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CATHODE HEATER COMPENSATION AS APPLIED TO DEGENERATIVE DC POWER SUPPLY

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CATHODE HEATER COMPENSATION AS APPLIED TO DEGENERATIVE VOLTAGE STABILIZED DC POWER SUPPLIES

by

Robert C. Ellenwood
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I. *ABSTRACT*

A new method of compensating a degenerative-type voltage stabilizer which simplifies the design of precision-stabilized dc power supplies is discussed. If the operating voltages of the dc amplifier in the comparator circuit of the stabilizer are properly chosen, compensation for the line-voltage changes is obtained from the corresponding changes in the "heater-to-plate" transconductance. An equation for the overall stabilization factor of the compensated stabilizer is presented in terms of the stabilization factor of a simple degenerative stabilizer. Output-voltage changes of less than 0.005 percent for ± 10 percent change in line voltage were obtained from experimental tests of sample power supplies with 350-volt output.

Table of Contents

II. *INTRODUCTION*

To improve the accuracy of UHF measurements, it was found expedient to develop several precision-stabilized dc power supplies[1]. Although each power supply was designed for use with a specific instrument it was required that each:

1. Produce the required dc output of several hundred volts.
2. Be designed for a current drain of several hundred milliamperes with an approximately constant load resistance.
3. Have stability such that the output voltage be practically independent of line-voltage changes expected in the laboratory.
4. Have as simple a curcuit as possible to facilitate repairs and adjustments.

Neher and Pickering in a 1939 report[2] observed that under certain conditions the experimental performance of a stabilized power supply was better than their theoretical prediction. They found that the lower the screen grid voltage of one of the component tubes, the better the voltage stabilization. This phenomenon could be attributed to the greater cathode temperature control of the amplifier-tube plate-current at lower screen voltages. Since the cathode temperature depends on the heater voltage, the variations in heater voltage can be employed to improve the voltage stabilization for variations in line voltage.

In view of the disagreement in literature in the usage of the terms "regulation" and "stabilization", it is desirable to define these terms as used in this paper. "Stabilization" refers to the reduction of output-voltage, or output-current fluctuations. "Regulation" refers to the percentage change of output voltage of a power supply as the power-supply output-current is changed.

III. *GENERAL THEORY AND DESIGN CONSIDERATIONS*

The majority of commercially available general-purpose stabilized power supplies that furnish several hundred milliamperes at several hundred volts are of the degenerative amplifier type. The basic circuit of this type of stabilizer is shown in Fig. 1. The degenerative dc amplifier (T2 in Fig. 1) is in a comparator circuit[3] which compares the output voltage of the stabilizer with some reference voltage. The overall stability of the power supply is no better than the stability of the reference voltage. Dry cells or standard cells can be used as precision reference voltage standards.

The equation of stabilization for the stabilizer circuit of Fig. 1 is usually given as follows:

$$F = 1 + \frac{r_{p1}}{R_L} + \frac{R_2\mu_1 \ (\mu_2 + 1)}{r_{p2} + R_2} \qquad (1)$$

where

F = stabilization factor $\left(\frac{\Delta V_{in}}{\Delta V_{out}}\right)$

ΔV_{in} = change in dc voltage input to stabilizer

ΔV_{out} = change in dc voltage output

r_{p1} = plate resistance of the control tube (T_1).

R_L = external load resistance

R_2 = plate load resistance of dc amplifier (T_2).

μ_1 = amplification factor of the control tube (T_1).

μ_2 = amplification factor of the dc amplifier (T_2).

r_{p2} = plate resistance of the dc amplifier (T_2).

It is seen from the above equation that the theoretical stabilization factor (F) for a given load (R_L) is limited by the amplification factors and the plate resistances of the given tubes. It is noted that the stabilization factor (equation 1) does not directly consider the effect of line-voltage changes on the heater voltage. The heater voltage is proportional to the line voltage in most power supplies.

Precision measurements often require the use of a dc power supply with output voltage practically independent of line-voltage changes. A stabilization factor (F_L) which includes the effect of variations in the line voltage on the heater voltage is developed in the appendix and given in equation 2, in terms of the stabilization factor (F), of equation 1.

$$F_L = \frac{F}{N_p\left[1 - \frac{R_2 \mu_1 r_{p2} S_{h2} N_h}{r_{p2} + R_2}\right]} \qquad (2)$$

where

$$F_L = \frac{\text{change in line voltage } (\Delta V_L)}{\text{resultant change of output voltage } (\Delta V_{out})}$$

$N_p \approx$ turns ratio of plate transformer.

$N_h \approx$ turns ratio of heater transformer.

$S_{h2} = \frac{\Delta i_{p2}}{\Delta e_{h2}} =$ heater-to-plate transconductance

The term "Transconductance" is used for want of a better term to describe the effect on the plate current of heater voltage, acting through its control upon the initial velocity of the electrons emitted by the cathode. Although the term is dimensionally correct no attempt is made to defent it as rigorously correct. It is evident from Equation (2) that, if the denominator equals zero, F_L approaches infinity, which indicates perfect stabilization with respect to line-voltage changes. If the other factors in the denominator are of the proper order of magnitude, nearly perfect stabilization can be obtained by adjusting the heater-to-plate transconductance (S_{h2}) of the dc amplifier tube (T_2). Therefore, the design of a heater-compensated power supply requires a family of characteristic curves for the dc amplifier tube (T_2 of Fig. 1) which presents the plate current as a function of heater voltage and screen grid voltage.

IV. *DESCRIPTION OF OPERATION*

Measurements were made on the stabilized power supply shown in Fig. 2 for the purpose of analyzing its heater compensation. It was found that the output voltage is sensitive to small changes in the heater voltage of the dc amplifier tube (T_2) but independent of the heater voltage of the control tube (T_1).

Since the compensation is effected through the dc amplifier tube T_2, a study was made of the operation of the amplifier curcuit. When a change occurs in the heater voltage, the change in the plate current (Fig. 3) of the amplifier tube results in a proportional change in the voltage V_d across R_2 which appears on the grid of the control tube T_1. In this way additional compensation for a line-voltage change can be obtained from the heater-voltage change. The change in voltage V_d per 20-volt change in line voltage was measured for various values of screen voltage. It was found that the lower the screen voltage the greater the incremental change in the voltage drop per unit change in heater voltage (See Figs. 4 and 5). Since the heater-to—plate transconductance, S_{h2} in equation 2, is defined as the change in plate current per unit change in heater voltage with all other tube voltages held constant, it is seen that the incremental change in the voltage drop per unit change in heater voltage, the ordinate of Fig. 5, is proportional to S_{h2}. Therefore the transconductance S_{h2} varies with the screen grid voltage as in Fig. 5. The screen grid voltage at which S_{h2} has the proper value for maximum stabilization can be selected from experimental data such as shown in Fig. 6.

The improvement with heater compensation of the stabilization of a power supply is shown in Figs. 7a, 7b, and 7c. The performance of the power supply without heater compensation is shown in Fig. 7a. It is seen that with a constant heater voltage an increase in line voltage of 10 volts resulted in an increase in output voltage of about 0.1 volt. The effect of changes in heater voltage is presented in Fig. 7b. With the input voltage to the stabilizer, V_{in}, held constant and the screen grid voltage set at the value for maximum stabilization, an increase of 10 volts in the primary voltage of the heater transformer resulted in a decrease in the output voltage of about 0.1 volt. Thus it is seen that the heater voltage can be employed to provide the additional compensation which the degenerative type-voltage stabilizer usually lacks for perfect stabilization with respect to line-voltage changes. Fig. 7c shows that, with the primaries of the high-voltage and heater transformers connected to a common line voltage and the screen grid voltage set at its proper value, the heater-compensated power supply has a maximum deviation of output voltage of 0.01 volt for a line-voltage change of ± 10 percent. This is a variation of less than 0.0005 percent in output voltage per volt change in the line.

