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TECHNICAL BULLETIN

ROGERS' ADDITRON XA34*

The Rogers' Additron XA34 is an electrostatically focussed radial double beam tube, designed primarily for use as a binary adder tube in high speed digital computing devices.

The internal construction of the tube is shown diagrammatically in Figures 1-3. Twelve control elements, placed symmetrically on a circle around the cathode are connected internally to form the three control electrodes (g1,1, g1,2 and g1,3, collectively referred to as g1**). Twelve collector elements, alternate ones connected internally to form two collector electrodes (a1 and a2, collectively referred to as a), are placed on a circle and opposite the gaps between the control elements. The collector elements are shielded from each other by the screen (g2).

If one of the eight possible combinations of a zero voltage and a positive voltage is applied to the three control electrodes of the additron, the electrostatic field set up in conjunction with the self-bias of the tube directs the electron beams to either a sum (a1) or a carry (a2) collector element, to neither or to both according to Table I. This corresponds to the function table for binary addition where $E_{c1,1}$*** is the augend input, $E_{c1,2}$ the addend input, $E_{c1,3}$ the carry input (from the preceding stage). I_{b1} is the sum output and I_{b2} the carry output (to the following stage), whether the positive voltage represents a 1-digit and the zero voltage a 0-digit, or vice-versa.

TABLE I

$E_{c1,1}$	$E_{c1,2}$	$E_{c1,3}$	I_{b1}	I_{b2}
0	0	0	0	0
+	0	0	+	0
0	+	0	+	0
0	0	+	+	0
+	+	0	0	+
+	0	+	0	+
0	+	+	0	+
+	+	+	+	+

* Developmental Type Number
** All symbols according to JAN specifications unless otherwise noted.
*** All voltages referred to ground, not to the cathode.

Design Notes

Figures of merit for an additron are:-

(a) Time factor

This is the ratio $\frac{E_{c1} \times (C_{in} + C_{out})}{I_b}$ (sec.)

For directly coupled tubes, $C_{in} + C_{out}$ is 15 uuf* and either collector current for $E_{c1} = 100V$. is 1.6 milliamperes (Table II), giving for the time factor a value of about 1 microsecond.

For cathode follower coupling, neglecting the effect of the cathode follower input capacity, C_{in} is zero, and C_{out} is 10 uuf. The current is 2.3 milliamperes (Table IV). The time factor is thus about 0.5 microsecond.

These values determine the ultimate speed with which the tubes can be satisfactorily operated.

(b) Control ratios CR_1 and CR_2

For each collector, the control ratio is defined as the ratio of the lowest desirable current to highest undesirable current and is a measure of the effectiveness with which that collector distinguishes between a 1- and a 0-digit.

The control electrodes, when positive, draw currents which are functions of the input voltage combinations and for which allowance must be made in the design of a circuit. These currents can be used to equalize the input potentials approximately, when two or three grids are positive, by placing resistance in the input circuits. The way in which equalization occurs can be deduced from the curves in Figure 4, which shows that when the potential of one positive grid changes slightly, the grid currents change so as to drive the potentials of the other positive grids in the same direction. This tendency toward equalization is more evident in Figure 5.

Figure 4 also shows that the tube will tolerate inequalities of 10% in nominally equal input potentials.

When the output of one additron directly drives the input of another additron, the equivalent input resistance of the second tube is equal to the equivalent output resistance of the first one, provided the coupling is effected by a low impedance device such as a neon light or a condenser (Figure 6).

Where direct coupling is used, it is recommended that the cathode resistor be zero and that the cathode potential be between 35% and 42% of the input potential. The equivalent load resistance should be 63,000 ohms or greater. The equivalent circuit and typical operating conditions for direct coupling are shown in Figure 7 and Table II respectively.

* For capacitances etc., see Technical Data Sheet, which is attached.

TABLE II

E_{bb} (volts)	E_{c2} (volts)	E_{cc1} (volts)	E_k (volts)	R_a (ohms)	R_{g1} (ohms)	R_k (ohms)	I_{b1} (mA)	I_{b2} (mA)	CR_1	CR_2
300	125	100	35	63,000	63,000	0	1.6	1.6	3.0	15
250	125	75	27.5	68,000	68,000	0	1.2	1.2	2.5	15
250	125	50	20	72,000	72,000	0	0.7	0.7	2.5	30

If the additrons are coupled by cathode followers (Figure 8), the currents to positive control electrodes are of less importance in designing the circuit, but it may still be advisable to retain some resistance in the input circuits for equalization of the control electrode voltages as explained above. The equivalent circuit for cathode follower coupling is shown in Figure 7, where Rgl in this case will have a small value. In Table III are shown typical operating conditions for the case where the input resistance to the additron is zero and Table IV shows an intermediate case where the values of R_k and Rgl are between the values for the cases shown in Table II and Table III.

TABLE III

E_{bb} (volts)	E_{c2} (volts)	E_{cc1} (volts)	E_k (volts)	R_a (ohms)	R_{g1} (ohms)	R_k (ohms)	I_{b1} (mA)	I_{b2} (mA)	CR_1	CR_2
300	125	100	18	42,000	0	5,600	2.5	2.5	4.0	30
250	125	75	14	47,000	0	6,300	1.7	1.7	3.5	30
250	125	50	10	56,000	0	6,800	1.1	1.1	3.0	35

TABLE IV

E_{bb} (volts)	E_{c2} (volts)	E_{cc1} (volts)	E_k (volts)	R_a (ohms)	R_{g1} (ohms)	R_k (ohms)	I_{b1} (mA)	I_{b2} (mA)	CR_1	CR_2
300	125	100	27	47,000	7,500	4,200	2.3	2.3	3.5	30
250	125	75	20	56,000	10,000	4,700	1.4	1.4	3.0	30
250	125	50	14	63,000	12,000	5,600	0.9	0.9	2.5	40

The values of the control ratios depend on the values of E_{cc1}, Rgl, E_k and R_k. In Figure 9 the variation of $I_{c1,1}$ with $E_{c1,1}$ is shown for the case where $E_{c1,1} = E_{c1,2}$ and $E_{c1,3} = 0$. The slope of this curve increases rapidly as the grid potential approaches the screen potential. For this reason, the screen voltage should be held at the maximum of the grid swing or above. The difference between collector and screen supply voltages must be at least equal to the desired signal output.

The bleeder circuit (see Figure 6 and Figure 8) may be so designed that the coupling neon lights extinguish when the carry collector receives current. However, this method of equalization of negative inputs is not absolutely necessary, since the carry collector voltage swings between two levels, one determined by the screen potential, the other by the collector supply voltage. If the circuit is designed such that the neon lights are always conducting, a condenser should be placed in parallel with the neon lights.

The measurements of Table V were made on one additron under the conditions indicated and in the equivalent circuit (see Figure 7) to illustrate the manner in which the currents to the various electrodes depend on the combination of input potentials.

TABLE V

(a) Test Conditions:-

$E_{bb} = +250V$; $E_{c2} = +125V$; $E_k = +27.5V$.

$R_a = 63{,}000$ ohms; $R_{g1} = 63{,}000$ ohms; $R_k = 0$.

$E_{ccl,1}$	$E_{ccl,2}$ (volts)	$E_{ccl,3}$	I_{b1} (mA)	I_{b2} (mA)	$I_{cl,1}$ (uA)	$I_{cl,2}$ (uA)	$I_{cl,3}$ (uA)	I_{c2} (uA)
0	0	0	0.4	0.9	0	0	0	0
75	0	0	1.5	0.03	60	0	0	400
0	75	0	1.7	0.05	0	50	0	500
0	0	75	1.5	0.04	0	0	100	460
75	75	0	0.3	1.2	490	500	0	80
75	0	75	0.3	1.2	480	0	500	90
0	75	75	0.2	1.2	0	520	510	100
75	75	75	1.6	1.4	630	640	630	210

$$CR_1 = \frac{1.5}{0.3} = 5.0$$

$$CR_2 = \frac{1.2}{0.05} = 24$$

(b) Test Conditions:-

$E_{bb} = +250V$; $E_{c2} = +125V$; $E_k = +14V$.

$R_a = 47{,}000$ ohms; $R_{g1} = 0$; $R_k = 6{,}300$ ohms.

$E_{ccl,1}$	$E_{ccl,2}$ (volts)	$E_{ccl,3}$	I_{b1} (mA)	I_{b2} (mA)	$I_{cl,1}$ (uA)	$I_{cl,2}$ (uA)	$I_{cl,3}$ (uA)	I_{c2} (uA)
0	0	0	0	0	0	0	0	0
75	0	0	2.3	0.05	130	0	0	80
0	75	0	2.2	0.04	0	170	0	170
0	0	75	2.2	0.06	0	0	100	90
75	75	0	0.4	2.2	1050	1200	0	370
75	0	75	0.4	2.2	990	0	1200	500
0	75	75	0.3	2.2	0	1150	1100	520
75	75	75	2.2	2.0	1010	1090	1050	680

$$CR_1 = \frac{2.2}{0.4} = 5.5$$

$$CR_2 = \frac{2.0}{0.06} = 33$$

TABLE V (Cont'd.)

(c) Test Conditions:-

E_{bb} = +250V; E_{c2} = +125V; E_k = +20V.

R_a = 56,000 ohms; R_{g1} = 10,000 ohms; R_k = 4,700 ohms.

$E_{cc1,1}$	$E_{cc1,2}$ (volts)	$E_{cc1,3}$	I_{b1} (mA)	I_{b2} (mA)	$I_{c1,1}$ (uA)	$I_{c1,2}$ (uA)	$I_{c1,3}$ (uA)	I_{c2} (uA)
0	0	0	0	0	0	0	0	0
75	0	0	1.8	0.04	70	0	0	110
0	75	0	1.8	0.04	0	50	0	150
0	0	75	1.8	0.05	0	0	120	180
75	75	0	0.4	1.9	900	930	0	310
75	0	75	0.3	1.9	820	0	1000	430
0	75	75	0.3	1.9	0	960	980	420
75	75	75	1.9	1.8	970	1000	1000	710

$$CR_1 = \frac{1.8}{0.4} = 4.5$$

$$CR_2 = \frac{1.8}{0.05} = 36$$

The process of addition usually involves two discrete steps. First, the numbers to be added are applied to the control electrodes of the tube. Second, the addition is carried out. Usually it is desirable to have the tube operative only during the second step. If the cathode is the gating element, its potential is normally above the highest of the input potentials and a negative pulse to the cathode permits the addition to take place.

The screen may also be used for gating. Currents to the output elements are effectively cut off when the screen is at cathode potential. In this case the positive control electrodes will draw current. The use of the screen as a gating element is also facilitated by the small screen currents (approximately half the output currents).

