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SOME HIGH IMPEDANCE CURRENT GENERATING CIRCUITS

by

J. H. McGuire

Summary

A basic high impedance current generating circuit is described together with practical designs developed from it.

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Fire Research Station,
Boreham Wood,
Herts.

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1) Introduction

It is often necessary, as in the stabilization of electromagnetic lens systems and in the use of analogue computers, to apply to a network a current which is independent of the network impedance. One way of doing this is to apply to the load, through a very high resistance, a voltage waveform having the same time characteristic as the required current waveform. This is obviously inefficient and is often very inconvenient as it necessitates the generation of an E.M.F. many times the potential difference developed across the load.

This note describes the basic and practical designs of a circuit which will generate current waveforms with a reasonable efficiency.

2) Two simple current generating circuits

Figure 1 illustrates the simple high impedance current generating circuit which forms the basis of the various circuits described in this note. Its performance is analysed in Appendix 1 where it is shown that the arrangement of Figure 2 is an equivalent circuit. If Z_o is resistive the circuit waveform will be substantially that of the applied voltage waveform, though it may be noted that this may be modified somewhat if Z_o is complex.

In cases where the output capacity of the circuit must be low and the source E_o is capable of supplying the output current I, the alternative circuit illustrated in Figure 3 may be used. The generator E_o will almost certainly constitute the largest stray capacity to earth in either arrangement. In Figure 1 this stray capacity will be connected directly across the output and can only be charged through the impedance Z_o. In the circuit of Figure 3, however, the stray capacity of the generator E_o will be shunted by the output impedance of the cathode follower.

The performance of the circuit is substantially that of Figure 1 and Appendix 1 is applicable provided that the factor μE_o be replaced by $(\mu + 1) E_o$ wherever it appears.

Where greater stability of current is required, improved circuits may be developed from those of Figures 1 and 3 by arranging for the potential drop across the valve to be maintained constant.

3) Pentode current generating circuits

The circuits of Figures 4a and 4b illustrate the use, as a current generator, of a pentode, the screen grid of which is maintained at a constant potential with respect to the cathode. The output current, in both circuits, will be independent of the output voltage to the extent that the valve behaves as an ideal pentode, i.e. to the extent that anode current is independent of anode voltage.

This type of circuit is of most practical value in generating a constant current and in this case E_o is constant, Z_o being a pure resistance. One floating supply may then serve for both E_o and V_{g} if a circuit of the type shown in Figure 4a is to be used. Such an arrangement is illustrated in Figure 4c.

4) Two and three valve current generator circuits

Figure 5 illustrates a circuit which is substantially of the same design as that of Figure 1 but which has a series valve in the HT line so that the potential difference across the cathode follower is maintained nearly constant. Since there is no current drain from the voltage source E_B a battery may be used as illustrated in the diagram.

It is shown in Appendix 2 that the arrangement of Figure 6 is an equivalent circuit and that, in most practical cases, the variation of output current with output voltage is μ times less than with the circuit of Figure 1, μ being the amplification factor of either valve.

If the output capacity of the circuit must be low and the source E_o is capable of supplying the output current I, the alternative arrangement of E_o and Z_o, described in Section 2, may again be used. The performance will be substantially the same and, for similar conditions, the value of the H T E_+ may again be reduced by an amount E_o.

With either arrangement it might also be convenient to connect the lower end of the potential source E_B to the lower end of Z_o and not to the valve cathode.

Where it is undesirable to include any batteries in the circuit a stability approaching the order of the above may be obtained by incorporating a third valve and neon stabiliser tubes. Such a circuit, operating on the same principle as the circuit of Figure 5, is illustrated in Figure 7. A similar circuit based on the alternative arrangement of E_o and Z_o would be cumbersome as it would require a negative supply line in addition to the positive H.T. supply.

5) Currents of opposite polarity

If currents of the opposite polarity are required, the load Z in the circuits of Figures 1-5 may be placed in series with the H.T. supply. With this arrangement the positive side of the H.T supply would be earthed and thus the lower end of the generator E_o would be at a fixed potential with reference to earth. The capacity of the generator E_o would therefore become unimportant and it would be pointless to use a modified arrangement of the circuit of Figure 3.

