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TRIGGER CIRCUITS

Thesis for the Degree of M. S.

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Stelios Mastorakis

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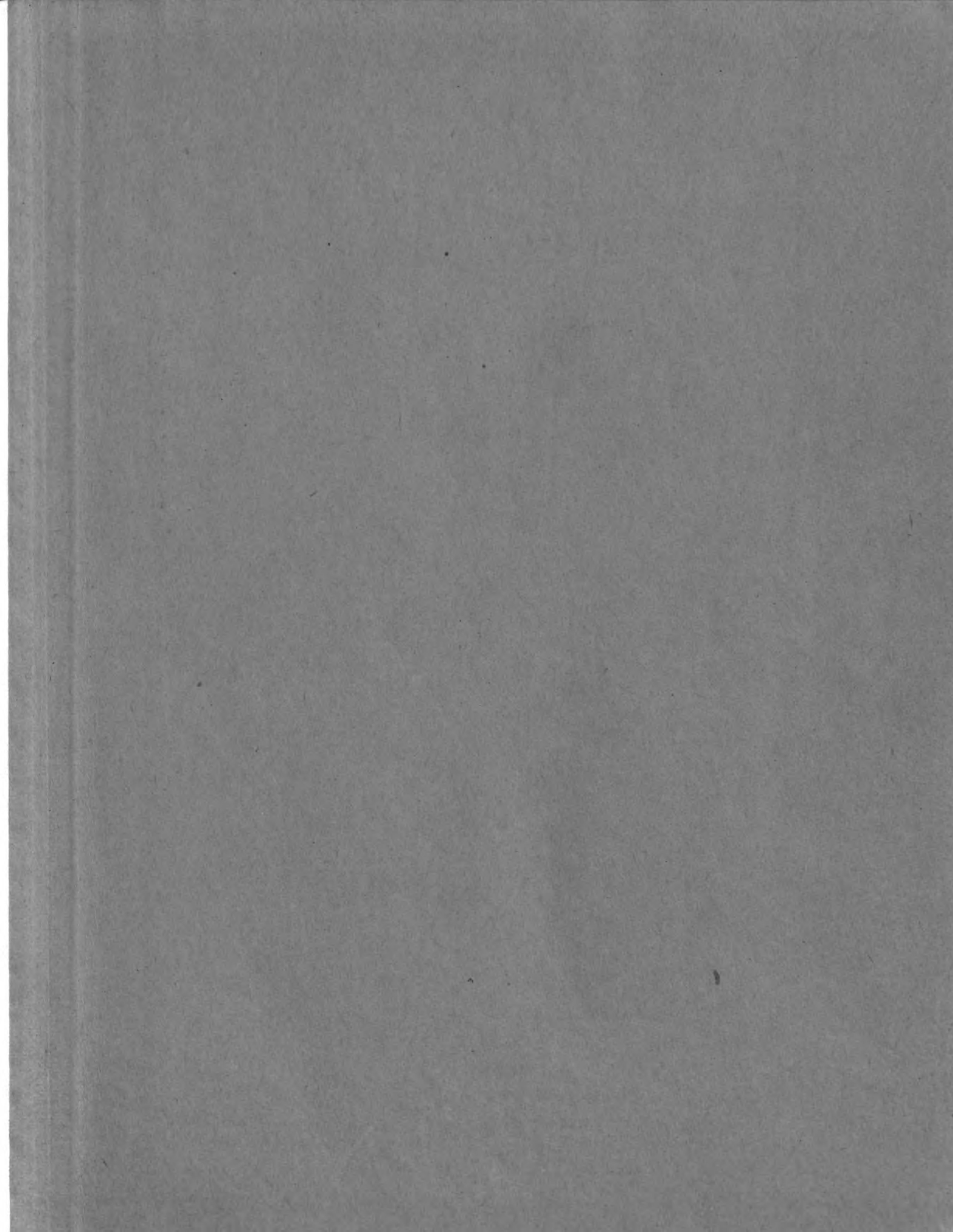
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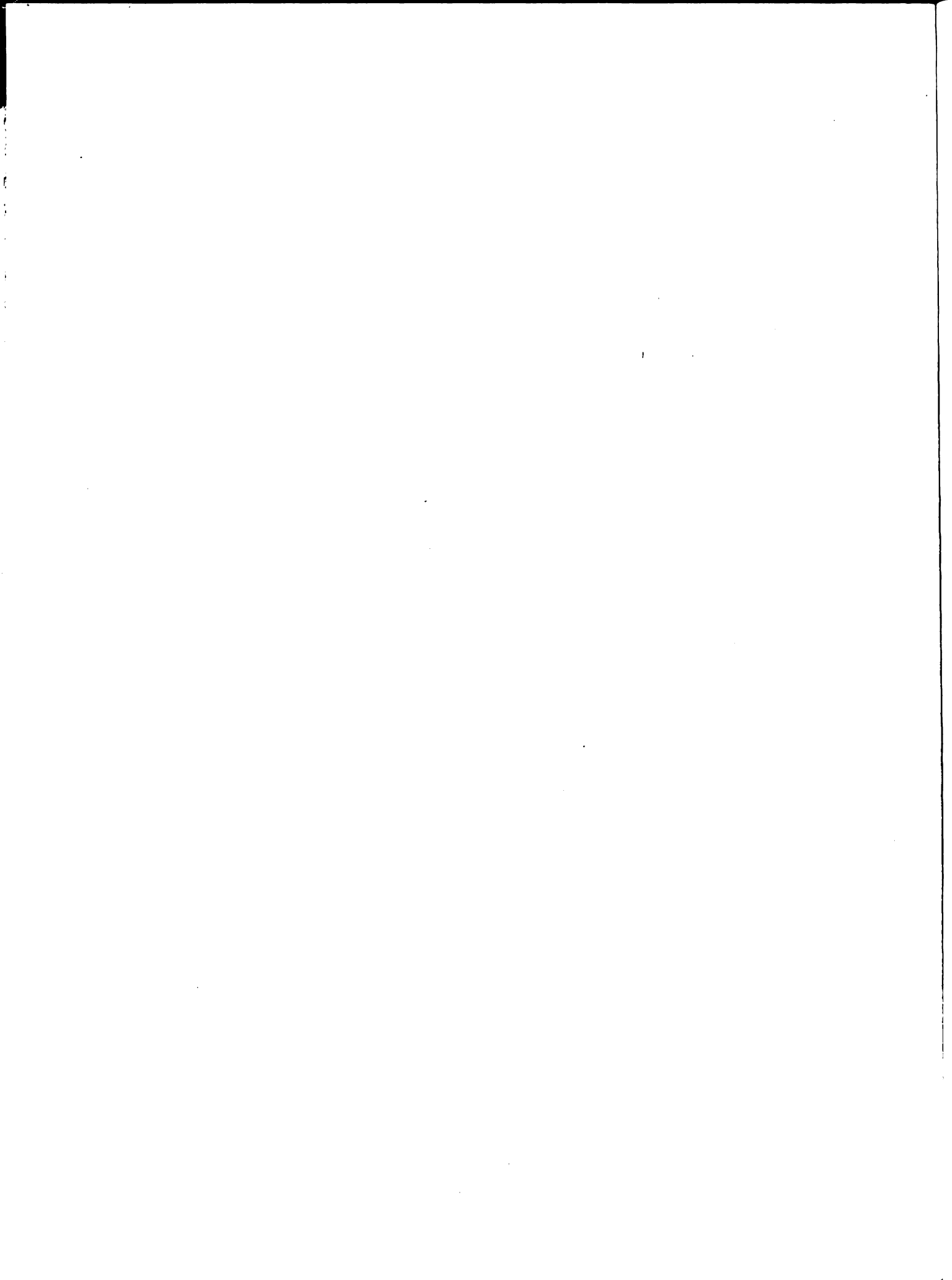
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TRIGGER CIRCUITS

