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Electronic Oscillators

Part 4: VHF and UHF Oscillator Circuits

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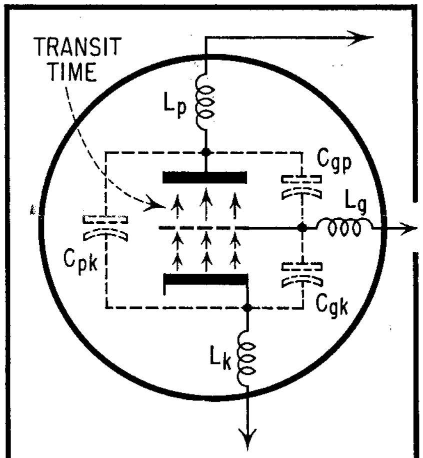
The last decade has seen a vast development of the frequencies above 30 mc, particularly the VHF (30-300 mc) and UHF (300-3,000 mc) ranges. The most important influences in this development have been radar, aircraft communications, and FM and TV broadcast services. In all these, oscillators play a vital role. This article discusses the features of oscillators designed for operation in these ranges and using vacuum tubes of conventional design.

Special Problems at Higher Frequencies

Vacuum tubes of conventional (although sometimes somewhat modified) design are now being used in commercially-available equipment as oscillators operating as high as 1,000 mc and above. However, successful operation in the VHF and UHF regions of the spectrum requires that certain difficulties be overcome. These difficulties arise from vacuum tube factors, and circuit factors, which, although not noticeable at low frequencies, take on special significance in the higher frequency ranges. Figure 1 illustrates these factors, which are, as far as the tube itself is concerned, transit time, lead inductance, and interelectrode capacitance. These electrical tube factors are discussed first, followed by additional important circuit and physical factors.

Transit time is the time it takes an electron in the tube's electron stream to travel from cathode to plate. If this transit time is appreciable compared to the period of 1 cycle at the desired frequency of oscillation, it is extremely difficult to sustain oscillation. This is because, as the transit time approaches the period of 1 cycle, the phasing between plate and grid voltages is affected in such a way as to introduce the effect of *shunting resistance* (conductance) between grid and cathode. Since all or part of the tuned circuit is connected or coupled between grid and cathode, the oscillating circuit is adversely loaded by this resistance effect. An undue amount of power may thus be dissipated, and in severe cases (higher frequencies and unsuitable tubes) sufficient energy cannot be fed back to sustain oscillation. Many tubes which have input impedances as high as 5 to 20 megohms at low frequencies (below 3 mc) have values as low as 20 to 200 ohms at 500 mc and higher.



TUBE FACTORS WHICH BECOME ESPECIALLY IMPORTANT AT HIGH FREQUENCIES

FIG. 1

Transit time is obviously a function of the spacing between the cathode and the plate of the tube; the greater the spacing, the longer it takes for the electrons to traverse the span. It is also a function of the relative grid-to-cathode spacing, since the effect on the *relation between* the grid and the plate is important. The G_m (transconductance) of the tube, which of course is influenced by these spacings, also affects transit-time. The conductance, which is the harmful effect, resulting from transit time, is directly proportional to G_m and inversely proportional to the *square* of the frequency. However, the G_m must be kept high to support oscillation and provide stability, so the transit time must be kept down by minimizing spacings and interelectrode capacitance. An increase in plate voltage reduces transit time by speeding up the electron stream, but increasing plate voltage over its rated value is likely to overload the tube, and so is not a satisfactory method.

The magnitude of the effect of transit time on input loading can be gauged from the following expression:

$$G_g = KG_m f^2 T^2$$

where:

G_g = grid input conductance due to transit time.

G_m = tube transconductance.

f = frequency of oscillation.

T = transit time from cathode to grid.

K = constant depending on tube construction.

Although this expression is derived for a negative grid, it is just as useful qualitatively in the case of an oscillator.

Note that the input conductance increases (resistance decreases) with the *square* of the frequency. Thus the input resistance of a tube at 100 mc can be expected to be only one ten-thousandth of its value at 1 mc.

Lead inductance the self-inductance of the wire connecting each tube element to its corresponding pin, cap or connector. At high frequencies it represents an appreciable *reactance* between the tube elements and the external oscillator circuit.