The circuit of Figure 5 would be simplified if the lower end of the potential source E_B were connected to the lower end of Z_o. The potential could then be derived from a potential divider across the H.T. line and in these circumstances the circuit of Figure 7 would be redundant

6) Conclusions

Several current generating circuits have been described and it is shown that a practical example of output current waveform will be constant, with variations in output voltage, to within 4½ per cent for the simple circuit and ¼ per cent for the more complex circuits. Equivalent circuits are given and it is shown that, if a valve with an amplification factor of 20 is used, the simple circuit operating from supplies not exceeding 500 volts will give the same performance (within limits) as a circuit including a high impedance generator of E.M.F. 4,500 volts. In the case of the more complex circuit, operating from supplies not exceeding 700 volts the E.M.F. of the equivalent high impedance generator would be of the order of 88 Kv, again assuming that valves with an amplification factor of 20 are used.

The circuits of Figures 4c and 3 have been used successfully to give constant and impulsive currents respectively in an electric analogue of heat conduction.

7) Acknowledgment

Acknowledgment is due to Mr. D. I. Lawson for drawing attention to one of the two relative arrangement of E_o and Z_o.

Appendix 1. A simple current generator

If, in the circuit of Figure 1, the valve is considered to be ideal and stray capacities are neglected, then the current flowing through the load Z is given by

$$I = \frac{E_a + \mu E_o}{R + (\mu+1) Z_o + Z} \qquad \text{...... (1)}$$

where μ and R are the amplification factor and equivalent DC resistance of the valve respectively.

Thus, provided the potential drop E across the load Z does not rise to such a level that the potential difference across the valve tends to zero, the circuit will behave as if it were the generator of an E.M.F. ($E_a + \mu E_o$) with an internal impedance $R + (\mu + 1) Z_o$ (see Figure 2).

The fractional variation of I with Z will be small provided Z is small compared with $R + (\mu + 1) Z_o$ and in these circumstances is given by

$$\frac{dI/dZ}{I} \hat{=} \frac{-1}{R + (\mu+1) Z_o} \qquad \text{...... (2)}$$

In many applications of the circuit the load Z will be complex and it may not be practicable to evaluate expression 2. The performance of such circuits is best described in terms of the potential drop E across the load Z rather than in terms of Z. It follows from the equivalent circuit of Figure 2 that provided E is small compared with $E_a + \mu E_o$, the fractional variation of I with E is

$$\frac{dI/dE}{I} \hat{=} \frac{-1}{E_a + \mu E_o} \qquad \text{...... (3)}$$

Thus if a valve with a μ of 20 is used in a circuit with an H.T. of 500 volts and E_o has a constant value of 200 volts then a typical value of the maximum excursion of E will be 200 volts. On substituting these values in expression 3 it will be seen that the fractional difference between the current when the potential difference across the load varies between 0 and 200 volts is

$$\left(\frac{\delta I}{I}\right)_{max} \triangleq 4\tfrac{1}{2}\%$$

In the equivalent circuit of Figure 2 the same potential difference E would be developed across the load if the generator developed an E.M.F. of 4,500 volts and had an internal impedance of $R + (\mu + 1) Z_o$.

Appendix 2. An improved current generator

If in the circuit of Figure 5, the valves are considered to be ideal and stray capacities are neglected, then the current flowing through the load Z is given by

$$I = \frac{E_{+} + \mu E_B + \mu(\mu+1) E_o}{(\mu+2) R + (\mu^2 + \mu + 1) Z_o + Z} \qquad \text{...... (4)}$$

where μ and R are the amplification factor and equivalent DC resistance of the valves respectively.

Thus, provided the potential drop E across the load Z does not rise to such a level that the potential difference across the valve tends to zero, the circuit will behave as if it were the generator of an E.M.F. $[E_+ + \mu E_B + \mu(\mu+1)E_0]$ with an internal impedance $[(\mu+2)R + (\mu^2+\mu+1)Z_0]$ see Figure 6.

The variation of I with Z will be small provided Z is small compared with $[(\mu+2)R + (\mu^2+\mu+1)Z_0]$ and in these circumstances is given by

$$\frac{dI/dZ}{I} \simeq \frac{-1}{(\mu+2)R+(\mu^2+\mu+1)Z_0} \qquad \ldots\ldots (5)$$

As with the previous circuit many applications will involve complex loads and in these cases the performance is best described in terms of E, as follows

$$\frac{dI/dE}{I} \simeq \frac{-1}{E_+ + \mu E_B + \mu(\mu+1)E_0} \qquad \ldots\ldots (6)$$

The order of variation likely to be encountered in practice may be found by substituting appropriate values in expression 6. Thus if $\mu = 20$, $E_+ = 700$ volts and $E_B = E_0 = 200$ volts then for a change in E of 200 volts $\left(\frac{dI}{I}\right)_{max} = 0{\cdot}23$ per cent.