IV. *COMPENSATION FOR TIME LAG*

A compensating voltage determined by the heater voltage of an indirectly heated cathode-type tube has a time lag dependent on the time necessary for the cathode temperature to come to equilibrium[4,5]. To reduce the effect of of this time lag, an RC circuit is applied between the input terminal (V_{in}, Fig. 1) and the screen grid of the dc amplifier. When a sudden change of line voltage occurs, the RC circuit applies the proper value of voltage to the screen grid of the dc amplifier to compensate for the thermal time lag of the cathode temperature. The time constant of the RC network was chosen to be that of the temperature change of the cathode.

The effect of the time lag in the heating of the cathode in the dc amplifier is shown in Figs. 8a,b,c,and d. This information is transferred from data recorded with a Brush magnetic recorder. As expected, the output voltage of the power supply changes instantaneously with the change of line voltage as illustrated in Figs. 8a, b, c. If heater compensation is used, the output voltage returns to its original value (Fig. 8c) at a rate dependent on the thermal lag of the cathode. When the RC circuit is added to apply a compensating voltage on the screen grid of the dc amplifier, the minute change in output voltage can not be recorded with the equipment on hand. When the voltage applied to the screen grid of the dc amplifier by the RC circuit (Fig. 8d) is compared with the change in output voltage obtained without the compensating RC circuit (Fig. 8c) it is seen that the two voltages return exponentially at the same rate to their original values.

VI. *DESIGN EXAMPLE*

A sample power supply was built which incorporates the above features. The complete circuit diagram is shown in Fig. 2 and a discussion of the circuit is given below.

This particular supply was designed to provide 350 volts dc at a full load of 250 milliamperes. In order to carry this amount of current six 6L6 current-control tubes are used in parallel. It is necessary that the plate transformer have sufficient capacity to supply 550 volts under full load to the plates of the 6L6 current regulators. The 6L6 tubes are used as triodes with a small resistor in each individual screen grid and control grid in order to damp these circuits to prevent oscillation.

The dc amplifier tube should have a high amplification factor in order to have maximum stability and minimum ripple. A rugged high-transconductance pentode with minimum plate current is desirable. A 6SJ7 was chosen although similar tubes could have been used. Only one stage of dc amplification is used. Additional stages would add very little, if any, to the stabilization of the given circuit. The dc amplifier cathode is connected to the negative terminal of the supply. A bank of small dry cell batteries is used as a reference voltage and is placed in the grid circuit of the dc amplifier. The differential voltage necessary for the stabilization indicated by equation (1) is obtained from the voltage difference between the reference voltage and the output voltage of the stabilizer. If the reference voltage is chosen to be nearly equal to the desired output voltage, the full output-voltage change of the stabilizer is placed on the control grid of the dc amplifier. The reference-voltage source was placed in the control grid circuit of the dc amplifier rather than in the cathode circuit or in some type of balanced dual-tube circuit. With this arrangement there is no possibility of current drain on the batteries under normal operating conditions. The batteries should be mounted in the power supply at a position of minimum temperature variation. No difficulty was experienced from ambient temperature change for the degree of stabilization required for laboratory measurements although some investigators have thermally insulated the batteries[6]. The following reasons for not using voltage regulator tubes as precision-voltage references have been given by Kirkpatrick[7], and Richards[8].

1. Random drift with time, excluding warm-up period.
2. Fluctuation caused by ambient temperature change.
3. Abrupt voltage-current characteristic changes initiating spontaneously within the tube. These show up as random or spurious voltage changes in stabilized power supplies.
4. Small changes in current through the VR tubes often cause large voltage changes across the tube or even oscillations. When the current changes the voltage change may or not be in the same direction of current change. Voltage may not return to original value when the current returns to original value.

The resistor in series with the reference battery limits the current drain on the battery. The 8-μfd capacitor between the positive output terminal and the dc amplifier control grid places the full amplitude of any surge voltage on the control grid of the amplifier and thereby facilitates stabilization. The resistors which determine the operating voltage of the control grid of the 6SJ7 are wire-wound to reduce the effect of ambient temperature change. The control grid leads of this tube were made as short as possible to avoid pick-up, since the amplifier has a high input impedance. The high voltage wires are carefully placed and insulated. The battery in the control grid circuit of the 6L6 tubes is necessary to place these tubes in the linear region of their operating characteristics. The RC circuit, consisting of a 16-μfd capacitor, a 0.2-megohm resistor and a 50,000-ohm variable resistor between the dc voltage input of the stabilizer and the screen grid of the dc amplifier was selected experimentally.

A straightforward experimental procedure was followed in the circuit for best stabilization at the desired output voltage. The screen grid and the control grid of the dc amplifier were attached to variable-voltage dividers and their voltages adjusted to give the desired output voltage (350 volts). The line voltage was then changed from 100 to 120 volts and the output voltage noted for various values of screen grid voltage. The results are shown in Fig. 6, from which it is apparent that a screen grid voltage of 12.5 volts gives maximum stabilization.

The voltage regulation of the power supply as a function of load impedance was measured and the results presented as in Fig. 9, from which the internal resistance of the power supply is calculated to be 2 ohms. The regulation can be slightly improved, if necessary, by conventional feed-back circuits[9], but neither output terminal of the power supply can be connected to the chassis. The curve (Fig. 9) illustrates that a 30-milliampere output-current change from the normal operating current of 250 milliamperes caused only a 0.01 percent output-voltage change. Thus the stabilizer could be represented by a constant voltage generator with a 2-ohm internal impedance. This regulation is adequate for most laboratory equipment.

The following summary of pertinent experimental measurements was obtained from the completed power supply:

Output voltage	350 volts dc
Input voltage to stabilizer	550 volts dc
Amplifier screen grid voltage	12.5 volts dc
Amplifier control grid voltage	-0.95 volts dc
Output ripple	1.9 millivolts (rms)
Internal resistance	2 ohms
Overall stabilization factor $\frac{\Delta \text{ line voltage}}{\Delta \text{ output voltage}}$	500
Percent voltage change $\frac{\Delta \text{ output voltage}}{\text{output voltage}}$	0.003 percent for ± 10 percent line-voltage change

VII SUMMARY

Heater compensation has been applied to a degenerative voltage stabilizer to obtain a variation of less than 0.0005 percent in output voltage per volt change in line voltage. The high stability was obtained without sacrificing simplicity of design. The amount of compensation from the heater voltage action is a function of the screen grid voltage of the amplifier tube. Experimental methods are given for determining the correct screen grid voltage for maximum stability.

The writers wish to acknowledge the work done by Robert C. Minnick, a summer employee from Johns Hopkins University who made many of the experimental measurements.