In the conventional grounded-cathode oscillator circuits, cathode lead inductance is of particular importance. The reason for this is illustrated in Fig. 2(A). The cathode lead inductance L_k is in series with both the plate and the grid r-f return circuits. It therefore develops a feedback voltage E which is degenerative, the same as in the case of an unbypassed cathode resistor in an audio amplifier. At high enough frequencies, the degenerative effect seriously interferes with oscillation. The presence of cathode lead inductance (L_k) causes the effective voltage between grid and cathode of the tube to have a different phase angle than that of the externally-applied voltage. The difference is due to the feedback voltage across L_k due to plate current. The result is a conductance component in input admittance which adds to the conductance due to the transit time.

It has been shown that input conductance due to L_k is

$$G_g = \omega^2 G_m L_k C_{gk}$$

where:

G_g = input conductance due to L_k.

ω = angular velocity of oscillation ($2\pi f$)

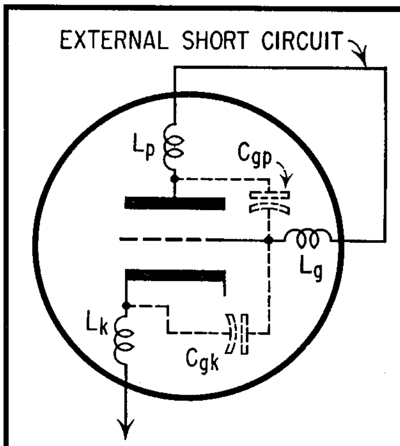
G_m = tube transconductance.

L_k = cathode lead inductance.

C_{gk} = grid-cathode interelectrode capacitance.

Bad effects also result from inductances of other leads, as is discussed later in this article.

To reduce the effect of lead inductance, many tubes designed for high frequency use are supplied with two or more leads and external connections from the same element. The two or more leads can then be connected together right at the socket. This connects the lead inductances in parallel, thus reducing the total lead inductance effect to the inductance of one lead divided by the number of leads so connected. This is illustrated for a cathode lead in Fig. 2(B).



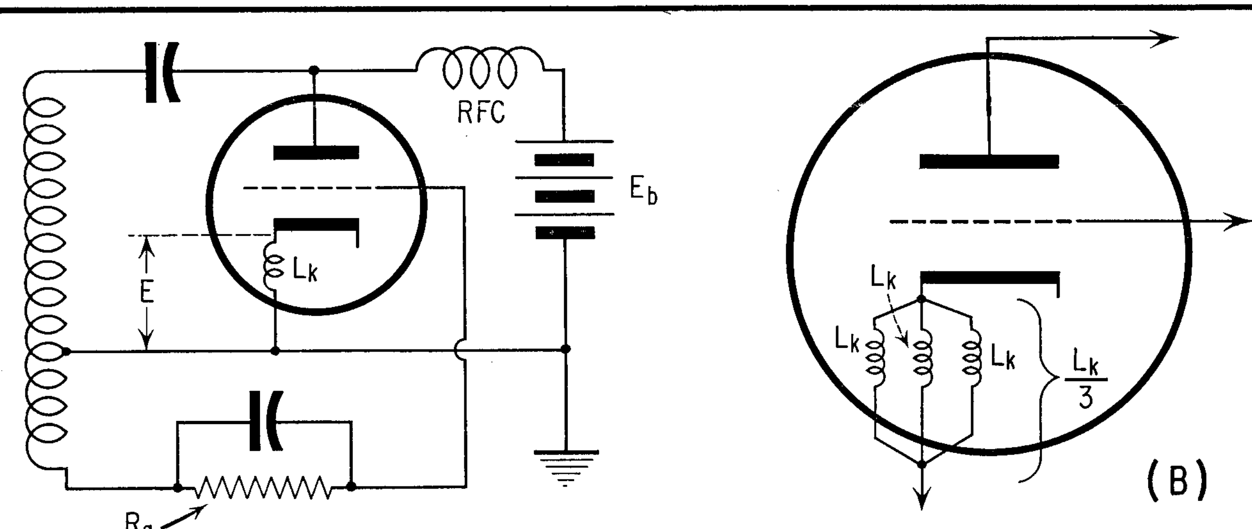
LIMIT OF HIGHEST FREQUENCY BY LEAD INDUCTANCE AND INTER-ELECTRODE CAPACITANCE

FIG. 3

Interelectrode capacitances have a shunting effect due to their relatively low reactance value at high frequencies. The charging current through these capacitances results in power loss in the resistance of the circuit and adds to the power loss in the dielectric, which is the insulating material of the tube.

