RCA MANUFACTURING COMPANY, INC.
A RADIO CORPORATION OF AMERICA SUBSIDIARY
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RCA RADIOTRON
DIVISION

APPLICATION NOTE No.100
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APPLICATION NOTE
ON
OPERATION OF THE 6SA7

The 6SA7 is a single-ended pentagrid converter designed to perform the functions of oscillator and mixer in all-wave receivers. Structurally, the 6SA7 differs from other converter tube types in two important respects: (1) all electrodes including the signal grid terminate at base pins, and (2) there is no electrode which functions only as oscillator anode.

The single-ended construction employed in the 6SA7 effects an appreciable saving in installation cost because a flexible grid lead and top-cap connector are not required; in addition, the lead connecting to the signal-grid terminal of the socket can be made short and rigid. Because there is no electrode in the 6SA7 that serves only as oscillator anode, the oscillator circuit shown in Fig.2A is recommended for use with this tube type. In this circuit, the screen and the plate function as oscillator anode and are at ground potential for the oscillator frequency. The construction of the oscillator coil and the switching arrangement suggested in this Note for use with the 6SA7 are simpler than those often employed with other converter tube types. As a result, an appreciable saving in coil and circuit cost may be realized.

Description of the 6SA7

As shown in Fig.1, the 6SA7 consists of a heater, cathode, a grid (G_1) for the oscillator function, a screen (G_2 and G_4), a pair of collector plates mounted on the side rods of G_2, a signal grid (G_3), a suppressor (G_5), and a plate. The suppressor is connected to the shell, and the two grids forming the screen are connected together inside the tube. The presence of the suppressor increases the tube's plate resistance and, therefore, increases conversion gain. This action of the suppressor is especially important when the tube is operated with a plate-supply voltage as low as the screen voltage, as in an ac-dc receiver. An important function of the screen and collector plates is to minimize the effect of signal-grid voltage on the space charge near the cathode. The negative voltage on the signal grid repels electrons traveling toward the plate and turns some of these electrons back toward the cathode. Any of these electrons which reach the region near the cathode affect space-charge conditions in this region. It can be seen from Fig.1 that, because of the position of the signal-grid side rods with respect to the collector plates, the collector plates intercept most of the returning electrons. The electrons returned by the signal grid, therefore, have little effect on the space charge near the cathode. Because of the shielding effect of the screen, the electrostatic field of the signal grid also has little effect on the space charge. Thus, the collector plates and the screen serve to isolate the cathode space charge from the signal grid.

The result is that a change in signal-grid voltage produces little change in cathode current. Although a change in signal-grid voltage produces a change in plate current, this change is accompanied by an opposite and almost equal change in screen current. An r-f voltage on the signal grid, therefore, produces little modulation of the electron current flowing in the cathode circuit. This feature is important because it is desirable that the impedance in the cathode circuit should produce little degeneration or regeneration of the signal-frequency input and intermediate-frequency output. Another important feature is that, because signal-grid voltage has little effect on the space charge near the cathode, changes in avc bias produce little change in oscillator transconductance and in the input capacitance of the No.1 grid. There is, therefore, little detuning of the oscillator by avc bias.

Adjustment of the Oscillator Circuit

In the circuit of Fig.2A, the oscillator circuit provides peak plate current at the time when the oscillating voltage (E_k) on the cathode (with respect to ground) and the oscillating voltage (E_g) on the No.1 grid are at their peak positive values. For maximum conversion transconductance, this peak value of plate current should be as large as possible. The effect on plate current of the positive voltage on the cathode is approximately the same as would be produced by an equal voltage, of negative sign, applied to the signal grid. Hence, the amplitude of oscillating voltage on the cathode limits the peak plate current. This amplitude should, therefore, be small.

During the negative portion of an oscillation cycle, the catnode may swing more negative than the signal grid. If this occurs, the signal grid will draw current unless the oscillator grid is sufficiently negative to cut off cathode current. This signal-grid current will develop a negative bias on the signal grid and may also cause a negative bias to be applied to the r-f and i-f stages through the avc system. As a result, sensitivity will be decreased. In order that signal-grid current should be prevented, the d-c bias developed on the oscillator grid should be not less than its cut-off value.

