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N 7 onr - 28808

TRIGGERING OF THE ECCLES-JORDAN CIRCUIT

by

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Abstract

The Eccles-Jordan trigger circuit is essentially a two-stage d-c amplifier in which the output is connected to the input and the overall d-c amplification is therefore caused to be unity. The stability and triggering characteristics of the trigger circuit may be analyzed by means of a diagram showing curves of direct output voltage vs. direct input voltage of the basic amplifier, together with the line corresponding to equality of input and output voltages. Such a diagram shows clearly the manner in which the stability is affected by biasing voltage.

Triggering from one stable state to the other is explained with the aid of dynamic characteristics of output voltage vs. input voltage of the amplifier.

Although the Eccles-Jordan trigger circuit can be analyzed on the basis of current-voltage diagrams similar to those discussed in the Seventh Technical Report of Navy Research Project N 7 onr - 28808 (Technical Report No. NR 075-139), a more instructive and productive approach is to consider the circuit as a two-stage direct-coupled amplifier in which the output terminals are connected to the input terminals. Because the output voltage must be equal to the input voltage in the closed system, possible conditions of equilibrium can be determined by constructing a curve of direct output voltage vs. direct input voltage of the amplifier and observing the points on the curve at which the output and input voltages are equal. Such a curve can be constructed either graphically or from experimental data.

Figure 1a shows the basic Eccles-Jordan trigger circuit, in which, for the sake of simplification of analysis, coupling between stages is assumed to be made through biasing batteries, rather than with the aid of the usual resistance voltage divider. In Fig. 1b the circuit is redrawn in the form of a two-stage amplifier. The curve of output voltage e_o vs. input voltage e_i may be derived from a transfer characteristic of output voltage e_o' vs. input voltage e_i of one stage determined experimentally or constructed graphically from the plate characteristics of the tube at the known values of plate-supply voltage E_{bb}, grid-supply voltage E_{cc}, and coupling resistance r_b. Because the bias-supply voltage E_{cc} of each stage has the same effect as an equal change of input voltage to that stage, different transfer characteristics need not be constructed for different values of E_{cc}.

Figure 2 shows the measured transfer characteristic, output voltage vs. input voltage, of one stage using a 6J6 twin triode, a plate-supply voltage of 90, a coupling resistance of 4700 ohms, and zero supplementary biasing voltage E_{cc}. Corresponding curves of output voltage vs. input voltage for the two-stage amplifier at various values of E_{cc} are shown in Fig. 3. In practical circuits, the flow of grid current through series grid-circuit resistance prevents the grid voltage from rising appreciably above zero. In the construction of the curves of Fig. 3, therefore, the assumption was made that the upper limit of grid voltage is clamped at zero. The manner in which the curves were constructed can be readily seen by following the procedure for an input voltage e_i of -3 volts when

E_{cc} is -1 volt. For this input voltage, the grid voltage of tube 1 is -4 volts and the curve of Fig. 2 shows that the output voltage e_o' of the first stage is -2 volts. The grid voltage of the second tube is $e_o' + E_{cc} = -3$ volts. For this value of grid voltage, the curve of Fig. 2 shows that e_o is -5.5 volts. Similarly, when e_i is -1 volt, Fig. 3 shows e_o' to be -22.5 volts. The grid voltage of the second tube is -23.5 volts, which biases this tube beyond cutoff and makes the output voltage zero.

Because the input voltage must equal the output voltage when the output terminals are connected to the input terminals, possible equilibrium values of output and input voltage are those corresponding to the intersection of the voltage transfer characteristic with the straight line corresponding to the relation $e_o = e_i$. Figure 4 shows that one state of equilibrium is that corresponding to point a, for which $e_o = 0$, i.e., for which tube 2 is completely cut off. A second state of equilibrium corresponds to point c, where tube 1 is cut off. A third state of equilibrium is that corresponding to the intersection b of the ($e_o = e_i$)-line with the falling portion of the voltage transfer characteristic. The following analysis, which is similar to that used in Seventh Technical Report of Navy Research Project N 7 onr - 28808 (Technical Report No. NR 075-139), indicates that point b corresponds to unstable equilibrium, and points a and b to stable equilibrium.