Limitation by Tube of Minimum Tuned Circuit Size

The oscillation frequency is determined not by the external tuned circuit constants alone, but by the



(A) EFFECT OF CATHODE LEAD INDUCTANCE

THREE LEADS FROM CATHODE COMBINE TO FORM REDUCED EFFECTIVE L_K

FIG. 2

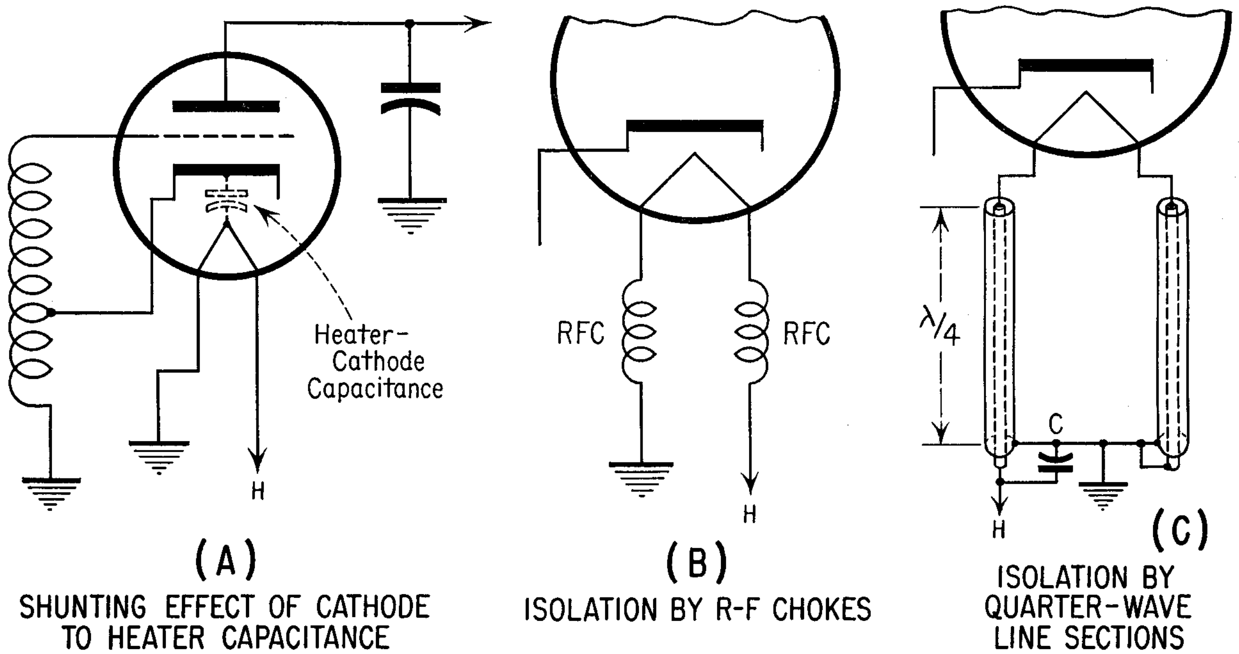


FIG. 4

external tuned circuit plus the lead inductance and interelectrode capacitances of the tube. The combined effective tuned circuit thus reaches an irreducible minimum size (and maximum resonant frequency) when the external tank is replaced by a direct short circuit. The effective tuned circuit is then composed of the lead inductances and the interelectrode capacitance, as illustrated in Fig. 3. Since nothing further can be done to decrease inductance or capacitance, the tube has reached its upper frequency limit even though transit time might allow it to operate at a higher frequency.

Thus, if a tube is to oscillate at a very high frequency, its lead inductance and interelectrode capacitance must be small enough to allow resonance with some sort of external tuned circuit. Preferably, the plate, grid and cathode must be located so that a high frequency tuned circuit can be directly connected without intervening leads.