VIII. APPENDIX

Derivation of Theory of Cathode Compensation for a Degenerative Type Voltage Stabilizer

Since the plate current of the current-control tube (T_1) (Fig. 10), connected as a triode, was found to be independent of heater voltage when operated over a line-voltage range of 100 to 120 volts, the plate current I_1 may be represented as follows:

$$I_1 = f(V_{g1}, V_{p1}) \tag{1}$$

From a consideration of the variational current and voltage relationship,

$$dI_1 = \frac{\partial I_1}{\partial V_{g1}}_{(dV_{p1} = 0)} dv_{g1} + \frac{\partial I_1}{\partial V_{p1}}_{(dv_{g1} = 0)} dV_{p1} \tag{2}$$

It is common practice to define the above partials as follows:

$$S_i = \frac{\partial I_1}{\partial V_{g1}}_{(dV_{p1} = 0)} = \text{transconductance of tube } T_1. \tag{3a}$$

$$\frac{1}{r_{p1}} = \frac{\partial I_1}{\partial V_{p1}}_{(dv_{g1} = 0)} = \text{reciprocal of variational plate resistance} \tag{3b}$$

It is desired to obtain a relationship between the incremental change of output voltage (ΔV_{out}) as a result of a change of input voltage (ΔV_{in}). By differentiating the linear equation obtained by applying Kirchoff's second law to the plate-cathode circuit of T_1, the following is obtained:

$$dv_{p1} = dv_{in} - dI_3 R_L \tag{4}$$

By Kirchoff's first law,

$$I_1 = I_2 + I_3 \tag{5a}$$

Current I_2 is very small (see Fig. 3) in comparison with I_3, therefore

$$I_1 \approx I_3 \tag{5b}$$

The following relationships are evident from Fig. 10.

$$dV_{p1} \approx dV_{in} - dI_1 R_L \tag{6a}$$

and

$$dV_{g1} = - dI_2 R_2 \tag{6b}$$

The incremental change in plate current of tube T_2 must be obtained as a function of the input and output voltage changes. For the dc amplifier (T_2) operated with screen grid voltage practically constant, it was shown (see Fig. 3) that the variational plate current was a function of the heater voltage. Therefore,

$$I_2 = f(V_{g2}, V_{h2}, V_{p2}) \tag{7}$$

and as before,

$$dI_2 = S_2 dV_{g2} + \frac{1}{r_{p2}} dV_{p2} + S_{h2} dV_{h2} \tag{8}$$

where

$$S_2 = \frac{\partial I_2}{\partial V_{g2}} \quad (dV_{p2} = dV_{h2} = 0) \quad = \text{variational grid-to-plate transconductance} \tag{9a}$$

$$\frac{1}{r_{p2}} = \frac{\partial I_2}{\partial V_{p2}} \quad (dV_{g2} = dV_{h2} = 0) \quad = \text{reciprocal of variational plate resistance.} \tag{9b}$$

$$S_{h2} = \frac{\partial I_2}{\partial V_{h2}} \quad (dV_{p2} = dV_{g2} = 0) \quad = \text{variational heater-to-plate transconductance.}$$

To put equation (8) in terms of input and output voltage variation, the following equations are used:

$$dV_{g2} = dV_{out} \tag{10a}$$

$$dV_{c2} - dV_{out} \approx dI_2 R_2 \tag{10b}$$

To evaluate the stability of the circuit with respect to line-voltage changes, it will be assumed that the changes in input voltage (V_{in}) and heater voltage (V_{h2}) are proportional to the change in line voltage. These relations expressed in the form of equations are

$$\frac{dV_{in}}{dV_{line}} = C_1 \tag{11a}$$

or

$$\frac{dV_{h2}}{dV_{in}} = C_2 \tag{11b}$$

Placing equations (10a,b) and 11b) in Equation (8) and simplifying,

$$dI_2 = dV_{out} \frac{S_2 r_{p2} + 1}{r_{p2} + R_2} + \frac{r_{p2} S_{h2} C_2}{r_{p2} + R_2} dV_{in} \tag{12}$$

Placing Equations (12), (6a), (6b) in Equation (2) and simplifying,

$$dI_1 \left(1 + \frac{R_L}{r_{p1}}\right) \approx - dV_{out} S_1 R_2 \frac{S_2 r_{p2} + 1}{r_{p2} + R_2} - dV_{in} \left[\frac{S_1 R_2 V_{p2} S_{h2} C_2}{r_{p2} + R_2} - \frac{1}{r_{p1}} \right] \tag{13}$$

Since

$$dI_1 \approx dI_3 = \frac{dV_{out}}{R_L}. \tag{14}$$

$$dV_{out} \left[\frac{r_{p1} + R_L}{r_{p1} R_L} + S_1 R_2 \frac{S_2 r_{p2} + 1}{r_{p2} + R_2} \right] \approx - dV_{in} \left[\frac{S_1 R_2 r_{p2} S_{h2} C_2}{r_{p2} + R_2} - \frac{1}{r_{p1}} \right] \tag{15}$$

from which

$$\frac{dV_{in}}{dV_{out}} \approx \frac{\dfrac{r_{p1} + R_L}{r_{p1} \; R_L} + S_1R_2 \; \dfrac{S_2r_{p2} + 1}{r_{p2} + R_2}}{\dfrac{S_1R_2r_{p2}S_{h2}C_2}{r_{p2} + R_2} + \dfrac{1}{r_{p1}}} \qquad (16)$$

Since stabilization as a function of line voltage is desired, the stabilization factor F_L is defined by the following equation:

$$F_L = \frac{dV_{line}}{dV_{out}} \qquad (17)$$

From equating (16) and (11a)

$$F_L \approx \frac{1}{C_1} \left[\frac{\dfrac{r_{p1} \; (r_{p2} + R_2)}{R_L} + r_{p2} + R_2 + S_1r_{p1}R_2(S_2r_{p2} + 1)}{r_{p2} + R_2 - S_1r_{p1}R_2r_{p2}S_{h2}C_2} \right]$$

or

$$F_L \approx \frac{1}{C_1} \left[\frac{\dfrac{r_{p1} + R_L}{R_L} \; (r_{p2} + R_2) + \mu_1R_2(\mu_2 + 1)}{r_{p2} + R_2 - \mu_1R_2r_{p2}S_{h2}C_2} \right] \qquad (18)$$

By considering the original stabilization factor (F) as shown by equation (1) in Section III, it is seen that

$$F_L \approx \frac{F}{C_1 \left[1 - \dfrac{R_2\mu_1r_{p2}S_{h2}C_2}{r_{p2} + R_2} \right]} \qquad (19)$$

IX REFERENCES

1. H. E. Sorrows, R. C. Ellenwood, and W. E. Ryan, NBS, CRPL Report 9-1, Nov. 8, 1946
2. H. V. Neher and W. H. Pickering, Rev. Sci. Inst. 10, 35 (1939)
3. F. V. Hunt and R. W. Hickman, Rev. Sci. Inst. 10, 6 (1939)
4. J. S. Ashworth and J. C. Mouzon, Rev. Sci. Inst. 8, 127 (1937)
5. R. C. Evans, Rev. Sci. Inst. 5, 371 (1934)
6. N. L. Anderson, J. R. Dunning and D. P. Mitchell, Rev. Sci. Inst. 8, 497 (1937)
7. G. M. Kirkpatrick, Proc. Inst. of Radio Engr. 35, 485 (1947)
8. L. A. Richards, Rev. Sci. Inst. 4, 479 (1933)
9. A. Jacobsen and J. V. Holdam, Rad. Lab. Series (No. 21), P. 548