The characteristics of Figs. 2 to 4 are static characteristics constructed from graphically or experimentally determined steady values of direct voltage. If these curves also held for varying values of e_i and e_o, regardless of the rate of change or frequency of e_i, point b would correspond to stable equilibrium, since any departure of e_i from the value at b would cause e_o to differ from e_i, in violation of the requirement that e_o must equal e_i. It is well known, however, that shunt capacitances in the circuit of Fig. 1b cause the ratio of a change of output voltage to a change of input voltage to fall off as the frequency or the rate of change of voltage is increased. Therefore, if the input and output voltages e_i and e_o initially have values corresponding to point b and the magnitude of e_i changes rapidly from that value, the resulting curve of e_o vs. e_i will have a lower slope, as indicated by the dotted curve of Fig. 11. If the time rate of change of e_i is increased, the slope of the dynamic voltage transfer characteristic becomes lower. If de_i/dt is great enough, the slope of the dynamic characteristic at b may become unity, i.e., the variational voltage amplification may become unity. The increment of input voltage may then take place without violating the requirement that e_o and e_i remain equal. Once this action starts, it must continue, inasmuch as any reduction of de_i/dt below the instantaneous value for which de_o/de_i is unity would violate the requirement of equality of input and output voltages. The input and output voltages therefore continue to change, the path of operation following the line $e_o = e_i$ until point a or point c is reached. Points a and c are stable, because a change in e_i from the value at either of these points produces no change in e_o, whereas an equal change would be required in order to carry the point of operation away from these values while maintaining e_o equal to e_i.

If operation is at point a, i.e., if tube 2 is cut off, the circuit can be triggered by the application of additional negative bias to tube 1. Except at negative values of E_{cc} of magnitude in the order of half the cutoff value or greater, the minimum triggering voltage that can cause triggering is equal to the value of e_i at point d. This value is the maximum value (negative) of e_i at which tube 2 is cut off. The manner in which triggering takes place can be seen by noting that the application of a negative triggering voltage equal to the voltage at d displaces the voltage transfer characteristic to the right by an amount equal to this voltage, so that point d is made to coincide with the origin, as shown in Fig. 5a. Points a, b, and d then merge into a single point, which is unstable, since the operating point can transfer to c in the manner already explained for point b. When E_{cc} is negative and of sufficient magnitude to reduce the equilibrium plate current of tube 1 to a low value, point b may differ from points a and d when a and d coincide, as shown in Fig. 5b. The minimum triggering voltage, which is that necessary to make the transfer characteristic tangent to the ($e_o = e_i$)-line, is then slightly larger than the value of e_i corresponding to point d in Fig. 4.

The mechanism of transfer from point a to point c is even simpler if the triggering voltage applied to the grid of tube 1 is sufficient to bias tube 1 to cutoff. The amplifier loop is then in effect opened at tube 1 and e_o', e_o, and e_i rise exponentially at rates determined by the circuit resistances and capacitances and the characteristics of tube 2.

When operation is at point a, the circuit can also be triggered by raising the grid voltage of tube 2 to slightly above the cutoff point. The effect upon the diagram of Fig. 4 is to lower the transfer characteristic until point d lies on the $(e_o = e_1)$-line, or (at negative values of E_{cc} that reduce the current of tube 2 to a low value) the transfer characteristic is tangent to the $(e_o = e_i)$-line.

Examination of the circuit of Fig. 1b shows that the minimum negative increment of grid voltage that will cause triggering is that which is required to lower the grid voltage of the conducting tube from the value E_{cc} to the negative value E' at which the grid voltage of the nonconducting tube becomes equal to the cutoff value, as shown in Fig. 6a. Therefore, the minimum magnitude of a negative triggering pulse is

$$\left|\Delta E_n\right| = E_{cc} + \left|E'\right|$$

When the grid voltage of the conducting tube is clamped at zero, the value of E' ranges from about 0.2 to 0.3 times the cutoff voltage E_{co}.

