

Feb. 10, 1948.

G. A. MORTON

2,435,840

COMPUTING DEVICE

Filed Dec. 28, 1943

5 Sheets-Sheet 1

Fig. 1.

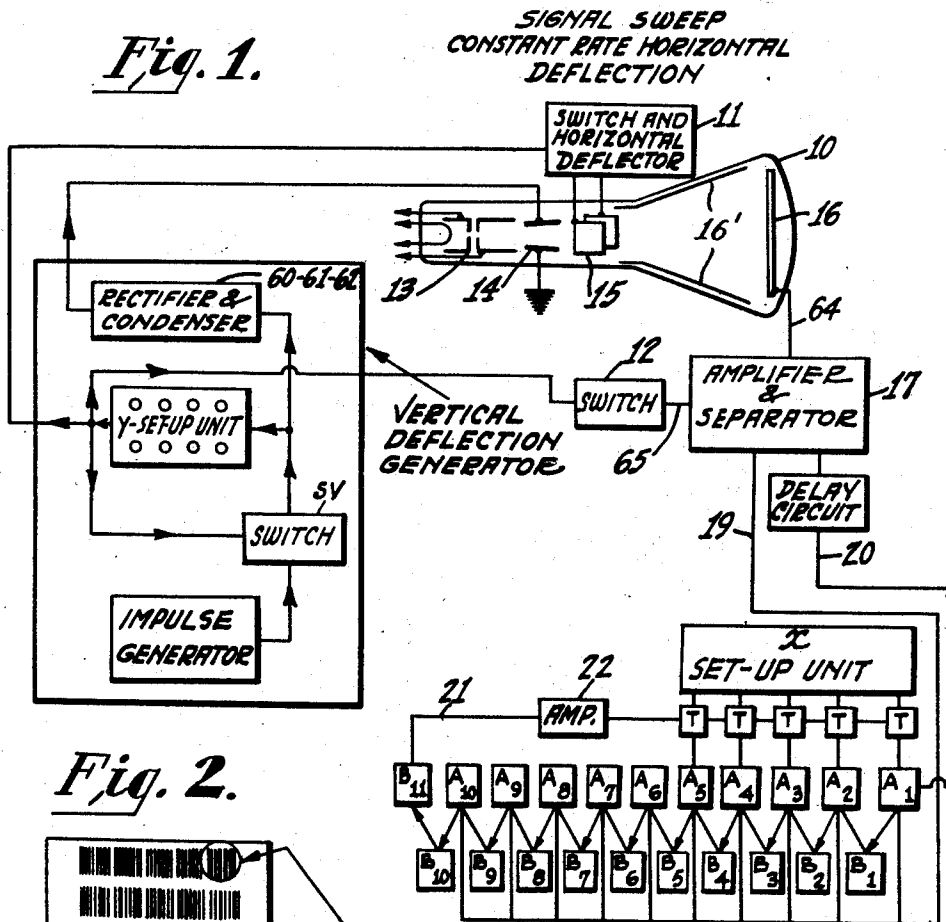


Fig. 2.

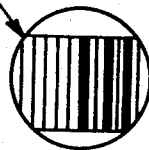
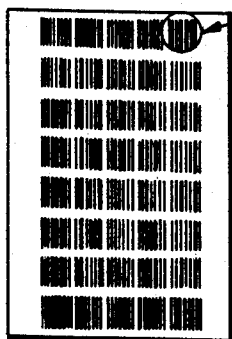


Fig. 2 a.