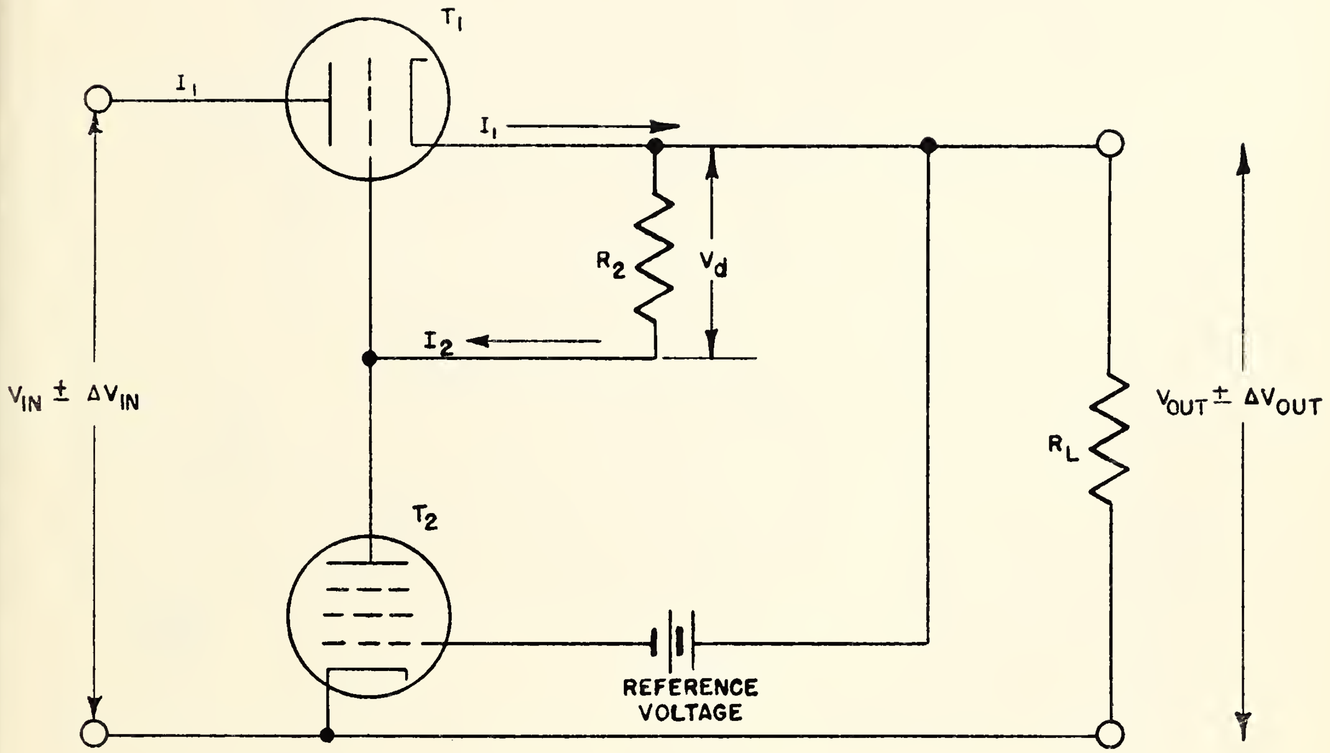


FIG. 1 SIMPLIFIED DEGENERATE VOLTAGE STABILIZER SCHEMATIC

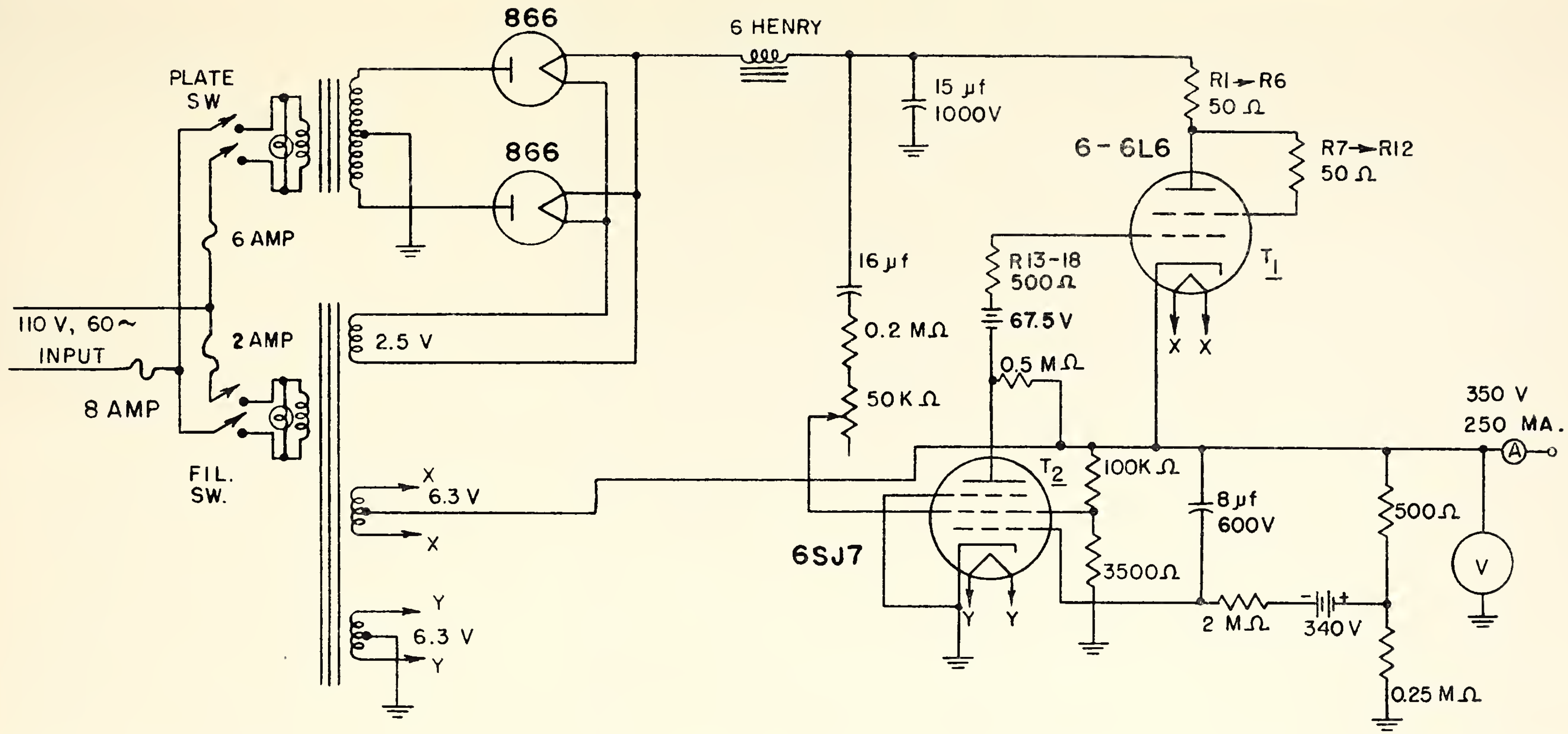


FIG. 2 HEATER-COMPENSATED POWER SUPPLY.