Because the peak plate current depends on how far positive the oscillator grid swings with respect to cathode, it is desirable that this positive swing be as large as possible. It follows that the oscillator grid-leak resistance should be low. This resistance, however, should not be so low as to cause excessive damping of the tank circuit. It has been found, for operation in frequency bands lower than approximately 6 megacycles, that all these requirements are generally best satisfied when the oscillator circuit is adjusted to provide, with recommended values of plate and screen voltage, a value of E_K of approximately 2 volts peak, and an oscillator-grid current of 0.5 milliampere through a grid-leak resistance (R_g) of 20000 ohms. With a 20000-ohm grid-leak resistance, the rectification efficiency of the No.1 grid is approximately 0.7. Since the bias on this grid is 10 volts (0.5 milliampere x 20000 ohms), the peak value of E_g is approximately $10/0.7 = 14$ volts. With a 10-volt bias and a peak oscillator-grid voltage of 14 volts, the peak positive voltage of the oscillator grid with respect to cathode is 4 volts. If a higher value of R_g were used, the rectification efficiency would be higher; hence for the same value of E_g, the peak positive voltage of the oscillator grid with respect to cathode would be lower, and, therefore, the conversion transconductance would be lower.

In the low- and medium-frequency bands, the recommended oscillator conditions can be readily obtained. However, in the frequency band covering frequencies higher than approximately 6 megacycles, the tank-circuit impedance is generally so low that it is not easy to obtain these oscillator conditions, especially at the low-frequency end of the band. For optimum performance in this band, it is generally best to adjust the oscillator circuit for maximum conversion gain at the low-frequency end of the band. This method of adjustment has the disavantage that, when the oscillator is tuned to the high-frequency end of the band, E_K will be greater than 2 volts peak and conversion gain will, therefore, be less than the maximum obtainable. However, this disadvantage is usually outweighed by the considerations that overexcitation at the high-frequency end of the band improves frequency stability, that some decrease in conversion gain at the high end of the band can be tolerated because the r-f tuned circuits have higher impedance at this end of the band, and that a good factor of safety is provided against the possibility of oscillation being stopped by a decrease in line voltage.

Maximum conversion gain at the low-frequency end of the high-frequency band is usually obtained by adjustment of the oscillator circuit to give a value of E_K of approximately 2 volts peak and an oscillator-grid current of 0.20 to 0.25 milliampere, with a grid leak of 20000 ohms. Because the oscillator-grid bias voltage developed under these conditions is less than the cut-off value, some signal-grid current may be observed. In tests which have been made on typical receivers, this signal-grid current and the resultant signal-grid bias have been small and have caused no difficulty.

The use of a tube voltmeter connected across the cathode coil is suggested as the simplest method of obtaining approximately optimum oscillator adjustments in all bands. Since the impedance of the 6SA7 cathode circuit is never very high, the requirements with respect to voltmeter input conductance and capacitance are not very severe; a diode with a 100000-ohm resistor and a microammeter would be satisfactory. Adjustment should be made for approximately 1.5 volts RMS at the low-frequency end of each band; when push-button circuits are used, the cathode voltage for each push-button position should be in the range from approximately 1 volt to 3 volts RMS for best results.

The curves of Fig.3 show how conversion transconductance varies when oscillator-grid current changes with tuning or with circuit adjustment. The solid-line curves were taken with a-c voltages applied to the cathode (with reference to ground) and to the No.1 grid (with reference to cathode) from an external generator. With the amplitude of cathode voltage fixed, the amplitude of voltage on the No.1 grid was varied. The No.1-grid voltage and cathode voltage were in phase, as they are in a self-excited oscillator circuit. The solid-line curves show conversion transconductance plotted against No.1 grid (oscillator-grid) current for different fixed values of cathode voltage. These curves illustrate the desirability of having E_k not larger than about 2 volts peak. Larger values of E_k give reduced conversion transconductance. With lower values of E_k it is difficult to obtain strong oscillation. The dashed-line curves of Fig.3 show conversion transconductance for different fixed values of $P = E_k/(E_k + E_g)$. Hence, the dashed-line curves show how conversion transconductance varies with grid current when the oscillator is self-excited with a fixed position of the cathode tap on the tank coil.

