DYNAMIC

THE DYNAMIC CHARACTERISTICS OF A PENTODE, in which a resistance load is inserted in the plate circuit, is of particular importance in the design of high signal level resistance-coupled amplifiers. This characteristic will be found more convenient for calculations, when maximum output voltage is desired, than the plate characteristics generally supplied.

If only a small output voltage with maximum gain is required there is considerable latitude in the choice of the operating point without the occurrence of perceptible distortion and the usual plate characteristic curves are applicable.

In studying pentode dynamic characteristics, a family of plots for sharp cut-off pentodes, 6SJ7, 6SH7 and 6AG7 were prepared, Figures 1 to 7. In these plots a family of characteristics for a particular plate load and supply voltage is shown. The plate current and the plate voltage were plotted as a function of the control grid voltage using the screen voltage as a parameter. In each case the tube chosen for measurement was the average of six tubes tested.

The shape of these curves for different screen-grid voltages will be found somewhat similar, with a nearly straight portion at the middle, gradual

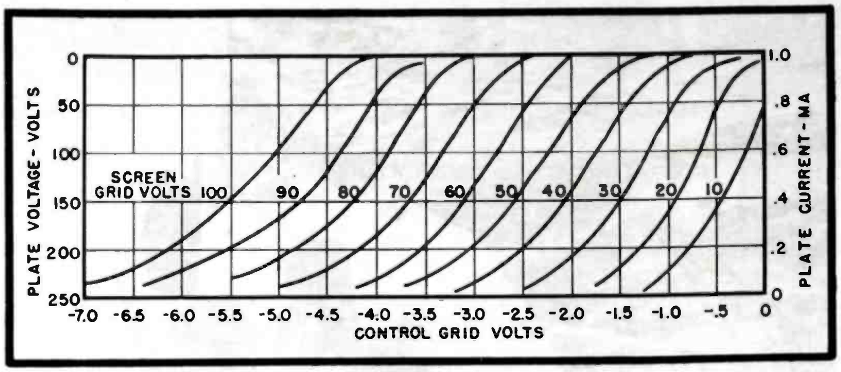


Figure 1

Dynamic characteristics of 6SJ7. Supply voltage, 250; load resistance, .25 megohm; heater voltage, 6.3.

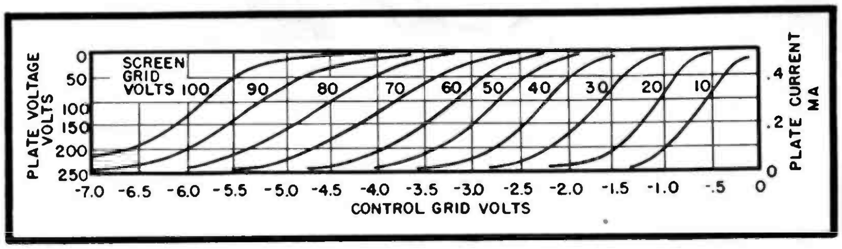


Figure 2

Dynamic characteristics of 6SJ7. Supply voltage, 250; load resistance, .5 megohm; heater voltage, 6.3.