350 VOLTS DC 250 MILLIAMPERES

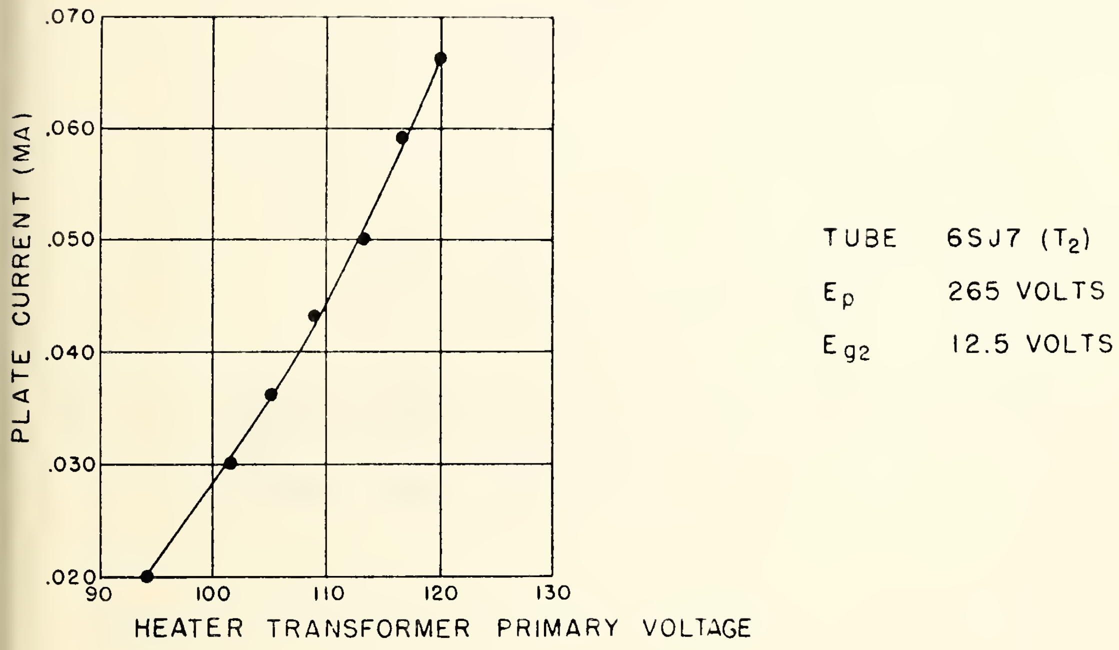


FIG. 3 PLATE CURRENT VS HEATER TRANSFORMER PRIMARY VOLTAGE.

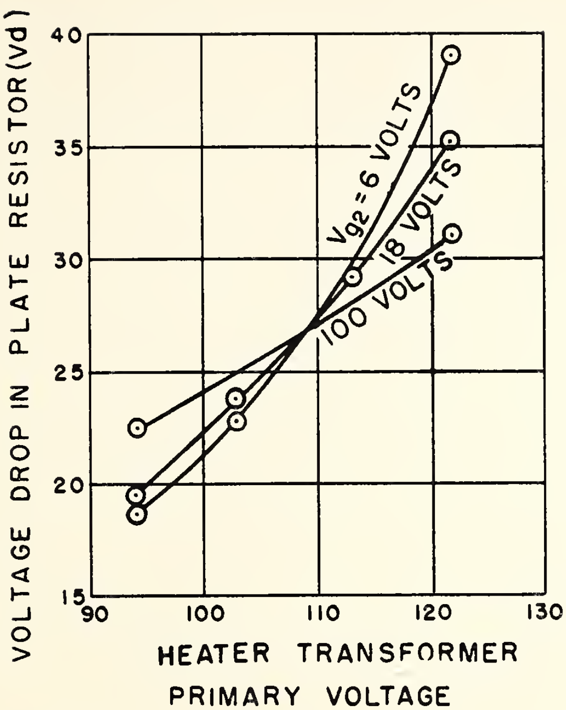


FIG. 4 VOLTAGE DROP IN DC AMPLIFIER (6SJ7) PLATE LOAD RESISTOR VS HEATER VOLTAGE AS A FUNCTION OF SCREEN GRID VOLTAGE.

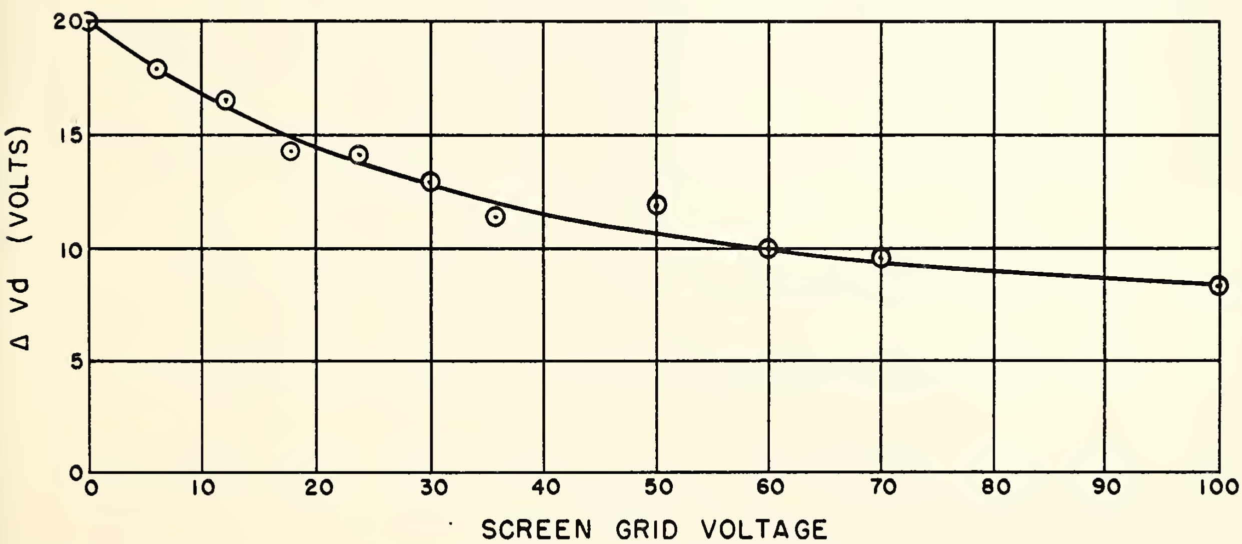


FIG. 5 CHANGE IN VOLTAGE DROP ACROSS RESISTOR (R_2) FOR 20 VOLTS CHANGE IN AC LINE VOLTAGE VS SCREEN GRID VOLTAGE.

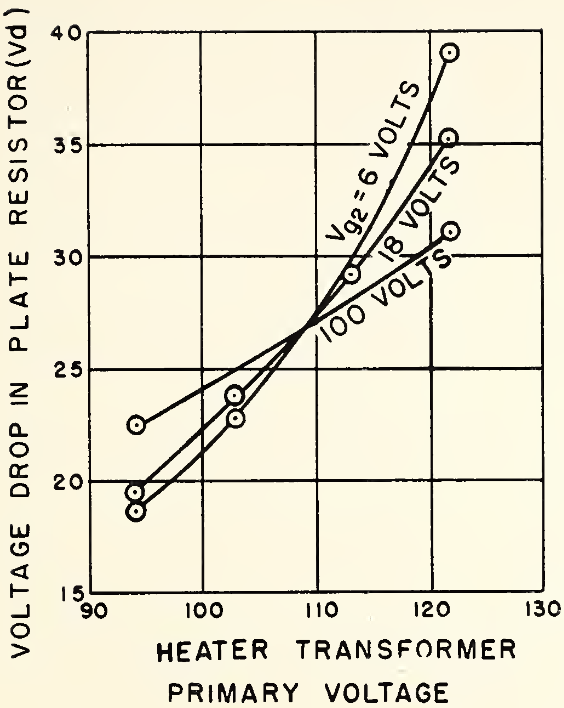


FIG. 4 VOLTAGE DROP IN DC AMPLIFIER (6SJ7) PLATE LOAD RESISTOR VS HEATER VOLTAGE AS A FUNCTION OF SCREEN GRID VOLTAGE.