In the equivalent circuit of Figure 6 the same potential difference would be developed across the load if the generator developed an E.M.F. of 88·7 Kv and had an internal impedance of $(\mu+2)R + (\mu^2+\mu+1)Z_0$.

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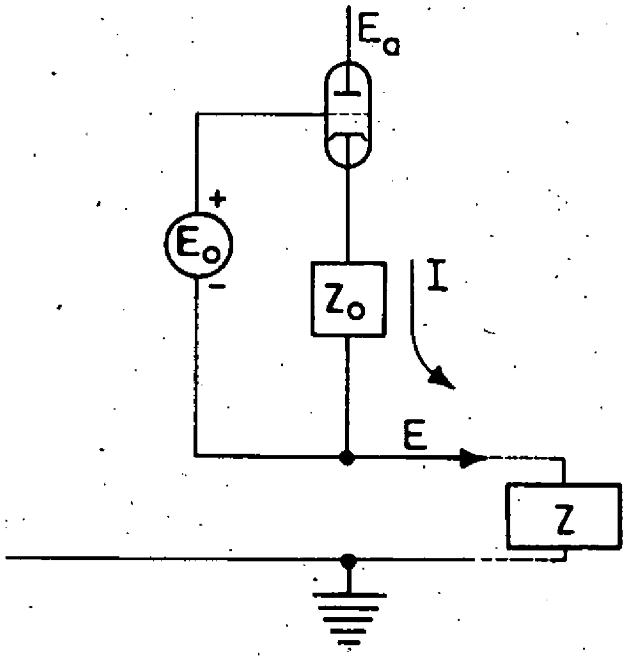

FIG. I. A SIMPLE POTENTIOMETRIC CURRENT GENERATING CIRCUIT.

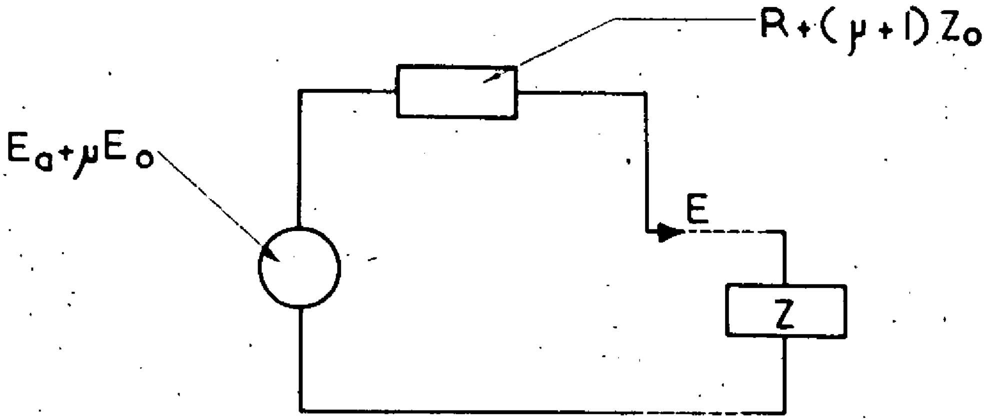

FIG. 2. EQUIVALENT CIRCUIT OF FIG. I.

