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A RADIO CORPORATION OF AMERICA SUBSIDIARY
Harrison, New Jersey

RCA RADIOTRON
DIVISION

APPLICATION NOTES

APPLICATION NOTE No.50
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APPLICATION NOTE
ON
OPERATION OF THE 6L7 AS A MIXER TUBE

The 6L7 is a 6.3-volt metal-shell tube intended for use as a mixer (first detector) in superheterodyne receivers, although its characteristics enable it to perform other functions. It is the purpose of this Note to discuss operation of the 6L7 as a mixer; subsequent Notes will analyze its operation in other circuits.

The pentagrid-converter tube now in general use is a good frequency-converting device at medium radio frequencies. When a tube of this type is operated at frequencies higher than 15 or 20 megacycles, however, its conversion conductance is substantially less than that in the standard broadcast band, even though the oscillator voltage is maintained at a satisfactory value throughout the frequency range of the receiver. The cause of this decreasing conversion conductance with increasing frequency has been traced to an undesirable effect produced by space-charge coupling between oscillator and signal grids. This phenomenon is inherent in the operation of this type of tube and is serious when the ratio of signal frequency to intermediate frequency is very large.

Variations in potential of the oscillator grid of a pentagrid converter modulate the electron stream from the cathode. These cause corresponding variations in the space charge surrounding the signal grid. If the intermediate frequency is low compared to the signal frequency, so that the impedance of the signal circuit is appreciable at oscillator frequency, this varying space charge will cause a voltage of oscillator frequency to be developed across the signal circuit. This generated voltage will be 180° out of phase with the oscillator-grid voltage when the oscillator frequency is higher than that of the signal circuit; it will be in phase with the oscillator-grid voltage when the oscillator frequency is lower than that of the signal circuit. Since the oscillator is usually adjusted for the higher-frequency setting in order to obtain a reasonably high tuning ratio, the combined effect of the oscillator-frequency voltages on the two grids is to reduce the conversion conductance of the tube. This effect increases with frequency because of: (1) the increasing ratio of signal frequency to intermediate frequency, and (2) the increasing value of L/C as the receiver is tuned toward the high-frequency end of a band. The use of a separate oscillator tube coupled to the normal oscillator grid does not reduce this space-charge variation phenomenon, because, as previously pointed out, this effect is inherent in the operation of pentagrid converter tubes.

A second disadvantage of operating a pentagrid converter tube at high radio frequencies is the shift in oscillator frequency which occurs when the signal-grid bias is varied. This frequency shift is due to a transconductance between signal grid and oscillator anode. The use of a separate oscillator tube coupled to the normal oscillator grid will eliminate this undesirable characteristic.

Both of these high-frequency effects may be greatly minimized, with a consequent increase in gain, by replacing the pentagrid converter with an r-f amplifier pentode whose suppressor is connected to an external oscillator. However, the plate impedance is so low and the oscillator-voltage requirements are so high as to prohibit the use of this system in many receivers. These disadvantages may be overcome by increasing the amplifying action of the suppressor; a screen interposed between suppressor and plate will maintain the plate resistance at a satisfactory value. A further refinement may be made by inserting a grounded suppressor between plate and oscillator screen. This hypothetical tube, which is substantially the new 6L7, thus requires five grids for good mixing at high radio frequencies.

Fig. 1 shows the relative positions of the elements of the 6L7. The tube consists, as may be seen, of a heater, a cathode, five concentric grids, and a plate. Grid No.1, which is nearest the cathode, is one of two control grids. It is of the remote cut-off type and, because the r-f signal to be converted is applied between it and cathode as shown in Fig. 2, may be referred to as the signal grid. The remote out-off characteristic of this grid minimizes r-f distortion and cross-modulation effects when its bias is under the control of the a.v.c. system. Grid No.2 serves the same purpose as the screen in a conventional tetrode; it accelerates the electrons toward the plate and reduces the G_1-G_3 capacitance to a small value. (The numerical subcript denotes the grid number.) Grid No.3, interposed between screens G_2 and G_4, is the second control grid of the tube and has a sharp cut-off characteristic. This grid may be referred to as the oscillator grid, because the output of the external oscillator is connected to it. Grid No.4 is another screen; it increases the plate resistance of the tube, reduces the G_3-P capacitance, and functions similarly to the screen in a conventional tetrode; G_2 and G_4 are connected together internally. Grid No.5 is a suppressor; it is connected to the cathode internally and serves to limit the effects of secondary emission from the plate; because of the suppressor, it is possible to operate the tube at low plate voltages.