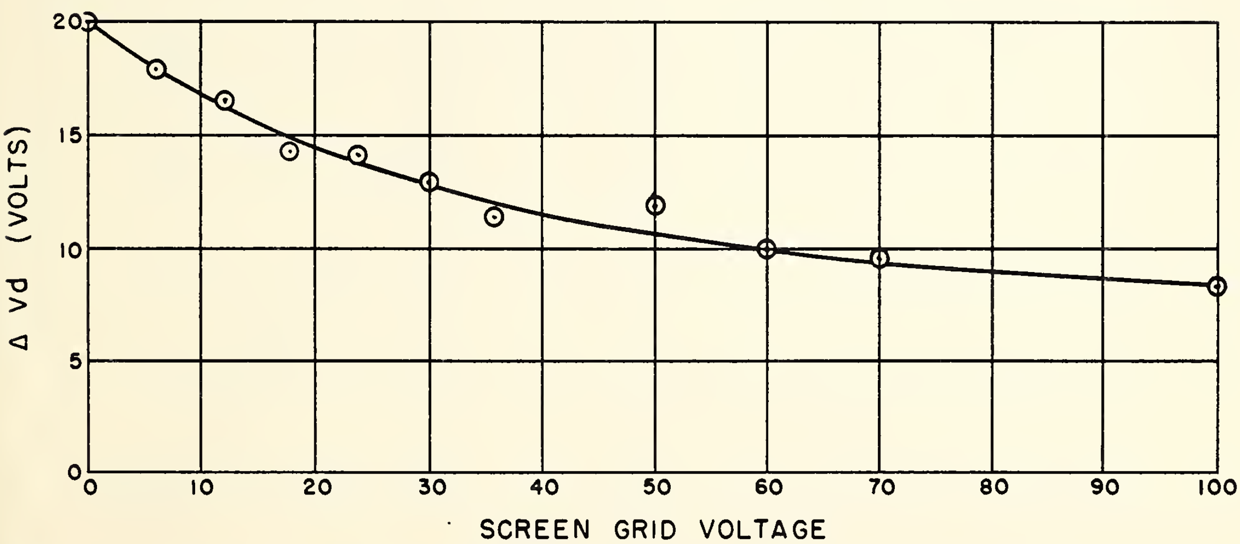


FIG. 5 CHANGE IN VOLTAGE DROP ACROSS RESISTOR (R_2) FOR 20 VOLTS CHANGE IN AC LINE VOLTAGE VS SCREEN GRID VOLTAGE.

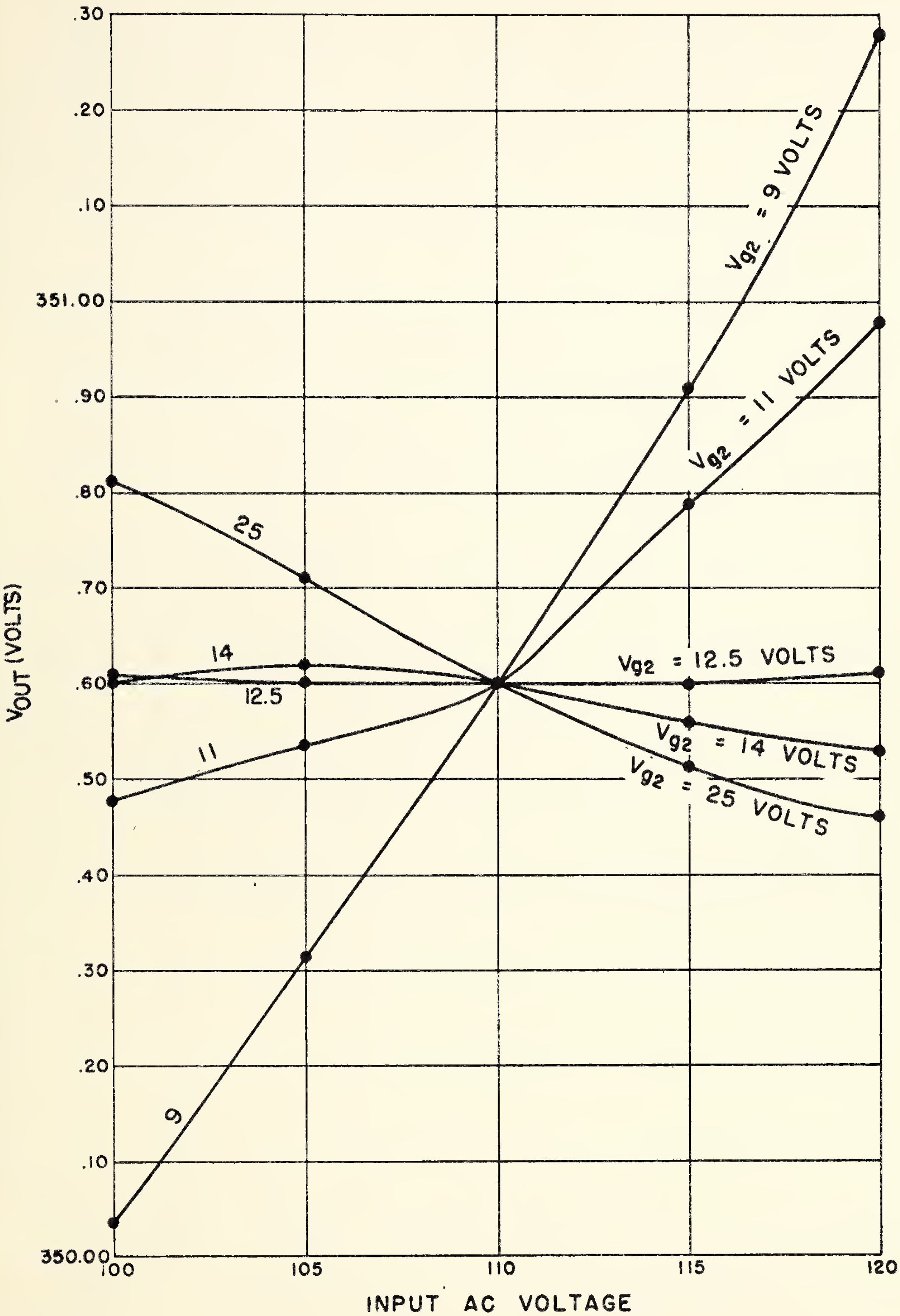


FIG. 6 STABILIZED DC OUTPUT VOLTAGE FOR VARIOUS SCREEN GRID VOLTAGES.