By

Stelios Mastorakis

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THESIS

TRIGGER CIRCUITS

Definition

Circuits that possess two or more stable operating conditions, that is circuits in which one or more currents or voltages change abruptly from one stable value to another stable value at a critical value of some voltage or resistance and change back abruptly to approximately their original values at a different critical value of the controlling voltage or resistance are called "trigger circuits."

Criterium for a trigger circuit

The criterium as to whether a circuit element can serve as the basis of a trigger circuit can be determined from the characteristic current-voltage curve of the element.

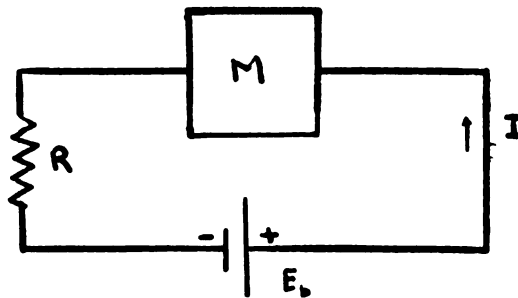


Fig. (1)

Let us have the circuit element M, in series with a resistance R, and a battery supply E_b fig. (1). The voltage across the element M is given by the relation:

$$E = E_b - IR$$

This voltage across the element is also a function of the current through the element according to the equation:

$$E = f(I)$$

This equation represent the characteristic curve of the element X. Equation $E = E_b - IR$ is that of a straight line, xy, the resistance line, through a point on the voltage axis corresponding to the supply voltage E_b , having a negative slope in amperes per volt equal to the reciprocal of the resistance in series with the element. Equilibrium values of currents are determined by the intersection of the characteristic curve with the resistance line.

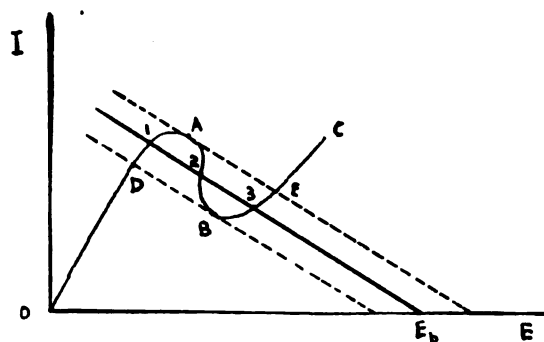


fig. (2)

If the characteristic curve has a portion whose slope is negative, the resistance line may intersect the curve in three points 1,2,3, as seen in fig. (2), indicating that there are three possible equilibrium values of current. An increase of current at constant E_b and R from that represented by point 2 is accompanied by a decrease of voltage across the element M . More voltage is thus made available to send current through the resistance and the current will rise further in the same manner. Any increase in current through the element reduces the voltage available across the resistance and thus causes a further reduction of current. Point 2, therefore corresponds to unstable equilibrium and practically is not observed experimentally. If the applied voltage is raised progressively from zero, the intersection will move along the branch OA of the characteristic curve. When the intersection is at A, an infinitesimal increase of voltage will cause the current to fall abruptly to the value of E. Further increase of supply voltage causes the intersection to rise toward C. If the battery voltage is then continuously decreased, the intersection will move down the branch BC until point B is reached at which the current will again jump abruptly to the value corresponding to point D.

It is seen that similar abrupt changes of current result if the slope of the resistance line is varied by changing the resistance R , or even if the characteristic curve is displaced vertically or horizontally. With trigger elements incorporating vacuum tubes this displacement can be accomplished by varying the electrode voltages. From the above analysis it follows that a circuit element whose current-voltage characteristic has a portion with negative slope may serve as the basis of a trigger circuit.

Practical Trigger circuits

The best known trigger circuit is that of Eccles and Jordan shown in basic form in fig. (3).

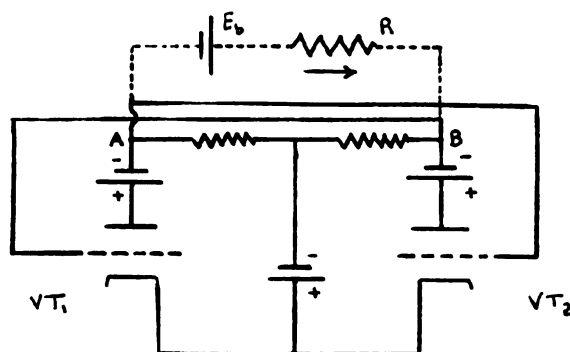


Fig. (3)

This circuit functions by virtue of the fact that only one tube at a time passes plate current. Let it be assumed that both tubes can conduct simultaneously. Then an increase of current in either tube

increases the negative grid voltage of the other tube, which reduces the plate current of that tube. This in turn reduces the negative grid voltage of the first tube and causes further increase of plate current of the first tube. The action is cumulative and only one tube conducts at a given time. In verification of the general theory, let us find experimentally the current-voltage characteristic curve and the resistance line of the circuit by using the battery E_b connected to the points A and B. The curve of external current versus voltage between A and B is found to be of the form shown in fig. (4), when the battery E_b is connected to the points A and B through a resistance R as shown in fig. (3), then the corresponding resistance line is of the form of MN in fig. (4).

