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DIVISION

APPLICATION NOTES

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APPLICATION NOTE ON THE USE OF THE 57 OR 6C6 TO OBTAIN NEGATIVE TRANSCONDUCTANCE AND NEGATIVE RESISTANCE

Among the circuit combinations possible with three-grid tubes in which the connections to all three grids are brought out, one combination of particular interest produces a simple and reliable negative-resistance device. It is the purpose of this note to explain the operation of such a device utilizing the 57 or 6C6 and to give suitable operating conditions for these types. These types are particularly well suited for this application.

In vacuum tubes connected in the usual manner, a rise (change in positive direction) in control-electrode voltage causes a rise in anode current. With a resistive anode load, the anode voltage drops with a rise in anode current; thus, the grid-voltage change and the anode-voltage change are in exact opposition. In order to make oscillations possible, it is necessary to feed back energy from the anode circuit to the control-electrode circuit in such a way as to increase the controlling voltage. Since, with a resistive grid and a resistive plate circuit, the voltage changes in the two circuits are in opposition, it is not possible to provide feedback in a simple way. Ordinarily, either reactive circuits or magnetic coupling is used in the oscillator arrangement to adjust properly the phase of the voltage feedback from anode to control electrode. Both methods require a more complicated oscillator circuit than that required with simple two-terminal negative-resistance devices such as, for example, the Dynatron.

If the anode current of a tube could be made to decrease when the control-grid voltage is raised, the grid-voltage change and the plate-voltage change with resistive circuits would no longer be in opposition but would be in the proper relation to produce feedback effects. Such an arrangement would avoid the feedback complications of the ordinary oscillator, since only a large fixed condenser between the control electrode and anode is necessary to transmit anode-voltage fluctuations to the control electrode in proper phase. A tube in which the anode current drops when the control-electrode voltage rises has a grid-plate transconductance opposite in sign to that of the usual tube, and may therefore properly be described as a tube having negative grid-plate transconductance.

If the No.3 grid (suppressor) of the type 57 or 6C6 is used as a control electrode and is made more negative, some of the electrons will be turned back toward the cathode; the plate current, therefore, decreases. See Fig. 1a. The electrons which are turned back, however, are attracted by the positive voltage impressed on the No.2 grid (screen), and pass to it so as to increase its current. If, then, the No.2 grid be considered as the anode in place of the usual plate and the No.3 grid be considered as the control electrode, the arrangement will have negative grid-plate transconductance. When a pentode is used in this fashion, the current which passes to the usual plate is not employed. This is similar to conventional applications where the screen current is not utilized. Although no mention has been made of the No.1 grid, this grid does have a valuable function in the tube, because it can be used to control the total amount of cathode current and, therefore, the magnitude of the effect. In this respect, it is analogous to the function of the No.1 grid in the Pliodynatron. In addition, it exerts a limiting action on the total current so that the No.2 grid resistance is increased.

A circuit using the 57 in this manner to obtain a negative resistance is shown in Fig. 1b. The No.1 grid can, for simplicity in explaining the operation, be connected directly to the cathode. The usual plate is connected to a positive potential. The No.3 grid is connected to the No.2 grid through a large condenser, C. A suitable negative bias is applied to the No.3 grid through the high-resistance grid leak, R. The negative resistance is exhibited between terminals A and B. The operation of the circuit is as follows:

An instantaneous rise in voltage across the terminals AB is transmitted by the condenser C to the No.3 grid, which has its potential increase, thereby decreasing the No.2 grid current. Since the No.3 grid is biased negatively and draws no current, the total current in whatever circuit is connected to AB is determined only by the No.2 grid current. It is, therefore, evident that the instantaneous rise in voltage across AB is accompanied by a drop in current. This is the characteristic of a negative resistance. From the explanation, it is seen that the negative resistance occurs only for variations in voltage which are rapid since, otherwise, the condenser C does not transmit the variations. A static characteristic taken on the arrangement shows no negative resistance, although the negative resistance is present for alternating voltages. As either the condenser C or the grid leak R is made larger in value, the lowest frequency to which the circuit behaves as a negative resistance is made less. The condenser C and the grid leak R must be chosen in the same way as the coupling condenser and leak in a resistance-coupled amplifier, i. e., the condenser reactance must be small compared to the grid-leak resistance, to transmit satisfactorily the lowest frequency to be used.