It should be noted that the curves of Fig.3 obtain for $E_{cs} = -1$ volt. An avc circuit applies approximately this value of bias to the signal grid at zero signal because of contact potentials. In a receiver, no other residual bias need be used.

Space-charge coupling between the No.1 grid and signal grid is present in the 6SA7, as in other converter types. This coupling is due to the effect of No.1-grid voltage on the space charge in the region of the signal grid. An important effect of space-charge coupling is to cause a voltage of oscillator frequency (f_o) to appear across the signal-grid circuit. This voltage is 180 degrees out of phase with the No.1-grid voltage when f_o is greater than the signal frequency (f_s). Thus, in the usual receiver in which f_o is greater than f_s, the effective modulation of the signal-grid-to-plate transconductance by a voltage of oscillator frequency is reduced; the value of conversion transconductance, which is proportional to this modulation, is also reduced.

In many converter tube types, the effects of space-charge coupling can be reduced by connecting a small condenser between No.1 grid and signal grid. Although this scheme reduces the voltage of oscillator frequency that appears across the signal-grid circuit, it is not recommended for use in self-excited circuits using the 6SA7. Tests in receivers with such a condenser show that: (1) sensitivity at frequencies in the region of 18 megacycles is not greatly improved, (2) the tendency to flutter increases, (3) frequency stability decreases, and (4) pull-in between signal and oscillator circuits increases. Because these undesirable effects are produced in self-excited circuits by capacitance between the No.1 grid and signal grid, the direct interelectrode capacitance between these grids has been made small. The base pins are arranged so that stray circuit capacitance between these grids can also be made small.

When the oscillator frequency is higher than the signal frequency and intermediate frequency, as is usually the case, the impedance between cathode and ground has inductive reactance at signal frequency and at intermediate frequency. Any signal-frequency and intermediate-frequency components of cathode current, therefore, produce degenerative voltages across the cathode impedance. The signal-frequency and intermediate-frequency components of electron current in the cathode circuit are minimized by the screen and the collector plates, as previously explained. The intermediate-frequency charging current which flows through the plate-to-cathode capacitance is small because this capacitance has a low value. Similarly, the signal-frequency charging current which flows through the capacitance between signal grid and cathode is small. Hence, the total signal-frequency and intermediate-frequency currents flowing in the cathode circuit are small. Because the impedance between cathode and ground is not large, there is little degenerative voltage built up across this impedance. The slight amount of degeneration that does exist adds small values of positive conductance to the r-f input circuit and to the i-f output circuit. The total input conductance of the signal grid is the sum of this small positive conductance and the negative conductance due to transit-time effects.

The conversion transconductance of the 6SA7 for the 250-volt operating conditions is approximately 450 micromhos; the tube's plate resistance is approximately 0.8 megohm. The conversion gain, which is the ratio of i-f voltage across the plate load to r-f voltage input, is given by:

$$\text{Conversion Gain} = \frac{g_c r_p R_L}{r_p + R_L}$$

where g_c is the conversion transconductance of the tube, r_p is the plate resistance of the tube, and R_L is the resonant impedance of the i-f transformer measured across the primary terminals. The conversion gain for different values of R_L is shown by the solid-line curve of Fig.4; conversion-gain curves of two earlier comparable converter types are also shown.

Frequency Shift

In a converter tube used at high frequencies, it is desirable that changes in electrode voltages should not produce much effect on oscillator frequency. The curve of Fig.5 shows the frequency shift produced in a 6SA7 at 18 megacycles by changes in avc voltage; the frequency shift is only about 5 kc for an avc voltage of 15 volts. Variations in screen voltage also produce only small effects on oscillator frequency, as shown by the curve of Fig.6. In operation of a receiver, an observed value of frequency shift is due to simultaneous changes in a number of electrode voltages. Such changes occur, for example, when line voltage or when signal strength is changed. The relation between frequency shift and line voltage at 18 megacycles is shown by the curve of Fig.7; the curve of Fig.8 shows the relation between frequency shift and r-f input voltage at 18 megacycles. The data for Figs.5 to 8 were taken in a commercial receiver of typical design. These curves may not apply to other receivers, but show that frequency shift is small for reasonable changes in line voltage or signal input.