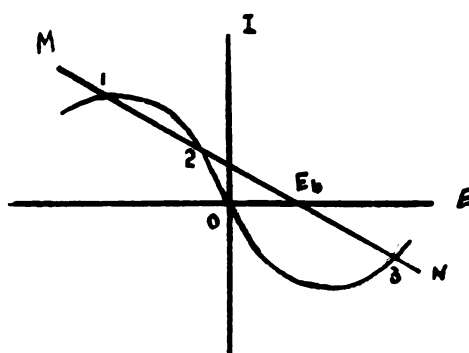


fig. (4)

If R exceeds in magnitude the value of the reciprocal of the slope of the curve at point O, then abrupt changes of current through R and of voltage

between A and B can be made to occur by varying E_b or shifting the characteristic by changing the operating voltages of the tubes. As R is increased, MN becomes more nearly horizontal and in the limiting case, when R is infinite, becomes the voltage axis. The external current is then zero, but changes in electrode voltages can cause an abrupt transfer of current from one tube to the other and a reversal of voltage between A and B.

The need of more than one voltage supply is avoided by the use of the circuit of fig. (5), in which the coupling between tubes is made by means of voltage dividers.

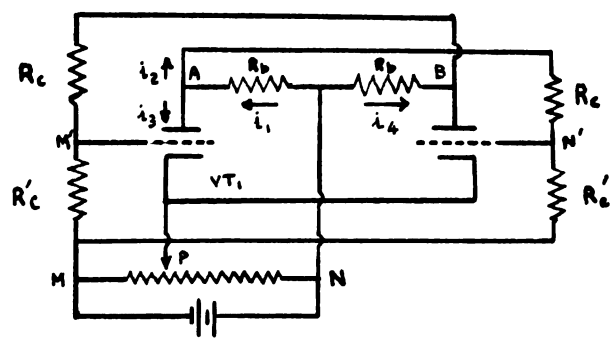


fig. (5)

Let the total current flowing in the left-hand lead resistance be i_1 , equal to the sum of i_3 , of plate current and i_2 of current in the potential divider.

The voltage at the plate of the left-hand tube is:

$$E_{NP} = i_1 R_b \quad \text{volts}$$

The entire difference of potential across the first potential divider, $AR_C R'_C M$, is therefore:

$$(E_{NP} - i_1 R_b) + E_{MP} \quad \text{volts.}$$

of which,

$$\left[(E_{NP} - i_1 R_b) + E_{MP} \right] \left(\frac{R'_C}{R_C + R'_C} \right) \quad \text{volts}$$

appear across the lower section of the divider, R'_C , consequently the grid of the right-hand tube is held at a potential of

$$\left[(E_{NP} - i_1 R_b) + E_{MP} \right] \left(\frac{R'_C}{R_C + R'_C} \right) - E_{MP} \quad \text{volts}$$

This grid voltage is sufficiently negative to ensure that the plate current of the right-hand tube will be very small if not actually zero. In other words, the right-hand tube is biased near the cutoff level, in some cases below the cutoff level. Consequently, the right-hand plate potential has risen nearly to the level of the plate-supply voltage. The potential of the right-hand plate is therefore almost equal to E_{NP}

Hence the voltage across the second potential divider is:

$$E_{NP} + E_{MP} \quad \text{volts}$$

If the grid current of the left-hand tube could be neglected, this grid would be held at a voltage of:

$$(E_{NP} + E_{MP}) \left(\frac{R'_C}{R_C + R'_C} \right) \quad \text{volts}$$

above the potential of the M point or

$$(E_{NP} + E_{MP}) \left(\frac{R'_C}{R_C + R'_C} \right) - E_{MP} \quad \text{volts}$$

Although this highly positive value is reduced nearly to zero by the actual grid current superimposed upon the network, the grid potential remains slightly positive, being high enough to permit the i_3 current to flow through the tube with the low internal voltage drop of: $E_{np} - i_3 R_b$

Hence, the entire system of highly unequal currents and unequal voltages is now self-consistent and self-perpetuating, there being no unbalanced voltages tending to produce or assist any further change.

Design of the Trigger Circuit

The design of a trigger circuit such as the one shown in fig. (6), is a relatively easy matter. All that is required is to make sure that with one tube conducting the grid of the other is below the cutoff value, and that the tube which is nonconducting makes the grid of the opposite tube zero or even positive.

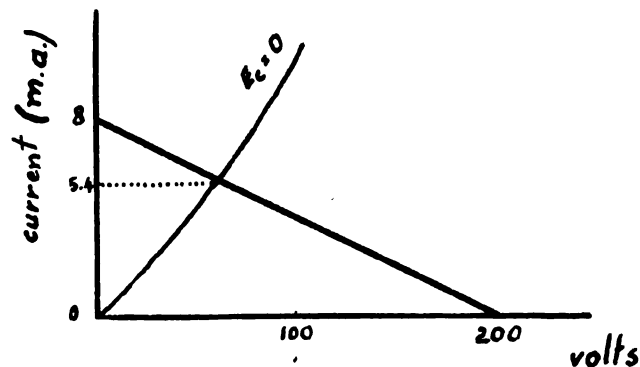


fig. (6)

Choosing $R_b = 25,000$ ohms. $E_p = 200$ volts. $E_k = 45$ v.
and using a 6J5 triode:

$$I_p \text{ (total)} = \frac{200}{25,000} = 0.008 \text{ amp.}$$

The load line intersects the zero grid voltage characteristic at a current value of 5.4 ma. fig. (6).

This leaves for the voltage at the plate of the left hand tube:

$$E_{np} = i_p R_b$$

$$200 - (0.0054)(25,000) = 200 - 135 = 65 \text{ v.}$$

The cutoff grid voltage for a 6J5 operating at 200v. plate voltage is -15v. according to the characteristic curve. In order to be sure that the circuit will not trigger prematurely, we shall be safer by placing the grid of the nonconducting tube VT_2 at a level considerably more negative with respect to the cathode than this value; let us decide for instance at -25v. With the cathode established at a level of 45v., point N' must therefore be at a level of $45 + (-25) = 20$ v. Let us assume that VT_1 is conducting and VT_2 is nonconducting. Point A will then be at a level of $45 + 65 = 110$ v. while point B will be at a level about 200v. if the resistances R_C and R'_C of the voltage divider are of high value compared to the 25,000 ohm load resistor; As point N' must be at a potential of 20 v. and A at 110 v. it means that the resistances R_C and R'_C must be in the

$$\text{ratio: } \frac{110 - 20}{20} = \frac{9}{2} \dots$$

In this case R_C can be made 450,000 and R_C' 100,000 ohms.

Let us check now whether the resistors R_C and R_C' which will make tube VT_2 nonconducting (by making its grid 25v. negative with respect to the cathode) will also make the grid of tube VT_1 zero with respect to the cathode as we had assumed.