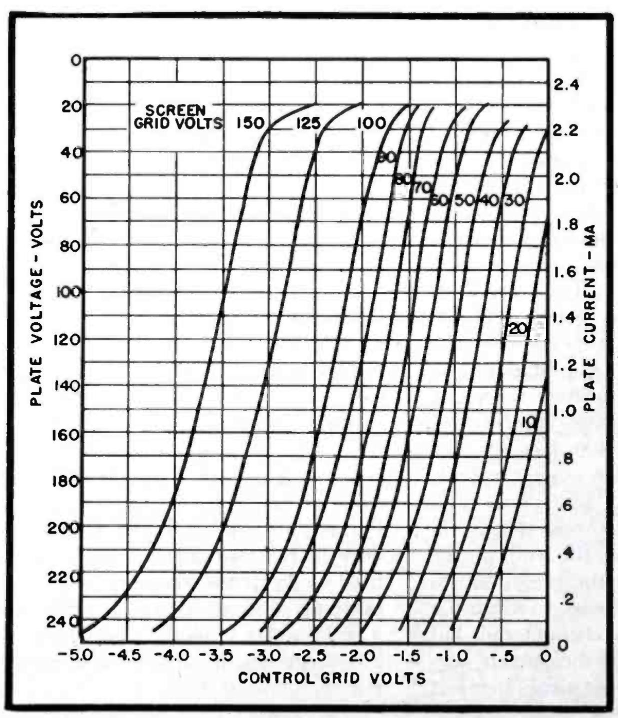
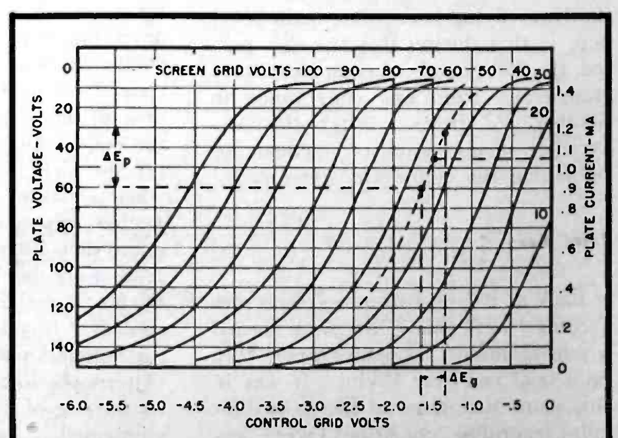


Figure 4 (left)

Dynamic characteristics of 6SH7. Supply voltage, 250; load resistance, .1 megohm; heater voltage, 6.3.

Figure 3

Dynamic characteristics of 6SJ7. Supply voltage, 150; load resistance, .1 megohm; heater voltage, 6.3.



CHARACTERISTICS OF PENTODES

Analysis of the Use of Dynamic Characteristics of Pentodes in Designing High Signal Level Resistance-Coupled Amplifiers. Measurements Made with 6SJ7, 6SH7 and 6AG7 Sharp Cut-Off Pentodes Offered in a Group of Plots.

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curvature at the lower end and a fairly sharp top bend.

Prepared also were a screen-grid current family of curves (Figures 8 to 14) for the 6SJ7, 6SH7 and 6AG7, to study the function of control grid voltage using the screen grid voltage as a parameter. These curves should prove useful for estimating the portion of the total tube current drawn by the screen grid.

Plate and Dynamic Characteristic Design Procedures

To analyze the usefulness of the dynamic characteristics as a design approach, design steps using plate and dynamic characteristics were studied.

Design Steps Using Plate Characteristics: It is first necessary to choose the plate load resistance, supply voltage, and plate and screen voltages of, let us say, a 6SJ7.

The value of the load resistance is determined from frequency response considerations. For this example let us suppose a load resistance equal to .1 megohm; supply voltage, 150; plate and screen grid voltages, 45.

In the next step the plate current must be calculated. Since the voltage drop in the load resistance is equal to the supply voltage minus the plate voltage, the plate current is $\frac{150-45}{100{,}000} \times 1{,}000$, or 1.05 ma.

The receiving tube characteristics (Figure 15) are then entered on the plot of the operating plate and screen voltages for the 6SJ7 tube and we find the grid bias voltage and screen current. We note, for example, that at a plate current of 1.05 ma the bias would be −1.5 volts, and the screen current at this bias voltage would be 0.35 ma.

In the next step the cathode current and bias resistance is calculated.

The cathode current is the sum of the plate and screen grid current and is equal to 1.05 + .35 or 1.40 ma. The bias resistance is equal to the bias voltage divided by the cathode current or $\frac{1.5}{1.4} \times 1{,}000 = 1{,}070$ ohms. A commercial value of 1,000 ohms would be used.

It is then necessary to compute the screen grid voltage dropping resistance, if one is used, to give the correct screen grid operating voltage.