The value of the negative resistance produced may be calculated as follows: When the instantaneous voltage on the No.2 grid rises a small amount ΔE, a rise in current $\Delta E/r_{g2}$ would be expected where r_{g2} is the No.2 grid resistance. At the same time, however, the condenser to the No.3 grid permits its voltage to rise an amount ΔE: this tends to lower the No.2 grid current by an amount $s_{m3-2}\Delta E$. The effective resistance of the combination is represented by the change in voltage divided by the total change in current and is therefore given by:

$$\text{Resistance} = \Delta E/\Delta I = \Delta E/(\Delta E/r_{g2} - s_{m3-2}\Delta E) = 1/(1/r_{g2} - s_{m3-2})$$

In the 57 and 6C6 tubes, $1/r_{g2}$ is much smaller than s_{m3-2} under best operating conditions to produce negative resistance. The negative resistance produced is, therefore, approximately the reciprocal of the negative transconductance between the No.3 and the No.2 grid. The lowest negative resistance is thus found at the point having highest negative transconductance.

Suitable operating conditions for a tube may be found by choosing a value for No.1 grid voltage (E_{c1}), No.2 grid voltage (E_{c2}), and plate voltage (E_b) to give a reasonable cathode current and then by varying No.3 grid voltage (E_{c3}) to find the point of maximum transconductance to the No.2 grid. This value of E_{c3} may then be used as the bias value.

Typical operating conditions for the two types of tubes are:

	Type 57	Type 6C6
Heater Volts (E_f)	2.5	6.3
No.1 Grid Volts (E_{c1})	0	0
No.2 Grid Volts (E_{c2})	100	100
No.3 Grid Volts (E_{c3})	-10	-10
Plate Volts (E_b)	22.5	22.5
No.2 Grid Milliamperes (I_{c2})*	4	4.1
Plate Milliamperes (I_b)*	2.9	2.4
No.3 Grid to No.2 Grid Transconductance - micromhos (s_{m3-2})	-320	-280
Negative Resistance Produced - ohms*	3400	4000

*Approximate

In addition to the operating conditions for the values given, the 57 and 6C6 may be operated over a wide range of voltages. For example, increasing E_{c1} in the negative direction reduces the cathode current and increases the negative resistance. If E_b is increased, E_{c3} must be increased in the negative direction by approximately the same ratio in order to continue to operate at the center point of the negative-resistance characteristic. No improvement in operating characteristics is obtained by raising E_b. An increase in E_{c2}, though not advised from the point of view of tube life, will cause an increase in s_{m3-2} and hence a decrease in the negative resistance.

The complete negative-resistance performance of a three-grid tube may be predicted from the No.2 grid characteristic curves, i.e., the I_{c2} vs. E_{c2} curves for various values of E_{c3} (holding E_{c1} and E_b constant) may be used to plot the dynamic characteristics. Such a set of characteristics is shown in Fig.2 for a type 57 tube.

The dashed-line curves indicate the dynamic negative-resistance characteristics to be expected at the terminals AB in Fig. 1b when the frequency is sufficiently high to make the condenser reactance negligible as compared with the grid-leak resistance.

In order to utilize the negative-resistance circuit for the production of oscillations, it is simply necessary to connect a parallel tuned circuit to the terminals AB of Fig. 1b. Variation of the No.1 grid voltage provides a simple and convenient method of controlling the strength of oscillation. This is illustrated by the curve of Fig. 3. It should be pointed out that the advantages of simplicity, stability, and good waveform obtainable with the Dynatron are all present in the negative-transconductance method. In addition, THE NEGATIVE RESISTANCE PRODUCED DOES NOT DEPEND ON SECONDARY EMISSION so that a degree of uniformity and reliablity not ordinarily found in Dynatrons is present. The negative resistance produced is lower than that of most tubes used as Dynatrons when the same cathode current is permitted. This is an advantage, since the lower negative resistance permits oscillation with a higher-loss tuned circuit. At the same time, the total shunt capacitance of the tube, feedback condenser and leak may be made almost as small as that of most commercial tubes used as Dynatrons.

To give practical data on the advantages of the 57 and 6C6 tubes over the Dynatron method of obtaining negative resistance and to compare results with similar data taken on the 57 and 6C6 in the negative-transconductance circuit, measurements were taken on some type 24-A tubes used as Dynatrons. The results are presented briefly in the following analysis. The data were taken on 24-A tubes of present production having carbonized plates. The voltage conditions were adjusted to obtain approximately the same cathode current as that of the 57 and 6C6 tubes.

	Type 57	Type 6C6	Type 24-A (Dynatron-operated)
Mean Negative Resistance	3400 ohms	3900 ohms	59000 ohms
Average Deviation from Mean	8%	3%	44%
Maximum Deviation from Mean	23%	15%	87%

Although the 24-A tubes tested were extremely poor as Dynatrons because of the use of carbonized plates, it is believed that the variations between tubes as measured by the percentage deviations from the mean are typical. Thus, the use of a more suitable plate material might lower the negative resistance to an average of 20,000 ohms or so, but the variations between tubes expressed in per cent would probably remain nearly the same for tubes chosen at random.