With tube VT_2 nonconducting, point B will be just a few volts below the 245v. level owing to the small current taken by the voltage divider. With the resistors R_C and R_C' equal to 450,000 and 100,000 ohms respectively point M' would be at a level of approximately 55v. or 10v. positive with respect to the cathode level. When M' is connected to the grid of tube VT_1 , grid current will begin to flow and will prevent the grid from becoming more than a fraction of a volt positive with respect to the cathode.

If this check had revealed that the grid failed to become zero or positive, another start with different load resistor, (cathode resistor) would have to be made.

Triggering Methods

A common method of triggering the circuit is to insert a negative pulse in the grid of let us say VT_1 through a small coupling capacitor in series, fig. (7)

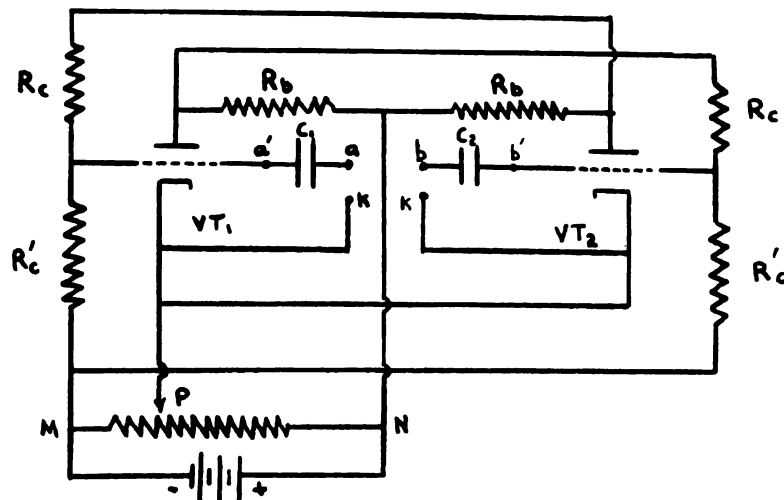


fig. (7)

The charge on the plate of this capacitor cannot be altered instantly due to the resistance in series with this capacitor. Hence, by applying a negative pulse at a, k the drop in the potential of point a produces a corresponding drop in potential at a', no alteration in the potential difference between the plates of the capacitor being possible in this first instant. If VT_1 was already not conducting, that is the grid a' was blocked below cutoff, the tube does not respond, the negative pulse being disregarded. However, if tube VT_1 has been carrying the heavy current, the sudden reduction of the positive potential of its grid causes a

sudden and violent drop in current accompanied by a simultaneous rise in current of tube VT_2 . If the instantaneous current values meet and pass, the circuit triggers, flipping over to the opposite terminus condition.

The steeper the pulse the better because a sloping wave front permits a portion of the available voltage to be expended in the capacitor C_1 , so a decreased portion is available for use at $\underline{a'}$. The capacitor $\underline{C_1}$ cannot be made larger to compensate a sloping wave front because its twin $\underline{C_2}$ ties the grid $\underline{b'}$ to the inactive potential source 2, and the desired rapid rise in potential of $\underline{b'}$ must be accompanied by an alteration in the charge of $\underline{C_2}$ which for that reason must be kept as low as possible at that phase of the triggering action; a large value of capacitance decreases the sensitivity by limiting the suddenness of the rise of current in the plate resistor which is important for the triggering action. Actually, condensers of value 25 or $50\mu f$ can be used.

The circuit having switched the main current over to VT_2 , then disregards any additional negative pulses imposed at point $\underline{a}$ while awaiting the occurrence of the next negative pulse applied at point $\underline{b}$.

In some applications the points a and b are joined together, fig. (8), pulses from a single external channel being applied simultaneously to each coupling capacitor, C_1 and C_2 .

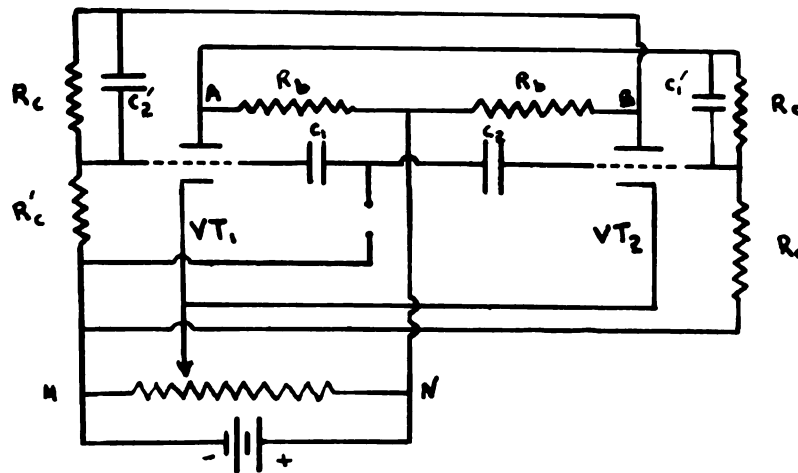


fig. (8)

In this case, the use of the commutating capacitors C'_1 and C'_2 is necessary to prevent the circuit from stalling when equal negative pulses are applied simultaneously to coupling capacitors C_1 and C_2 .

Suppose that tube VT_1 is conducting, application of a negative pulse at the common input terminal causes a sharp drop of plate current through tube A. The resultant sudden rise of plate voltage transferred through C'_1 to the grid of tube B overpowers the negative pulse, of external origin, that is applied through C_2 to the grid of tube VT_2 . The first pulse flips the main current over from A to B, the next pulse flips it back. The size of C'_1 and C'_2 is not critical. Usually they are twice as large as C_1 and C_2 .

Trigger Circuit using pentodes

A modification of the basic circuit is obtained by using pentodes as shown below fig. (9).