The voltage drop in this resistance

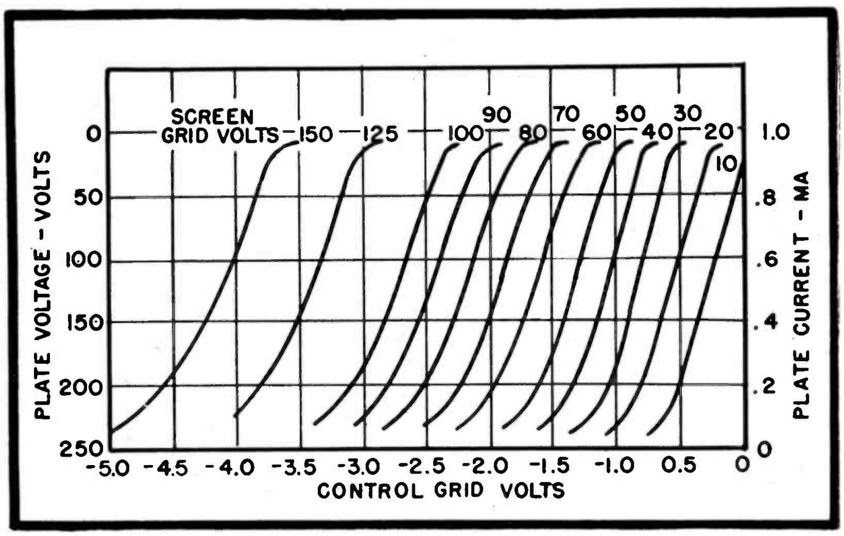
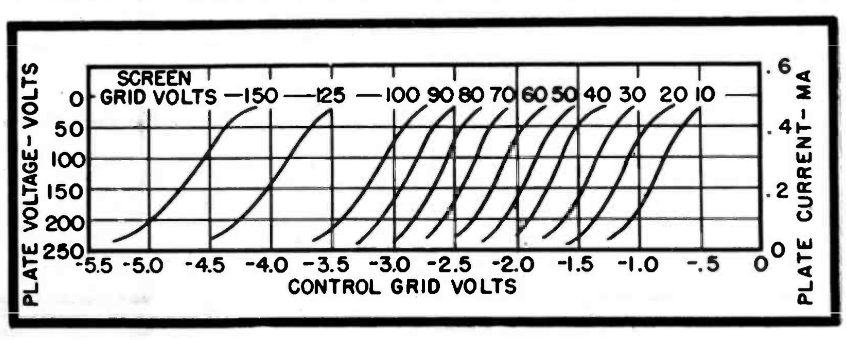
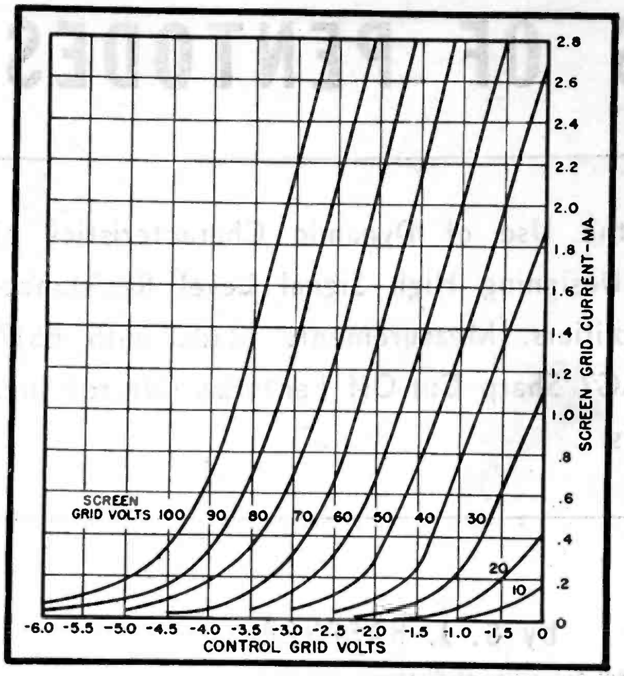


Figure 5
Dynamic characteristics of 6SH7. Supply voltage, 250; load resistance, .25 megohm; heater voltage, 6.3.

