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RCA Application Note

on

OPERATION OF THE 6SB7-Y

The basic requirements for frequency conversion in a receiver operating in the 88 - to - 108-megacycle frequency-modulation band can be satisfied with tubes of conventional design. The pentagrid-converter type of tube, with oscillator voltage developed at the No. 1 grid, is adaptable to operation in this frequency range, and this type has the advantage of high input impedance at the signal grid. High oscillator transconductance is desirable for the development of a stable oscillator, and high conversion transconductance is advantageous, particularly because circuit impedances tend to be low in this frequency band. For metal tubes, the use of a mica-filled phenolic base tends to reduce the drift in oscillator frequency during the warming-up period. These features are also desirable at lower frequencies; for example, an increase in conversion transconductance results in increased gain and improved signal-to-noise ratio in the standard broadcast band. The 6SB7-Y is a pentagrid converter tube having the features mentioned above.

Description of the 6SB7-Y

In its structure and basing, the 6SB7-Y is similar to the well-known 6SA7. It is a single-ended tube, housed in a metal envelope. The arrangement of elements is shown in Fig. 1. The 6SB7-Y has a formed No. 1 grid which results in a very efficient utilization of the cathode area. The spacing between grids No. 3 and No. 4 is somewhat less than for the 6SA7. The No. 3 grid (signal grid) side rods and the channels attached to the No. 2 grid serve, as in the 6SA7, to reduce the effect of No. 3 grid voltage on the cathode current. As with the 6SA7, a Hartley-type oscillator circuit is generally used in which the cathode is connected to a tap on the oscillator coil. Typical operating conditions and ratings for the 6SB7-Y are given in Table I.

The manner in which conversion transconductance, plate current, screen current, and cathode current vary with oscillator grid current when the oscillator voltage is applied from a separate source is shown in Fig. 2. The cathode-current curve closely approximates the curve which

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would be obtained with self-excitation but, in general, the plate current is lower and the screen current is higher when self-excitation is used. The cathode current reaches 22 milliamperes, the maximum rated value, when the grid current drops to 90 microamperes. This value of grid current applies when the grid resistor is 20,000 ohms; the developed dc voltage is 1.8 volts.

The curves of Fig. 3 show how the conversion transconductance various with the control-grid (No. 3) voltage. The initial slope is high because the 6SB7-Y has a higher ratio of conversion transconductance to plate current than most other converter tubes. This higher ratio is desirable for obtaining low noise, but it results, necessarily, in a steeper slope to the curve of conversion transconductance versus bias. Inspection of the curves of Fig. 3 show that a conversion transconductance as low as 3.5 micromhos is reached with approximately 20-volts negative bias. When the 6SB7-Y is used with a 6SK7 if tube, the gain reduction of the converter will be considerably more than that for the if tube at a given bias. This condition is undesirable, but it can be avoided by arranging the circuit so that less avc voltage is applied to the converter tube than to the if tube. When the 6SB7-Y is used with one or more 6SG7 tubes, the balance between their cutoff characteristics is practically the same as the balance between cutoff characteristics of a 6SA7 converter used with 6SK7 if tubes.

<u>Oscillator Considerations</u>

The curves of Fig. 4 show how the conversion transconductance varies with cathode voltage and oscillator grid current. In the design of oscillator circuits for use with the 6SB7-Y, emphasis must be placed on operation with low voltage at the cathode. This method of operation results in very low power output from the oscillator, since the power developed is the product of the RMS values of the oscillator-frequency components of cathode voltage and cathode current. The oscillator-frequency component of cathode current will have an RMS value of approximately 17 milliamperes as determined from the dc value under conditions of substantially complete modulation; hence, when the cathode voltage is 0.8 volts RMS the oscillator power output is approximately 14 milliwatts.