Theory of Operation of 6L7 as a Mixer

The manner in which the 6L7 produces an intermediate-frequency component of plate current when it is connected to operate as a mixer may be described as follows:

An r-f signal applied to G_1 modulates the electron stream by virtue of the G_1-P transconductance (s_{m1}). The r-f component of the plate current is, therefore, $E_g\ s_{m1}$, where E_g is the signal voltage. The oscillator voltage applied to G_3 varies s_{m1} between zero and a maximum, s_{m1} being maximum at the peak positive potential of G_3 and minimum at the peak negative potential of G_3. Thus, regardless of the manner in which s_{m1} varies, there is an alternating component of s_{m1} having the same frequency as that of the oscillator. If the signal is represented by $E_g \cos \omega t$ and the component of s_{m1} at oscillator frequency is represented by $s_{mo} \cos \rho t$, the instantaneous plate current will be:

$$I_p = E_g s_{mo} \cos \omega t \quad \cos \rho t = \frac{E_g\ s_{mo}}{2} \left[\cos(\rho + \omega)t + \cos(\rho - \omega)t \right]$$

where ω is the angular velocity of the signal and ρ that of the oscillator; s_{mo} is the peak value of the alternating component of s_{m1} having the same frequency as that of the oscillator. The difference-frequency, or i-f, component of this plate current is

$$I\ (\text{i-f}) = \frac{E_g\ s_{mo}}{2} \cos(\rho - \omega) \qquad (1)$$

Thus, it is seen that the i-f component of the plate current increases directly with signal strength and with s_{mo}.

If I (i-f) is to be a maximum for a given signal strength, then s_{m1} must be varied by the oscillator in such a manner that s_{mo} is a maximum. The ideal relation between s_{m1} and E_{c3} for maximum s_{mo} is shown by curve (a) of Fig. 3; for this case,

$$s_{mo} = \frac{2\ s_{m1}\ (\text{max.})}{\pi}$$

If the relation between s_{m1} and E_{c3} is linear, as shown by curve (b), then,

$$s_{mo} = \frac{s_{m1}\ (\text{max.})}{2}$$

The conversion conductance (s_c) of a mixer tube is defined as

$$s_c = \frac{I\ (\text{i-f})}{E_g}, \text{ so that Eq. (1) becomes } s_c = \frac{s_{mo}}{2}$$

For curves (a) and (b) of Fig. 3, then, s_c is as follows:

Curve (a) $$s_c = \frac{s_{m1}\ (\text{max.})}{\pi}$$

Curve (b) $$s_c = \frac{s_{m1}\ (\text{max.})}{4}$$

Characteristics as a Mixer

Heater Voltage (A.C. or D.C.)		6.3	Volts
Heater Current		0.3	Ampere
Plate Voltage		250 max.	Volts
Screen Voltage (Grids No.2 and No.4)	100	150 max.	Volts
Signal-Grid Voltage (Grid No.1)	-3	-6 min.	Volts
Oscillator-Grid Voltage (Grid No.3)	-10	-15	Volts
Peak Oscillator Voltage (Min.)	12	18	Volts
Plate Current	2.4	3.3	Milliamperes
Screen Current (Grids No.2 and No.4)	6.2	8.3	Milliamperes
Conversion Conductance	350	350	Micromhos
Signal-Grid Voltage for Conversion Conductance of 5 Micromhos	-30	-45	Volts
Plate Resistance	Greater than 1		Megohm
Maximum D-C Resistance in G_3 Circuit	50000	50000	Ohms
Direct Interelectrode Capacitances (Approx.):*			
Grid No.1 to Plate		0.0005 max.	μμf
Grid No.1 to Grid No.3		0.12	μμf
Grid No.1 to All Other Electrodes		8.5	μμf
Grid No.3 to Plate		0.25	μμf
Grid No.3 All Other Electrodes		11.5	μμf
Plate to All Other Electrodes		12.5	μμf

*Shell connected to cathode

The table of characteristics recommends for a given plate voltage of 250 volts two screen voltages, 100 and 150 volts. Although the space-charge phenomenon discussed previously is very small in the 6L7, it has been found that electrons repelled by the oscillator grid during its negative voltage excursions enter the vicinity of the signal grid and cause a current to flow in that circuit. At high radio frequencies, where this effect is appreciable, the signal-grid bias must be increased to -6 volts to prevent the flow of this current. The screen voltage may be raised to 150 volts in order to compensate for the consequent decrease in conversion conductance. For all-wave receivers, it is preferable to maintain the screen voltage at 150 volts and the minimum signal-grid bias at -6 volts in all bands.