Operation of the 6SA7 with a Separate Oscillator

The 6SA7 may be used with a separate oscillator. A typical circuit for such operation is shown in Fig.2E. With separate excitation, there is no oscillating voltage on the cathode. The amplitude of oscillation, therefore, can well be made higher than the amplitude used in self-excitation. As a result, somewhat higher conversion transconductance can be obtained with separate excitation than with self-excitation. When separate excitation is used, it may be desirable to neutralize the effects of space-charge coupling by connecting a small capacitance between the No.1 grid and No.3 grid, as shown in Fig.2E.

The curves of Fig.10 show conversion transconductance and cathode current vs No.1-grid current under separately excited conditions. The recommended minimum value of I_{c1} = 0.18 milliampere is that at which the recommended maximum value of cathode current (14 ma.) flows. The cut-off characteristic for separate excitation with 0.5 milliampere of No.1-grid current is shown in Fig.9. It can be seen from Fig.9 that a -2 volt bias on the signal-grid gives greatest conversion transconductance under the conditions for which the curve was taken. Hence, when the 6SA7 is operated with separate excitation under these conditions, it is recommended that a minimum signal-grid bias of -2 volts be used. If the curve of Fig.9 is moved 2 volts in the positive direction along the horizontal axis, the curve is very nearly correct for the recommended self-excited conditions.

Suggested Circuits

Alternative oscillator connections for the circuit of Fig.2A are shown in Figs.2B and 2C. In Fig.2B, the tank current of the oscillator circuit flows through the cathode coil and contributes to grid-plate coupling; this contribution is not present in the circuit of Fig.2C. These circuits are recommended when the series padding condenser is to be adjustable. Fig.2B places this condenser at a small r-f potential, and is satisfactory in most cases. Fig.2C permits grounding one side of the condenser. Typical wave-band switching connections for the oscillator circuit are shown in Fig.2D. The optimum oscillator conditions for these circuits are approximately the same as those for Fig.2A.

Operation of the 6SA7 with Reduced Screen Voltages

In some applications, it may be desirable to operate the 6SA7 with a screen voltage less than 100 volts. Screen voltage can be made considerably less than 100 volts without excessive loss of conversion gain. For example, measurements on a typical receiver show that sensitivity is reduced only about 25% when the screen voltage of the 6SA7 is reduced from 100 volts to 70 volts. When the 6SA7 is operated with self-excitation and reduced screen voltage, the adjustment of feedback voltage on the cathode should be made so as to insure that oscillation will continue when line voltage is low.

6SA7

STRUCTURE AND SOCKET CONNECTIONS

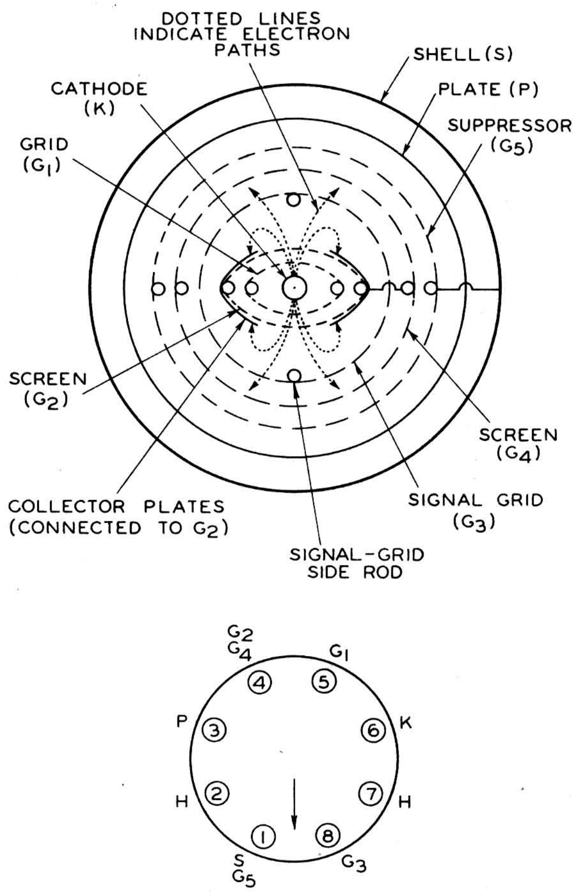
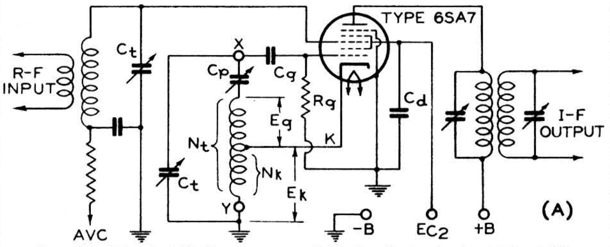