The voltage at the oscillator grid must be such that the power absorbed by the grid, grid resistor, and circuit is equal to the power delivered from the cathode. Consequently, the grid voltage developed with a given cathode voltage depends on the resonant impedance of the grid circuit. With the recommended grid-resistor value of 20,000 ohms, the grid voltage developed in the standard broadcast band for a cathode voltage of 0.8 volts is sufficient to produce a rectified grid current of approximately 0.35 milliampere. When the circuit impedance is lower, as is the case at the low-frequency ends of the short-wave bands, the power available with 0.8 volts at the cathode is not sufficient to produce this much rectified current. The curves of Fig. 4 show that when a compromise is necessary, the conversion transconductance obtained with normal cathode voltage and reduced grid current is considerably higher than that obtained with increased cathode voltage and high grid current. Cathode voltages below 0.5 volts at standard line voltage should be avoided because of the danger of oscillation failure should the line voltage drop. Accordingly it is recommended that the cathode voltage be adjusted to a value between 0.5 and 0.8 volts RMS, at the point in each frequency band giving the lowest cathode voltage. This point is generally the low-frequency end of the band when the circuits are tuned with variable capacitors.

Converter Considerations in the Standard Broadcast Band

The curves of Fig. 5 show sensitivities obtained in the 550-1650 kilocycle band as the cathode voltage is varied. The signal is applied at the converter grid. Curves taken with type 6SA7 in the same receiver are shown for comparison. An increase in gain approximately proportional to the increase in conversion transconductance is obtained. The calculated noise equivalent resistance for the 6SB7-Y is 78,000 ohms, assuming full shot-effect fluctuation in the plate current. The actual value is probably somewhat lower. Since this value is of the same order as the circuit impedances generally realized at broadcast frequencies, the increase over circuit noise is 2 to 3 db. The amount of further improvement obtainable by use of an rf stage is thus small. In the frequency range of 550 to 1650 kilocycles, the observed equivalent noise sideband input in a typical receiver with an antenna gain of 5 was 0.5 microvolts.

In order to maintain good signal-to-noise ratio for larger signals, it is important that the amount of avc voltage applied to the converter tube be kept moderate. Ideally, the first-tube gain should remain at the maximum until the signal level is so great that noise is no longer important. In practice, however, application of about half as much avc voltage to the converter as that used for the if tube is satisfactory when a 6SK7 if tube is used. When the if tube is a 6SG7, a larger fraction or full avc voltage is advisable.

Application in the Short-Wave Bands

It is recommended that the cathode voltage for short-wave bands be adjusted to approximately 0.8 volts at the low-frequency end of each band. As the oscillator is tuned to higher frequencies, the voltage will rise and there will be some loss of sensitivity. The space-charge coupling effect, causing induction of oscillator-frequency voltage on the signal grid, occurs in the 6SB7-Y as in other tubes using inner-grid injection of the oscillator voltage, and causes a further reduction in sensitivity. Neutralization by use of a capacitor between the oscillator and signal grids is not advisable because it tends to increase frequency shift with avc voltage. This shift is greater with the 6SB7-Y than with the 6SA7 and is an additional reason for reduction of the relative avc voltage on the 6SB7-Y in the shortwave bands. Maintenance of satisfactory frequency shift is aided by the present tendency to limit the frequency coverage in a single short-wave band, thereby allowing use of a larger minimum capacitance. A resistor of about 10 ohms in series with the oscillator (No. 1) grid may be required to prevent parasitic oscillations.

Inductance in the cathode lead should be kept as low as possible. The voltage drop in the part of the cathode-lead inductance not coupled to the coil is of no assistance in maintaining oscillation and furthermore, it acts to reduce the gain at the higher frequencies. The fact that this voltage tends to be in phase quadrature with the oscillator voltage also leads to the flow of signal-grid current in the tube. Similar considerations apply to other converter tubes, but the low optimum values of cathode voltage for the 6SB7-Y accent the importance of maintaining low voltage drop in the cathode lead. Use of a twisted-pair or concentric connection between the tube, coil and band switch may be advisable in some cases.

