June 29, 1926. 1,590,263

J. S. STONE

AMPLIFIER

Filed Jan. 4, 1923 2 Sheets-Sheet 1

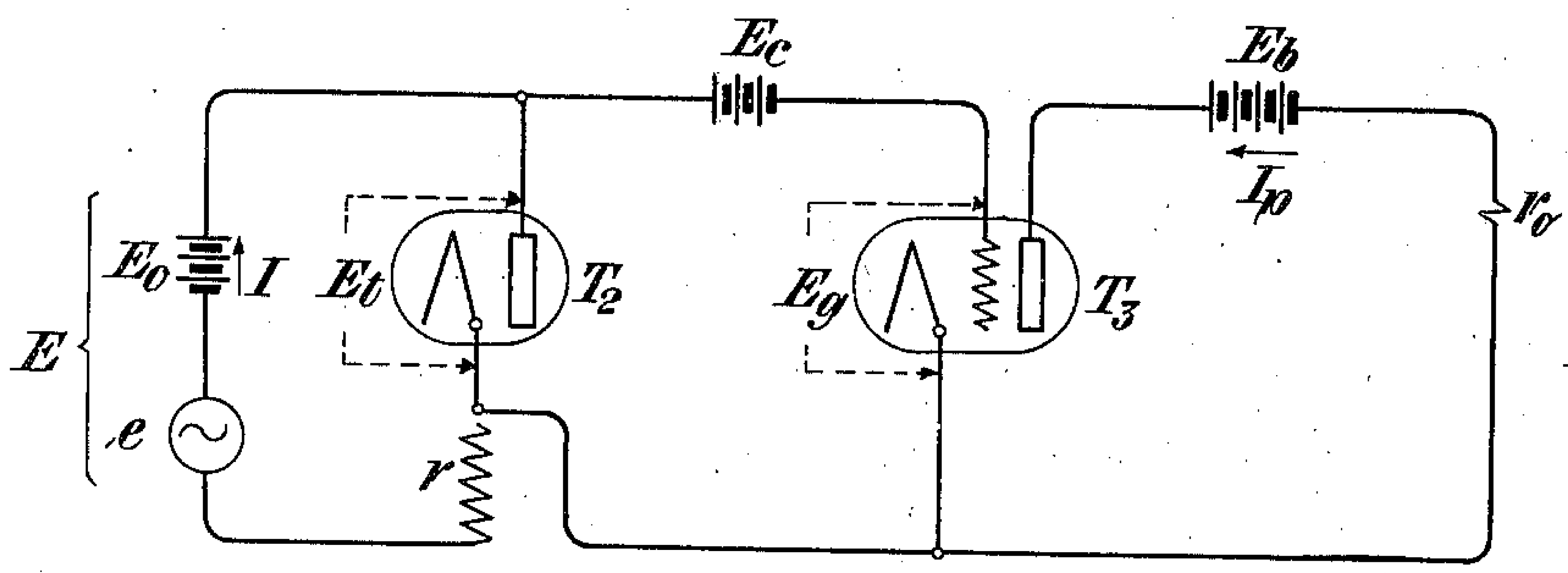