In most applications, a figure of merit for a negative-resistance device of the class in which the Dynatron and the negative-transconductance method fall is given by 1/CR where C is the total effective shunt capacitance, and R the negative resistance. On this basis, the 24-A's which have an effective capacitance of approximately 0.010 micro-microfarads would have a figure of merit of 1.7.

If it is assumed that more suitable plate material could be used, this figure might be increased to 5. In the 57 or 6C6 circuit, the tube contributes about 0.012 micro-microfarads to the shunt capacitance and the external coupling condenser and leak may be caused to contribute as little as 0.006 micro-microfarads. The figure of merit is then approximately 15 or three times as great as the best figure given for the Dynatron.

Electron transit-time effects limit the upper frequency at which the 57 or 6C6 will oscillate to approximately 20 megacycles. This limitation makes it impracticable to use these tubes as oscillators in all-wave receivers or at frequencies much above 15 megacycles. The negative-transconductance tube can, however, be used to advantage as a two-terminal oscillator in receivers, measuring devices, or other equipment in which the frequencies involved are lower than 15 megacycles. No tickler coils or taps are required for this type of oscillator. This is a feature which greatly simplifies the switching problem for apparatus employing more than a single frequency band, since but one switching terminal need be considered for each band; the other terminal can be connected permanently in the circuit.

Figure 1b shows how the 57 or 6C6 can be connected for use in a voltage-controlled negative-resistance oscillator in conjunction with a tuned circuit. This arrangement will produce sinusoidal oscillations. Figure 1c illustrates a relaxation-oscillation circuit using the 57 or 6C6 in a current-controlled circuit. For operation at small amplitudes, the oscillations are approximately sinusoidal.