Operation in the Frequency-modulation Band

As frequencies are increased it becomes increasingly difficult to study the performance of a tube apart from the associated circuits. To obtain performance data for the 6SB7-Y in the 88-to-108 megacycle band, a system including a tuned rf stage, the converter circuits, and two if stages is used. Type 6SG7 tubes are used in the rf and if stages. The if amplifier operates at 10.7 megacycles with a band width of approximately 160 kilocycles. A square-law voltmeter is connected to the output of the second if stage. The schematic diagram of the test circuit is shown in Fig. 6.

The if amplifier gain measured from the first if grid to the tube voltmeter is approximately 1500, and the if gain from the 6SB7-Y grid signal grid to the tube voltmeter is approximately 18,000. The latter figure varies somewhat with different 6SB7-Y oscillator circuit adjustments. Transformers and other circuit elements used in the if amplifier are of conventional design. One side of the heater of the 6SB7-Y is connected to the cathode and to ground through the cathode section of the oscillator coil; an rf choke is thus necessary in the other heater lead. This connection is recommended because the cathode is connected to a tap in the oscillator circuit and when the heater is grounded variations in the heater-cathode capacitance resulting from vibration of the tube will cause variations in the oscillator frequency and consequently, microphonics.

The oscillator frequency is 10.7 megacycles above the signal frequency. The main tuning control is a ganged capacitor of conventional design with FM and AM sections. The incremental capacitance is approximately 16 uuf per section and a tuning range greater than 88 to 108 megacycles is obtained. Best results are obtained by inserting wipers for contact to the rotor in all sections and by grounding the capacitor frame solidly to the chassis. With a cushioned mounting, the use of several short braided connections between capacitor frame and ground would, presumably, accomplish the same result.

Initial adjustments are made on the oscillator circuit, with the 6SB7-Y signal grid connected to the chassis. The tap on the oscillator coil is adjusted to the position giving maximum grid current, and the inductance of the oscillator coil and the trimming capacitance across this coil are adjusted to give the desired frequency range with the tuning capacitor used. The signal grid is next connected to a tap on the signal-grid coil, and the signal is introduced from a signal generator to another tap on this coil. A 300-ohm resistor is used as a dummy antenna between the signal generator and the tap. The signal-grid circuit is adjusted to track with the oscillator circuit, and the best positions for the cathode tap on the oscillator coil and the grid tap and signal-input tap on the signal-grid coil are determined.

The rf stage is then added, the signal is introduced through the 300-ohm resistor to a tap on the rf grid coil, and the rf grid circuit is aligned with the other circuits. A readjustment of the tap for the 6SB7-Y signal grid is generally necessary when the rf stage is added, and some adjustment of capacitance on this circuit is required.

Criteria for Adjustment

The cathode tap on the oscillator coil is adjusted for maximum gain. Measurement of the oscillator-frequency voltage at the cathode when the frequency is above 100 megacycles is difficult, so the relation between the 6SB7-Y plate current and the cathode tap position is recorded to aid in the duplication of a condition once obtained. The curves of Fig. 7 show the effects of changing the position of the cathode tap. Best results are obtained with adjustments a little below the position for maximum grid current. Because the position of the tap lead with respect to the coil is at least as critical as the location of the point at which it connects to the coil, it is advisable to use a plate-current meter to determine whether the cathode voltage is being increased or decreased by adjustment of the tap. An increase in the cathode voltage causes a decrease in plate current, and this trend continues for tap positions considerably above the position giving maximum oscillator grid current.

The input conductance of the 6SB7-Y signal grid is negative (this is to be expected from theoretical considerations) and oscillation or excessive regeneration is observed in the signal-grid circuit when the signal-grid tap is too high on the coil. The effect of variation of the signal-grid tap position on gain and noise is shown by the curves in Fig. 8. The high-gain portion of the curve corresponds to the highest tap position. Oscillation occurs when the tap is raised above one and five-eighths turns on a coil having two and a half turns. The use of a non-inductive resistance of about three ohms in series with the 6SB7-Y signal grid is effective for improving the stability of the system and for improving the uniformity of gain between 88 and 108 megacycles.