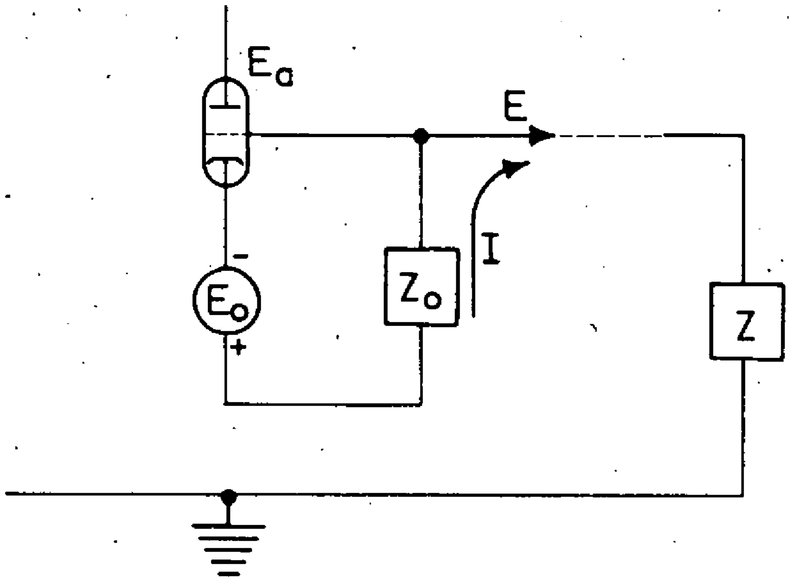

FIG. 3. AN ALTERNATIVE CURRENT GENERATING CIRCUIT.

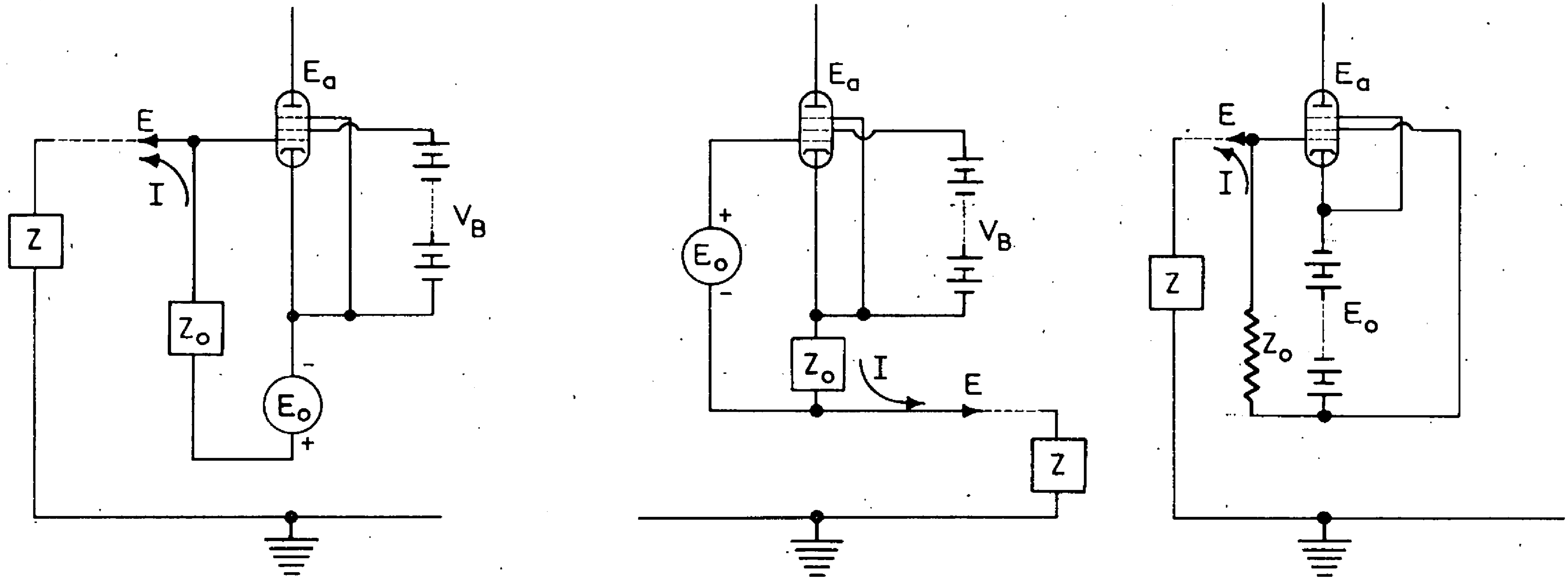

FIG. 4 a.

FIG. 4 b.

FIG. 4 c.

FIG. 4. PENTODE CURRENT GENERATING CIRCUITS.