Function tables other than that for binary addition may also be obtained. If the cathode is returned to a voltage approximately 55% of the input voltage, the outputs of Table VI (a) are obtained, while if a large cathode resistor is returned to a voltage negative with respect to the lower grid swing, the outputs of Table VI (b) are obtained.

TABLE VI

			(a)		(b)	
$E_{c1,1}$	$E_{c1,2}$	$E_{c1,3}$	I_{b1}	I_{b2}	I_{b1}	I_{b2}
0	0	0	0	0	+	+
+	0	0	0	0	+	0
0	+	0	0	0	+	0
0	0	+	0	0	+	0
+	+	0	0	+	0	+
+	0	+	0	+	0	+
0	+	+	0	+	0	+
+	+	+	+	+	+	+

Queries and comments regarding type XA34, the operating conditions and circuitry, are invited.

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TECHNICAL DATA SHEET FOR TYPE XA34

PHYSICAL CHARACTERISTICS

Bulb:	T6½
Base:	Small Button 9-pin
Overall Length:	2.50" maximum
Seated Height:	2.25" maximum
Diameter:	0.88" maximum

BASING

1	2	3	4	5	6	7	8	9
a2	g2	k	h	h	a1	g1,1	g1,2	g1,3

ELECTRICAL RATINGS

Heater Voltage	6.3V ± 10%
Sum Collector Voltage	330 maximum
Carry Collector Voltage	330 maximum

Direct Inter-electrode Capacities (No external shield)

Input Capacity	5.0 uuf
Output Capacity	10.0 uuf
Capacity a1 to a2	1.0 uuf
Capacity g1,1 or g1,2 or g1,3 to a1 or a2	0.5 uuf

DESIGN DATA

	1 Without Interstage Cathode Follower	2 With Interstage Cathode Follower
Ef	6.3V	6.3V
If	150 mA	150 mA
Ebb	250 Vdc	250 Vdc
Ec2	125 Vdc	125 Vdc
Ek	27.5 Vdc	14 Vdc
Eccl	75 Vdc	75 Vdc

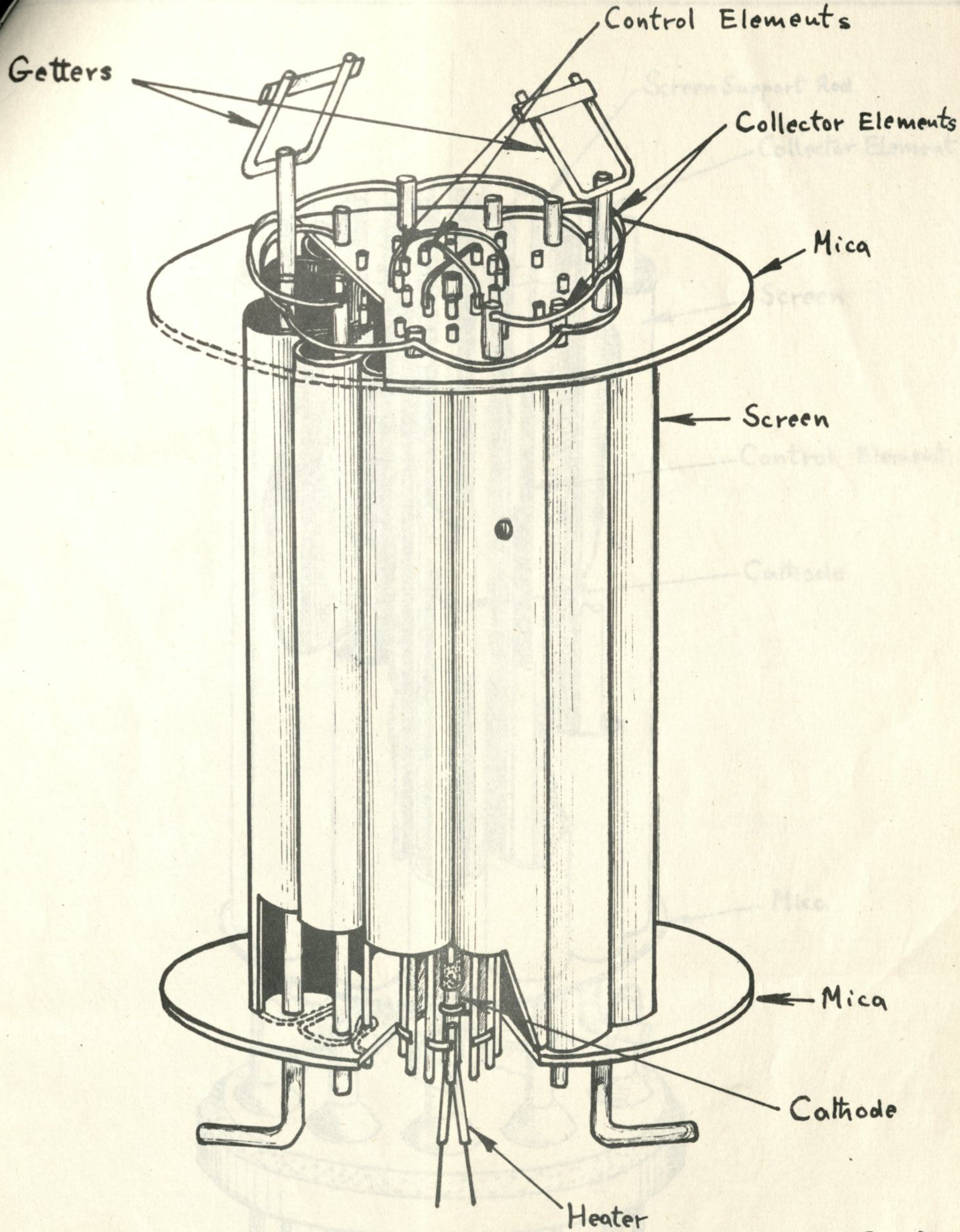

Control Elements
Getters
Collector Elements
Mica
Screen
Mica
Cathode
Heater

FIG. 1.

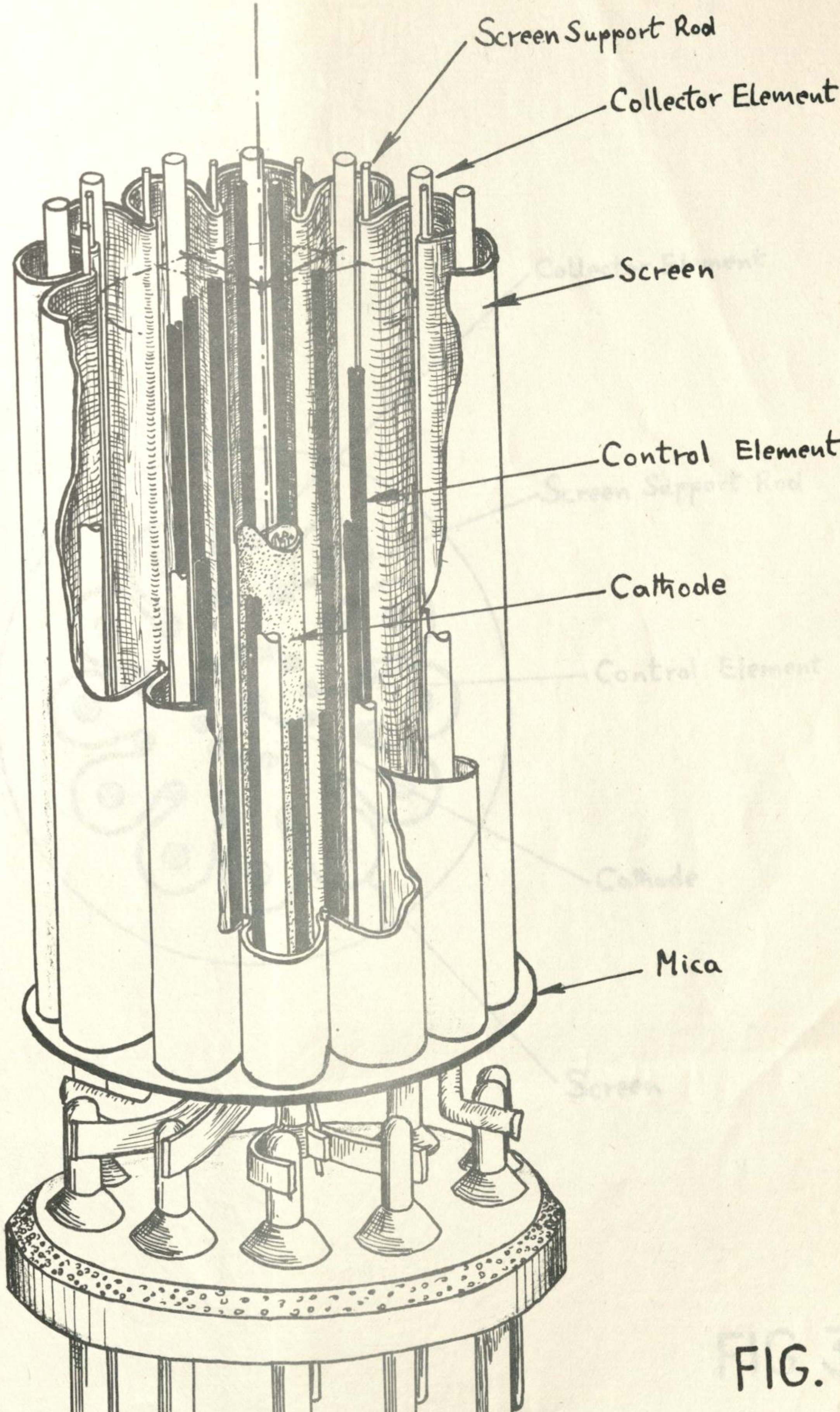

Screen Support Rod
Collector Element
Screen
Control Element
Cathode
Mica

FIG. 2.