Fig. 4 shows the relation between plate current (I_b) and Ec_1 for the two recommended values of screen voltage. Grid No.1 is seen to have a remote-cut-off characteristic so that it may readily be controlled by the a.v.c. system. Fig. 5 shows the relation between conversion conductance (s_c) and Ec_1 for the same two values of screen voltage. These curves show how the gain of the converter stage varies with a.v.c. voltage. The variation of s_{m1} with Ec_3 is depicted in Fig. 6. The actual variation of s_c with Ec_3 for different oscillator voltages is shown in Figs. 7 and 8; these families of curves are probably the most interesting from an application standpoint.

Considering only the solid-line curves for the moment, it is seen that the optimum value of s_c increases rapidly with small oscillator voltages and slowly for larger voltages. It is also well to note that the highest values of s_c are obtained when the oscillator voltage is much higher than the bias; of course, current then flows in the G_3 circuit of the 6L7. Because of the shape of the high oscillator-voltage curves in the region of Ec_3=0 comparatively constant gain may be expected within this region from the converter stage for varying oscillator voltages. Practically, this means that, for nearly constant bias on the oscillator grid, the conversion gain will remain substantially constant as the oscillator frequency is varied over a given tuning band. The minimum oscillator voltage in any tuning band, therefore, should be large enough to give nearly maximum s_c.

The foregoing analysis is based on the assumption that the oscillator voltage is obtained independently of Ec_3. Although this condition may be realized with some circuits, it is more practical to use either of the coupling circuits shown in Figs. 9 and 10. In the circuit of Fig. 9, G_3 of the 6L7 connects to ground through a 50000-ohm resistor; it also connects to the grid of the oscillator tube through the blocking condenser C. The voltage developed across the grid leak of the oscillator tube, therefore, appears across R and modulates the electron stream to produce the i-f component of plate current. If the oscillator voltage applied to G_3 is high, rectification takes place in the G_3 circuit, just as in a diode, and a rectified current will flow through R; the d-c component of this current produces a d-c voltage across R which contributes to the fixed bias developed by R_b. Thus, the total bias on G_3 is a function of the oscillator voltage.

In the circuit of Fig. 10, the d-c and a-c components of the voltage developed across R by the oscillator tube are applied to G_3; the d-c component of this voltage plus the fixed voltage across R_b equals the total bias on G_3. If the peak value of the a-c component of the oscillator voltage is greater than this total bias, rectification will occur in the G_3 circuit of the 6L7; the total bias Ec_3 will thus be augmented. From these considerations, it is clear that, once the voltage drop across R_b is fixed, the variation of s_c with Ec_3 depends on the type of coupling circuit and the characteristics of the oscillator used. The dotted curves of Figs. 7 and 8 show the variation of s_c with total grid bias for two typical circuits of the type shown in Figs. 9 and 10. The flat portion of each curve is of greatest importance to the set designer, since it determines the minimum oscillator voltage required for nearly maximum conversion conductance. The minimum oscillator voltage in each wave band in the receiver should be great enough to secure nearly maximum conversion conductance; any further increase in oscillator voltage, such as may be obtained when tuning from the low to the high-frequency end of any band, will not materially change the gain of the converter stage.

Consideration should be given to the G_3 input capacitance which shunts the tuned circuit of the oscillator through the oscillator-grid condenser. The oscillator coils and padding circuit should be so designed that the desired tuning range can be covered with this capacitance in the circuit. The use of but part of the voltage developed across the oscillator coil, the connection of G_3 to the plate instead of to the grid of the oscillator, or the use of the circuit of Fig. 9 with a smaller value of C will lower the effects of this capacitance.