Similarly, examination of Fig..1b shows that the minimum positive increment of grid voltage required for triggering is that required to raise the grid voltage of the nonconducting tube from its maximum negative value to its cutoff value, as shown in Fig. 6b. The magnitude of the maximum negative grid voltage of the nonconducting tube is the magnitude $\left|E_m\right|$ of the voltage across the plate resistor of the conducting tube, minus the (positive) biasing supply voltage E_{cc}. Therefore, the minimum magnitude of a positive pulse that can trigger the circuit is

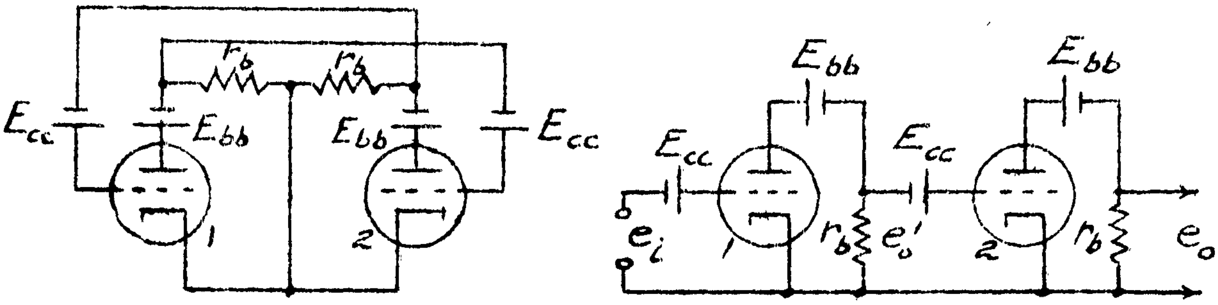
$$\left|\Delta E_p\right| = \left|E_m\right| - \left|E_{co}\right| - E_{cc}$$

When the grid voltage of the conducting tube is clamped at zero, $\left|E_m\right|$ becomes the voltage $\left|E_m\right|_o$ across r_b at zero grid voltage.

As positive biasing voltage is increased from zero, the value of $\left|\Delta E_n\right|$ increases, and that of $\left|\Delta E_p\right|$ decreases, the two values being equal when E_{cc} has the value given by the relation,

$$E_{cc} = (\left|E_m\right|_o - \left|E'\right|)/2$$

in which E' ranges from $0.2E_{co}$ to $0.3E_{co}$.


r_b
r_b
E_{cc}
E_{bb}
E_{bb}
E_{cc}
1
2
E_{bb}
E_{bb}
E_{cc}
E_{cc}
e_i
1
r_b
e_o'
2
r_b
e_o

(a) (b)

FIG. 1

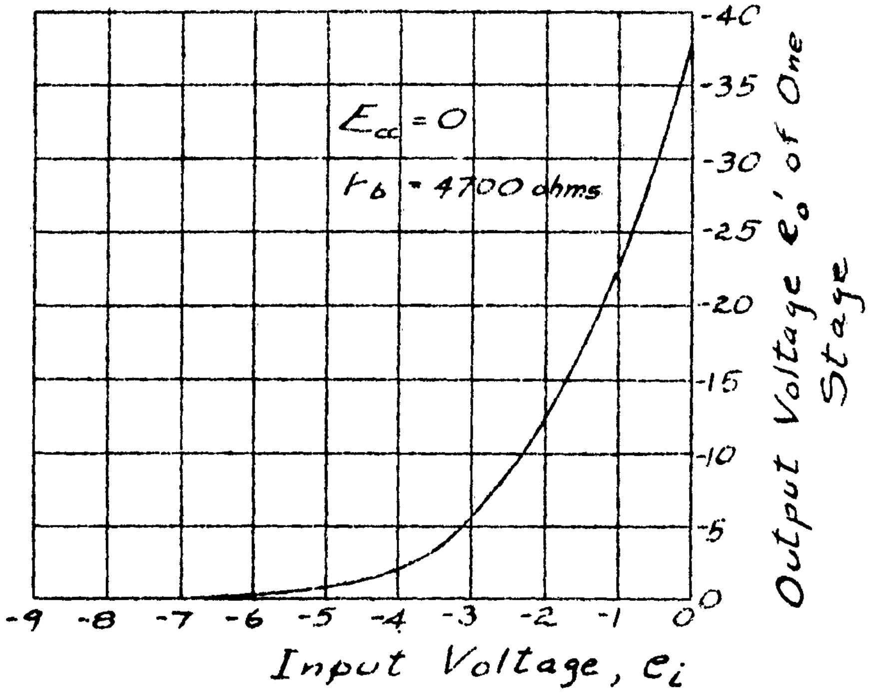

$E_{cc} = 0$
r_b = 4700 ohms
-40
-35
-30
-25
-20
-15
-10
-5
0
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
Input Voltage, e_i
Output Voltage e_o' of One Stage