Triodes are by far the most popular tube type for high frequency oscillators, because of their low interelectrode capacitance. Types with the highest G_m are of course the most suitable. As has been previously explained, having several leads from each of the active elements is also helpful.

Influence of Circuit Construction on High Frequency Operation

Even when the vacuum tube is properly chosen, high frequency op-

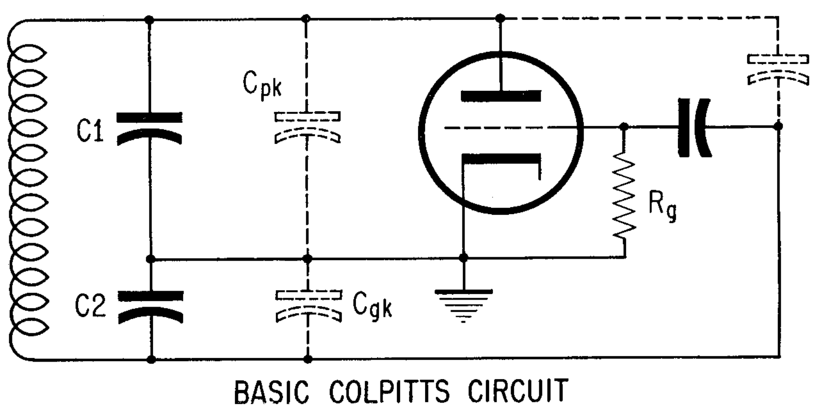


FIG. 5

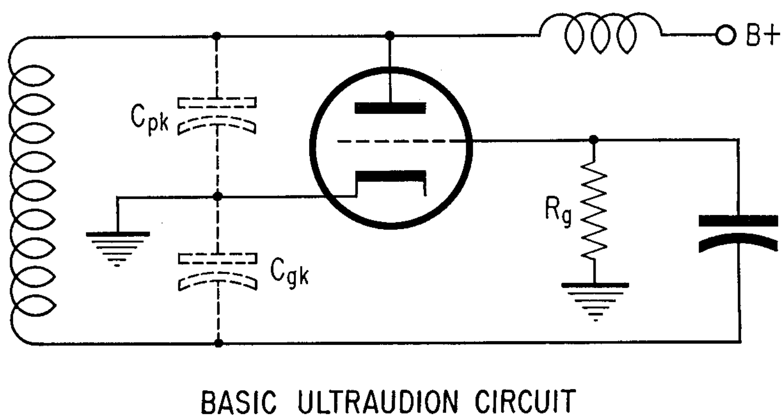
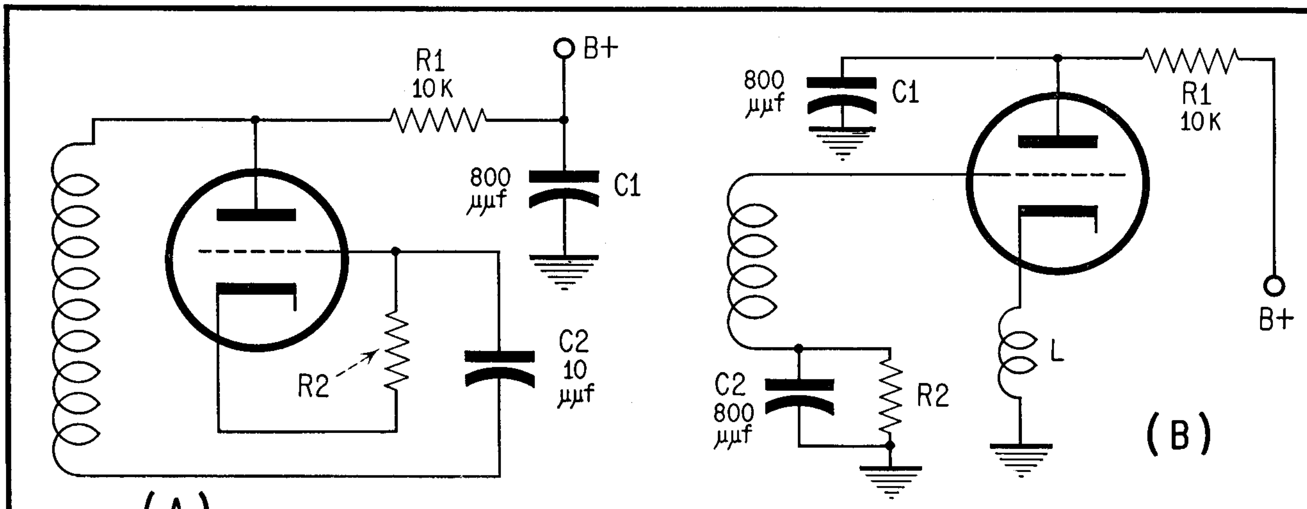