RELATIVE POSITION OF ELECTRODES OF THE 6L7

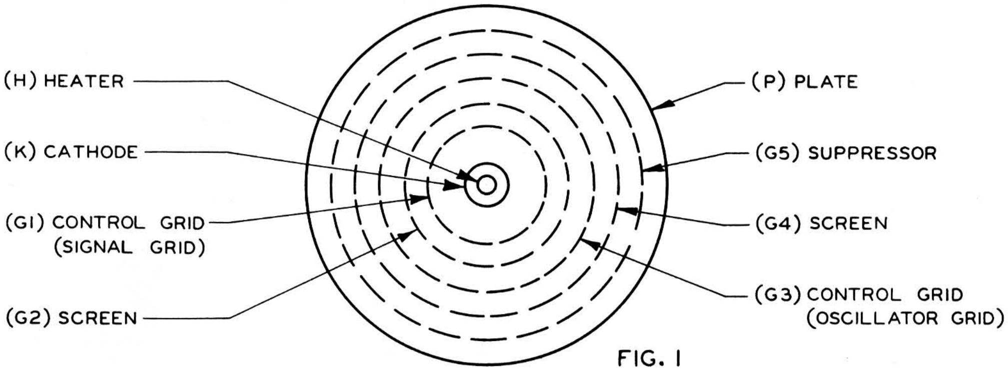

FIG. 1

CONNECTIONS OF THE 6L7 AS A MIXER

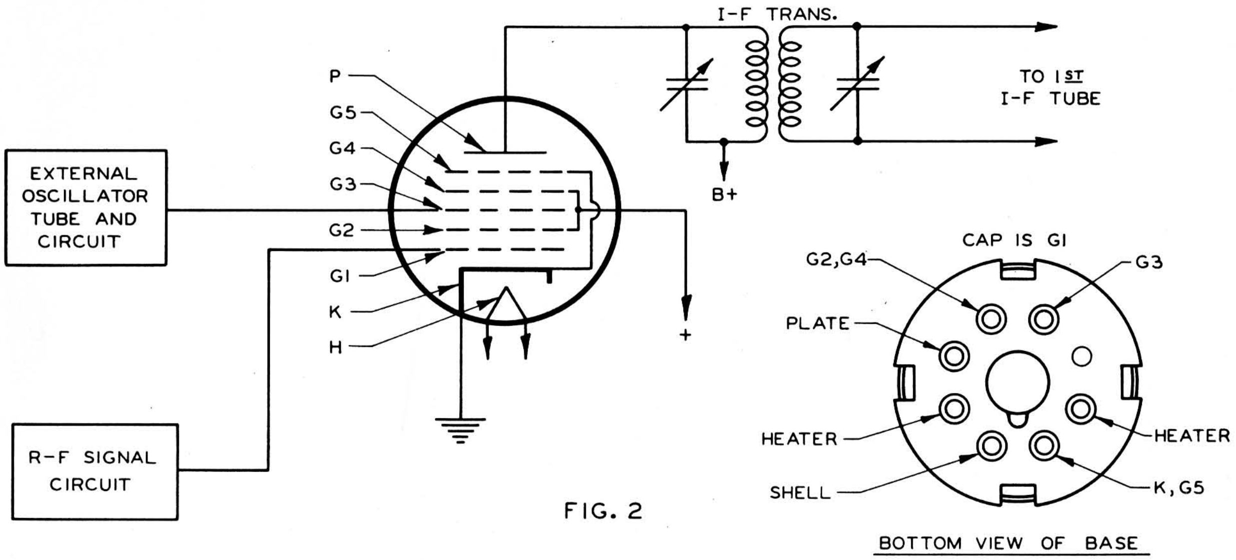

FIG. 2

BOTTOM VIEW OF BASE