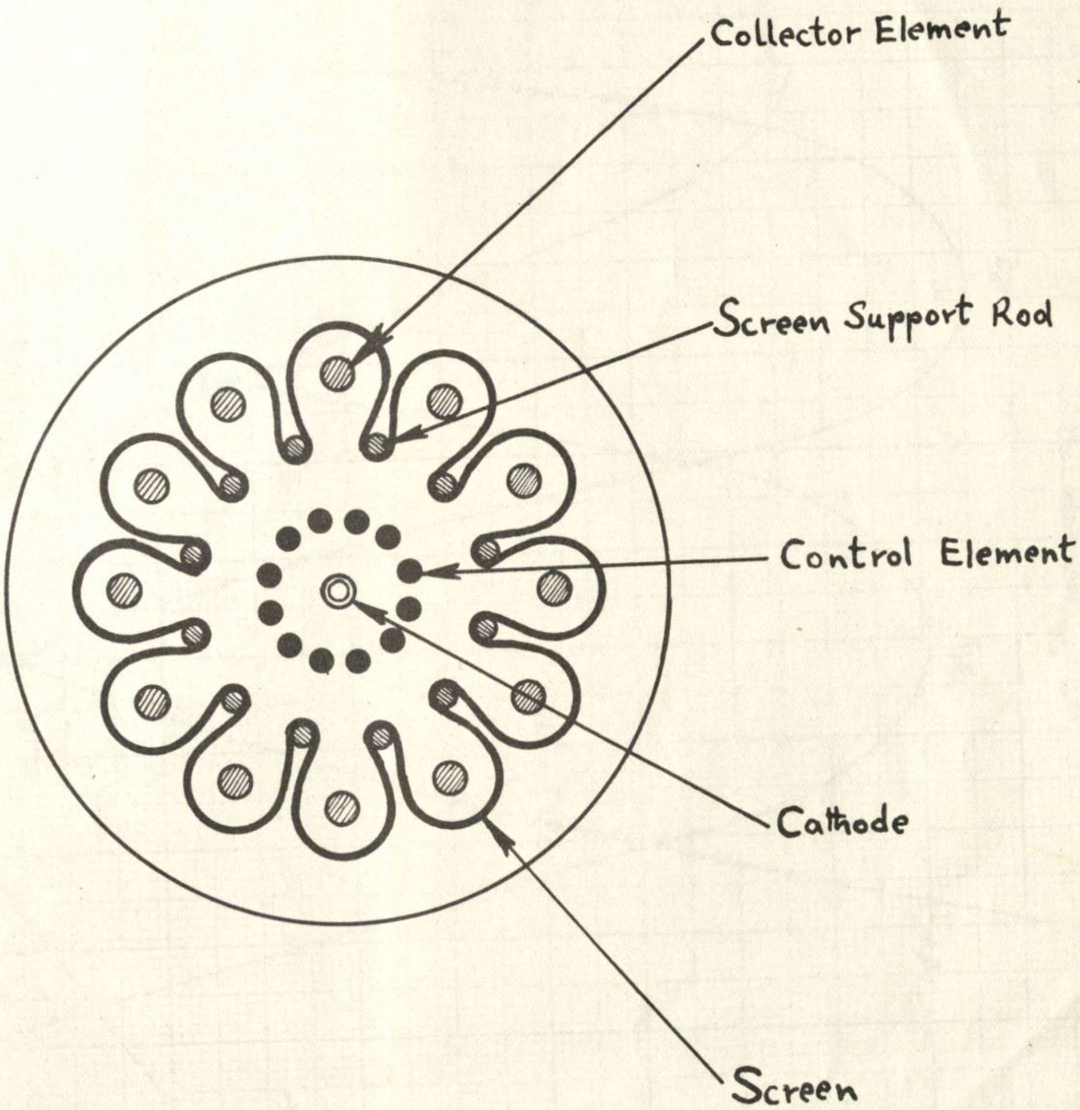

Collector Element
Screen Support Rod
Control Element
Cathode
Screen

FIG. 3.

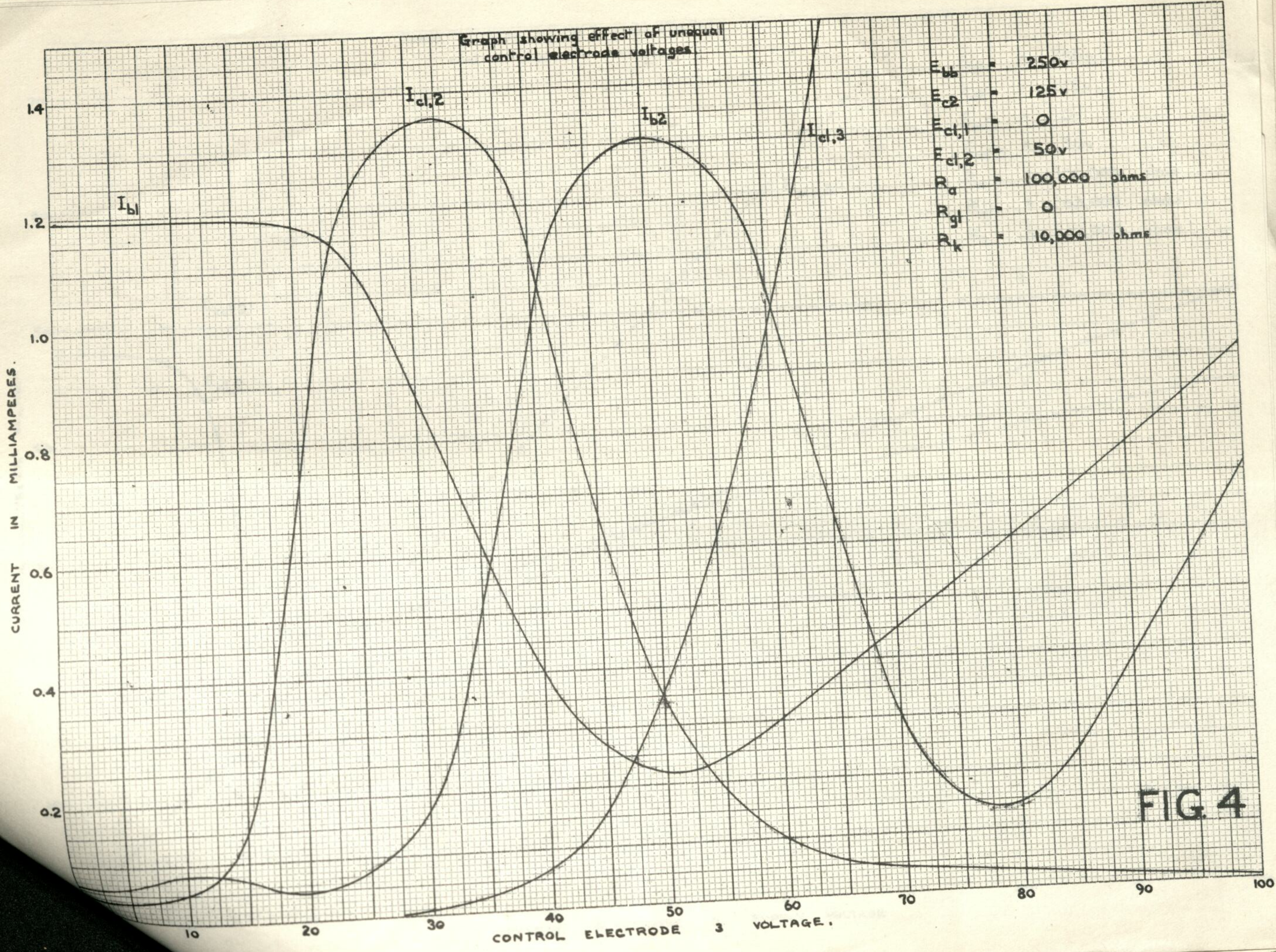

Graph showing effect of unequal control electrode voltages.
E_{bb} = 250v
E_{c2} = 125v
$E_{c1,1}$ = 0
$E_{c1,2}$ = 50v
R_a = 100,000 ohms
R_{g1} = 0
R_k = 10,000 ohms
I_{b1}
$I_{c1,2}$
I_{b2}
$I_{c1,3}$
CURRENT IN MILLIAMPERES.
0.2
0.4
0.6
0.8
1.0
1.2
1.4
10
20
30
40
50
60
70
80
90
100
CONTROL ELECTRODE 3 VOLTAGE.

FIG. 4

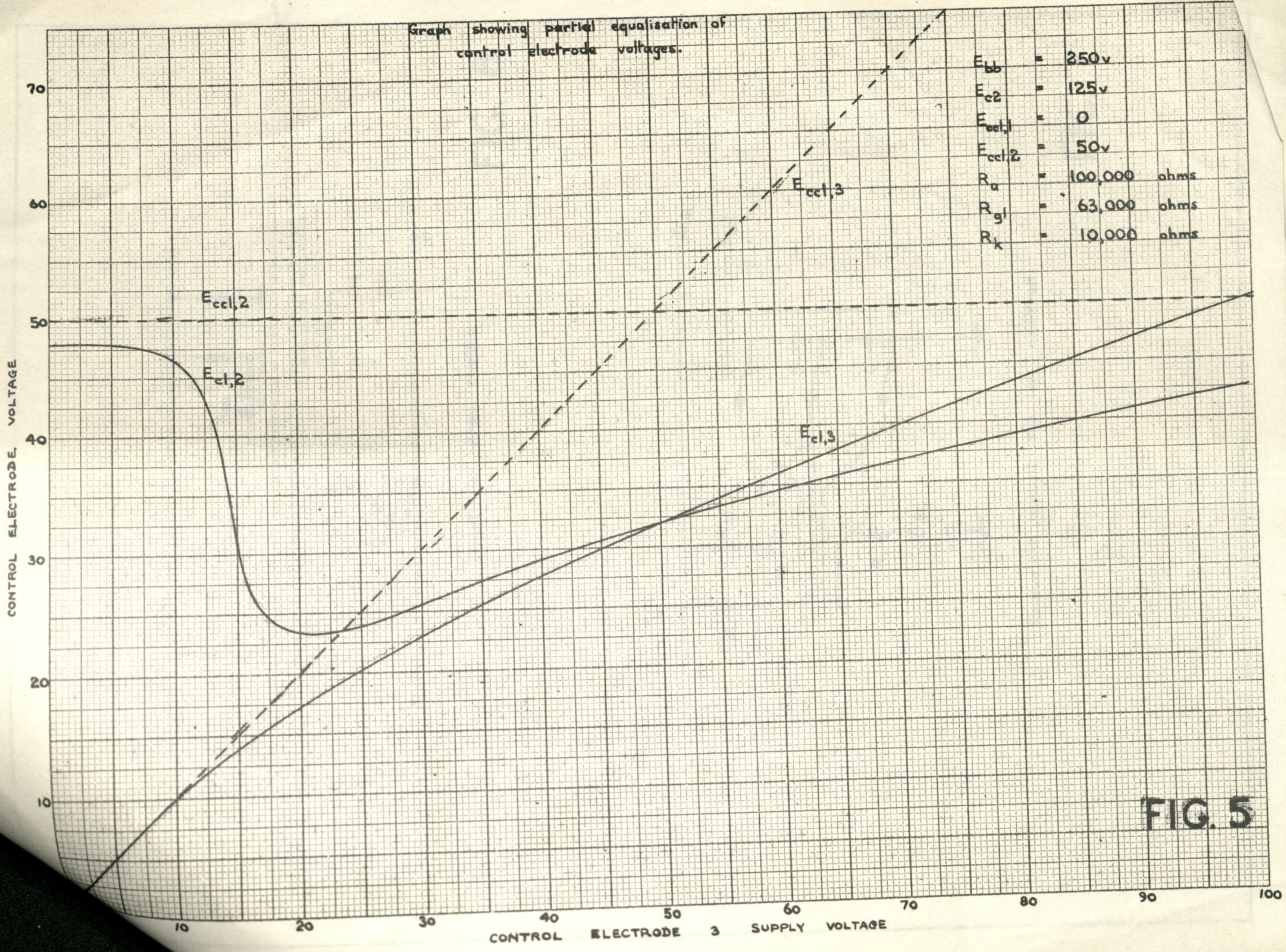
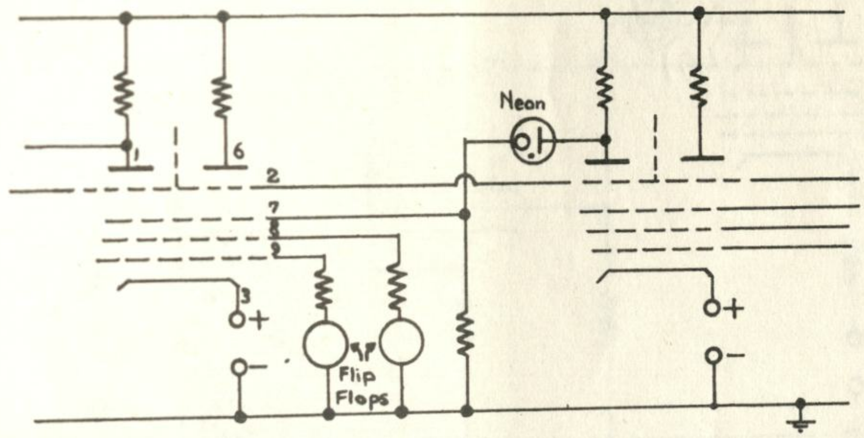
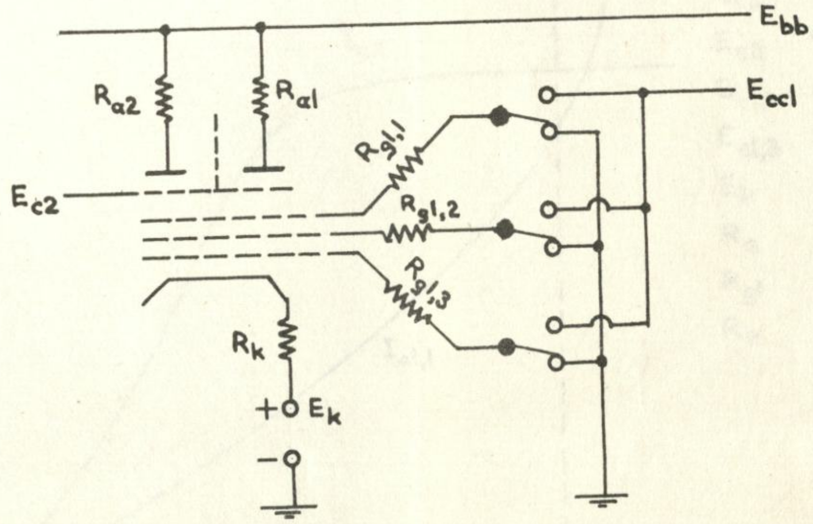