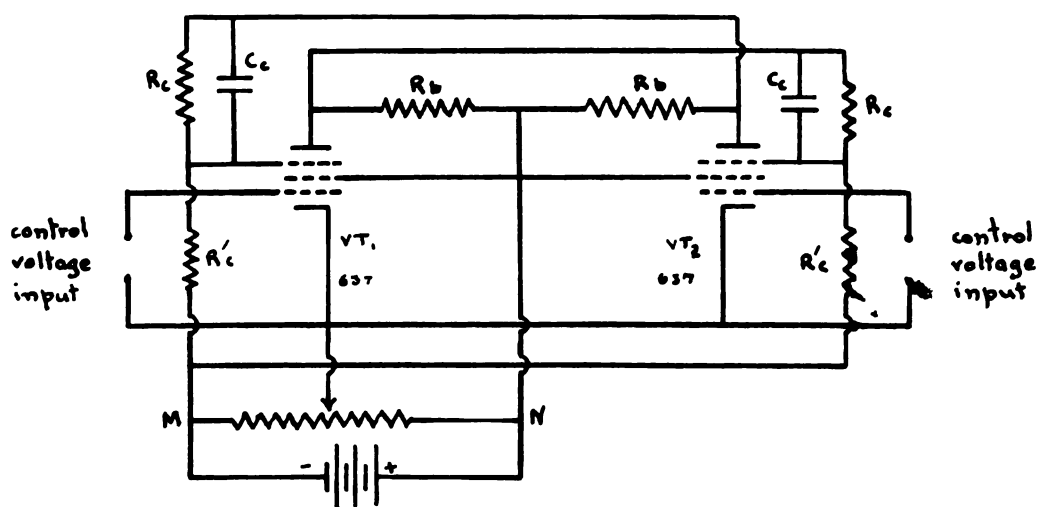


fig. (9)

Here, the suppressor grids of pentodes serve the same function as the triode control grids of the circuit described above. The screen grids are used in the normal manner and the control grids are used for triggering the circuit. One very desirable characteristic of this circuit is that the circuit may be triggered by a very small negative voltage impressed upon the control grid of the conducting tube, but it is insensitive to positive voltages applied to the control grid of either tube. The functions of the control and suppressor grids may also be interchanged but the resulting circuit is then sensitive to triggering voltage of either polarity.

A single pentode, under certain conditions, may also be used as a trigger tube. If the suppressor voltage of a pentode is varied with screen voltage, the change in suppressor voltage being proportional to the change in screen voltage and in the same direction, the curve of screen current versus screen voltage is of the form shown in fig. (10).

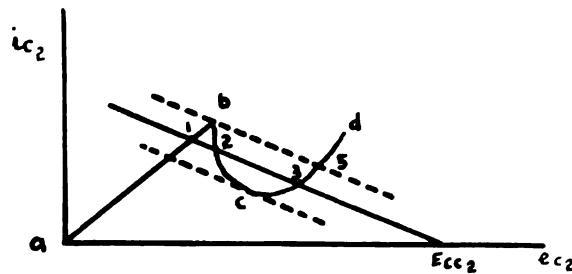


fig. (10)

A negative voltage impressed upon the suppressor grid causes electrons that have passed through the screen grid to turn back to the screen so high screen current results. A positive increment of suppressor voltage (decrease of negative voltage) allows more electrons to go to the plate and thus decreases the screen current, which means that the suppressor-screen transconductance is negative. Under proper operating conditions the screen current decreases with a positive increment of suppressor voltage even when the screen voltage is given an equal increment.

An increase Δe_{c_2} in the screen voltage is accompanied by an equal change Δe_{c_3} of suppressor voltage.

Δe_{c_2} would by itself change i_{c_2} by the amount $\Delta e_{c_2}/r_{g_2}$ and Δe_{c_3} acting alone would change i_{c_2} by the amount $\Delta e_{c_3} g_{32}$.

the net change of i_{c2} will be the sum of the two changes.

$$\Delta i_{c2} = \frac{\Delta e_{c2}}{r_{g2}} + \Delta e_{c2} g_{32} = \Delta e_{c2} \left(\frac{1}{r_{g2}} + g_{32} \right)$$

Since g_{32} has been shown to be negative, it follows that, if the magnitude of g_{32} exceeds the magnitude of $\frac{1}{r_{g2}}$, an increase of screen voltage is accompanied by a decrease of screen current. This means that between plate and screen the circuit will exhibit negative resistance of magnitude:

$$P = \frac{r_{g2}}{1 + r_{g2} g_{32}}$$

The current-voltage characteristic having a negative slope proves that such circuit can be used as a trigger circuit. With sufficiently high screen resistance, the load line corresponding to this resistance can intersect the $i_{c2}-e_{c2}$ characteristic at three points, 1,3,2. The currents corresponding to points 1 and 3 are stable. If the load line has a position to the left of that shown by the lower dashed line, the current can have only one value which must lie on the section a-b of the characteristic. As the line is moved to the right by increasing the supply voltage, the current increases continuously until the point b is reached, beyond which it will jump abruptly to the value corresponding to point 5. If the load line is then moved to the left by reducing the supply voltage, the current will have values corresponding to points on

the branch c-d of the characteristic until point c is reached, from which the current will jump to the value at 4. Similar abrupt changes of current are obtained when the other electrode voltages are varied or when the slope of the load line is changed by varying the resistance.

The connections realizing a pentode tube as a trigger circuit are shown below in fig. (11).

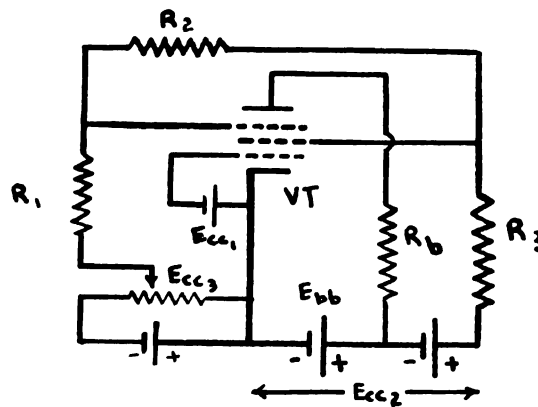


fig. (11)

In this circuit, the resistors R_1 , R_2 , R_3 , form a voltage divider which causes the suppressor voltage to vary with screen voltage in the desired manner. The combination of resistors also forms the screen load resistance. The operating voltages being properly chosen, the suppressor voltage corresponding to the upper values of screen current is so negative that the plate current is zero. The plate current corresponding to the lower values of screen current depends upon the circuit constants and operating-voltages. Thus the plate current

may be turned on and off abruptly by small changes of resistance or voltage.

Experimental values of resistances and voltages are as follows:

VT : 6J7

R ₁	100,000	ohms	E _{cc1}	$-\frac{1}{2}$	volts
R ₂	47,000	"	E _{cc2}	90	"
R ₃	100,000	"	E _{cc3}	-35	"
R _b	10,000	"	E _{bb}	$22\frac{1}{2}$	"

The following values have been obtained:

<u>E_{cc2} v.</u>	<u>E_{cc3} v.</u>	<u>I_{scr.} ma.</u>	<u>I_{pl.} ma.</u>
24	- 9	0.01	0
28	-8	0.04	0
33	-7	0.08	0
40	-6.5	0.12	0
45	-6	0.16	0
51	-5.5	0.20	0
56	-5	0.24	0
60	-4	0.27	0.02
62	-3.5	0.28	0.07
63	-3	0.26	0.22
65	-2	0.24	0.36
68	-0.5	0.22	0.54
80	1	0.25	0.72
90	2	0.30	0.85
100	3	0.35	0.95
109	4	0.40	1.05

These values give a good trigger characteristic curve.