FIG. 6



ULTRAUDION CIRCUITS USED IN TV RECEIVERS

FIG. 7

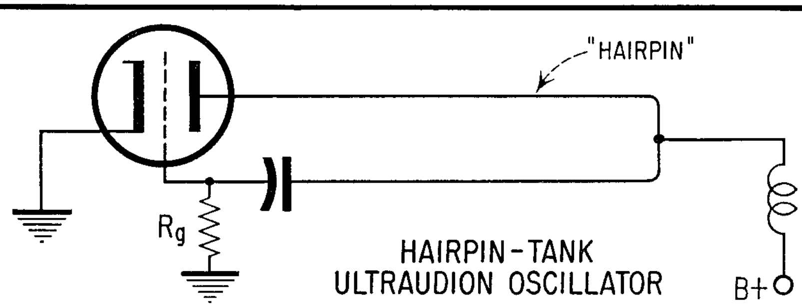
eration may be adversely affected by the character and construction of the circuit.

All kinds of circuit losses increase rapidly with frequency, and, if not properly controlled, may keep feedback from being sufficient to support oscillation. Wiring must be direct and of heavy-guage wire to combat skin effect, wherever r-f current flows. Any' points of r-f voltage should be either suspended in air or mounted on low-loss material such as polystyrene or polyethylene. Although chassis grounding should be as direct as possible, it should all be done at one point in each circuit, to prevent bad effects of r-f currents in the chassis. Soldered connections must be the best possible; any tendency toward a "cold joint" or "rosin joint" can introduce extreme losses and may prevent oscillation.

Operating the Heater at Cathode R-F Potential

The construction of modern vacuum tubes is such that there is an appreciable capacitance between the heater and the cathode (2 to 10 uuf). Thus, in circuits in which the cathode is operated above ground, serious shunting of the cathode can occur through this capacitance to the grounded heater, as shown in Fig. 4. This can be overcome by isolating the heater from ground as far as r-f is concerned, and operating it in the tube at the same r-f potential as the cathode. One way of doing this is shown at (B) in Fig. 4. An r-f choke is connected in each heater lead; the cathode r-f voltage can build up across the reactance of each choke, although the 60-cps alternating current for the heater is allowed to pass.

Another arrangement is shown in Fig. 4(C). Here the heater is isolated from r-f ground by means of a quarter-wave resonant transmission line section in each lead. Both line sections are short-circuited to r-f at the bottom (one directly, the other through capacitor C). This means that there is a high impedance at the other end between the inner conductor and the grounded outer conductor. The heater leads are fed through these inner conductors and are thus at a high impedance to ground, thus preventing shunting of the cathode.



HAIRPIN-TANK
ULTRAUDION OSCILLATOR

FIG. 8

Types of Circuits Used

Many of the same types of circuits used at low frequencies are also popular in the VHF and UHF ranges. Such circuits as the Hartley are frequently encountered, especially in the "grounded plate" form (see Article 2 of this series). High frequency versions may be a little difficult to recognize at first, as special tank circuits and other construction are often employed.

Of particular importance is the Colpitts circuit of Fig. 5, not only because it is sometimes used itself, but mainly because it is the basis of the very popular *ultraudion* circuit, which will be explained presently.

The Colpitts oscillator circuit is the same as the Hartley except that the cathode is tapped into the resonant circuit by means of a capacitance voltage divider C1-C2, instead of a tap on the coil. One advantage of this arrangement is that the two interelectrode capacitances C_{pk} and C_{gk} are not connected directly across parts of the coil, as they are in the Hartley. They are shunted by tuned circuit capacitors C1 and C2. The latter have large values, since they combine in series to provide the total external resonant circuit capacitance. The effect of interelectrode capacitance variation on the frequency of oscillation is thus minimized. There is one disadvantage in the Colpitts circuit when the oscillator is to be tuned over a range, as in receiver local oscillators. Either C1 and C2 must be tuned together, or another capacitor must be added across all or part of the coil to provide tuning adjustment. The relative values of

C1 and C2 determine the amount of feedback, just as adjustment of the tap did in the Hartley oscillator. Thus variation of either of these capacitors alone would vary feedback as well as frequency, an obviously unsatisfactory condition.