The signal-input tap is located near the mid point of the rf grid coil; its position is not critical with respect to either gain or noise.

Typical operating conditions for the 6SB7-Y when used in the FM band, based on the results obtained in the system described, are given in Table II. This table also contains data on the coils and tuning capacitors used.

Test Results and Observations

When the rf stage is omitted and signal is introduced through a tap on the 6SB7-Y signal-grid coil, the gain from signal generator to if grid can be adjusted to a value of 6 to 8. A gain of 12 is observed with the signal grid tapped at one and three quarter turns and the antenna tapped at one-half turn on the signal-grid coil, but with this adjustment some tubes oscillate when the antenna loading is removed. The equivalent noise is of the order of twelve microvolts; the gain of the system without the rf stage is not sufficient to permit an accurate determination.

When the rf stage is included, the gain from the signal generator to the if grid can be adjusted to approximately 70 while maintaining satisfactory stability. Higher values of gain may lead to oscillation with some tubes and to unnecessarily large variations in performance among different tubes. The equivalent noise referred to the signal generator terminals is approximately five microvolts, and this value is affected only slightly by variations in the 6SB7-Y operating conditions. This indicates that most of the noise is from the 6SG7 rf tube.

The thermal noise in the 300-ohm dummy antenna resistor is 0.9 microvolts for the if band width (160 kilocycles) used. When the equivalent noise is 4.5 microvolts the noise figure for the system expressed as a power ratio is 25, or 14 db. Values ranging from 2.8 to 6.3 microvolts, or 10 db to 17 db, are observed with various 6SG7 and 6SB7-Y tubes in the sockets. In terms of receiver performance, virtually noise-free reception can be expected when the signal amplitude is three or four times greater than the equivalent noise, referred to the signal source. Therefore, if sufficient overall gain and a good FM detector system are provided the combination of the 6SG7 and the 6SB7-Y is suitable for the reception of signals at about the 20-microvolt level.

Substitution of ceramic trimmers for the tuning capacitor sections does not change the gain or noise materially; but in the case of the oscillator tuning capacitor section, the substitution of a ceramic trimmer results in a considerable increase in oscillator grid current and a decrease in plate current at the low-frequency end of the FM tuning range. This suggests that the rf resistance of the ganged capacitor accounts for an appreciable fraction of the circuit losses when the capacitor is adjusted to maximum capacitance.

There are a large number of possible variations in circuit adjustments for a system like the one shown in Fig. 6. The total inductance for each circuit is determined by the range of the tuning capacitor. This inductance, when obtained with the large-diameter coils and the large wire sizes used, gives a tuned impedance of sufficient value to favor oscillation. The rf stage alone oscillates when both grid and plate connections are made to the top ends of their respective coils. Consequently, it is necessary either to use taps on these circuits or to use resistance loading to prevent oscillation. The use of taps or some other form of reduced coupling is more desirable since the selectivity of the circuits is thereby retained. The equipment designer generally does not have a free choice of coil sizes and location of parts, so it may well be that circuit impedances too low to cause oscillation will occur in some cases. In such cases, tapping or loading of the circuits is unnecessary, but the designer must be on guard against borderline cases in which some tubes or sets break into oscillation, although the majority of them are stable. For the present, we must expect somewhat greater variations in performance among tubes and other components at 100 megacycles than we are inclined to tolerate at lower frequencies, and we must provide correspondingly greater factors of safety in equipment design.

Frequency Drift

When a cold 6SB7-Y tube is inserted in the test circuit, with the circuit warmed up and adjusted to a signal frequency of 108 megacycles, the oscillator frequency decreases by approximately 45 kilocycles while the tube is heating. The frequency is within one or two kilocycles of the final value after ten minutes. The oscillator frequency is 119 megacycles, so the ratio of the increment in frequency to the operating frequency is 380 parts in a million. This can be interpreted as a change in effective capacitance across the oscillator circuit, amounting to 760 parts in a million. The calculated inductance of the oscillator coil is approximately 0.040 microhenry, and the total capacitance required for 119 megacycles is consequently 45 micro-microfarads. The warm-up drift is therefore approximately 0.035 micro-microfarads, referred to the oscillator coil terminals.