The most satisfactory method of controlling the circuit by voltage is to introduce the control voltage in series with the suppressor grid or the control grid. The control grid is the more sensitive, but the use of positive control-grid voltage may cause the flow of control-grid current, which may be objectionable.

However, the circuit described above was far from being critical in its operation. An experimental rearrangement of the values was made giving the following results.

$R_1 = 100,000$ ohms	$E_{cc_1} = -\frac{1}{4}$ volts
$R_2 = 50,000$ "	$E_{cc_2} = 115$ "
$R_3 = 100,000$ "	$E_{cc_3} = -55$ "
$R_b = 10$ "	$E_{bb} = 22\frac{1}{2}$ "

A resistance of 1,000 ohms had also to be inserted between the first grid and E_{cc_1} .

The trigger circuit obtained was very critical giving for the equilibrium values, for high screen current of 0.67 ma. plate current corresponding to 0 ma. and for low screen current of 0.52 ma. plate current corresponding to 1.4 ma. the circuit will be triggered by pulses of less than one volt in amplitude through a condenser or resistance in series with the suppressor grid. Suppressor grid gave better results compared to the control grid due to a small control grid current.

Modifications in Trigger Circuits

Phototubes can be used to control trigger circuits. In the basic trigger circuit, phototubes connected as shown in fig. (12), can trip the circuit.

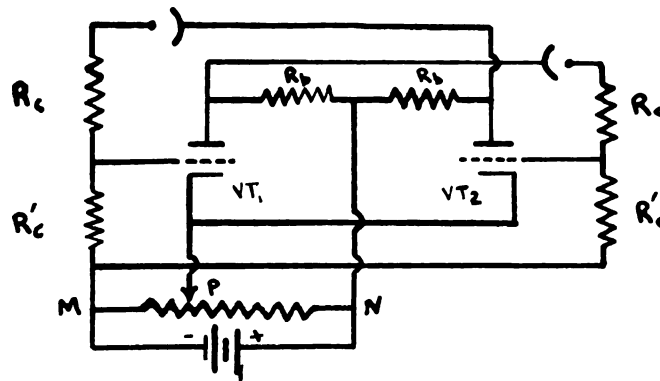


fig. (12)

As long as a light beam falls upon the phototubes, the stable condition is unaltered but as soon as the light beam is interrupted the abrupt change in current is enough to initiate the current transfer, that is the triggering action is performed. Resistance R_c can be omitted.

Phototubes connected as shown in fig. (13), can also trip the circuit.

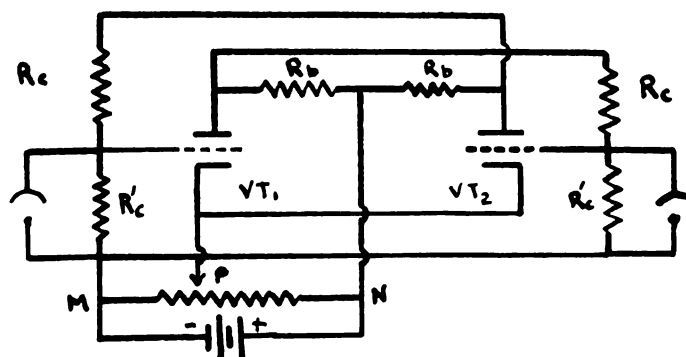


fig. (13)

The device is used in connection with illumination. An increase in illumination initiates again the current transfer. Also here again resistances R'_C can be omitted.

Applications of Trigger Circuits

Trigger circuits are used in a multitude of electronic circuits, from simple ones to some very complicated devices.

a) Voltmeter Circuit

A very useful type of meter for the measurement of crest or direct voltages is the slide-back type of voltmeter. A trigger circuit used in the construction of that type of voltmeter makes it a very sensitive instrument.

The theory of operation of a slide-back voltmeter is based upon the cutting off of triode plate current by negative grid voltage. Just sufficient negative grid bias is applied to a triode to reduce the plate current to zero. The addition of signal voltage in the grid circuit results in the flow of current during the positive half cycles of the signal voltage, and in order to prevent the flow of plate current at any time during the signal-voltage cycle, the bias must be increased by an amount equal to the positive crest signal. In operation the bias is adjusted to reduce the plate current to zero with and without signal

voltage, the difference in the two values of bias indicating the crest signal voltage of the positive half-cycle. To read direct voltages, the bias is adjusted to give any convenient reading of plate current. The change in bias required to return the plate current to this value when input is applied is equal to the input voltage.

A slide-back voltmeter based upon the trigger circuit is shown in fig. (14).

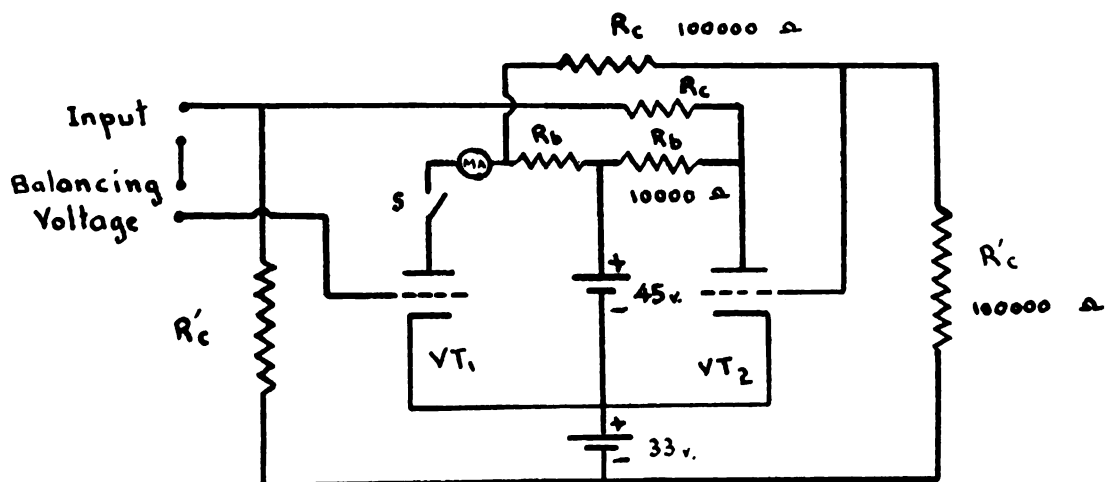


fig. (14)

To operate the meter switch S is first opened momentarily, which causes the plate current of VT₁ to stop flowing. The balancing voltage is then adjusted until the current transfers back from VT₂ to VT₁. The operation is then repeated with signal voltage applied. The difference in balancing voltages equals the direct or crest alternating voltage.

b) Counting Circuits

Talking about trigger circuits utilizing pentodes, we have seen that the triggering takes place only during the negative pulse, the positive pulse not affecting the distribution of currents. Using the circuit shown in fig. (15) an output voltage corresponding to the variations of currents can be obtained.