Graph showing partial equalisation of control electrode voltages.
E_{bb} = 250v
E_{c2} = 125v
$E_{ccl,1}$ = 0
$E_{ccl,2}$ = 50v
R_a = 100,000 ohms
R_{g1} = 63,000 ohms
R_k = 10,000 ohms
$E_{ccl,3}$
$E_{ccl,2}$
$E_{cl,2}$
$E_{cl,3}$
CONTROL ELECTRODE VOLTAGE
10
20
30
40
50
60
70
CONTROL ELECTRODE 3 SUPPLY VOLTAGE
10
20
30
40
50
60
70
80
90
100

FIG. 5



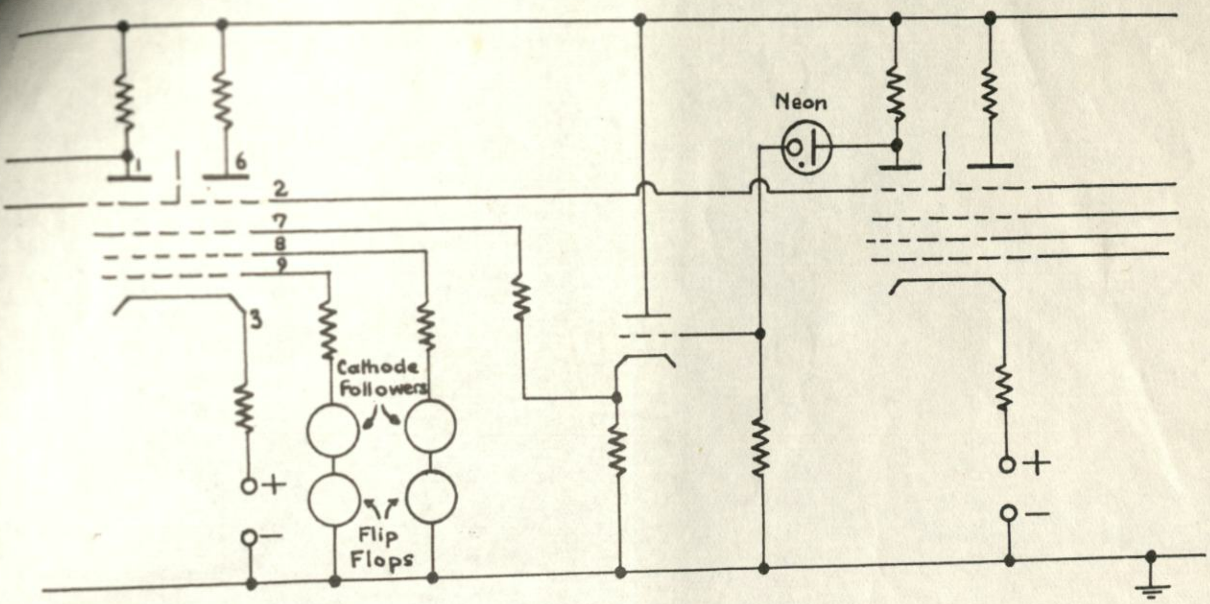
Circuit for direct coupling

FIG. 6



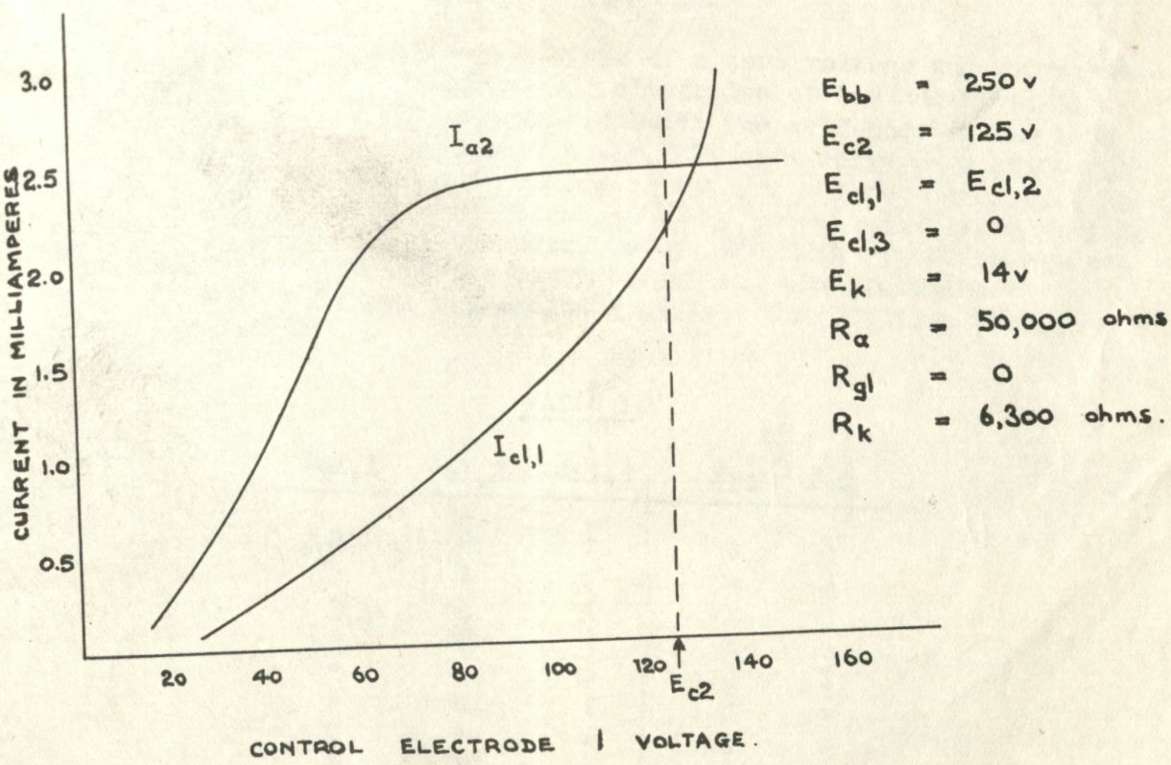
Equivalent circuit for an additron.

FIG. 7



Circuit for cathode follower coupling

FIG. 8



Graph of $I_{cl,1}$ against $E_{cl,1}$

FIG. 9

A NEW CLASS OF SWITCHING TUBES FOR DIGITAL APPLICATIONS

Summary:

Novel switching tubes embodying complete matrices or function tables are described. Particular reference is made to a tube capable of performing the binary addition of two digits and a 'carry' from a previous stage. Extensions are sketched to binary subtractor, binary adder-subtractor, multiplier, 3 x 8 matrix and other types.

The tubes are of receiving (miniature) tube size, contain a cylindrical cathode and input and output electrodes that are sections of concentric cylinders or conoids. There is one input electrode corresponding to each input channel and one output electrode corresponding to each output channel. A given combination of input potentials results in current flow in a given or given directions to a corresponding combination of output electrodes. Series resistors or other current limiting devices in either the cathode or input circuits restrict the spread of the electron beam or beams to a safe width.

Design considerations for reliability and speed are mentioned.

1. Introduction

The great size of electronic computers and similar electronic digital equipment is in a large measure due to the fact that the complex switches employed in such apparatus are built up from conventional triodes or pentodes each of which can perform a very elementary switching function only. Development of tubes that in themselves can provide more complex switching functions should promote the building of smaller, more compact and reliable machines.

This paper outlines a simple method of constructing switching tubes, which in general can be applied to embody in one tube any type of switching function, however complicated. Naturally, practical considerations are going to dictate which types of tubes will actually be developed. To illustrate the method, one specific tube, the Binary Adder tube will at first be described.