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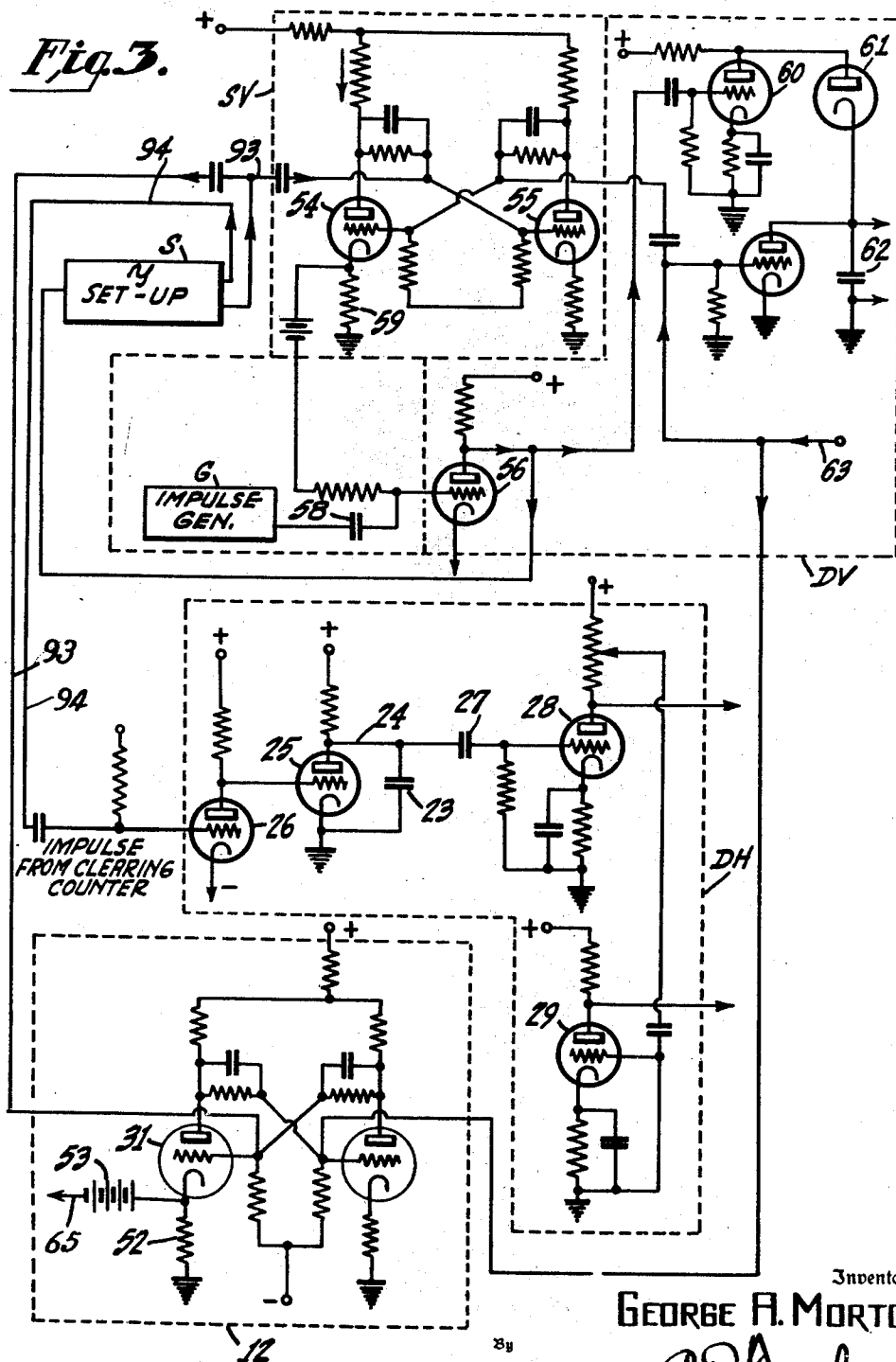
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Fig. 3.