Figure 6
Dynamic characteristics of 6SH7. Supply voltage, 250; load resistance, .5 megohm; heater voltage, 6.3.





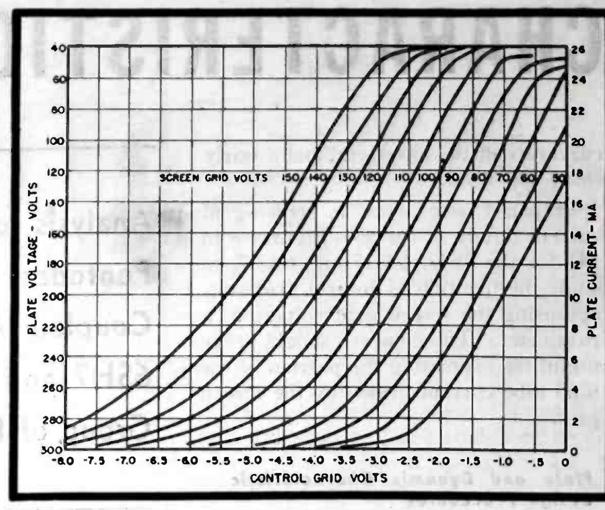


Figure 7 (above)
Dynamic characteristics of 6AG7. Supply voltage, 300; load resistance, 10,000 ohms; heater voltage, 6.3.

Figure 8
Dynamic characteristics of 6SJ7. Supply voltage, 250; load resistance, .25 megohm; heater voltage, 6.3.

is equal to the supply voltage minus the screen grid operating voltage and is numerically 150 – 45 or 105 volts. The resistance is equal to the voltage drop divided by the screen grid current or $\frac{105}{.35} \times 1{,}000$, or .3 megohm.

From the plate-characteristic curves (Figure 15) we then have to determine the G_m, μ and R_p at the operating bias voltage.

From the curves, at –1.5 volts grid bias voltage, $G_m = 1{,}050$, $\mu = 1{,}350$, and $R_p = 1.3$ megohms.

In the final step the voltage gain of the tube is computed. This is nearly equal to G_m times the parallel resistance of the load resistance and the grid resistance of the following tube.

Assuming a grid resistance of .25 megohm, the voltage gain of the tube is approximately $1{,}050 \times \frac{.25 \times .1}{.35}$ or

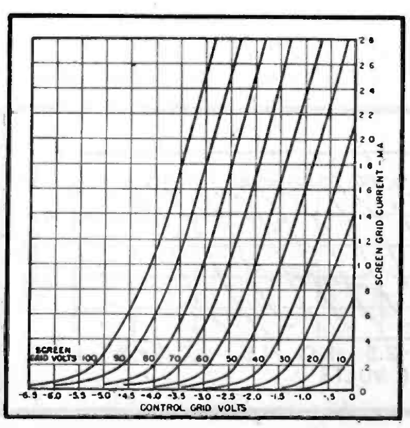


Figure 9
Screen-grid current characteristics of 6SJ7. Supply voltage, 250; load resistance, .5 megohm; heater voltage, 6.3.

75, with the cathode resistance sufficiently bypassed.

The maximum possible undistorted output voltage of the 6SJ7 pentode is of the order of 10 volts rms (obtained from dynamic characteristics plot) with the assumed supply voltage of 150 volts, operating voltages of 45 on the screen grid and plate, and a bias voltage of –1.5 volts.

It is well known that minimum distortion occurs with any triode when the control grid voltage is as small as possible without any risk of running into grid current. For a pentode, however, due to the control of the voltage on the screen grid, it is possible to adjust the operating conditions so that the working part of the characteristic (the *straight* portion) is well away from the grid current region. Since with a pentode the operating point can be arranged not to enter the grid-current region, the control-grid voltage swing is only limited by the curvature at each end of the dynamic characteristic.