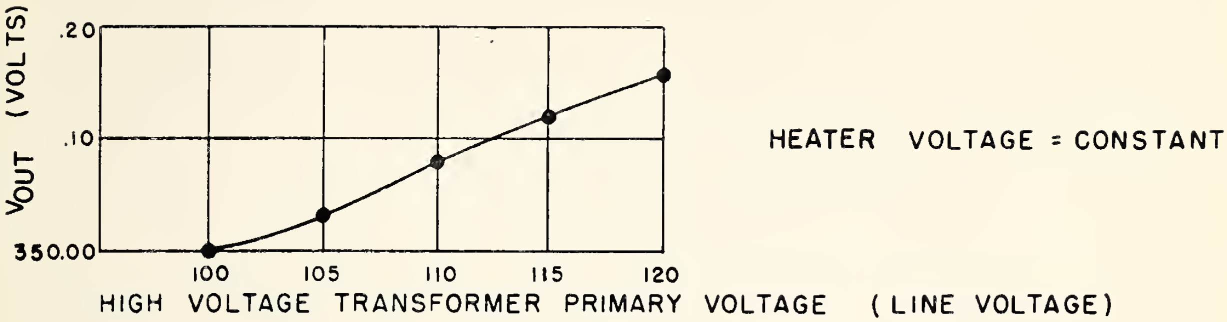


FIG. 7a STABILIZED DC OUTPUT VOLTAGE VS HIGH VOLTAGE TRANSFORMER PRIMARY VOLTAGE.

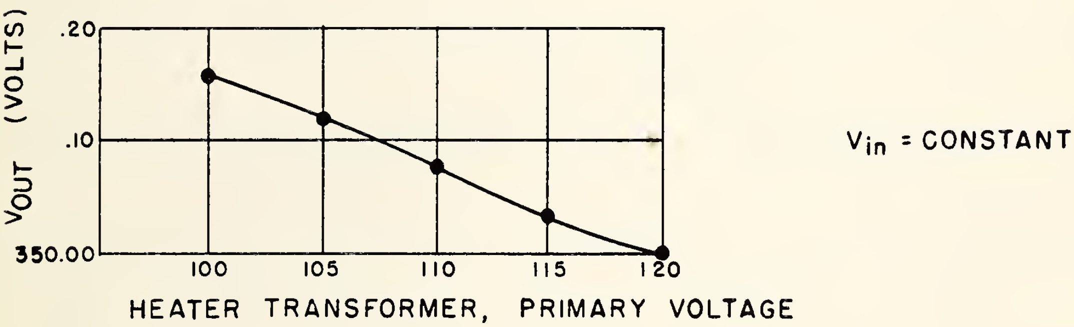


FIG. 7b STABILIZED DC OUTPUT VOLTAGE VS HEATER TRANSFORMER PRIMARY VOLTAGE.

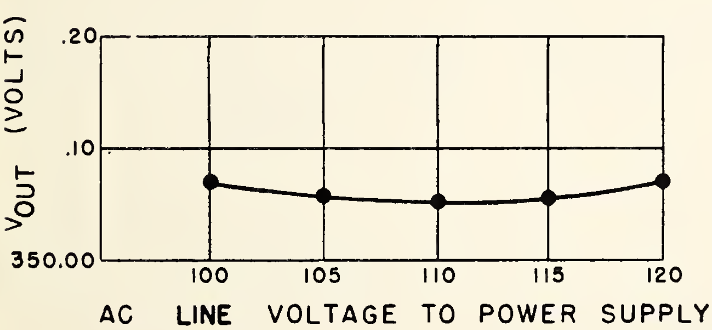


FIG. 7c STABILIZED DC OUTPUT VOLTAGE VS AC LINE VOLTAGE.

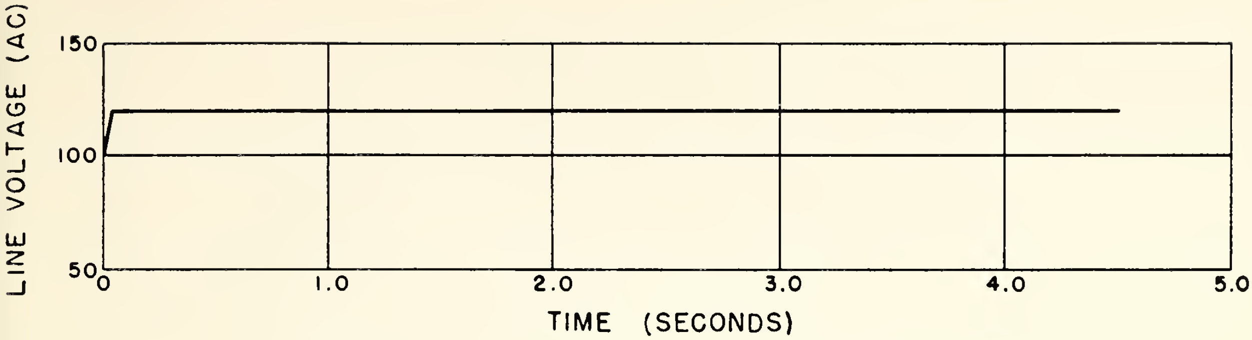


FIG. 8a LINE VOLTAGE INPUT VS TIME.

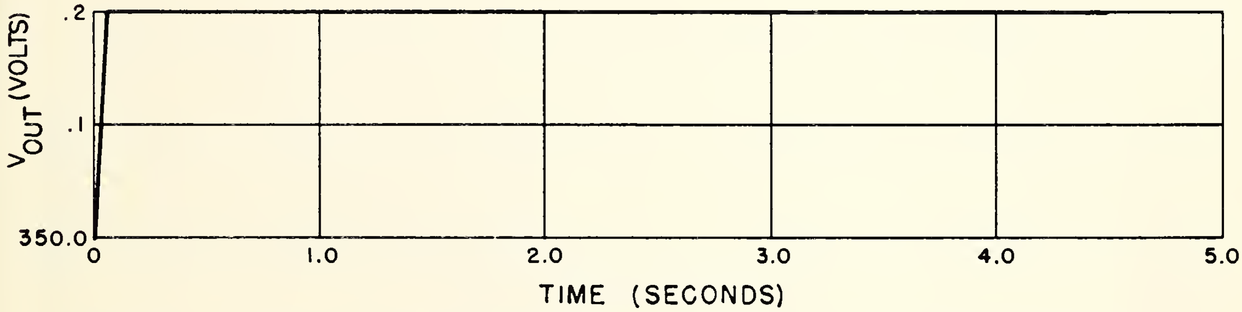


FIG. 8b V_{OUT} VS TIME (NO HEATER COMPENSATION — NO RC CIRCUIT)

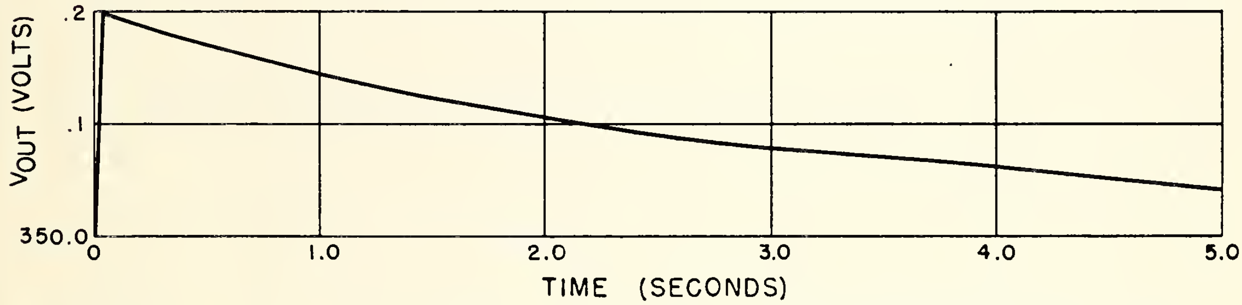


FIG. 8c V_{OUT} VS TIME (HEATER COMPENSATED — NO RC CIRCUIT)