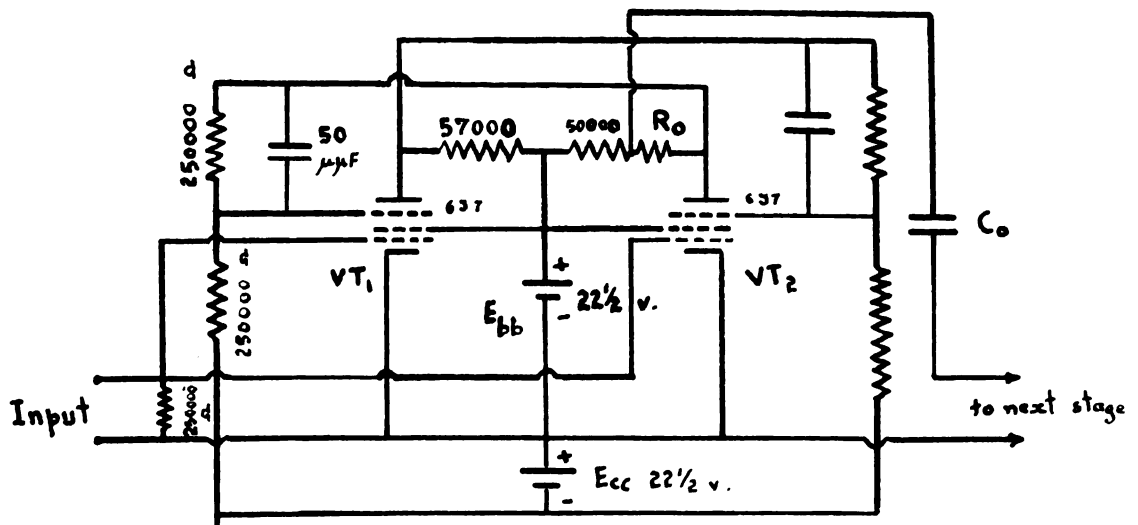


fig.(15)

When the current transfers from tube 2 to tube 1 due to a negative pulse applied at the input, we get a positive pulse in the output, a next negative pulse in the input transfers the current from tube 1 to tube 2, giving rise to a negative pulse for output. If the time constant R_0C_0 is very small compared to the interval between pulses, the output circuit yields sharp pulses, one positive and one negative for every pair of

negative pulses arriving at the input terminals. The positive pulse being disregarded, only the negative pulse triggers the next stage, so we see that every trigger circuit pair may be employed to cause a reduction by a factor of two in the number of negative pulses applied through the device. This process may be repeated using N successive stages of scale of two to obtain any scaling ratio, 2^N , desired.

The trigger circuit using a single pentode described previously can be used as a counting circuit. The connections of input and output pulses are shown in fig. (16).

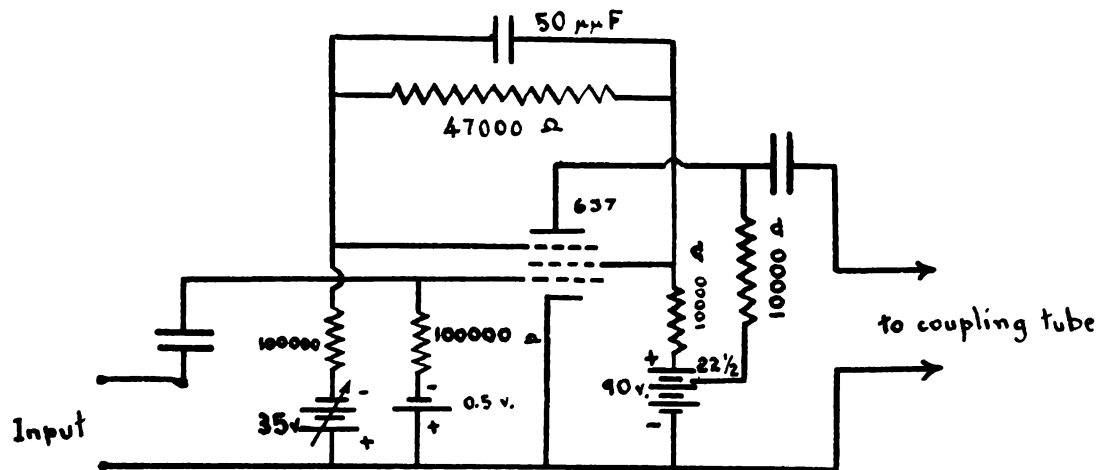


fig. (16)

In this case the circuit responding to a pulse of either polarity, coupling tubes must be used between stages.

c) Time Measuring Circuits

The charging or discharging of a condenser may be

readily used as the basis of a circuit for the measurement of time. In order to make use of this method it is necessary to find means for starting and stopping the charging current at the beginning and end of the time interval and for measuring the voltage of the condenser without discharging it. The condenser voltage may be measured by a simple form of vacuum tube voltmeter. The trigger circuit shown in fig. (5) can be used satisfactorily. The current may be caused to transfer from tube 1 to tube 2 by short circuiting R'_C of tube 1 and from tube 2 to tube 1 by short circuiting R'_C of tube 2. The voltage drop across the resistance R_b may be applied to the control grid of another tube, whose plate current charges a condenser. The charging current can then be started and stopped by causing the current to transfer from one tube of the trip circuit to the other.

Fig. (17) shows the diagram of a single timing circuit based on this principle.