Fig. 1

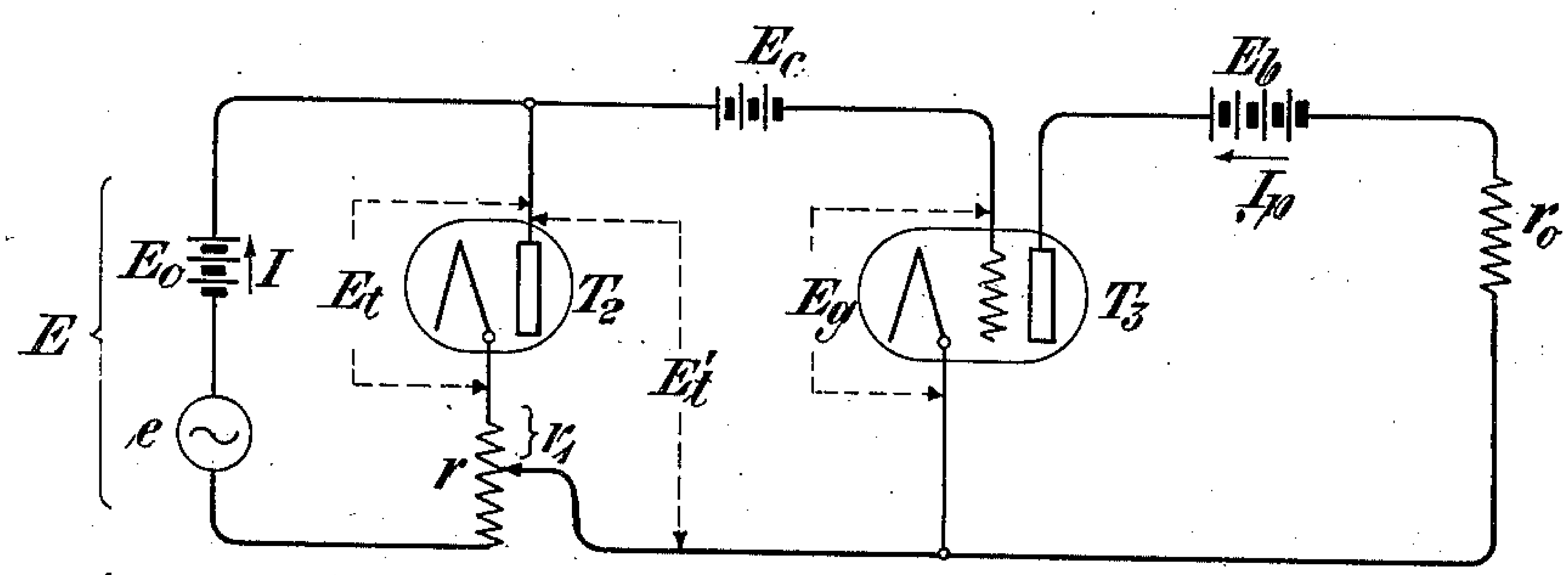

Fig. 2

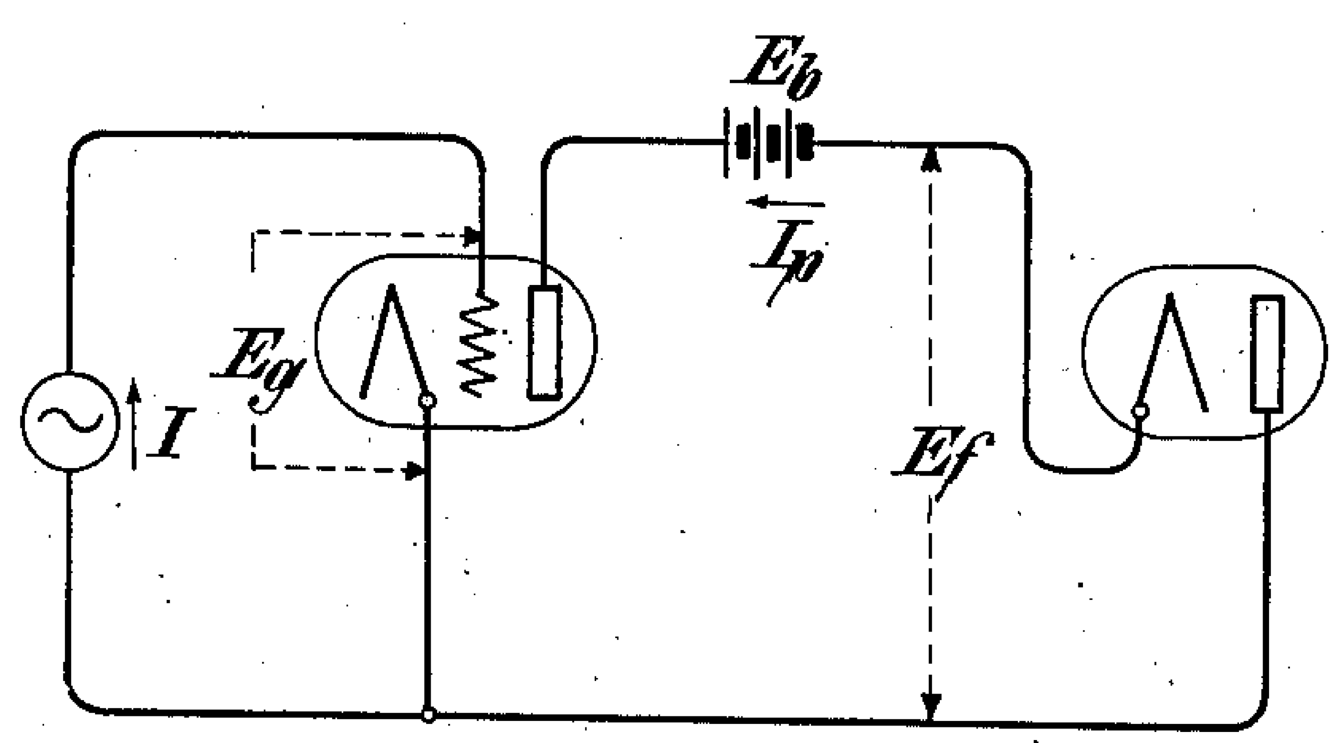

Fig. 3