TABLE I

RCA-6SB7-Y Ratings & Characteristics

Plate voltage	300 max.	volts
Screen (grids No. 2 & No. 4) voltage	100 max.	volts
Plate dissipation	2.0 max.	watts
Screen dissipation	1.5 max.	watts
Total cathode current	22 max.	ma.

Typical operation and characteristics:			
Plate voltage	100	250	volts
Screen voltage	100	100	volts
Control-grid (No. 3) voltage	-1	-1	volts
Oscillator-grid (No. 1) res.	20,000	20,000	ohms
Plate resistance (approx.)	0.5	1	megohm
Oscillator-grid current	0.35	0.35	ma.
Plate current	3.6	3.8	ma.
Screen current	10.2	10.0	ma.
Total cathode current	14.2	14.2	ma.
Conversion Transconductance	900	950	micromhos
Conv. Transcond. at -20 volts on grid No. 3	3.5	3.5	micromhos

Note: The transconductance between Grid No. 1 and Grids Nos. 2 and 4 connected to plate (not oscillating) is approximately 4500 micromhos under the following conditions: Grids No. 1, No. 3 and shell at zero volts; grids No. 2 and No. 4 and plate at 100 volts.

TABLE II

<u>Typical Operating Conditions for 6SB7-Y in FM Band</u>

Plate voltage		250 volts
Grids No. 2 and No. 4 supply voltage		250
Grids No. 2 and No. 4 resistor		12,000 ohms
Grid No. 1 resistor		20,000 ohms
Grid No. 3 resistor		3.3 ohms
Signal frequency	88	108 megacycles
Oscillation frequency	98.7	118.7 megacycles
Plate current	6.8	6.5 ma.
Grids No. 2 and No. 4 current	12.6	12.5 ma.
Grid No. 1 current	0.130	0.140 ma.

Coils: All 5/8 inch diameter, approximately 5/8 inch long.

Antenna: Two turns No. 14 wire + 1-1/4 inch lead No. 20 wire. Coil tapped at one turn.

Interstage: Two turns No. 14 wire + 1-1/4 inch lead No. 20 wire. Coil tapped at 1-1/4 turn.

Ganged tuning capacitor: 7-23 uuf each section.

The insertion of three 10-ohm resistors in parallel in the grid No. 3 circuit of the 6SB7-Y is helpful in preventing oscillation in the signal grid circuit and is helpful in reducing the variation of sensitivity between different frequencies.

Average gain from signal generator to first if grid is approximately 70 with a 300-ohm resistor in series with the signal generator. With an if bandwidth of 160 kilocycles, the equivalent input noise is approximately five microvolts.