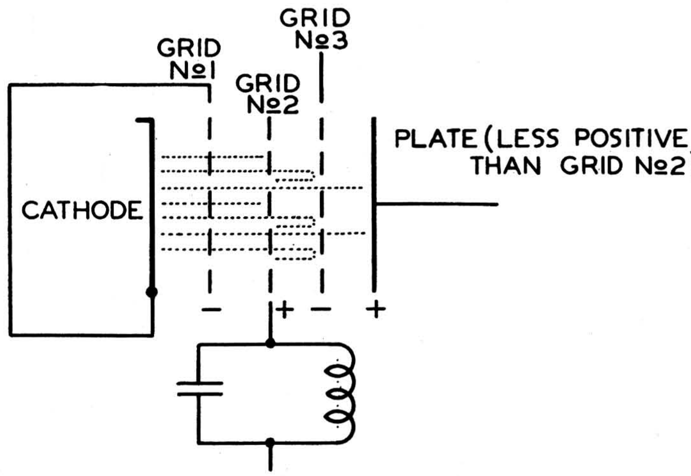

FIG. 1-A PATHS OF ELECTRONS IN A PENTODE WHEN OPERATED AS A NEGATIVE TRANSCONDUCTANCE TUBE

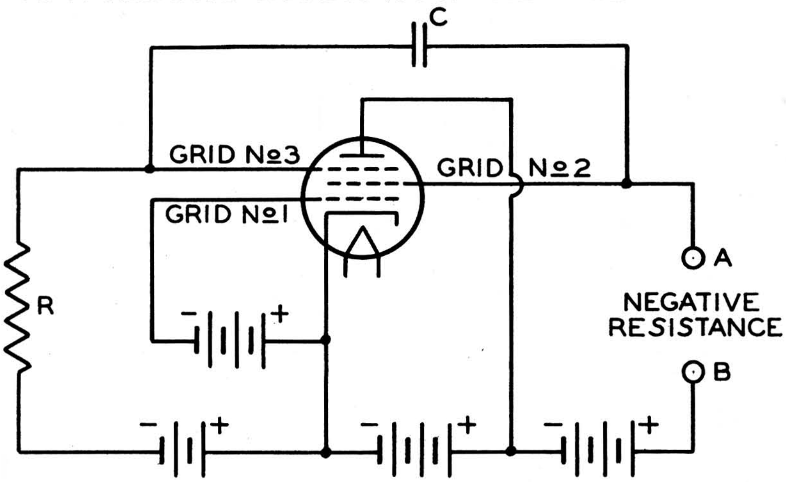

FIG. 1-B VOLTAGE-CONTROLLED OSCILLATOR CIRCUIT

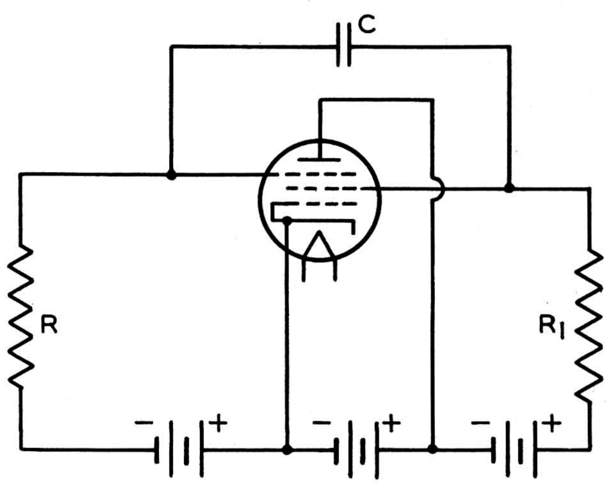

FIG. 1-C CURRENT-CONTROLLED RELAXATION OSCILLATOR CIRCUIT