2. The Binary Adder Tube

Most electronic computers use the binary system of number representation. Fig. 1 illustrates this method. For comparison, the decimal and the general methods of number representation are also illustrated.

Fig. 1a General method of representation

$$a_n a_{n-1} a_{n-2} \ldots\ldots a_2 a_1 a_o \, . \, a_{-1} a_{-2} \ldots\ldots a_{-m} \quad \text{means}$$

$$a_n r^n + a_{n-1} r^{n-1} + \ldots\ldots + a_2 r^2 + a_1 r^1 + a_o r^o + a_{-1} r^{-1} + a_{-2} r^{-2} + \ldots\ldots + a_{-m} r^{-m}$$

where r is the radix of the representation and a_i is the ith digit and can take the integer values 0, 1......, r-1, i.e. $0 \leq a_i \leq r-1$

Fig. 1b Decimal method of representation

$$\text{Radix } r = 10; \ 0 \leq a_i \leq 9;$$

891.82 means

$$8 \times 10^2 + 9 \times 10^1 + 1 \times 10^o + 8 \times 10^{-1} + 2 \times 10^{-2};$$

Fig. 1c Binary method of representation

$$\text{Radix } r = 2; \ 0 \leq a_i \leq 1$$

1101.101 means

$$1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^o + 1 \times 2^{-1} + 0 \times 2^{-2} + 1 \times 2^{-3}$$

which is equivalent to the decimal number

$$1 \times 8 + 1 \times 4 + 0 \times 2 + 1 \times 1 + 1 \times 1/2 + 0 \times 1/4 + 1 \times 1/8$$

$$= 13.625$$

It will be noted that in the binary number system, digits zero and one only are used. These are represented in electronic computers as two discrete potentials which will be referred to as a positive and negative potential respectively.

Fig. 2 illustrates a typical binary addition. Each digit column may be represented by an element as shown in Fig. 3 with three inputs and two outputs. Fig. 4 shows how these elements are combined to form a six digit adder.

Fig. 2 Typical Binary Addition

Carry	1	1	1	0	0	0
Augend	0	1	1	1	1	0
Addend	0	0	1	1	0	0
Sum	1	0	1	0	1	0

Fig. 3 Block diagram of single stage Binary Adder

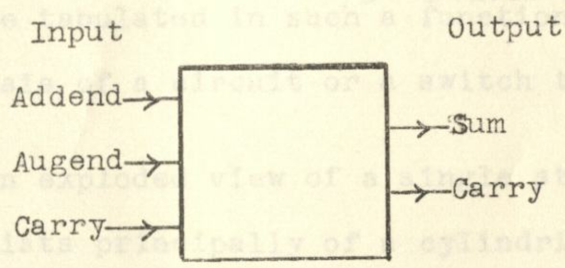


Fig. 4 Connection of 6 single stage Binary Adders to form a six digit adder

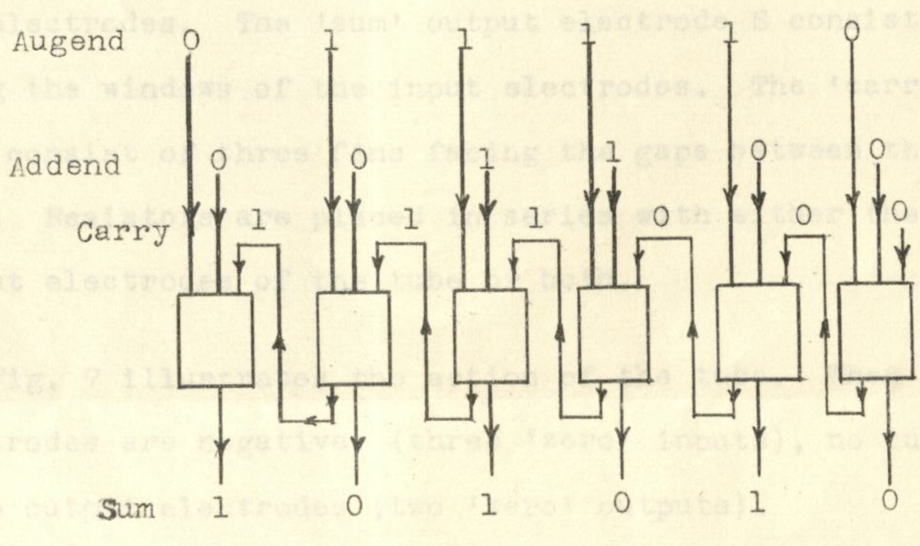


Fig. 5 Function table of Binary Addition

Inputs			Outputs	
Carry	Addend	Augend	Sum	Carry
0	0	0	0	0
1	0	0		
0	1	0	1	0
0	0	1		
0	1	1		
1	0	1	0	1
1	1	0		
1	1	1	1	1

The relationship between input and output signals to be effected by the Binary Adder element of Fig. 3 is shown in Fig. 5. This is called a function table. In general, any switching arrangement can be tabulated in such a function table which can be used as the basis of a circuit or a switch tube.

Fig. 6 is an exploded view of a single stage Binary Adder tube. This tube consists principally of a cylindrical cathode A, three symmetrically placed input electrodes, B, D, E, and two output electrodes C (carry) and S (sum). We note that each of the input electrodes has a central window and that there are gaps between the input electrodes. The 'sum' output electrode S consists of three fins facing the windows of the input electrodes. The 'carry' output electrodes consist of three fins facing the gaps between the input electrodes. Resistors are placed in series with either the cathode or the input electrodes of the tube or both.

Fig. 7 illustrates the action of the tube. When all three input electrodes are negative, (three 'zero' inputs), no current will flow to the output electrodes (two 'zero' outputs).

When one input electrode (one 'one' input) only is positive, electron current will flow through its window to the fin of the sum output electrode S facing the positive input electrode resulting in a sum output of 'one' and a carry output of 'zero'.

When two input electrodes are positive, (two 'one' inputs), current will flow through the gap between the positive input electrodes to the fin of the 'carry' electrode facing this gap. The total electron current flow in the tube is greatly restricted by the series resistor. The field configuration in the tube then confines the angular spread of the beam to a narrow region about the maximum potential gradient which in the case now under discussion leads through the gap between the two positive input electrodes. A 'carry' output of 'one' and a 'sum' output of 'zero' results.

Finally, when all three input electrodes are positive, current will flow through all windows and gaps to fins of both output electrodes resulting in both 'sum' and 'carry' outputs of 'one'. It will be noted that the tube corresponds to the element of Fig. 3 and obeys the relationships of the table shown in Fig. 5 and so can properly be termed a Binary Adder tube.

Note: It has been assumed above that a positive input voltage and current to an output electrode were to denote a 'one', a negative input electrode and absence of current to an output electrode were to denote a 'zero'. This correspondence can be reversed. As a matter of fact, when the tubes as here described are used to build up a multi-stage adder, alternate stages will use alternate correspondences unless phase inverters are used. Phase inversion can be obtained within the tube itself by using secondary emission from the output electrodes to make these electrodes go positive when current flows to them.

3. Generalization of the Switching Tube

We can now generalize on the principles of tube construction used in the Binary Adder tube. In this tube we have provided an input element corresponding to each input channel which may be at one of two discrete potentials. Each combination of input potentials results in a characteristic potential distribution in the region between the input electrodes and the cathode. The direction of the maximum potential gradient (unless the field is axially symmetrical) determines the direction of electron flow. For example, when two input electrodes are positive, the maximum potential gradient passes from the cathode to the gap between the two positive input electrodes.

The width of the electron beam is determined by the ratio of positive and negative potentials on the input electrodes with respect to the cathode. While the actual input potentials are fixed, this ratio is not fixed. Resistors in series with either the cathode or the input electrodes, or both, adjust this ratio and so restrict the width of the elctron beam to a desirable region. Finally, each output electrode is placed so as to intersect the maximum potential gradient when the correct combination of input potentials is applied.

The procedure as outlined above can be used to construct tubes corresponding to any kind of function table. While there are no theoretical limitations to the building up of more and more complex switching tubes, the physical limitations will dictate how far one can proceed. For very complicated switching functions it will probably be more economical to divide the action among several simple tubes rather than try to build the whole table into one tube. Also, it is expected that manufacturers will favor the construction of a few multi-purpose tubes rather than embark on the development of a long line of tubes each for one particular application only.

To illustrate the generality of the process, a few similar tubes will now be explained. A binary subtraction, its corresponding element and its function table are illustrated in Figs. 8, 9 and 10.

Fig. 8 Binary Subtraction

Minuend	1 0 1 1 0
Subtrahend	0 1 0 1 1
Carry	1 0 1 1 0
	0 1 0 1 1

Fig. 9 Block diagram of Single Stage Binary Subtractor

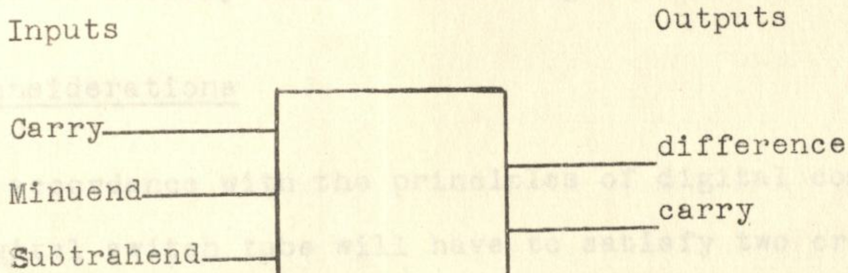


Fig. 10 Function table of Single Stage Binary Subtractor

Inputs			Outputs	
Carry	Subtrahend	Minuend	Difference	Carry
0	0	0	0	0
1	0	0	1	1
0	1	0	1	1
0	0	1	1	0
0	1	1	0	0
1	0	1	0	0
1	1	0	0	1
1	1	1	1	1

Fig. 11 shows a Binary Subtractor tube which differs from the Binary Adder tube only in the shape of the output electrodes. These have been changed so as to satisfy the table of Fig. 10. The similarity of Binary Adder and Binary Subtractor tubes suggests a combined Binary Adder-Subtractor tube as shown in Fig. 12. A fourth input element in this tube determines whether the tube delivers the sum or difference of the input digits to the output channel.

Fig. 13 is an exploded isometric view of a 3 x 8 matric or decoder tube in which one of 8 outputs is selected by one of the 8 combinations of input potentials to the three input electrodes.

Fig. 14 is a multiplier tube and Fig. 15 is a single-pole double-throw switch tube. Similarly, many other tubes can be constructed to satisfy various switching demands.