FIG. 2

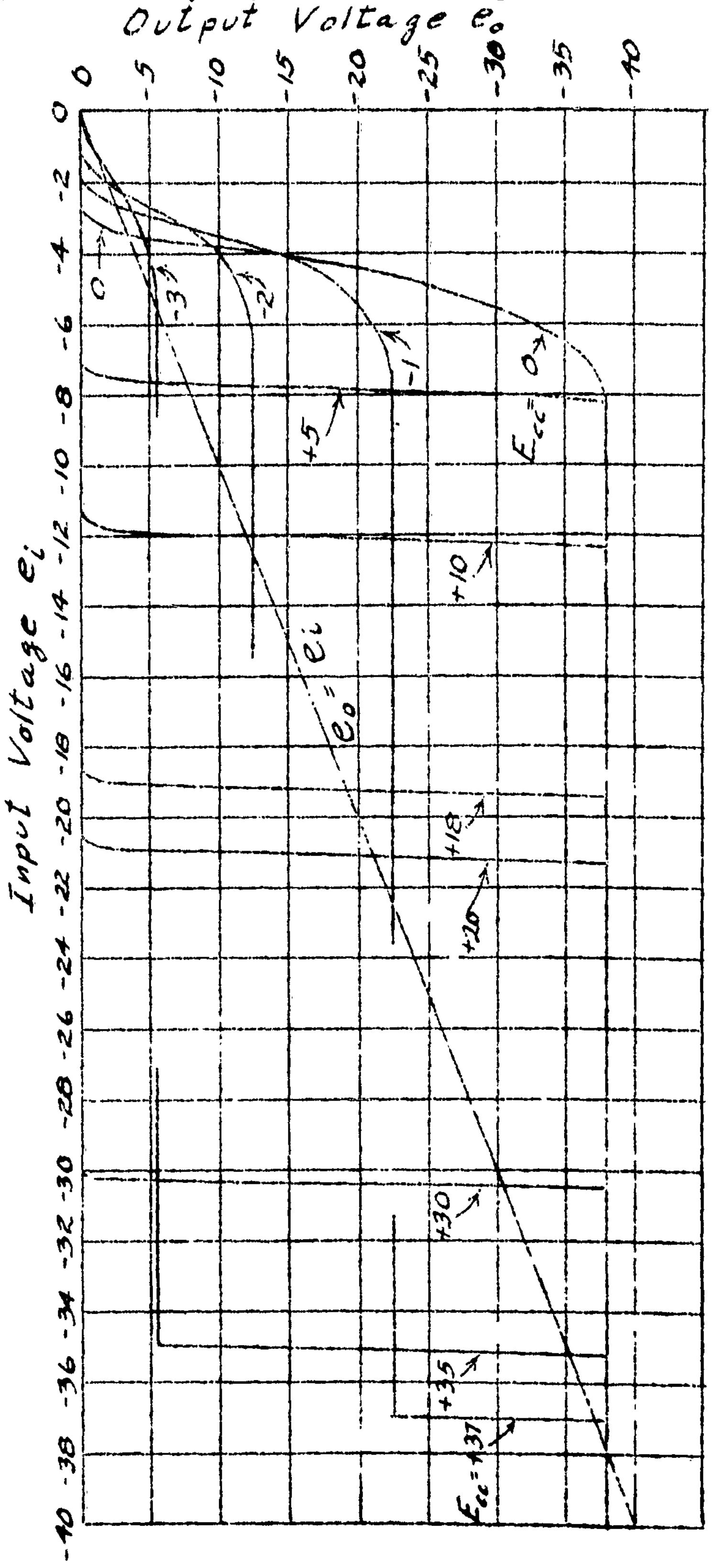

Output Voltage e_o
0
-5
-10
-15
-20
-25
-30
-35
-40
Input Voltage e_i
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
-32
-34
-36
-38
-40
0
-3
-2
-1
+5
E_{cc} = 0
+10
$e_o = e_i$
+18
+20
+30
+35
E_{cc} = +37