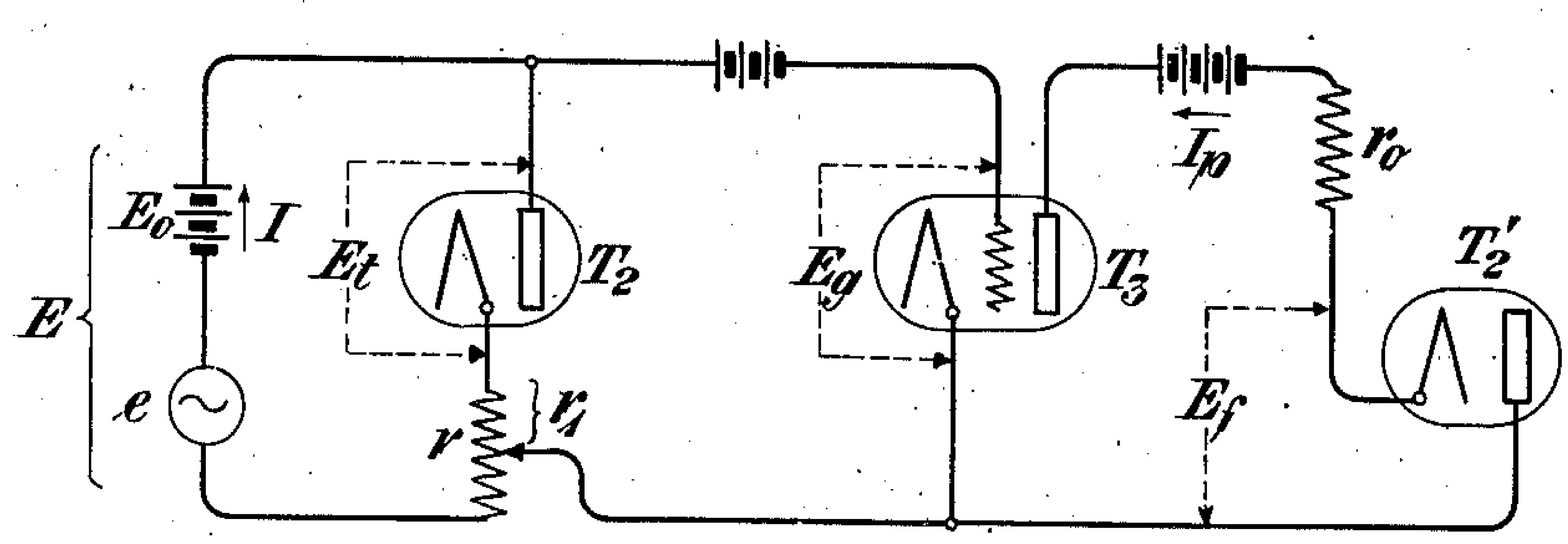

Fig. 4

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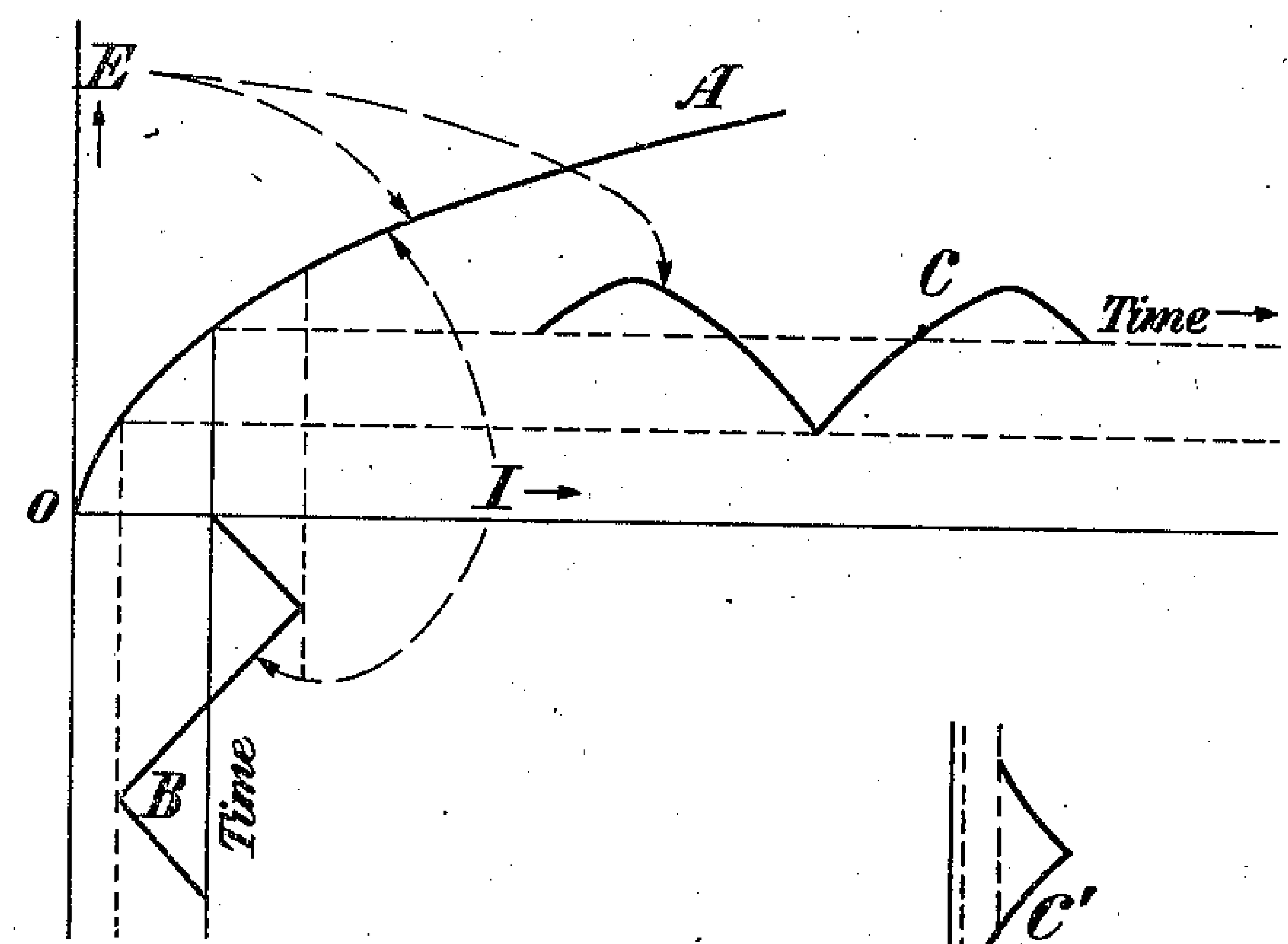