Although the plate characteristic of a resistance-coupled pentode is the basis of calculation, it is more convenient to use the dynamic characteristic to determine the maximum output voltage.

Design Steps Using Dynamic Characteristic Curves: Now let us take the foregoing example and solve it by using the dynamic characteristic curves.

First we select the plate load resistance and supply voltage: for the illustrative example the load resistance is .1 megohm and the supply voltage is 150.

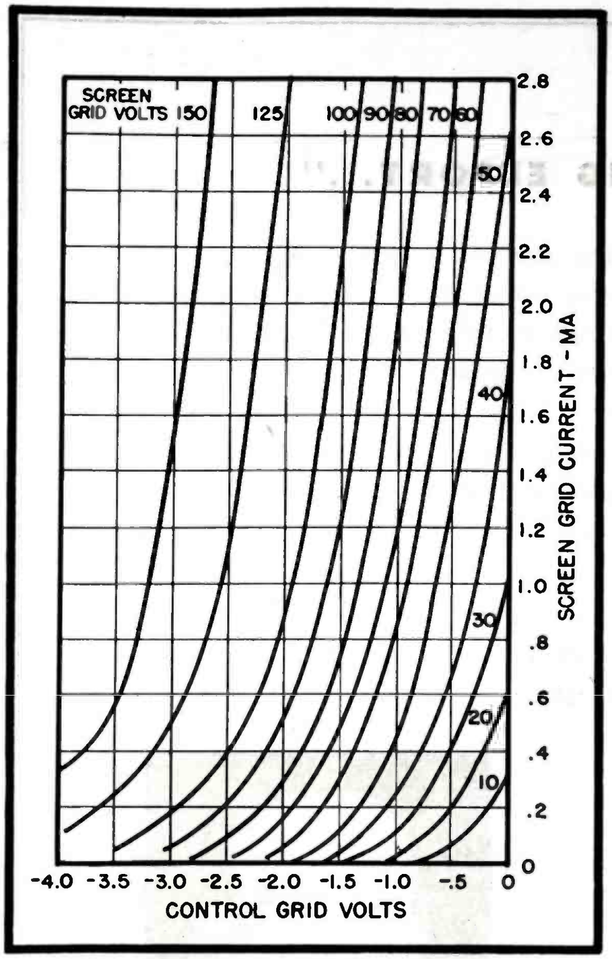
Finding Plate Current

From the dynamic-characteristic plot we find the plate current. This is applied to the plot with the supply voltage and load resistance for the tube used, and we select the curve from the family of curves corresponding to the value of assumed screen grid voltage. For maximum output voltage we should select a bias voltage in the middle of the *straight-line* portion of the particular curve chosen and read the plate current corresponding to this voltage.

In this example (from Figure 3) $I_p = 1.05$ ma at a bias of –1.5 volts and a screen grid voltage of 45.

Calculating Tube Gain

The gain of the tube is then calculated. Since the plate current is also the current flowing through the load resistance, there is a linear relation-