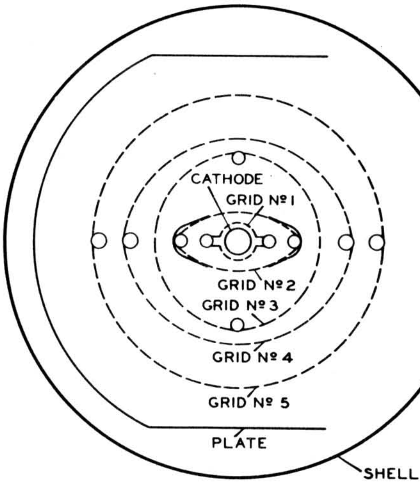

Fig. 1 RCA-6SB7-Y Electrode Structure and Arrangement

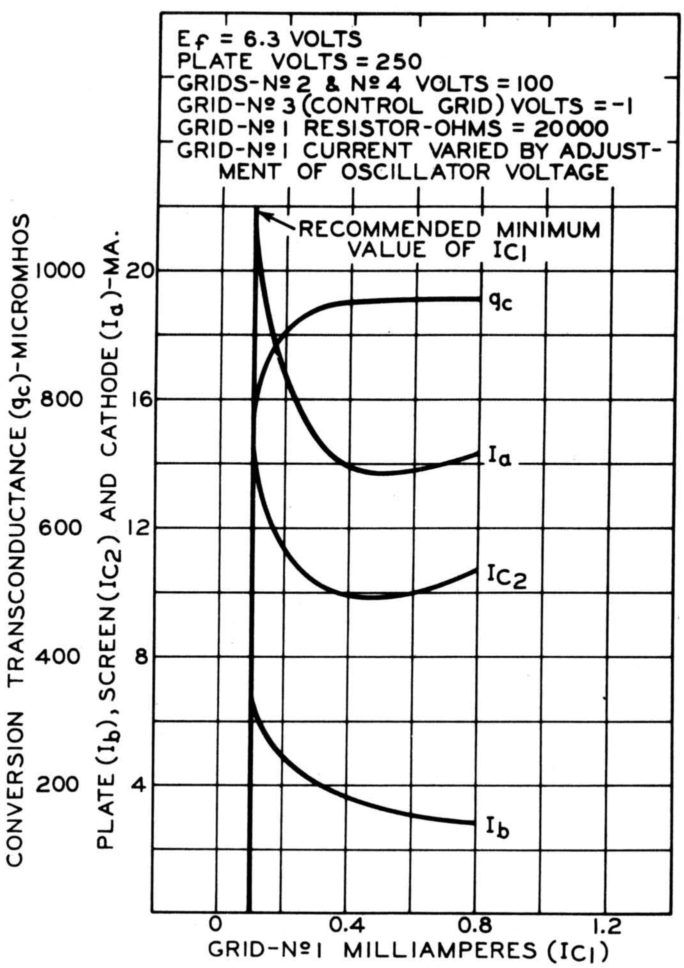

Fig. 2 RCA-6SB7-Y Operation Characteristics With Separate Oscillator Excitation

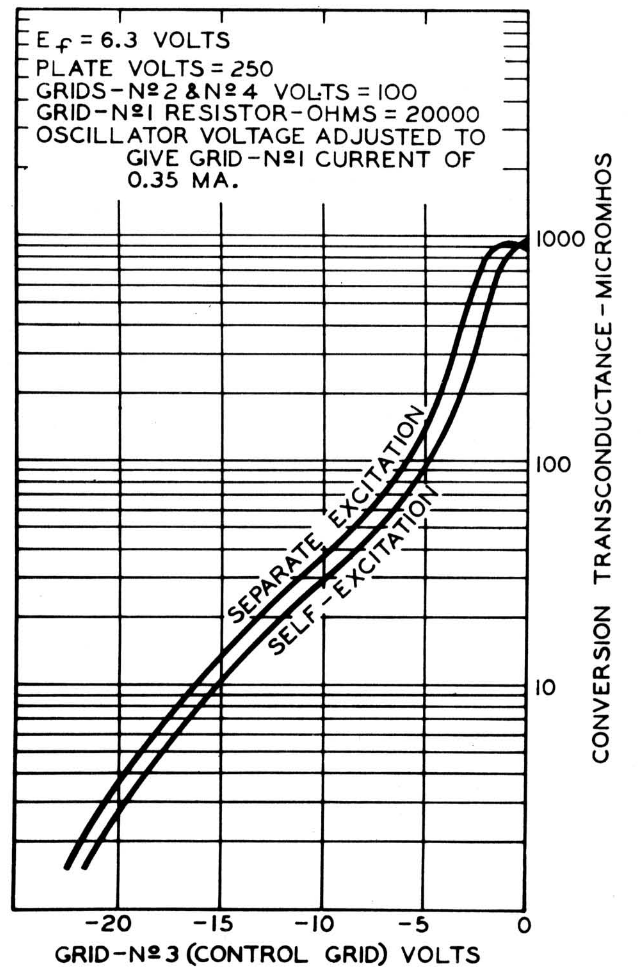