Fig. 5

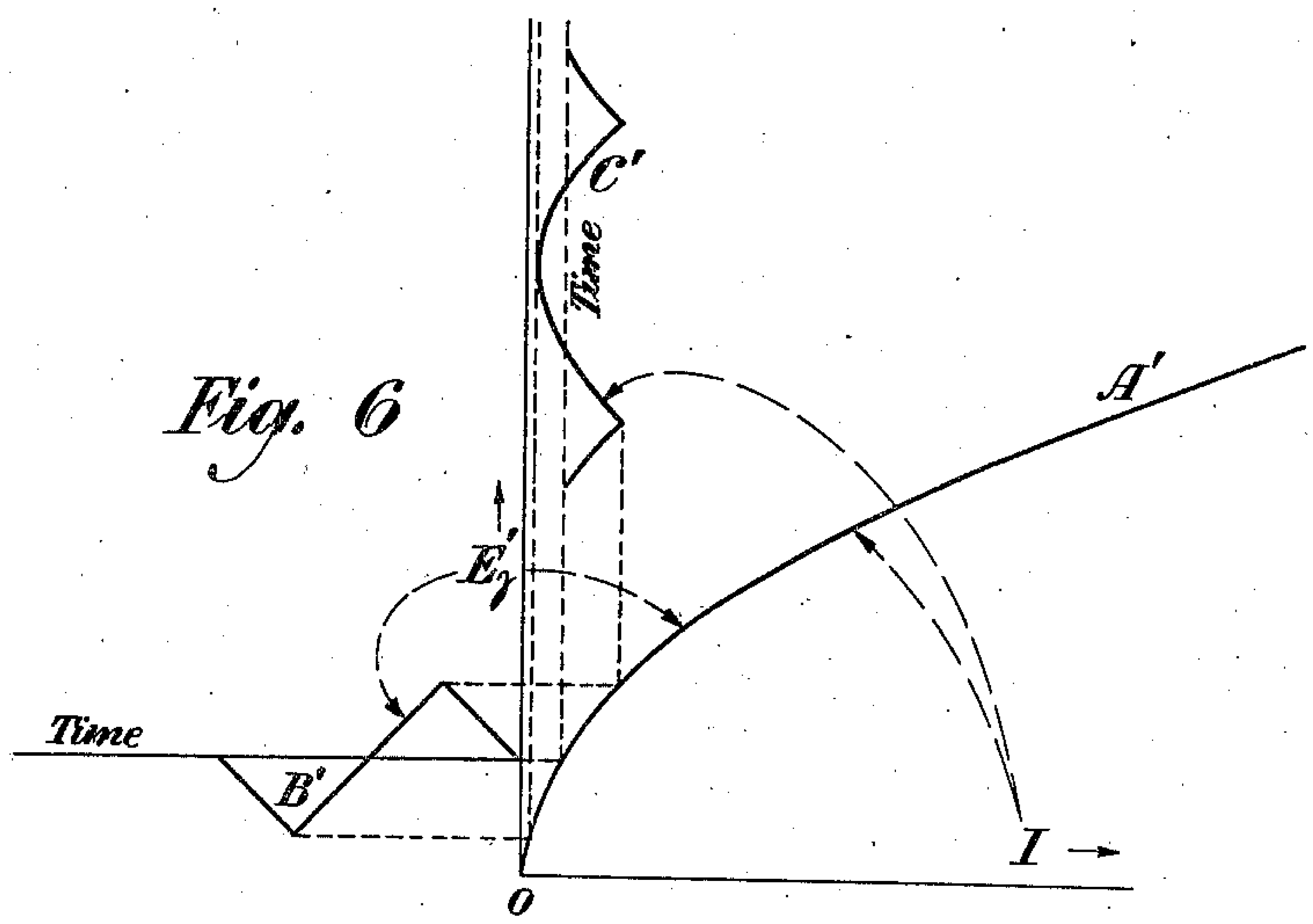

Fig. 6

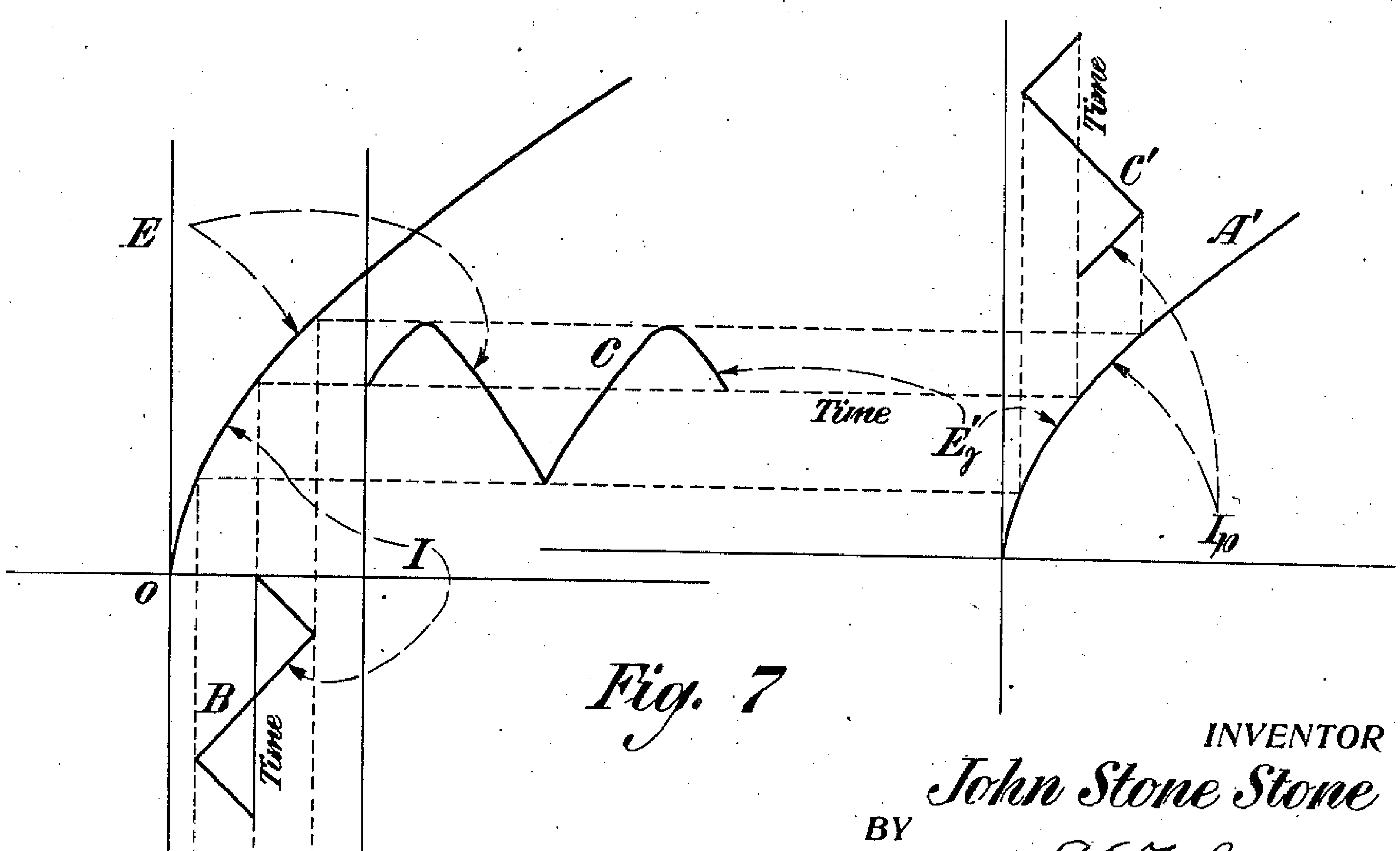

Fig. 7

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Patented June 29, 1926. **1,590,263**