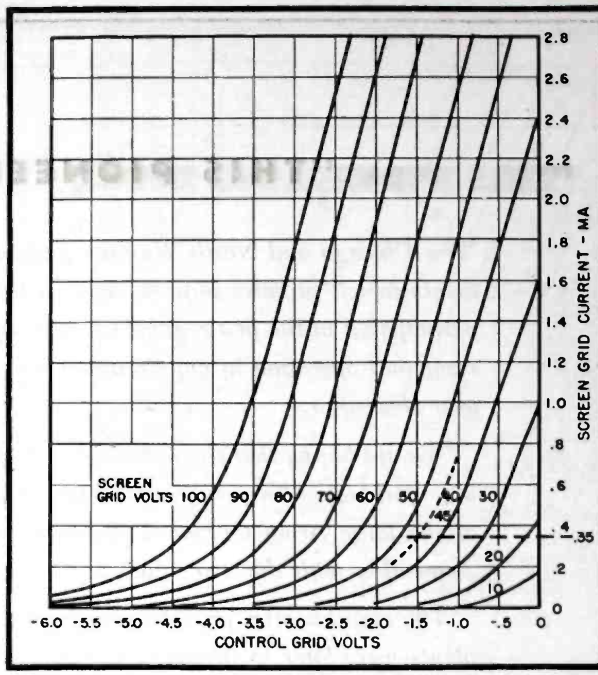


Figure 10 (above)
Screen-grid current characteristics of 6SJ7. Supply voltage, 150; load resistance, .1 megohm; heater voltage, 6.3.

Figure 11
Screen-grid current characteristics of 6SH7. Supply voltage, 250; load resistance, .1 megohm; heater voltage, 6.3.

ship between the plate current and the plate voltage. A plate voltage scale is shown on the left-hand side of the plot. The gain of the tube is $\Delta E_p/\Delta E_g$ or the slope of the dynamic characteristic curve. Since the load resistance is shunted by the grid resistance, R_g, of the following tube, the gain will be reduced to approximately $R_g/(R_g + R_L)$ of the gain just calculated.

For the 6SJ7, the gain from Figure 3, $\frac{\Delta E_p}{\Delta E_g}$ is $\frac{30}{.3} = 100$, and the net gain is $100 \times \frac{.25}{.35}$ or 71.5, with the cathode resistance sufficiently bypassed.

The screen grid current is then found by referring to the proper curve of Figures 8 to 14. The screen-grid dropping resistor is equal to the supply voltage minus the screen-grid voltage divided by the screen grid current.

Numerical Values for 6SJ7

The numerical values for the 6SJ7 example are, from Figure 10: Screen grid

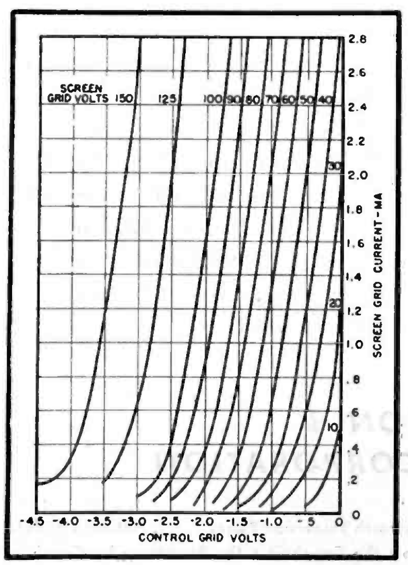
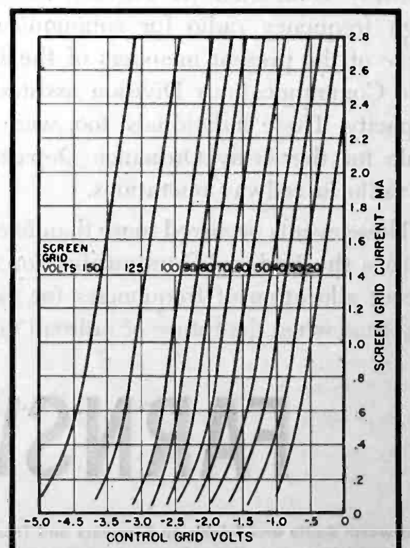


Figure 12 (left)
Screen-grid current characteristics of 6SH7. Supply voltage, 250; load resistance, .25 megohm; heater voltage, 6.3.

Figure 13
Screen-grid current characteristics of 6SH7. Supply voltage, 250; load resistance, .5 megohm; heater voltage, 6.3.



current, 0.35 ma; screen grid dropping resistor, $\frac{150-45}{.35} = .3$ megohm.

The bias resistance is then calculated. This resistance equals the bias voltage divided by the sum of the plate and screen currents.

The total cathode current is 1.4 ma.