FIG. 3

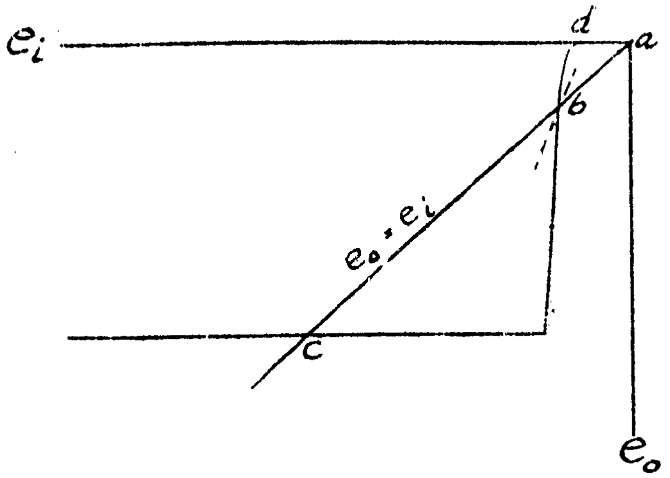


FIG. 4

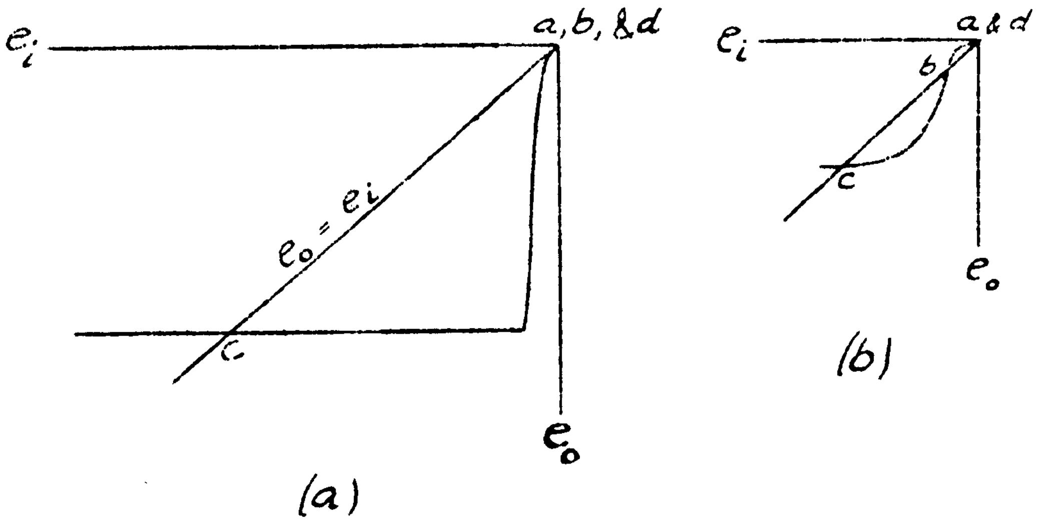


FIG. 5

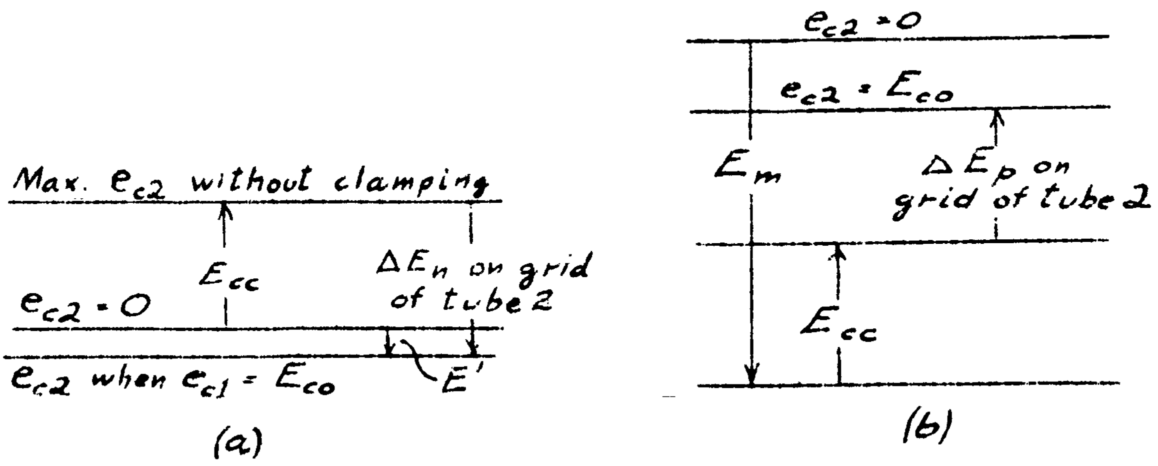


FIG. 6
(Tube 2 initially conducting)