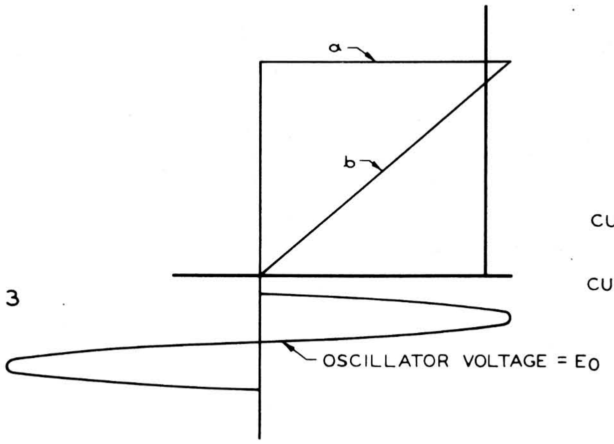

FIG. 3

CURVE (a) $S_{m_0} = \frac{2 S_{m_1}}{\pi}$

CURVE (b) $S_{m_0} = \frac{S_{m_1}}{2}$

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AVERAGE CHARACTERISTICS

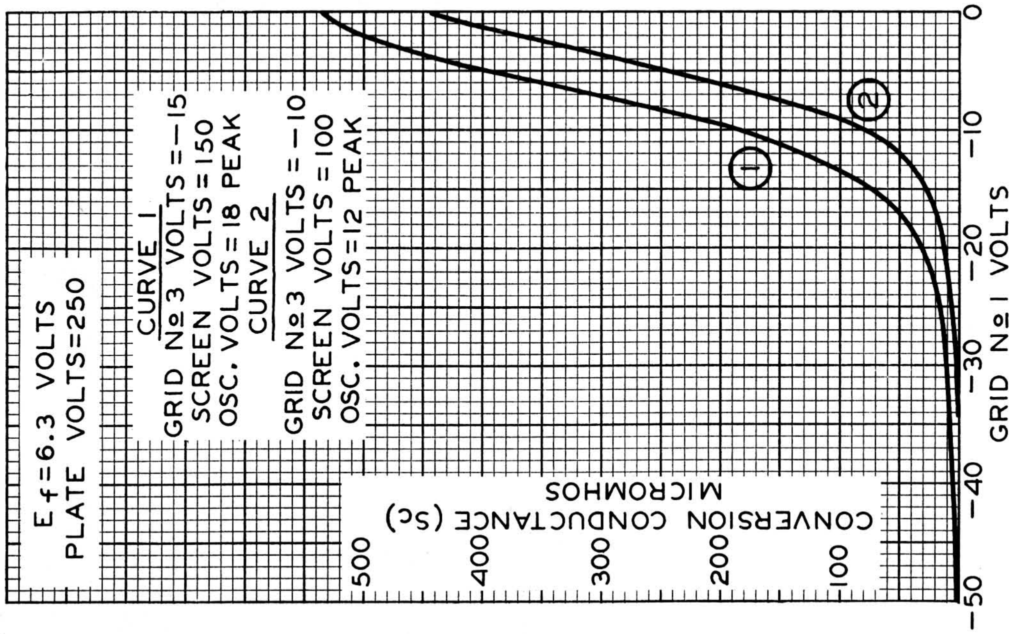

FIG. 5

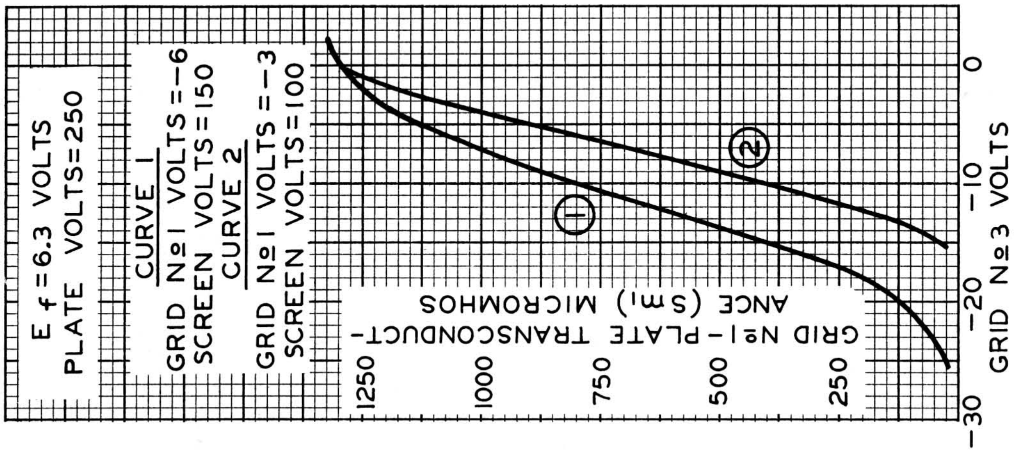

FIG. 6

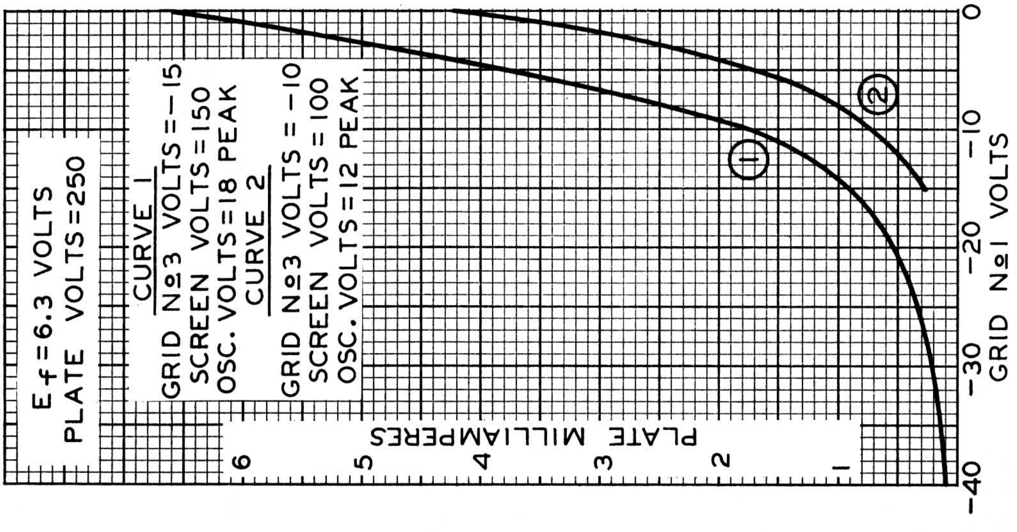

FIG. 4