UNITED STATES PATENT OFFICE.

JOHN STONE STONE, OF SAN DIEGO, CALIFORNIA, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

AMPLIFIER.

Application filed January 4, 1923. Serial No. 610,608.

The principal object of my invention is to provide a new and improved distortionless amplifier for variable electric currents. Another object of my invention is to combine transforming or amplifying units, each with a non-linear characteristic relation between input and output, in a system that shall give a linear characteristic. Another object of my invention is to combine thermionic vacuum tubes in a system that shall give amplification without distortion. All these objects and various other objects of my invention will be made apparent in the following specification and claims, taken with the accompanying drawings, wherein are disclosed a limited number of specific embodiments of the invention. I shall now proceed to describe these examples of the invention, with the understanding that the invention is defined in the appended claims.

Referring to the drawings, Figure 1 is a circuit diagram showing one embodiment of my invention; Figs. 2, 3 and 4 show modifications; and Figs. 5, 6 and 7 are characteristic diagrams.

Fig. 1 shows a system employing a two-electrode thermionic vacuum tube T_2 and a three-electrode thermionic vacuum tube T_3. An input electromotive force E is indicated as having the direct component E_o and the small superposed alternating component e. The output current I_p flows through the external resistance r_o. Other elements of Fig. 1 and their relation to one another will be readily apparent from the drawing, in connection with the following description of the manner of operation of the system.

It is known from experiment with a large number of tubes that the current and voltage across the electrodes of a two electrode tube have the relation that the current varies approximately as the square of the voltage. In the part of this specification immediately following, this square law will be assumed, but it will be pointed out that the conclusions to which it leads would be the same with a more general law for the current-voltage relation.

Accordingly, by the square law just referred to,

$$E_t = \sqrt{\frac{I}{\alpha_1}} \quad (1)$$

where α_1 is a constant. It is assumed that the battery E_c has its negative pole connected to the grid of the tube T_3 and that the electromotive force of this battery E_c is so high that the grid is always negative, and hence no appreciable current flows in the circuit of the battery E_c. Accordingly, the current through the tube T_2 is the current I through the battery E_o. It follows that

$$E = rI + \sqrt{\frac{I}{\alpha_1}} \quad (2)$$

Solving as a quadratic for $\sqrt{I}$ we get the result

$$E_t = \sqrt{\frac{I}{\alpha_1}} = -\frac{1}{2\alpha_1 r} + \frac{1}{2\alpha_1 r}\sqrt{1+4\alpha_1 rE} \quad (3)$$

For the tube T_3

$$E_g = E_t - E_c \quad (4)$$

Let r_o be negligible; inasmuch as the resistance across the plate and filament of a vacuum tube is always considerable, there will be many cases where this assumption will correspond closely with the fact, and in such cases the following discussion is applicable.

For the three-electrode vacuum tube, the general square law has been established experimentally which is embodied in the following equation for the tube T_3:

$$I_p = \alpha\left\{\frac{E_b}{\mu} + E_g + \epsilon\right\}^2 \quad (5)$$

that is, the plate current varies as the square of a function of the plate voltage and the grid voltage. μ is a constant depending on the design of the tube and ϵ is a small electromotive force corresponding to the intrinsic potential difference between the filament and the system constituted by the grid and plate. Substituting from equation (3) to equation (4) and then from equation (4) to equation (5), we get

$$I_p = \alpha\left(E\gamma - \frac{1}{2\alpha_1 r} + \frac{1}{2\alpha_1 r}\sqrt{1+4\alpha_1 rE}\right)^2 \quad (6)$$

where $E\gamma$ stands for

$$\frac{E_b}{\mu} + \epsilon - E_c.$$

Now let the system be adjusted so that

$$E\gamma = \frac{1}{2\alpha_1 r} \quad (7)$$

then equation (6) will reduce to

$$I_p = \frac{\alpha}{4\alpha_1^2 r^2}(1+4\alpha_1 rE) = \alpha E\gamma(E\gamma + 2E) \quad (8)$$

This shows that the output plate current for the system stands in linear relation with the input voltage E.