4. <u>Design Considerations</u>

In accordance with the principles of digital computer design, a digital switch tube will have to satisfy two criteria - reliability and speed. These criteria lead to important design considerations:

4.a <u>Reliability</u>: Departures from symmetry in tube construction and input signals will result in a deflection of the electron beam from the desired direction. This can be counteracted by so designing the tube geometry that the field from the outer electrodes will penetrate substantially into the region inside the controlling electrodes. When electrons due to lack of symmetry are leaving the cathode region in a displaced direction, they will be deflected towards the desired direction when approaching the input electrodes. This design procedure will result in the formation of six discrete collecting pockets which should permit considerable abberation in tube geometry and input signals. Fig. 16 illustrates the case where two electrodes are positive, one slightly more than the other, and one electrode is negative. The correcting effect near the gap will be evident.

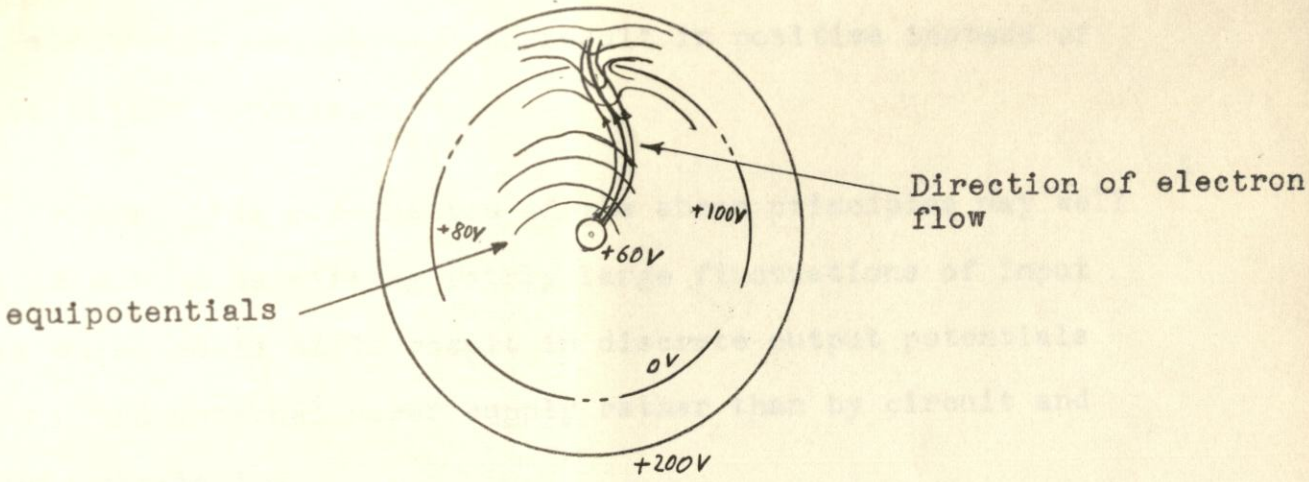


Fig. 16

Resistors in series with the input electrodes can be used to further reduce the effect of lack of symmetry. If, for instance, the input electrodes B and D of Fig. 6 are positive, and E is negative, and B happens to be more positive than D, the increased current flow towards B will cause a drop in its series resistor and so tend to decrease the difference in potential between B and D. Lastly, large series resistors in either the input circuits or the cathode circuit of the tube will result in a fine beam which will improve the definition of the output signal.

Another reliability consideration demands that the two discrete output voltage levels should be independent of input fluctuations. This can be achieved by interposing an electrode F (see Fig. 6) between the input and output electrodes with apertures permitting current flow to the output electrodes. In a proper design, an output voltage-current characteristic similar to a pentode can be achieved. This will result in 'bottoming' of the output electrode when current flows to it, if large enough output resistors are used. Another method to stabilize the output voltage levels is to design the output electrodes to have secondary emission ratios greater than unity and to use relatively large output resistors. The output electrode will then be caught at the potential of electrode F when current flows to it or will be at the supply potential when no current flows to it. By making electrode F more positive than the output electrode supply, current flow to the output electrodes can be made to result in positive instead of negative output signals.

A skilful combination of the above principles may well result in a tube permitting fairly large fluctuations of input signals which would still result in discrete output potentials defined by an external power supply rather than by circuit and tube characteristics.

4.b Speed: To attain a high speed of operation, the ratio of output current to output capacity should be large. Space charge repulsion of the electrons will limit the maximum current that can be drawn from the cathode in a structure as shown in Fig. 6. This limitation can be overcome by using a structure as shown in Fig. 17. It will be noted that each input electrode has been separated into a pair resulting in a symmetric double beam tube. This device greatly overcomes the shielding effects of the cathode and so permits better focusing of larger currents. This idea can be carried further by dividing each input electrode into three, four or more electrodes which are spaced at regular intervals and connected together. A four beam Binary Adder tube is shown in Fig. 18. It should be noted that multiple beam tubes also result in simpler structures for combined tubes, such as the Binary Adder-Subtractor tube. The output current can be increased also by utilizing secondary emission at the output electrodes of the tube.

Good focusing will require small cathode diameters. Having chosen the cathode diameter from structural considerations, it can then be shown that there exists an optimum input electrode diameter. For both larger and smaller input electrode diameters the usable current will decrease, in the former case due to the increased resistance of the equivalent diode, in the latter case due to the poorer focusing of the beam.

5. Applications

The tubes described here have the obvious applications for digital computers for which they have been designed. However, their applications extend to the far wider field of switch circuitry in general. At the University of Toronto these tubes are already used, for instance, in a discriminating radiation counter circuit. Code modulation, digital transmission, distributing systems, trigger circuits, telephone switching, etc. appear to offer a wide scope to these rather simple circuit elements.

Acknowledgment

The writer wishes to acknowledge with gratitude the enthusiastic support of this project by the National Research Council, the Defence Research Board and the Royal Canadian Navy. In particular, development work has been greatly promoted by Mr. P.A. Redhead of the National Research Council, who built the first tube sample; Lt. J.L. Belyea of the Royal Canadian Navy, who is sponsoring a wide program of development; and Mr. T. Van Dyk, Manager, Rogers Electronic Tubes Limited, who is carrying out this program.

January, 1950.

J. Katz

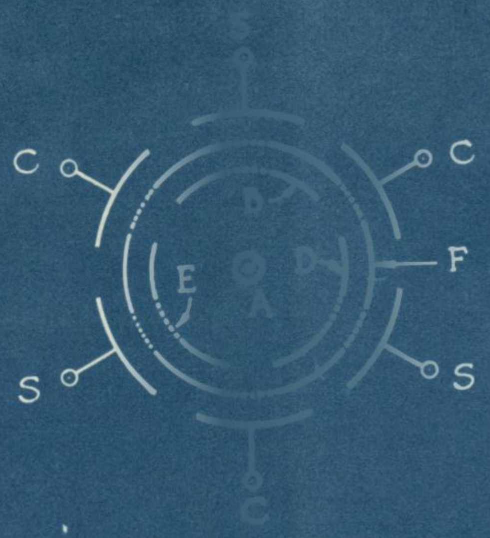
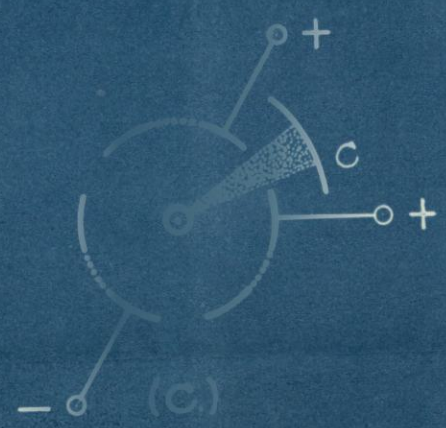


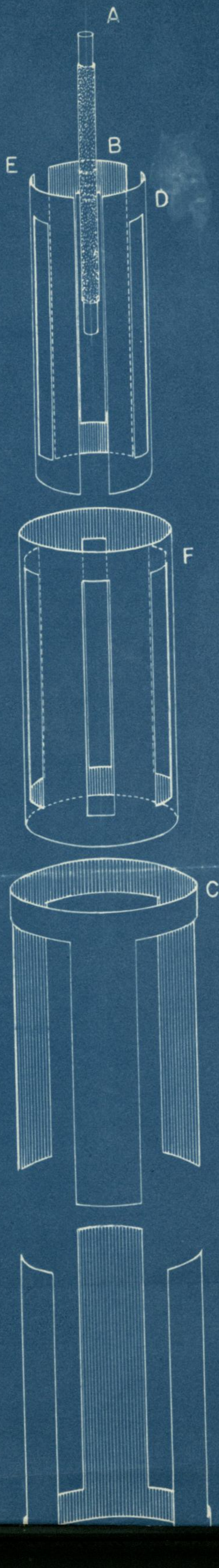
Figure 1

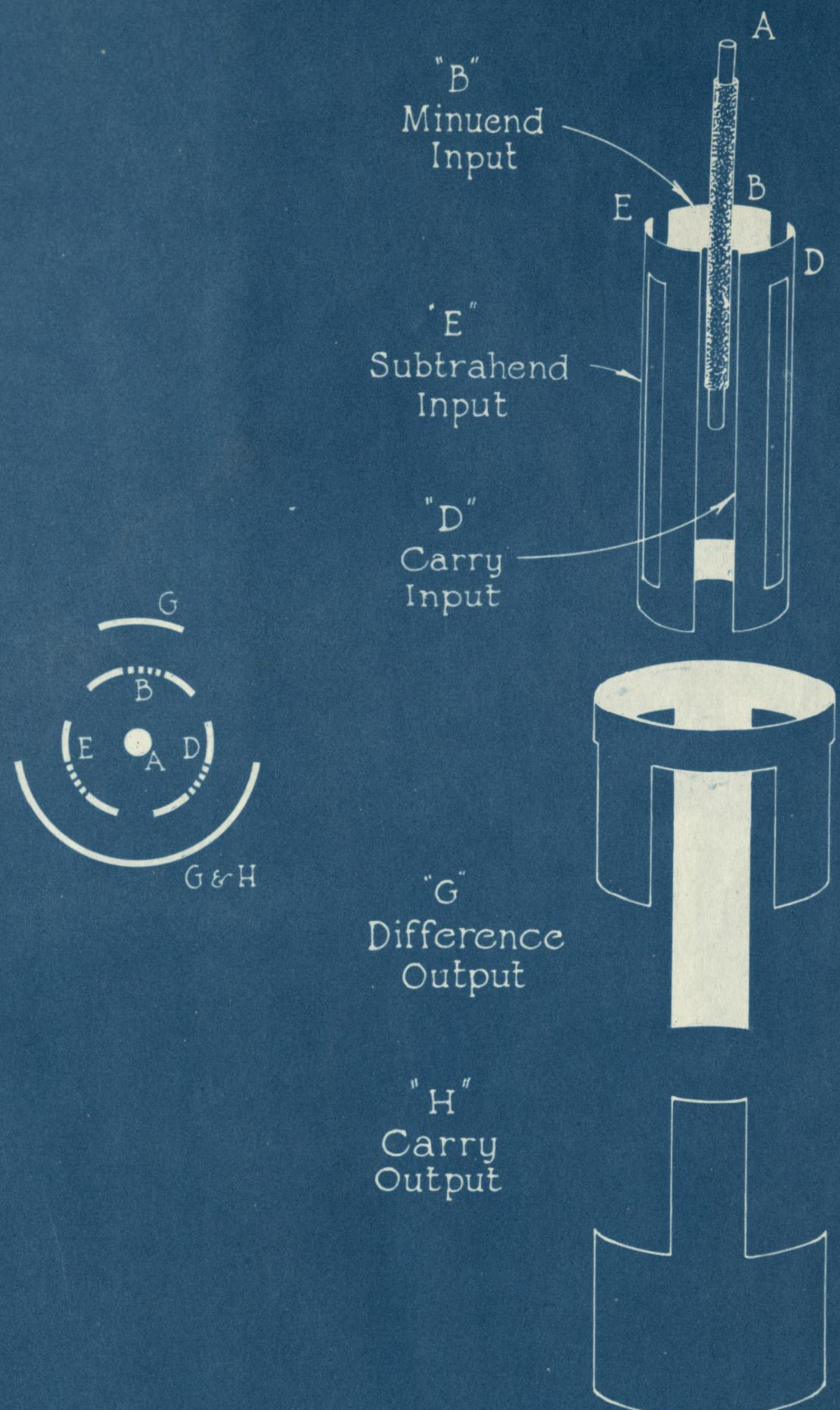
(a)

(b)



(c.)