FIG. 1

6SA7

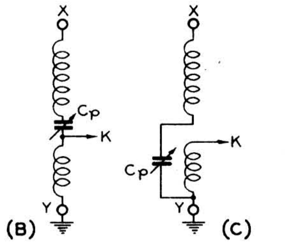
CIRCUITS

TYPICAL SELF-EXCITED CONVERTER CIRCUIT FOR TYPE 6SA7

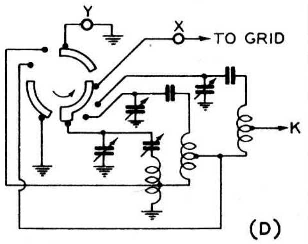


C_d = BY-PASS COND.
C_g = 50 $\mu\mu f$
C_p = PADDING COND.
C_t = TUNING COND.
N_t = TOTAL TURNS IN OSC. COIL
N_k = TURNS IN CATHODE SECTION OF OSC. COIL
R_g = 20000 OHMS

ALTERNATIVE OSCILLATOR CONNECTIONS



TYPICAL BAND-SWITCHING CONNECTIONS



APPROX. OSCILLATOR COIL DATA FOR CIRCUIT (A) FOR 1" DIAMETER FORM

BAND	TOTAL TURNS (N_t)	CATHODE SECTION TURNS (N_k)
BROADCAST	65	6
MEDIUM	33	3
SHORT WAVE	7	1.5

TYPICAL CONVERTER CIRCUIT FOR TYPE 6SA7 WITH SEPARATE OSCILLATOR

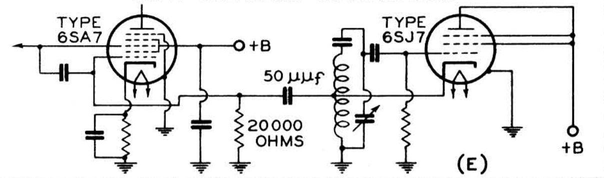


FIG. 2

6SA7

OPERATION CHARACTERISTICS
WITH SELF-EXCITATION

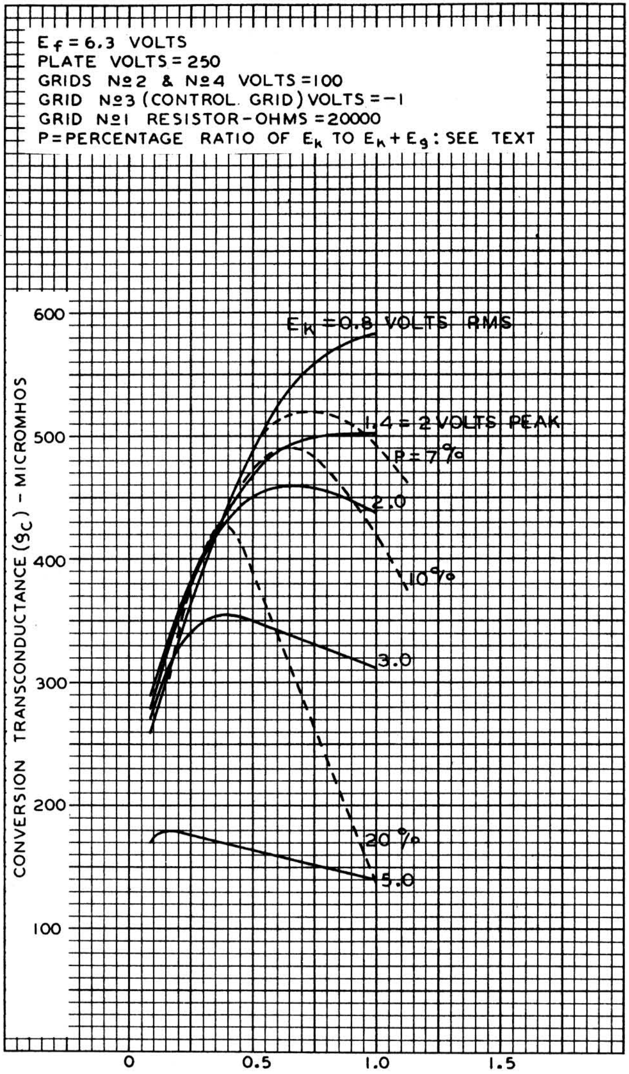


FIG. 3

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6SA7

