance. The resonant frequency is determined by the length and diameter of A , and the length, diameter and spacing of B and C . The oscillator shown uses the tickler circuit (§ 3-7), with the feed-back coil in the grid circuit; this inductance is the wire D in the diagram. Output is taken from the tank circuit by means of a hairpin coupling coil. Such a tank circuit also may be used in the ultraudion circuit, replacing the concentric line in Fig. 430-B. A variable condenser may be connected across the tank for tuning, if desired, although the Q may be reduced if a considerable portion of the tank r.f. current flows through it.

This type of circuit actually has lumped constants only when the length is small (10 per cent or less of the wavelength). At greater lengths it tends to act as a linear circuit, eventually evolving into the concentric line.

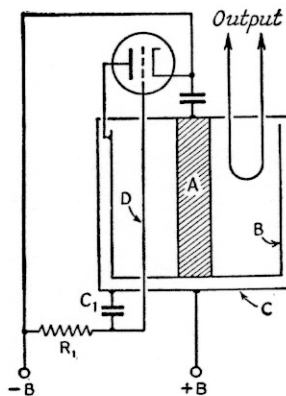


Fig. 431 — High- Q lumped-constant tank circuit in a v.h.f. oscillator. This drawing shows a cross-section of the tank, which is usually built of concentric cylinders. C_1 and R_1 are the grid condenser and leak, respectively. See Fig. 428 and text for discussion of circuit constants.