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OPERATION CHARACTERISTICS

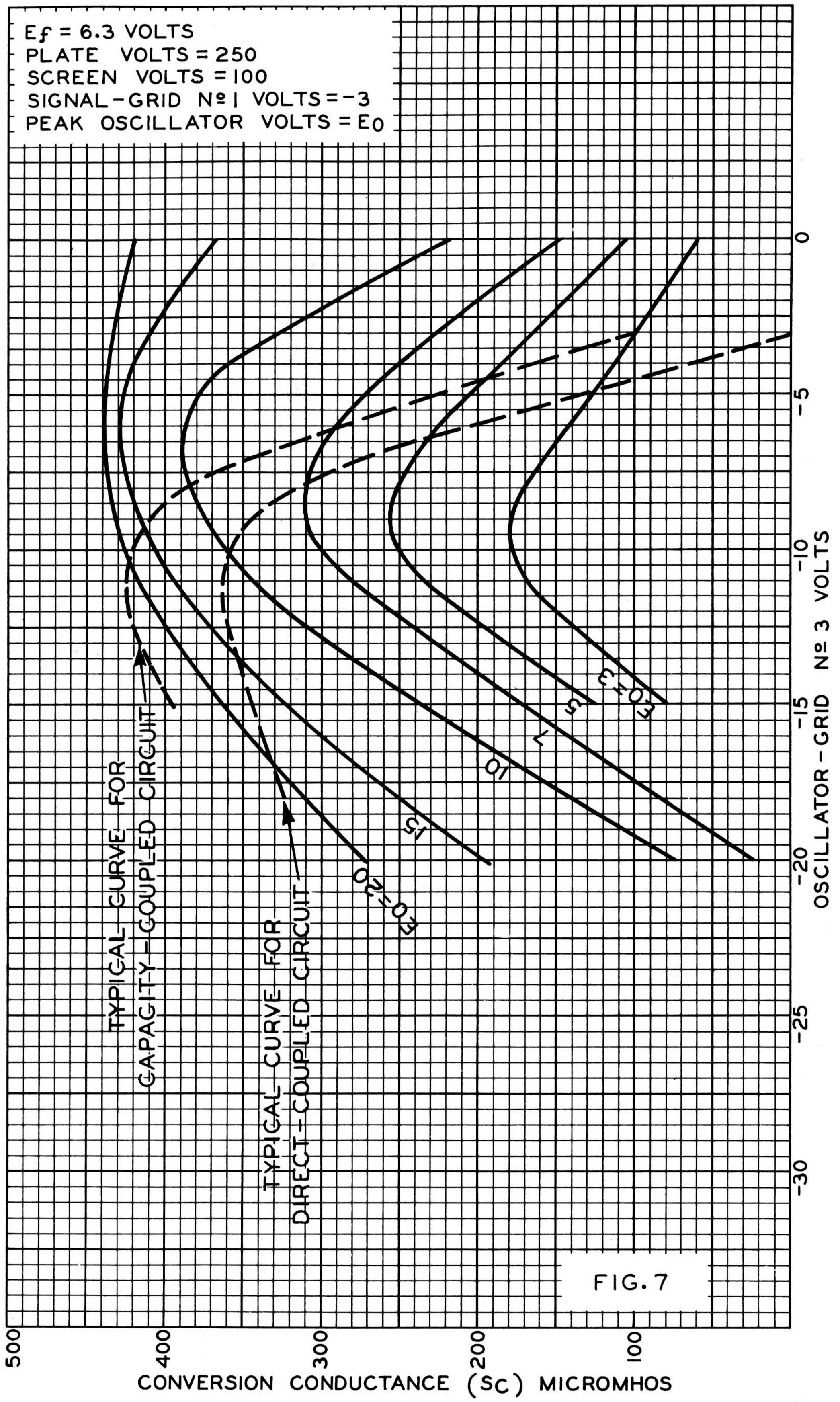

FIG. 7

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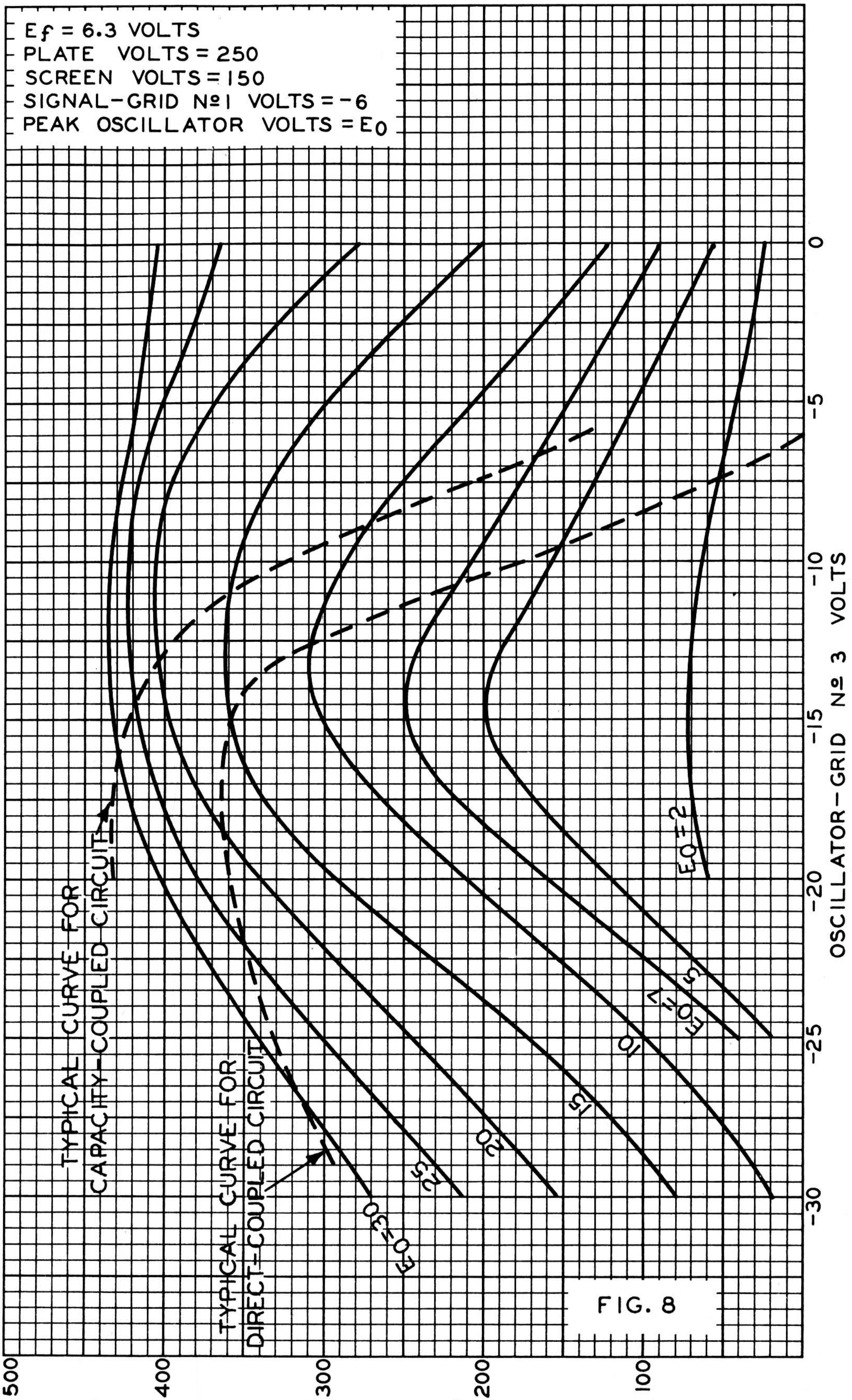