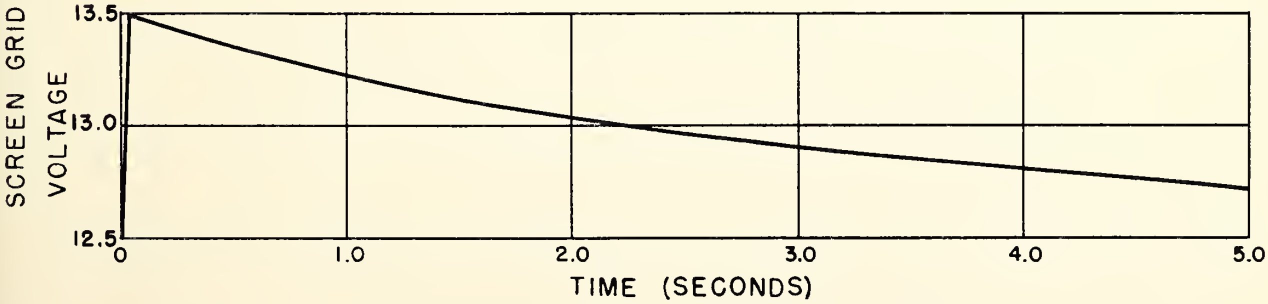


FIG. 8d SCREEN GRID VOLTAGE VS TIME. (RC NETWORK IN CIRCUIT)

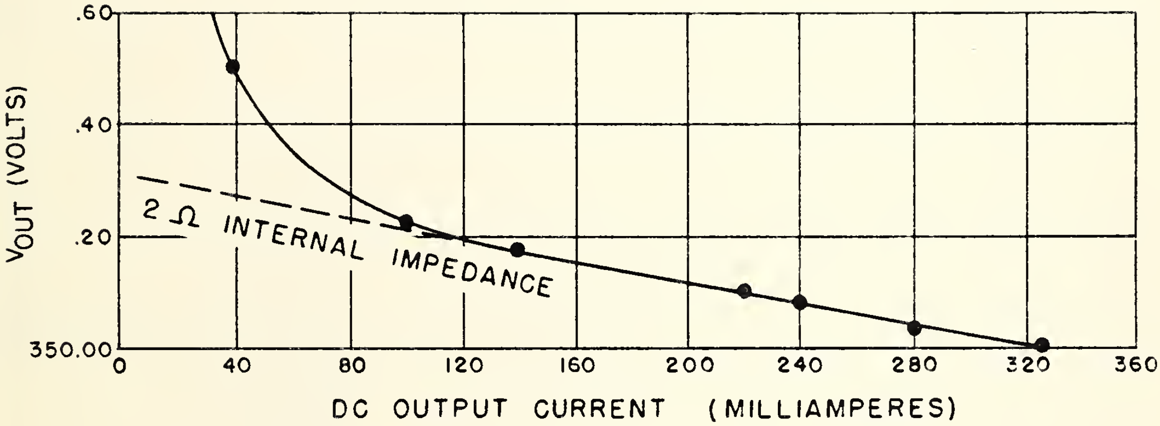
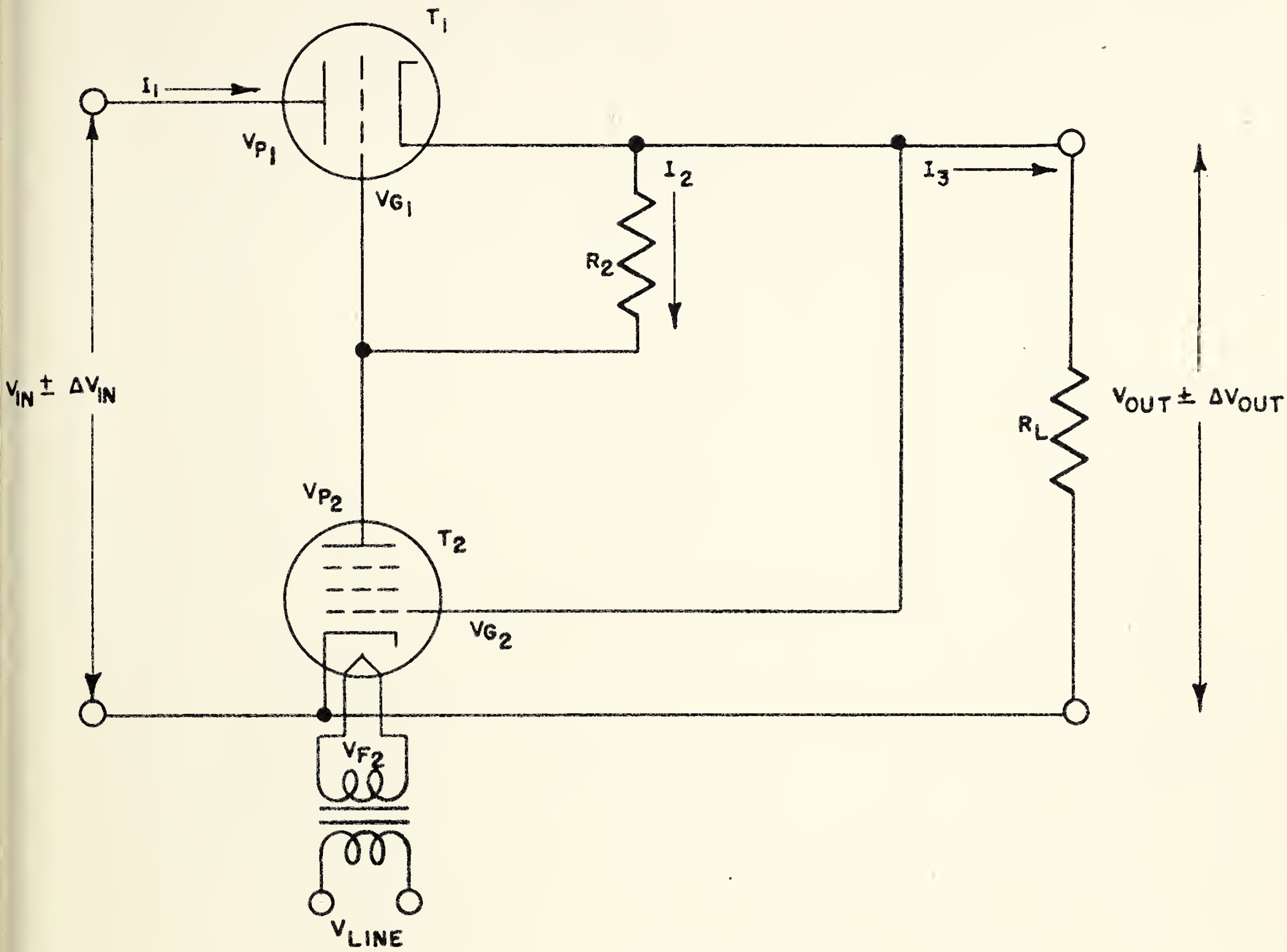


FIG. 9 OUTPUT VOLTAGE VS OUTPUT CURRENT.



APPENDIX FIG. 10 HEATER COMPENSATED DEGENERATE TYPE VOLTAGE STABILIZER

V_{P_1} = PLATE TO CATHODE VOLTAGE OF T_1

V_{G_1} = CONTROL GRID TO CATHODE VOLTAGE OF T_1

V_{P_2} = PLATE TO CATHODE VOLTAGE OF T_2

V_{G_2} = CONTROL GRID TO CATHODE VOLTAGE OF T_2

V_{F_2} = HEATER VOLTAGE OF T_2