The cathode resistance is $\frac{1.5}{1.4} \times 1{,}000 = 1{,}070$ ohms.

Plate Distortion

Referring to Figure 3 it is evident that the peak plate voltage swing on the straight part of the dynamic-characteristic curve, with the operating point assumed in the above example, is about 15 volts. Therefore, the maximum undistorted output voltage is approximately 10 volts rms.[1] An output voltage of about $25/\sqrt{2}$ rms volts can be obtained however with a small (in most cases unobjectionable) amount of distortion by allowing the swing to extend part way into the curved upper portion of the dynamic characteristic.

A good working rule for maximum possible output voltage is to select the working point at a current of approximately

$$\frac{0.56 \times \text{Supply Voltage}^2}{\text{Load Resistance}}$$

Substituting Numerical Values

Substituting numerical values for the problem in question we have $I_p = \frac{.56 \times 150}{100{,}000} \times 1{,}000$ or 0.84 ma.

At the bias voltage of −1.5 the operating plate and screen voltages are 66 and 41 from Figure 3. It is apparent from the curves that the maximum plate-voltage swing and hence the output voltage will be larger than that at the operating plate voltage of 45 volts. An estimated maximum output rms voltage from the curves with a small amount of distortion is $46/\sqrt{2}$ volts.

[1] See reference to this value in plate-characteristic distortion data.

[2] *Radiotron Designer's Handbook,* Amalgamated Wireless Valve Company, Pty., Ltd., Australia, p. 273.

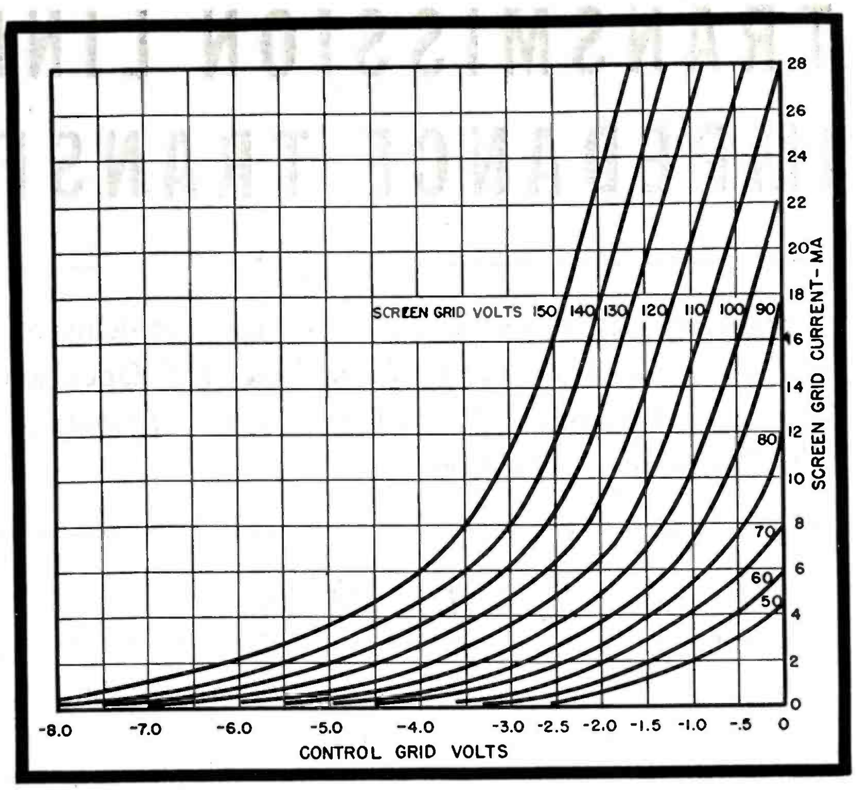


Figure 14

Screen-grid current characteristics of 6AG7. Supply voltage, 300; load resistance, 10,000 ohms; heater voltage, 6.3.

Figure 15

Characteristic curves of 6SJ7 used in design procedures employing plate and dynamic characteristics.