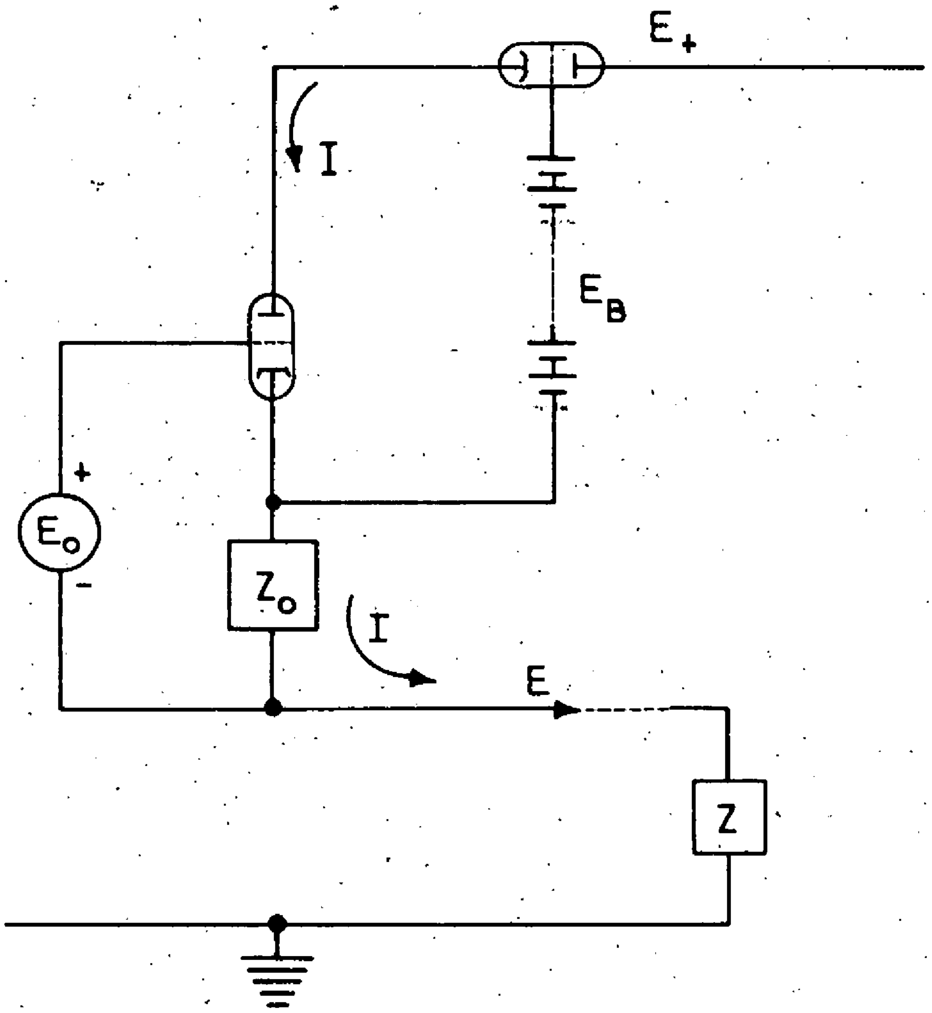

FIG. 5. AN IMPROVED CURRENT GENERATOR.