OPERATION CHARACTERISTICS
WITH SELF-EXCITATION

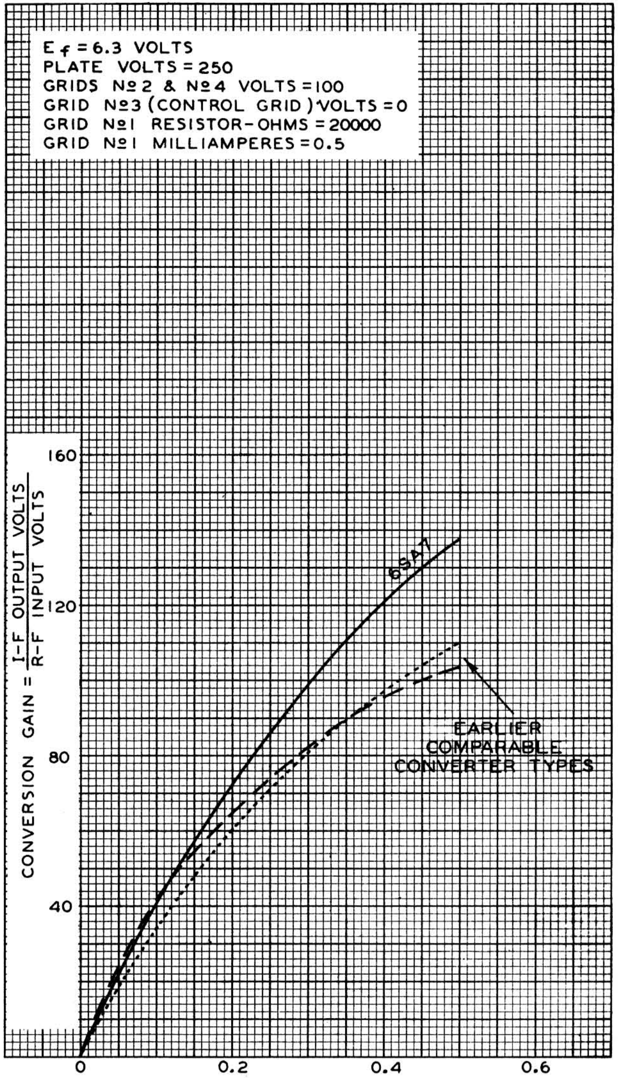

FIG. 4

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6SA7

FREQUENCY SHIFT IN TYPICAL RECEIVER
AT 18 Mc-250 VOLT OPERATING CONDITIONS-SELF-EXCITATION

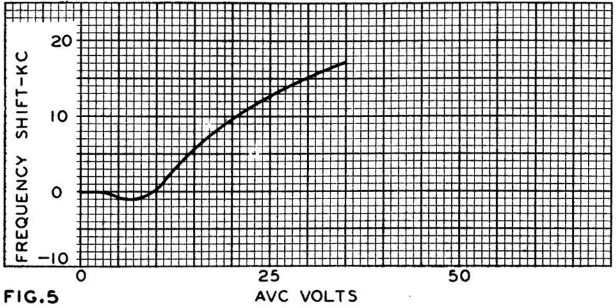

FIG.5

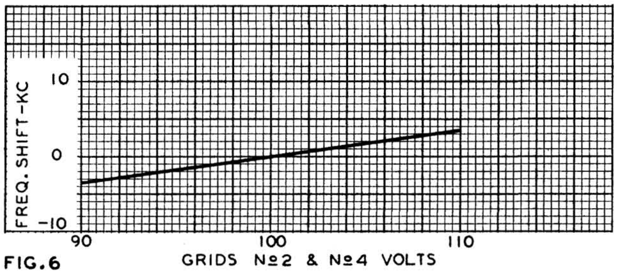

FIG.6

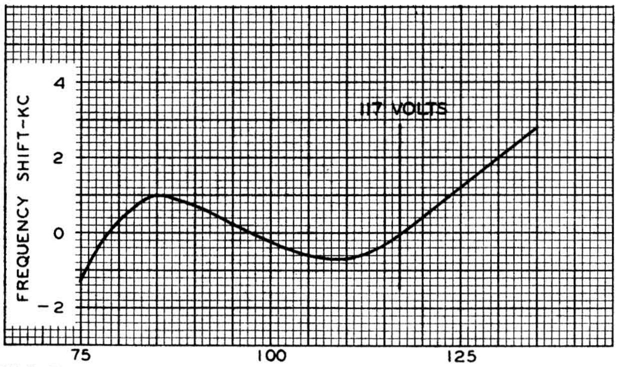

FIG.7

6SA7

FREQUENCY SHIFT IN TYPICAL RECEIVER—