Fig. 3 RCA-6SB7-Y Operation Characteristics

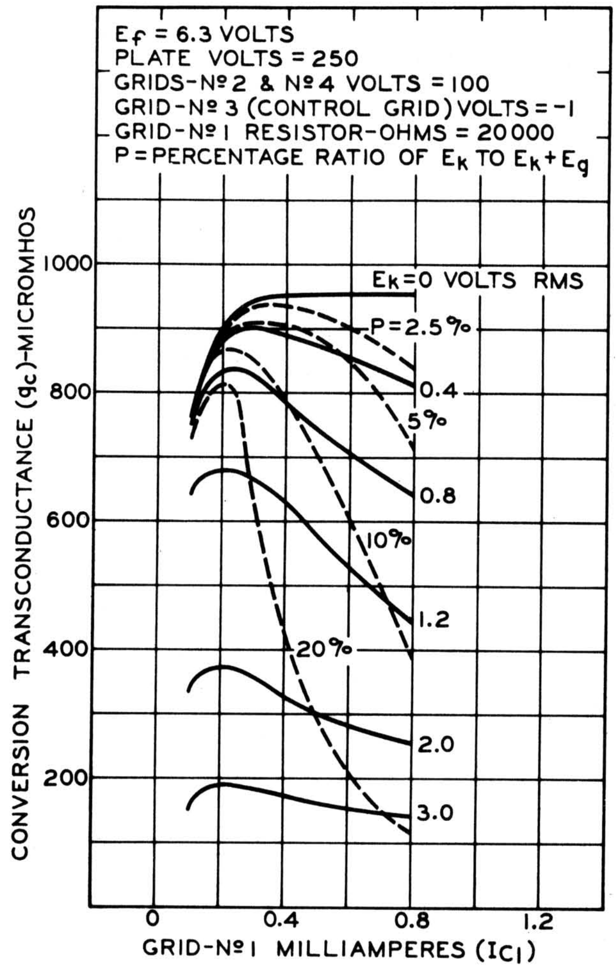

Fig.4 RCA-6SB7-Y Operation Characteristics With Self-Excitation

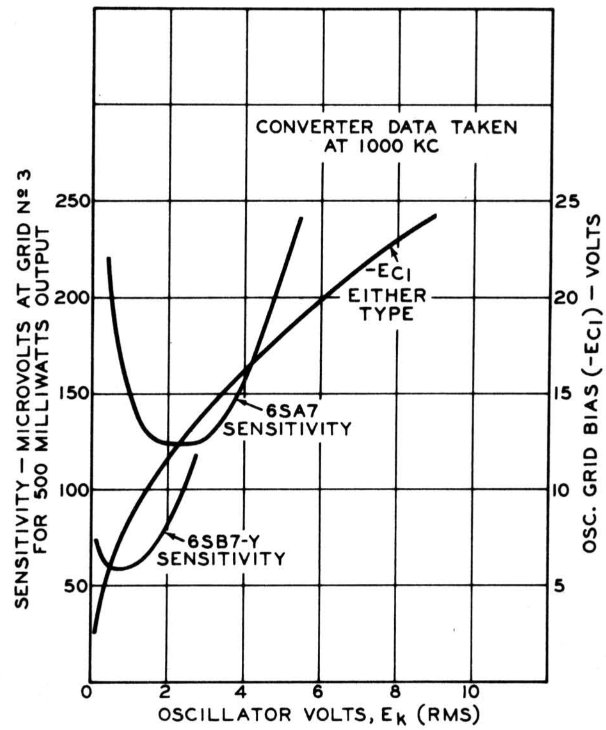

Fig.5 RCA-6SB7-Y Converter Sensitivity At 1000 Kilocycles

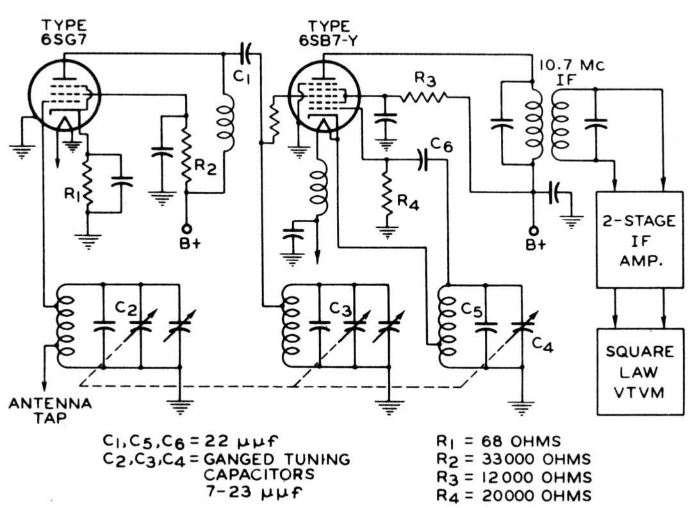