It is well known that with a single tube the relation between output and input is, in general, non-linear. This means that amplification will be accomplished only with distortion.

Referring to Fig. 5, the curve A exhibits the relation between voltage E and current I for a two-electrode tube. If the current is made to vary linearly with the time in the manner indicated by the diagram at B, the voltage will vary in the manner shown at C, whose points are found by projecting from the diagram B on the curve A and then the curve A to the curve C, keeping the time intervals uniform. It will be noticed that the diagram B is made up of straight line segments and that the corresponding lines in C are curve; thus the distortion is exhibited.

Referring to Fig. 6, this shows a diagram for the relation between output current I and equivalent voltage $E\gamma'$ for a three-electrode tube, where

$$E\gamma' = \frac{E_b}{\mu} + E_g + \epsilon \quad (8^a)$$

Assuming that the voltage $E\gamma'$ varies in relation to time, as indicated by the diagram at B′, the corresponding variation of the output current I is given by the curve at C′. The departure from linearity in curve C′ indicates the distortion.

Figs. 5 and 6 are combined in Fig. 7, which shows the operation of the device according to Fig. 1. If the current I of Fig. 1 varies in time according to the diagram B, then the output electromotive force superposed on battery E_c across the filament and grid of tube T_3 will vary according to the curve C. This electromotive force is a linear component of $E\gamma'$ as shown by equation (8^a), and the output current I_p will be found by projecting from curve C to A′ and thence to C′. Notwithstanding the curvature of diagram C, the straight line diagram B transforms through C to the straight line diagram C′, indicating absence of distortion between input and ultimate output.

Various measures have been tried and adopted to remedy the defect due to distortion in a single tube, as shown by Fig. 5 or Fig. 6. One plan depends on the fact that although the output characteristic is curved, if it is worked over a narrow range, the portion of the characteristic involved will be short and nearly straight. Another expedient is to employ a large external resistance in the plate circuit, which makes the characteristic more nearly straight. By my invention it is accomplished that the characteristic will be made straight as in Fig. 7, if two tubes be employed according to the plan outlined in connection with Fig. 1. The demonstration here given has involved the square law, but a review of the foregoing steps shows that the result may be made the same for a more general finite continuous, single valued functional relation, that is a linear relation would be obtained between the input electromotive force and the output current. In the following further examples of my invention, I employ the square law only by way of example for the more general relation.

In Fig. 2 a system is shown which differs from that of Fig. 1 in that the resistance r is tapped at an intermediate point with the part r_1, next to the tube T_2 as shown. Moreover, in this case r_o is not assumed to be negligible.

By a series of steps that parallel those taken for the case of Fig. 1, it may be deduced that in Fig. 2 the voltage E_t' is given by

$$r_1 I + \sqrt{\frac{I}{\alpha_1}} = -\frac{r-r_1}{2\alpha_1 r^2} + \frac{r_1}{r}E + \frac{r-r_1}{2\alpha_1 r^2}\sqrt{1+4\alpha_1 rE} \quad (9)$$

From the square law it follows that

$$I_p = \alpha\left\{E\gamma - \frac{r-r_1}{2\alpha_1 r^2} + \frac{r_1}{r}E + \frac{r-r_1}{2\alpha_1 r^2}\sqrt{1+4\alpha_1 rE} - \frac{r_o}{\mu}I_p\right\}^2 \quad (10)$$

This can readily be rewritten

$$\frac{r_o}{\mu}I_p + \sqrt{\frac{I_p}{\alpha}} = E\gamma - \frac{r-r_1}{2\alpha_1 r^2} + \frac{r_1}{r}E + \frac{r-r_1}{2\alpha_1 r^2}\sqrt{1+4\alpha_1 rE} \quad (10^a)$$

This is an equation between two variables I_p and E. Let us assume tentatively that the rational and irrational parts can be equated separately. This will make I_p a linear function of E in both equations, and these two equations will reduce to

$$I_p = \frac{\mu}{r_0}\left(E\gamma - \frac{r-r_1}{2\alpha_1 r^2} + \frac{r_1}{r}E\right) \quad (11)$$

and

$$I_p = \alpha\frac{(r-r_1)^2}{4\alpha_1^2 r^4}(1+4\alpha_1 rE) \quad (12)$$

It follows that when E=O

$$\frac{\mu}{r_0}\left(E\gamma - \frac{r-r_1}{2\alpha_1 r^2}\right) = \alpha\frac{(r-r_1)^2}{4\alpha_1^2 r^4} \quad (13)$$