The Ultraudion

The ultraudion circuit is undoubtedly the most popular of any of the circuits used for the VHF and UHF ranges. It is widely used as the local oscillator in communications, FM broadcast and TV broadcast receivers, because of its simplicity. The circuit is actually simply a Colpitts type in which the plate-cathode and grid-cathode interelectrode capacitances form the voltage divider across the coil. No external capacitors are then needed, although of course some form of trimmer or adjusting capacitor must usually be added across the coil, so the frequency can be set or varied.

The principle of the ultraudion is illustrated in Fig. 6, which shows how the interelectrode capacitances form the Colpitts-type voltage divider.

As with other oscillator types, any desired point in the r-f circuit can be chosen as ground, to suit convenience in the particular application. Two examples of ultraudion local oscillator circuits used in TV receivers are shown in Fig. 7. In the type at (A), the cathode is grounded. The plate is shunt fed through R1, which keeps it at r-f potential above ground. Optimum efficiency and power output would call for an r-f choke instead of R1. However, in this case, sufficient receiver injection voltage, and better stability can be obtained with the lower-priced resistor, because a voltage dropping resistor is probably necessary anyway. In the circuit at (B), the plate is grounded to r-f, through C1. This means that both the grid and the cathode must operate at above-ground r-f potential. The cathode is kept above ground by means of the cathode choke L, which allows d-c cathode current to pass through from ground to the tube.

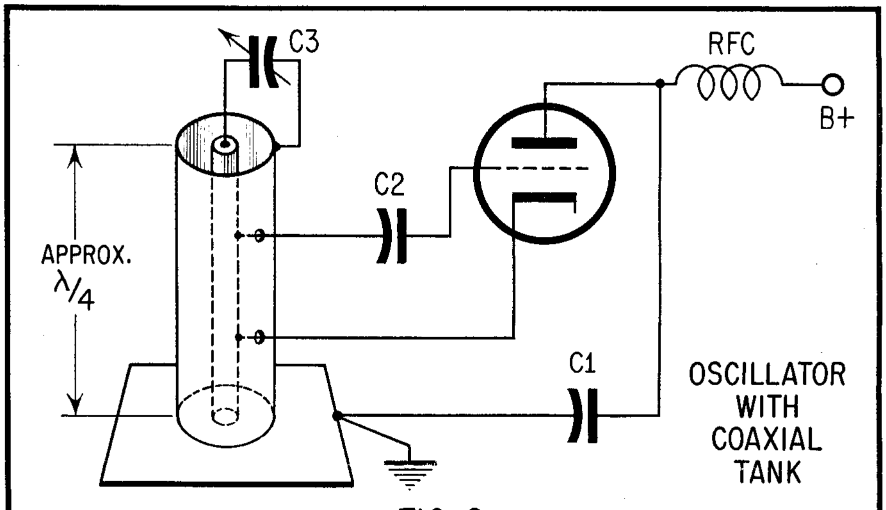


FIG. 9

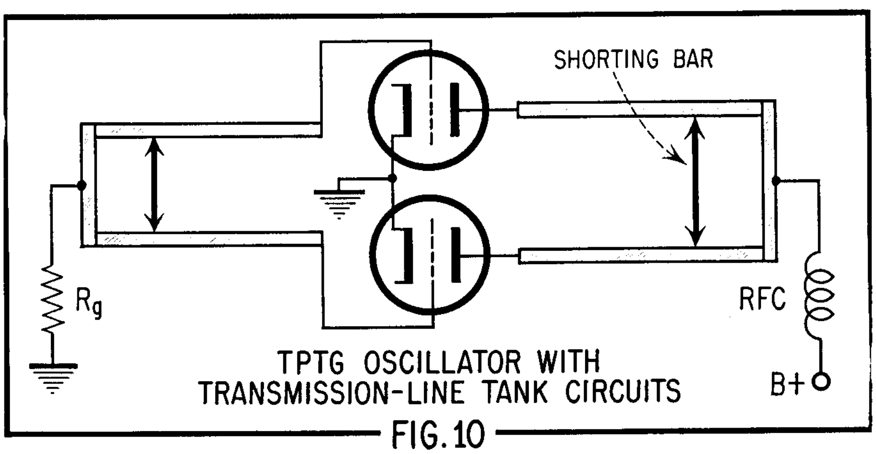
Use of Transmission Lines as Tank Circuits