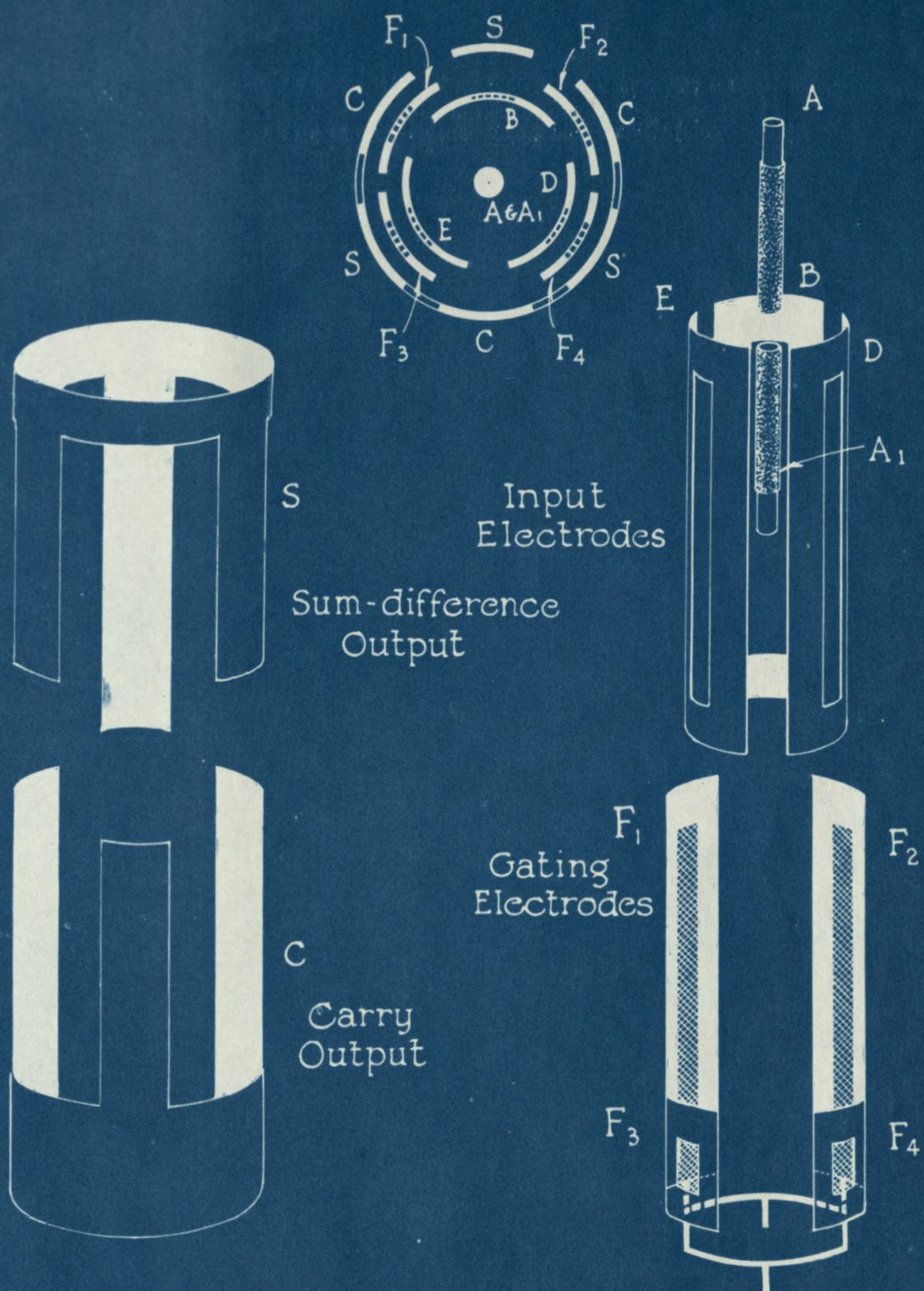




Binary Subtractor Tube

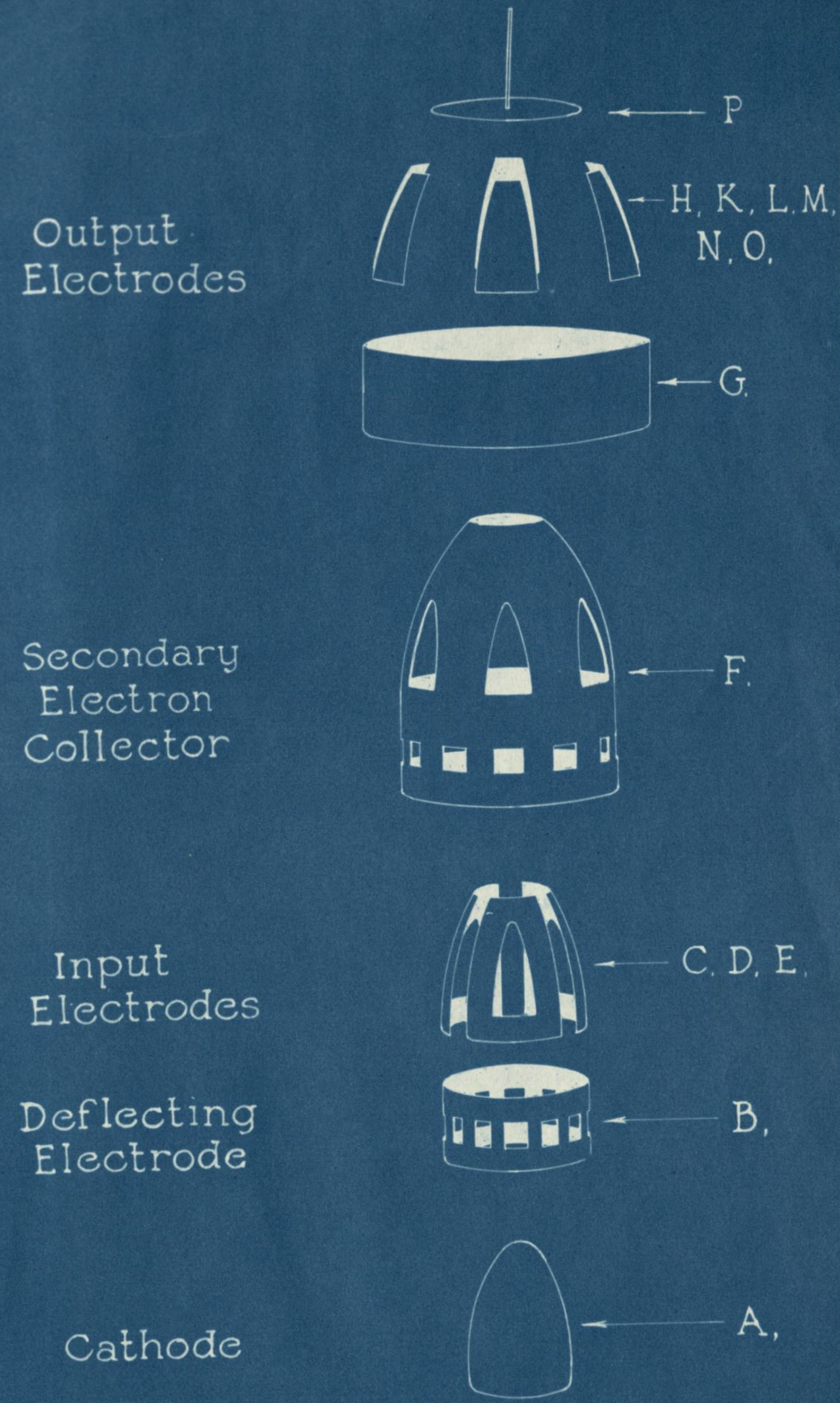
Figure 11

Line Reference Target LRT-BE4-V3



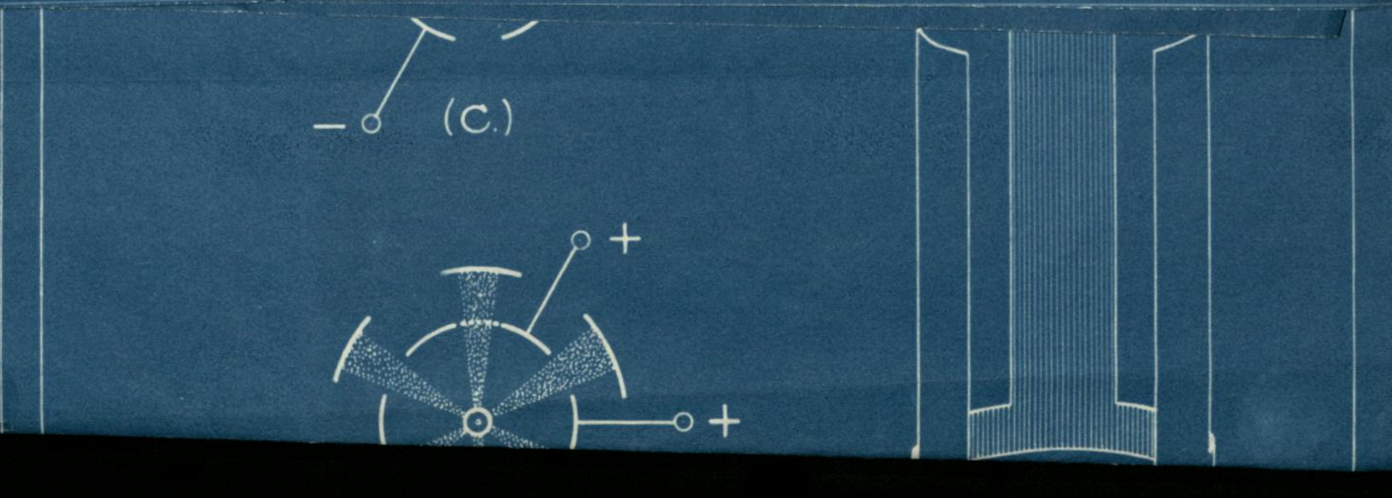
Binary Adder-Subtractor Tube

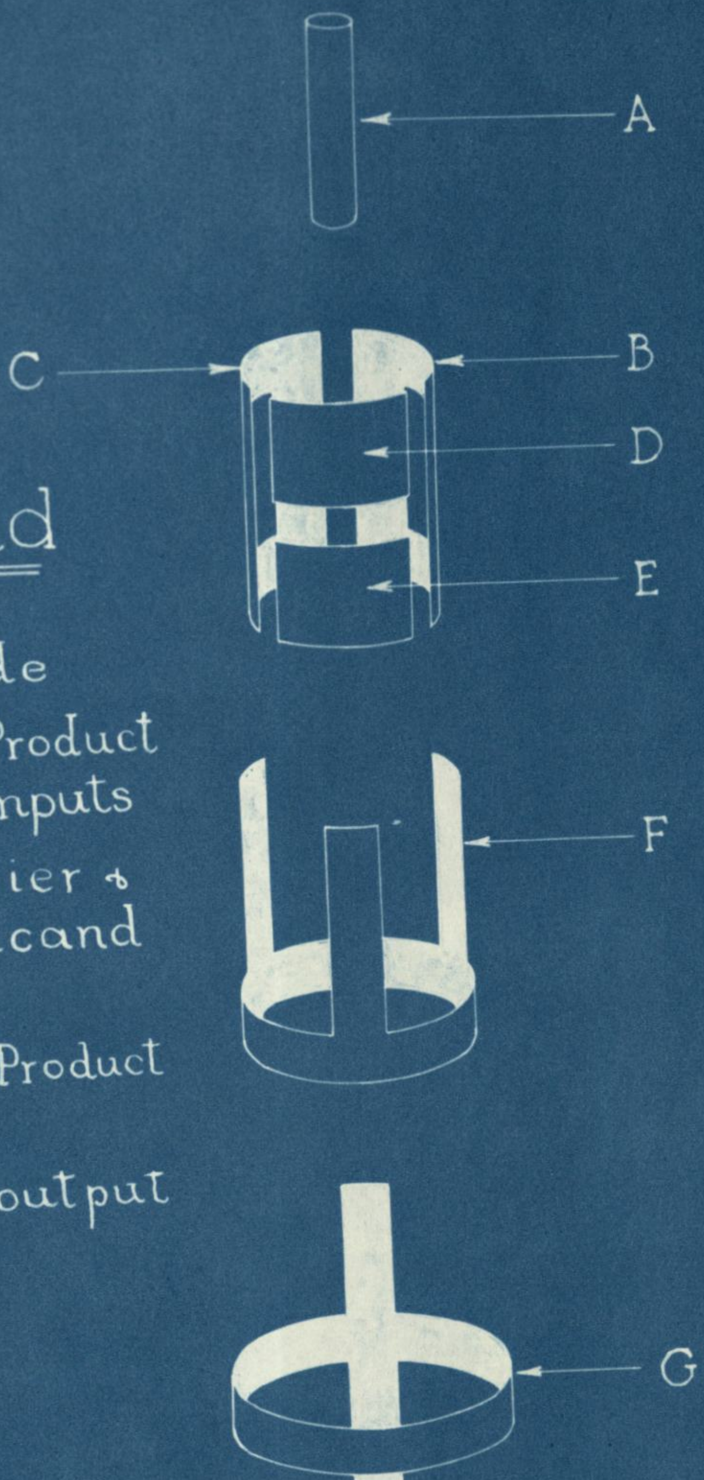
Figure 12



Isometric exploded view of Matrix Tube

Figure 13