FIG. 8

TYPICAL OSCILLATOR-COUPLING CIRCUITS FOR THE 6L7

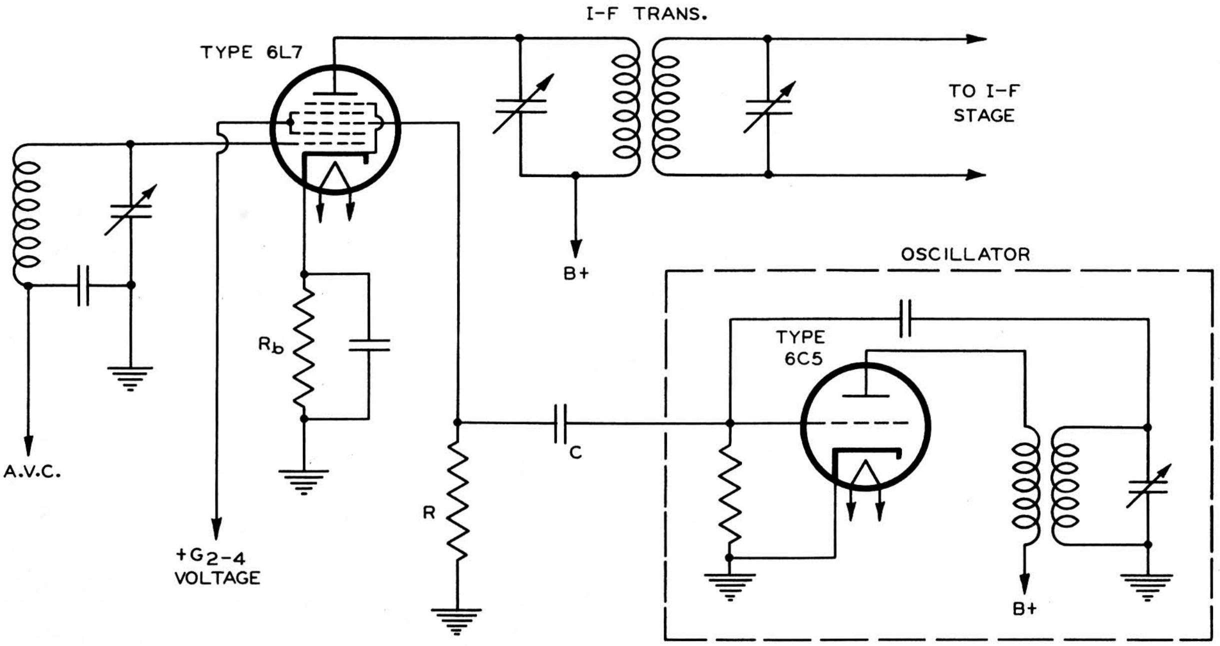
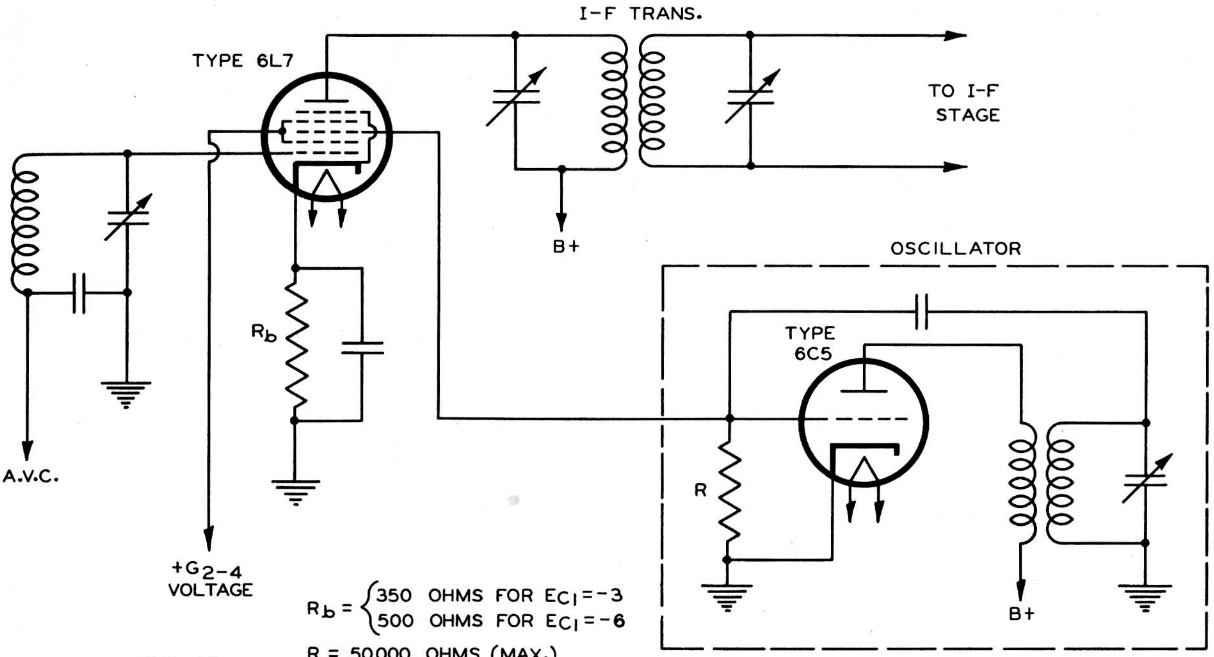


FIG. 9

$R_b = \begin{cases} 350 \text{ OHMS FOR } E_{C1} = -3 \\ 500 \text{ OHMS FOR } E_{C1} = -6 \end{cases}$

R = 50000 OHMS (MAX.)

C = 100 $\mu\mu f$



$R_b = \begin{cases} 350 \text{ OHMS FOR } E_{C1} = -3 \\ 500 \text{ OHMS FOR } E_{C1} = -6 \end{cases}$

R = 50000 OHMS (MAX.)

FIG. 10

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