RCA Cunningham Radiotron RADIO TUBES

TYPE 57

TYPICAL GRID №2 CHARACTERISTICS

TO SHOW PERFORMANCE AS A NEGATIVE-TRANSCONDUCTANCE TUBE

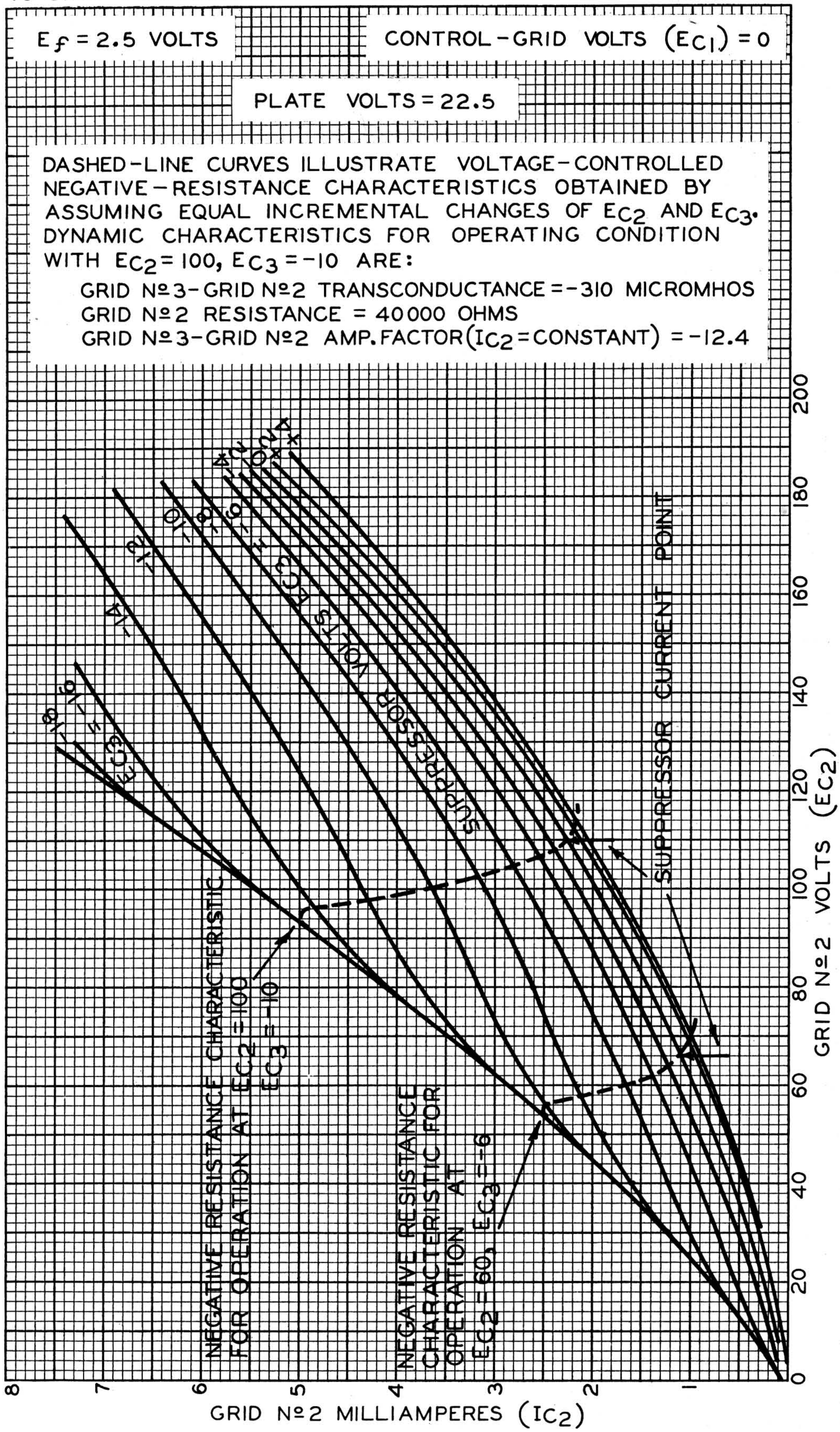

FIG. 2

REPRESENTATION OF
NEGATIVE RESISTANCE CHARACTERISTICS FOR TYPE 57

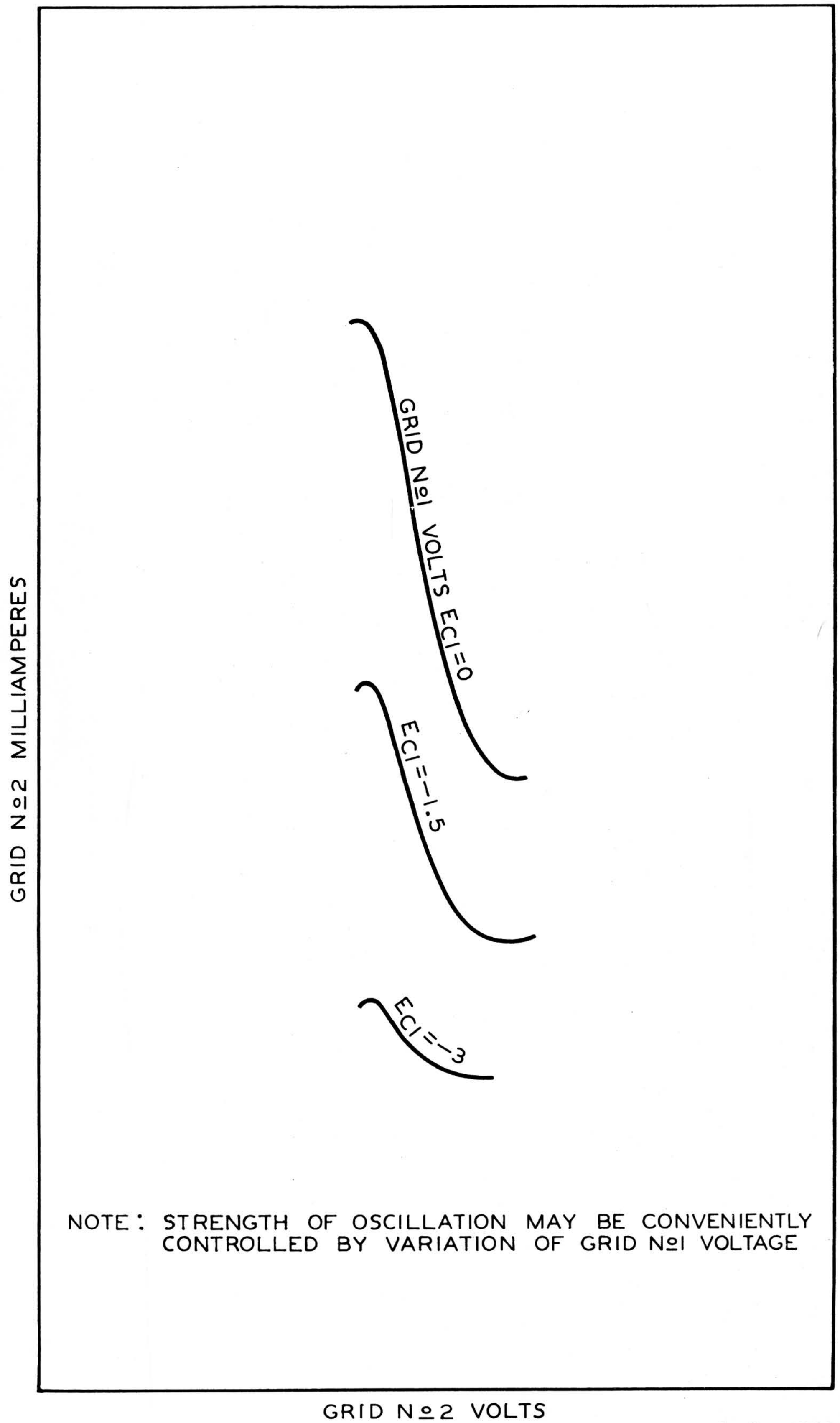

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FIG. 3