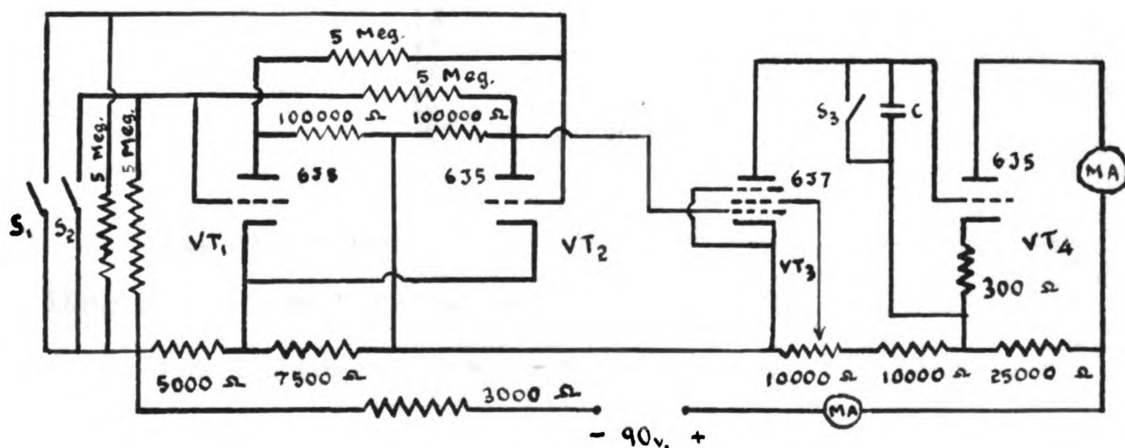


fig. (17)

Normally plate current flows in VT_2 . The voltage drop through R_D biases VT_3 , beyond cut-off, so that no plate current flows in VT_3 . The momentary closing of S_1 transfers the current from V_2 to V_1 , thus removing the bias from the grid of VT_3 and causing plate current to flow through VT_3 and charge the condenser C . Closing S_2 again transfers the current from V_1 to V_2 and stops the charging of C . The voltage of C , which is a function of the elapsed time is measured by the plate current of the voltmeter tube V_4 . The length of the time intervals which can be measured can be adjusted over a wide range by means of the condenser size and screen voltage of V_3 , which controls the amount of charging current. The 300 ohm resistor in the cathode circuit of V_4 provides sufficient bias to prevent the flow of grid current of V_4 into the condenser when the condenser voltage is low.

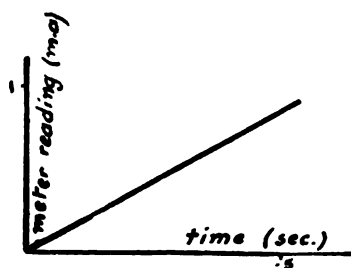


Fig. (18)

Fig. (18) shows the curve of meter reading against length of time interval for our circuit. The circuit holds its calibration over long periods if the screen

voltage of V_3 is not changed. To insure that this voltage cannot be accidentally changed, it is advisable in most applications to replace the potentiometer P with fixed resistors, reduction of battery voltage with use is compensated by means of R_c , the correct setting being indicated by the milliammeter.

d) Phasemeter

When we want to measure rapid alterations of phase between two sinusoidal voltages, trigger circuits can be used successfully.

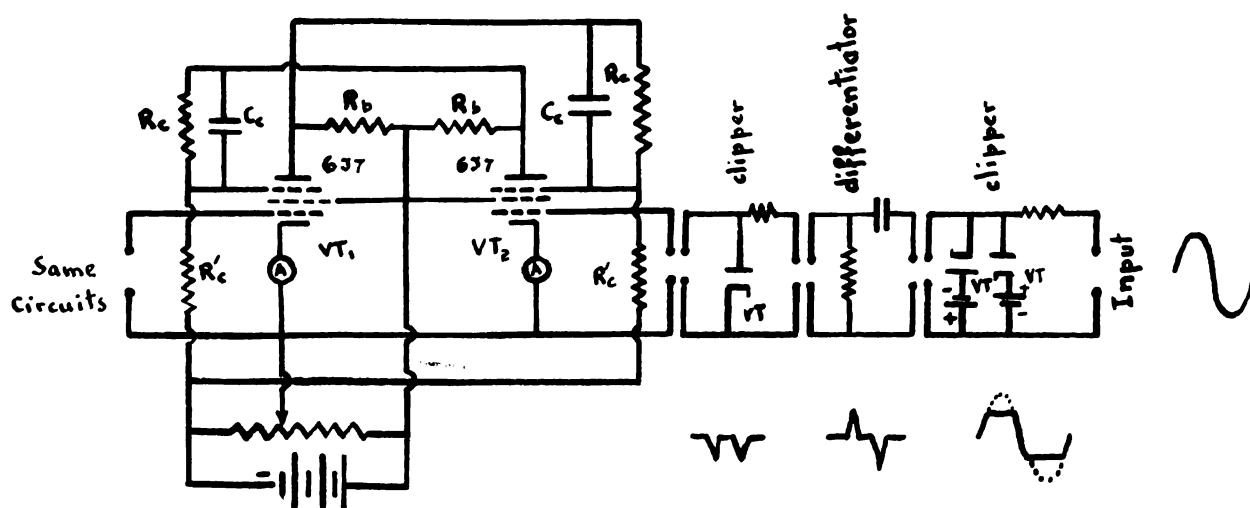


Fig. (19)

Having two sinusoidal voltages whose relative phase angle is to be determined, we apply one of the signal to the left-hand grid and the other voltage signal to the right-hand grid through a clipper to square the wave, then through a differentiator and then through a clipper to clip off the positive peaks, fig. (19).

If the voltages have a different phase relationship, the main current will flow for unequal intervals of time in each tube. As the current waves within the trigger circuit are rectangular, a d-c meter connected in the proper cathode lead reads an average current linearly proportional to the phase angle.

BIBLIOGRAPHY

- (1) H. J. Reich, "Electronics" August 1939 pp. 14-17
- (2) W. Richter, "Fundamentals of Industrial Electronic Circuits" McGraw-Hill Book Co. Inc. 1947 pp. 403-405
- (3) Cruft Electronics Staff, "Electronic Circuits and Tubes" McGraw-Hill Book Co, 1947 pp. 842-855
- (4) E. C. Stevenson and I. A. Getting, "Review of Scientific Instruments" November 1937 pp. 414-416
- (5) H. J. Reich, "Theory and Applications of Electron Tubes" McGraw-Hill Book Co. 1939 pp. 206-210, 509, 573, 588
- (6) W. Hushley and K. Feldman, "Canadian Journal of Research" May 1947 pp. 226
- (7) H. J. Reich and H. Toomim, "Review of Scientific Instruments" December 1937 pp. 502-504
- (8) B. Howland, C. A. Schroeder, J. D. Snipman Jr., "Review of Scientific Instruments" August 1947 pp. 551
- (9) T. H. Johnson, "Review of Scientific Instruments" July 1938 pp. 213
- (10) H. Lifschutz and J. L. Lawson, "Review of Scientific Instruments" March 1938 pp. 83

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