Fig.6 Schematic Diagram of 100-Megacycle Test Circuit

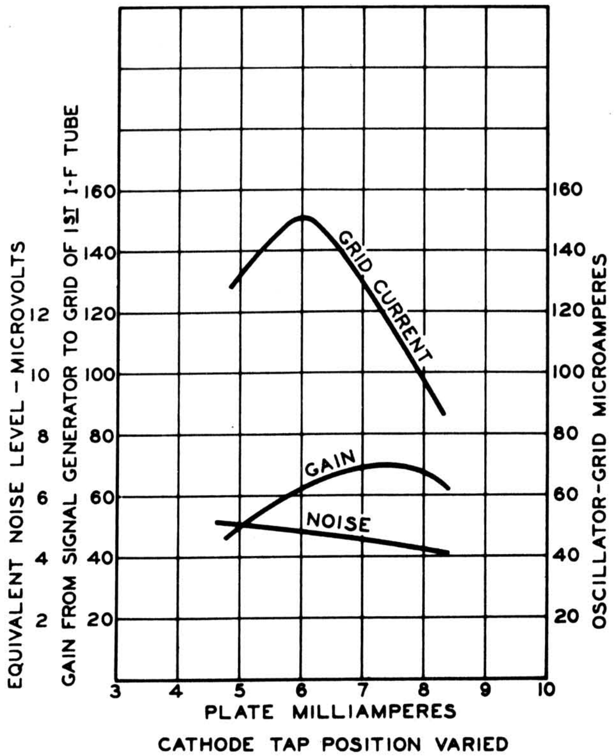

Fig. 7 Effect of Changing Cathode-Tap Position on Grid Current, Gain, and Noise

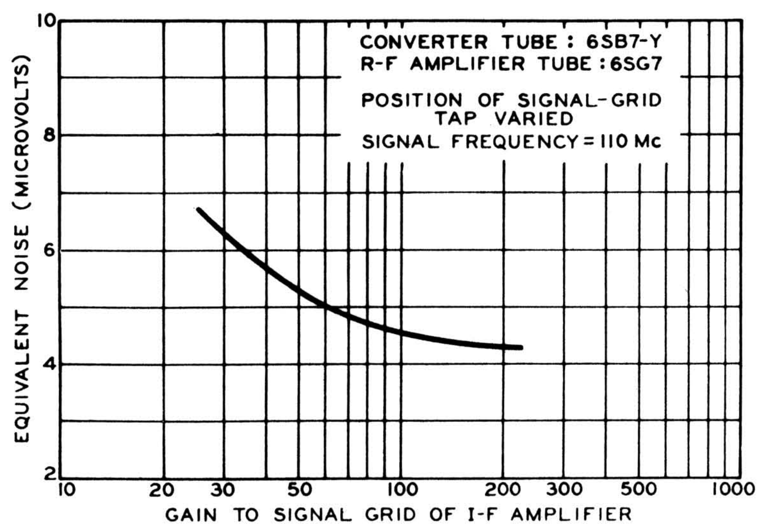

Fig. 8 Effect of Changing Signal-Grid-Tap Position on Gain and Noise