250-VOLT OPERATING CONDITIONS-SELF-EXCITATION

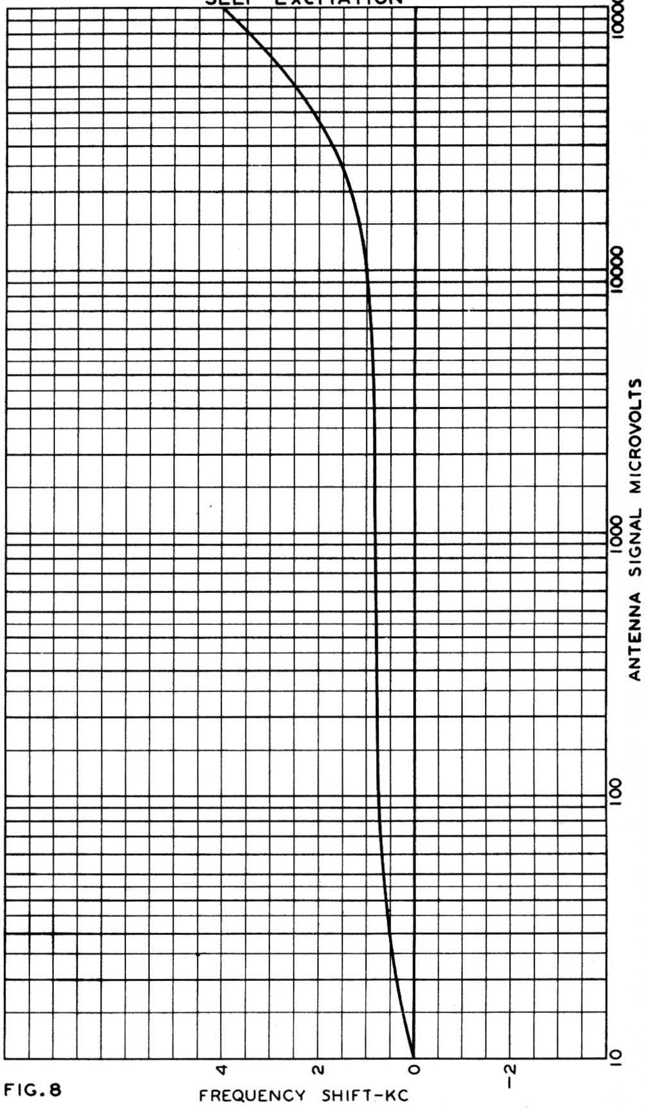

FIG.8

6SA7

OPERATION CHARACTERISTIC
WITH SEPARATE OSCILLATOR EXCITATION

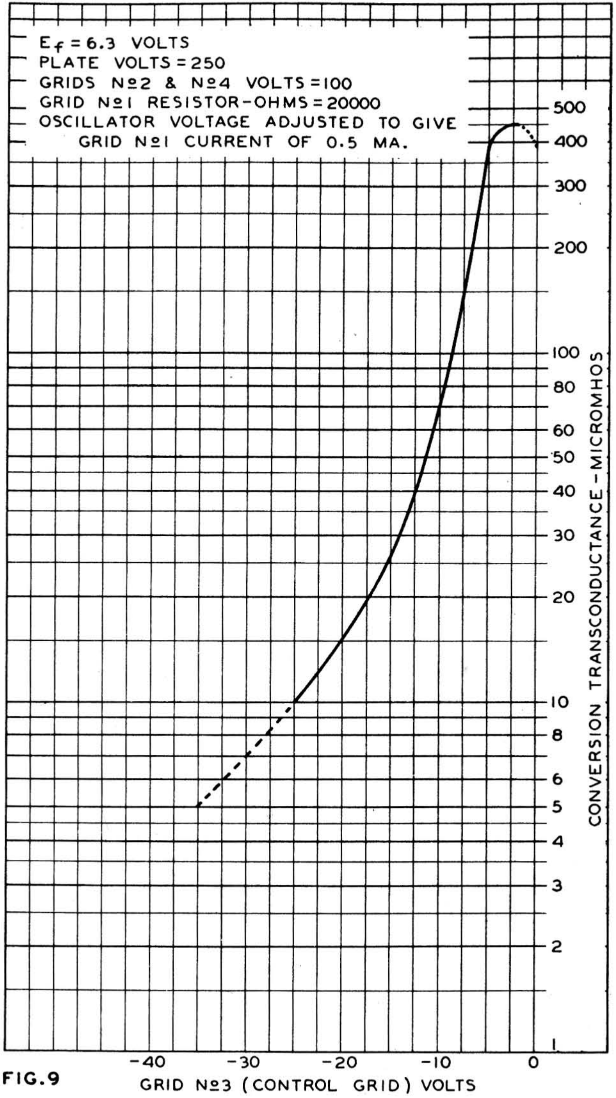

FIG.9

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6SA7

OPERATION CHARACTERISTICS
WITH SEPARATE OSCILLATOR EXCITATION

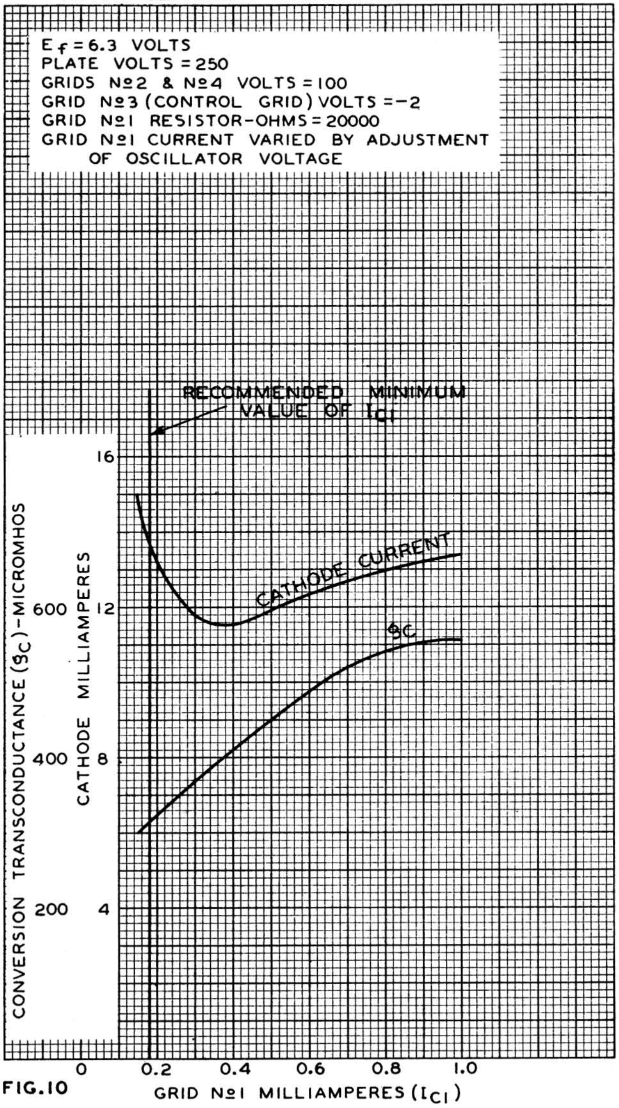

FIG.10

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