and thence it follows that the coefficient of E must be equal, giving

$$\frac{\mu}{r_0} = \alpha\frac{(r-r_1)^2}{\alpha_1 r_1 r^2} \quad (14)$$

substituting from (14) in (13) and reducing

$$E\gamma = \frac{2r-r_1}{4\alpha_1 r^2} \quad (15)$$

Hence we may say that imposing the conditions of equations (14) and (15) establishes the linear relation (11) between E and I_p. Evidently by proper design and adjustment, equations (14) and (15) can be established. Thus we see that in the system of Fig. 2, without neglecting r_0, if the adjustments are made to satisfy equations (14) and (15) then the output current I_p depends linearly on the input voltage E. It will be seen that Fig. 1 is a special case of Fig. 2 in which r_0=O; this condition necessitates the condition that r_1=O, thus reducing the value

$$E\gamma \text{ to } \frac{1}{2\alpha_1 r}.$$

In Figs. 1 and 2 the input voltage has been applied first to the two-electrode tube and the output current has been taken from the three-electrode tube. In Fig. 3 the order is reversed. Here the plate current is

$$I_p = \alpha\left(\frac{E_b}{\mu} + E_g + \epsilon - \frac{1}{\mu}\sqrt{\frac{I_p}{\alpha_1}}\right)^2 \quad (16)$$

whence

$$\sqrt{I_p} = \frac{\mu\sqrt{\alpha\ \alpha_1}}{\sqrt{\alpha}+\mu\sqrt{\alpha_1}}\left(\frac{E_b}{\mu} + E_g + \epsilon\right) \quad (17)$$

Accordingly, the potential difference across the two-electrode tube in Fig. 3 is

$$E_f = \sqrt{\frac{I_p}{\alpha_1}} = \frac{1}{1+\mu\sqrt{\frac{\alpha_1}{\alpha}}}\{E_b + \mu(E_g + \epsilon)\} \quad (18)$$

This exhibits a linear relation between the output voltage E_f and the input voltage E_g. If α_1 is small compared to α, equation (18) indicates amplification of potential without distortion.

In Fig. 4 there is illustrated a more general form of the circuit arrangements in which the inherent distortion of the audion amplifier is neutralized by the use of three tubes, in a sense combining the principle of Fig. 1 and the principle of Fig. 3. It is believed that a mathematical discussion will not be necessary for this case, having been sufficiently presented in connection with the earlier cases.

Fig. 4 shows explicitly that the kind of distortion produced by the audion amplifier may be neutralized at any remote point in the transmission line by the system here disclosed, because the resistance r_0 may represent the resistance of a transmission line.

I claim:

1. In combination, a two-electrode vacuum tube and a three-electrode vacuum tube, the terminals of the two-electrode tube being connected with the input terminals of the three-electrode tube, the circuits and their impedances being adjusted so that the output and input of the combination are in simpler linear relation.

2. In combination, two thermionic vacuum tubes, each with a non-linear characteristic and each with associated conductors forming a pair of input terminals and a pair of output terminals and means connecting the output of one tube with the input of the other, the combination being designed and adjusted so that the ultimate output shall be in linear relation with the initial input.

3. In combination, two thermionic vacuum tubes, each with a filament-cathode and a plate anode, one of said tubes also having a grid, said tubes having two terminals of one connected respectively with the two terminals of the other and having their circuit elements designed and adjusted mutually to compensate their distortion whereby the ultimate output of the combination will be undistorted in relation to the initial input.

4. In combination, a two-electrode tube with a resistance r comprised in its input circuit and with a portion r_1 thereof comprised in its output circuit, a battery of electromotive force E_c in said output circuit, a three-electrode tube having its input connected in said output circuit and having a resistance r_0 and a battery of electromotive force E_b comprised in its output circuit subject to the design equations

$$\frac{\mu}{r_0} = \alpha\frac{(r-r_1)^2}{\alpha_1 r_1 r^2}$$

$$E\gamma = \frac{2r-r_1}{4\alpha_1 r^2}$$

$$E\gamma = \frac{E_b}{\mu} + \epsilon - E_0$$

where μ, ϵ and α are constants for the three-electrode tube and α_1 is a constant for the two-electrode tube.

5. In combination, a two-electrode tube with a resistance r comprised in its input circuit and with a portion r_1 thereof comprised in its output circuit, a battery E_c in its output circuit, a three-electrode tube having its input connected in said output and having a resistance r_0 and a battery of electromotive force E_b comprised in its output circuit, the said resistances and electromotive forces being so proportioned in relation to the constants of the said tubes that the curvature of the volt ampere characteristic of one tube compensates for such curvature of the other tube and gives an over-all linear characteristic for the combination.

In testimony whereof, I have signed my name to this specification this 28th day of December 1922.

JOHN STONE STONE.