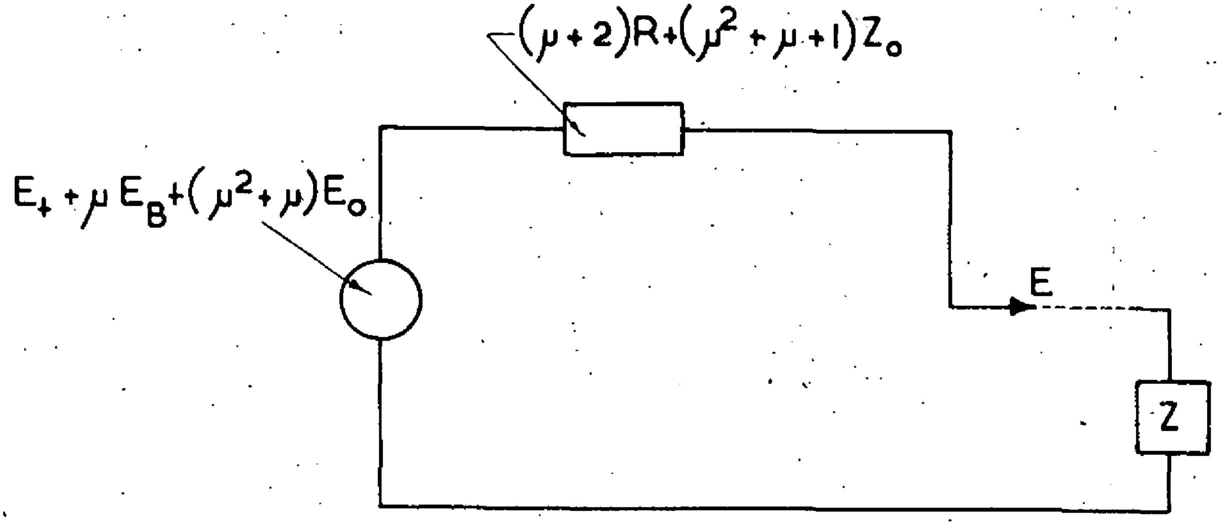

FIG. 6. EQUIVALENT CIRCUIT OF FIG. 5.

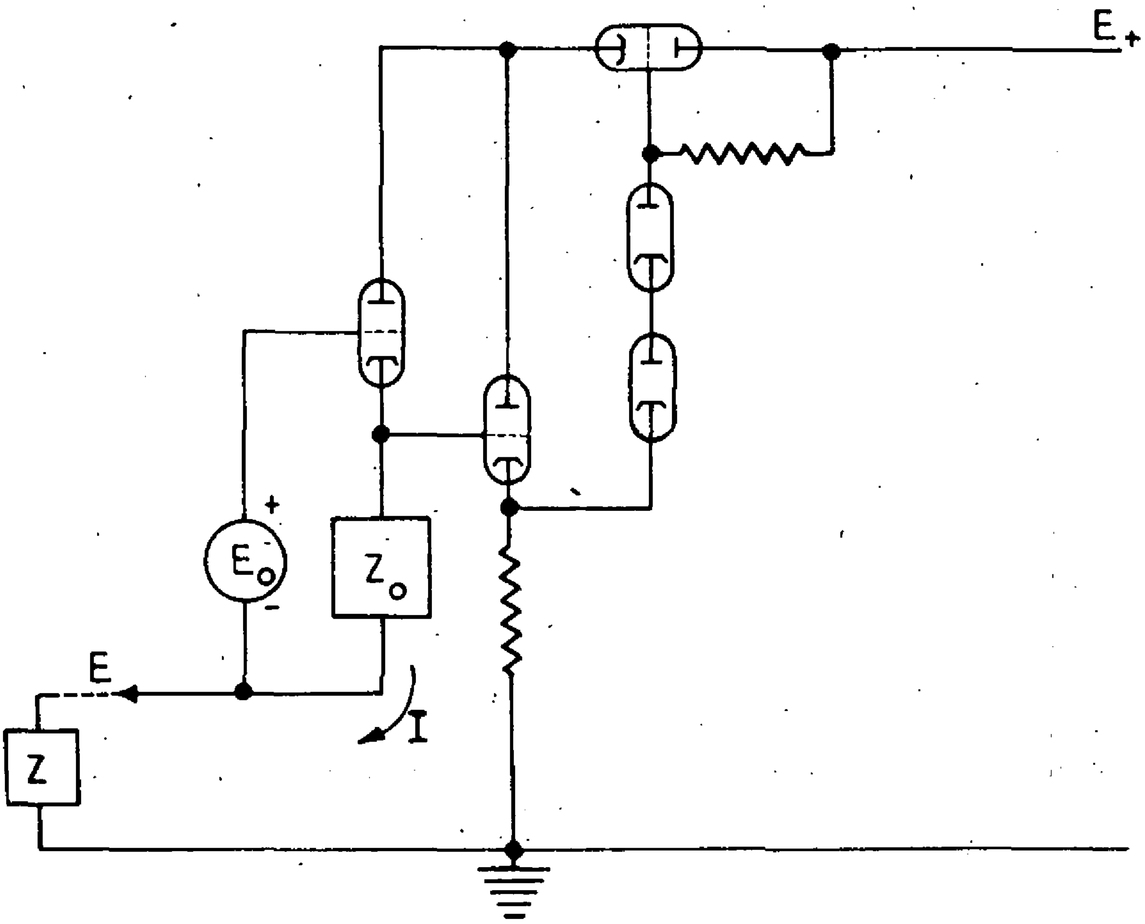

FIG. 7. A NEON TUBE STABILISED CURRENT GENERATING CIRCUIT~~S~~.