Because of the relatively high circuit losses and the effects of transit time at high frequencies, the inherent stability of an oscillator lessens as the frequency is increased into the VHF and UHF regions. One way to compensate for this is to design the resonant (tank) circuit so it has a very high Q, and thus tends to stabilize the oscillator as a whole. This can be done by using a resonant section of a transmission line as the tank circuit, instead of the ordinary coil and capacitor. For example, a quarter-wavelength section of transmission line, short-circuited at one end, exhibits at the other end the characteristics of a very high Q parallel-resonant circuit. By slight adjustment of the length of the line section, it can be made to combine with circuit and tube reastances plus added tuning capacitance if desired, to resonate at the required operating frequency. An open-ended line section a half-wavelength long can be used in the same way.

An example of the use of a line section for the tank circuit of an oscillator is shown in Fig. 8. Because of the appearance of the shorted line, which is usually fashioned from a single piece bent into shape, this arrangement is often referred to as the "hairpin" oscillator. Actually the circuit is an ultraudion, and the construction is about the simplest of any practical oscillator.

This application is not limited to open wire lines, but coaxial line sections also can be used. A Hartley circuit using a quarter-wave coaxial section is shown in Fig. 9. The line is shorted and grounded at the bottom, where the plate is also connected through C1. The circuit is thus a grounded-plate Hartley. The leads from the cathode and grid respectively are fed through the outer conductor of the line section and tapped onto the inner conductor. This simulates the connection of these leads to the tap and top respectively of a conventional coil. C3 is added for variation or adjustment of frequency. Sometimes frequency adjustment is provided by a shorting plug of metal between the inner and outer conductors, which is moved to change the electrical position of the bottom short circuit.

Push-pull oscillator circuits have the advantage at high frequencies that the combined effective interelectrode capacitances are lower than those of each tube alone. A typical push-pull tuned-plate-tuned-grid oscillator circuit using transmission line tanks is shown in Fig. 10.



TPTG OSCILLATOR WITH TRANSMISSION-LINE TANK CIRCUITS

FIG. 10

QUESTION:

Why buy TWO when ONE will do?

ANSWER:

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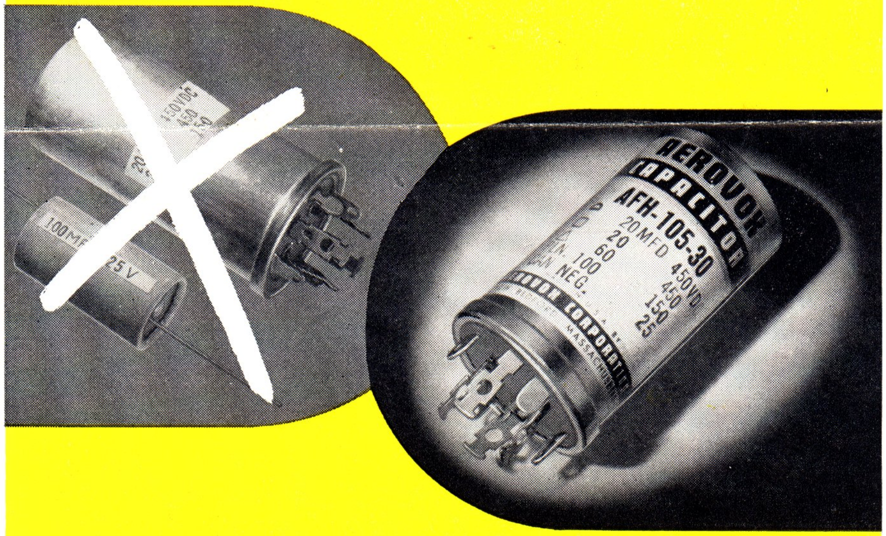

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