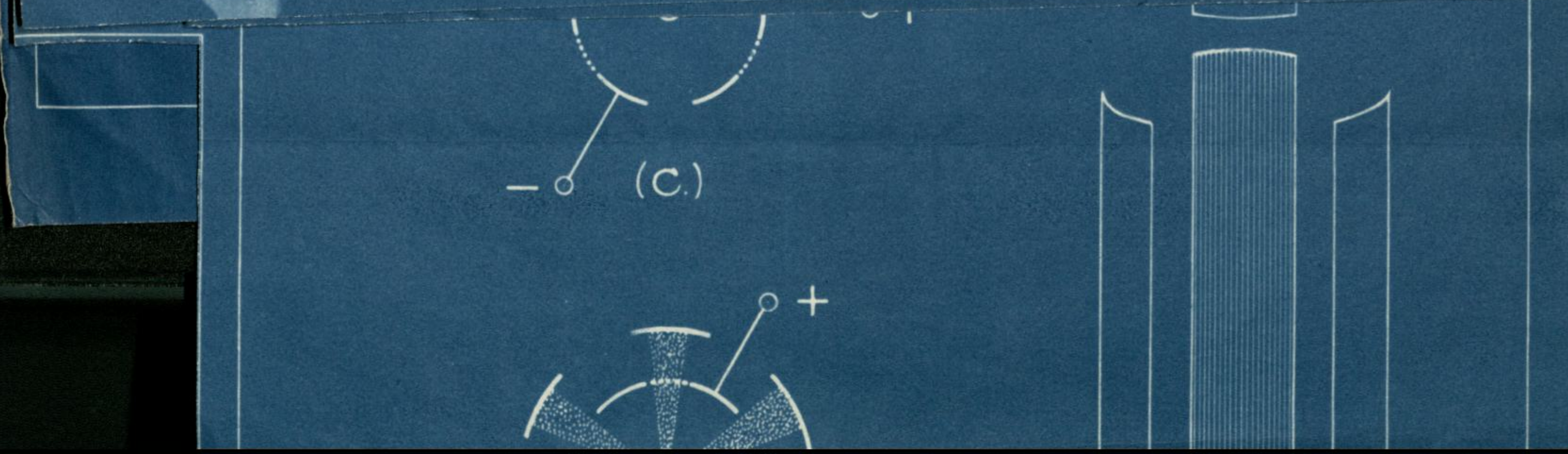


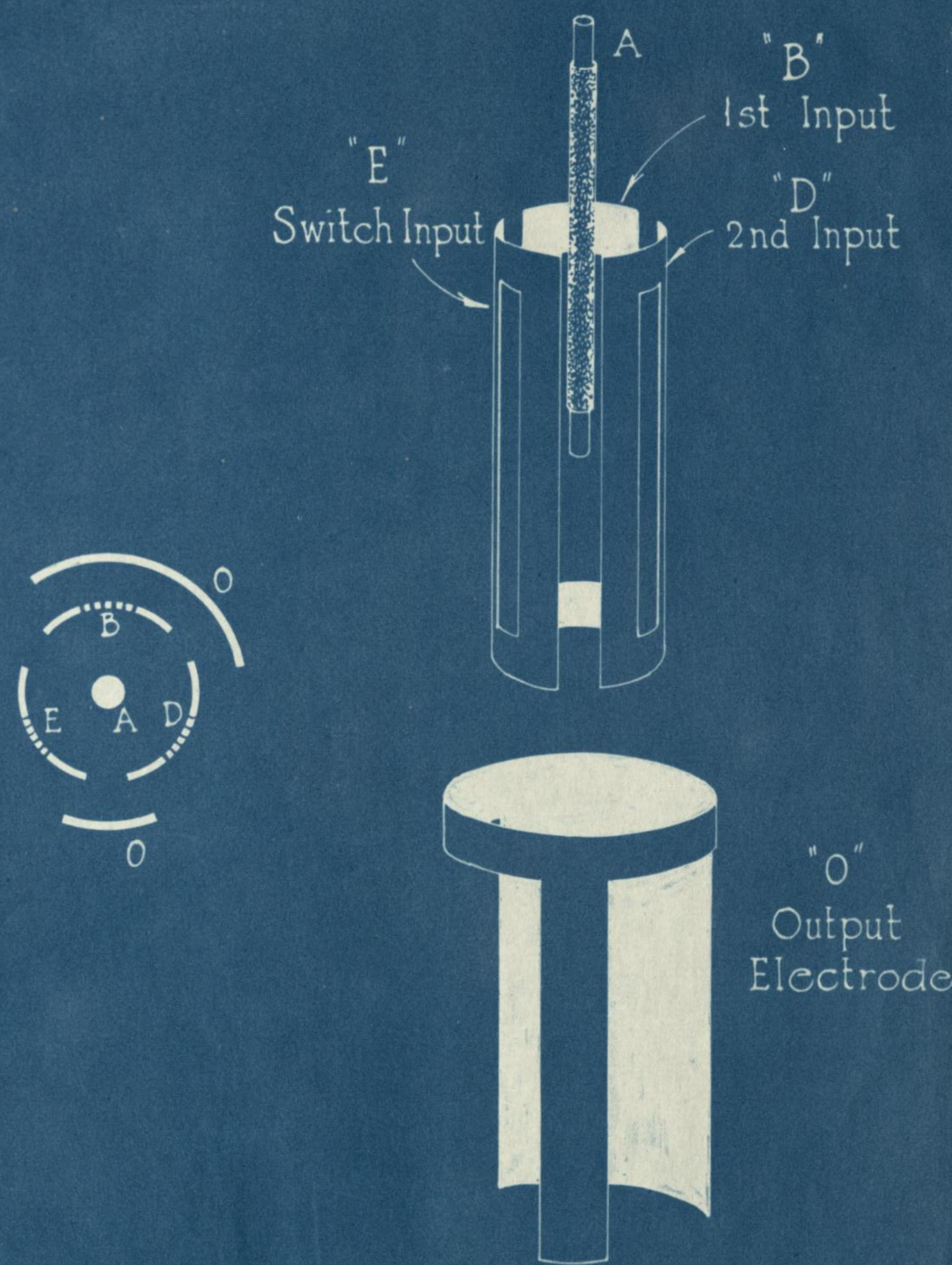
Legend

A - Cathode
B,C - Partial Product & carry inputs
D,E - Multiplier & multiplicand inputs
F - Partial Product output
G - Carry output

Isometric exploded view of Multiplier Tube

Figure 14





Single-pole, Double-throw Switch

Figure 15