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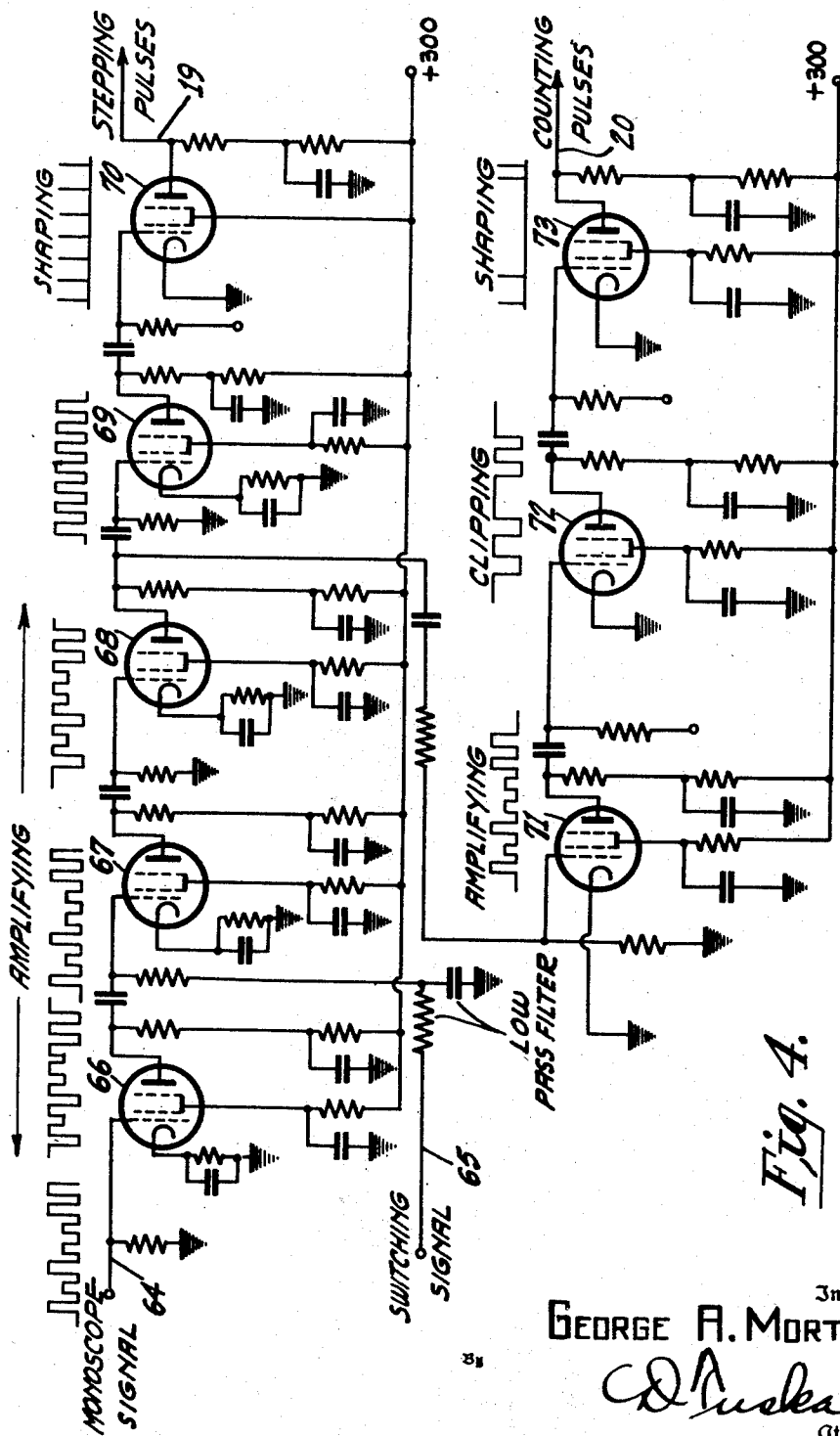
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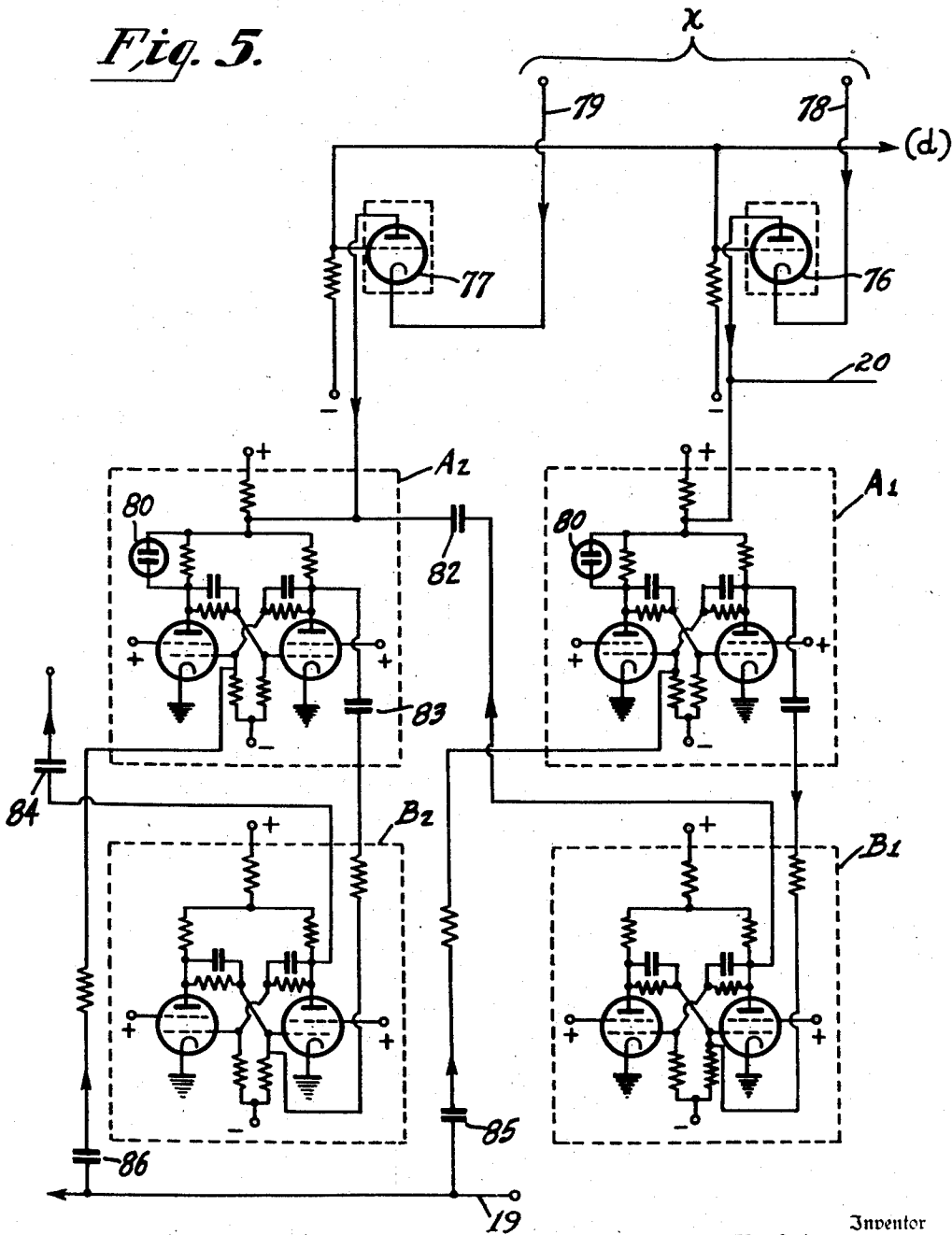
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COMPUTING DEVICE

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Fig. 5.



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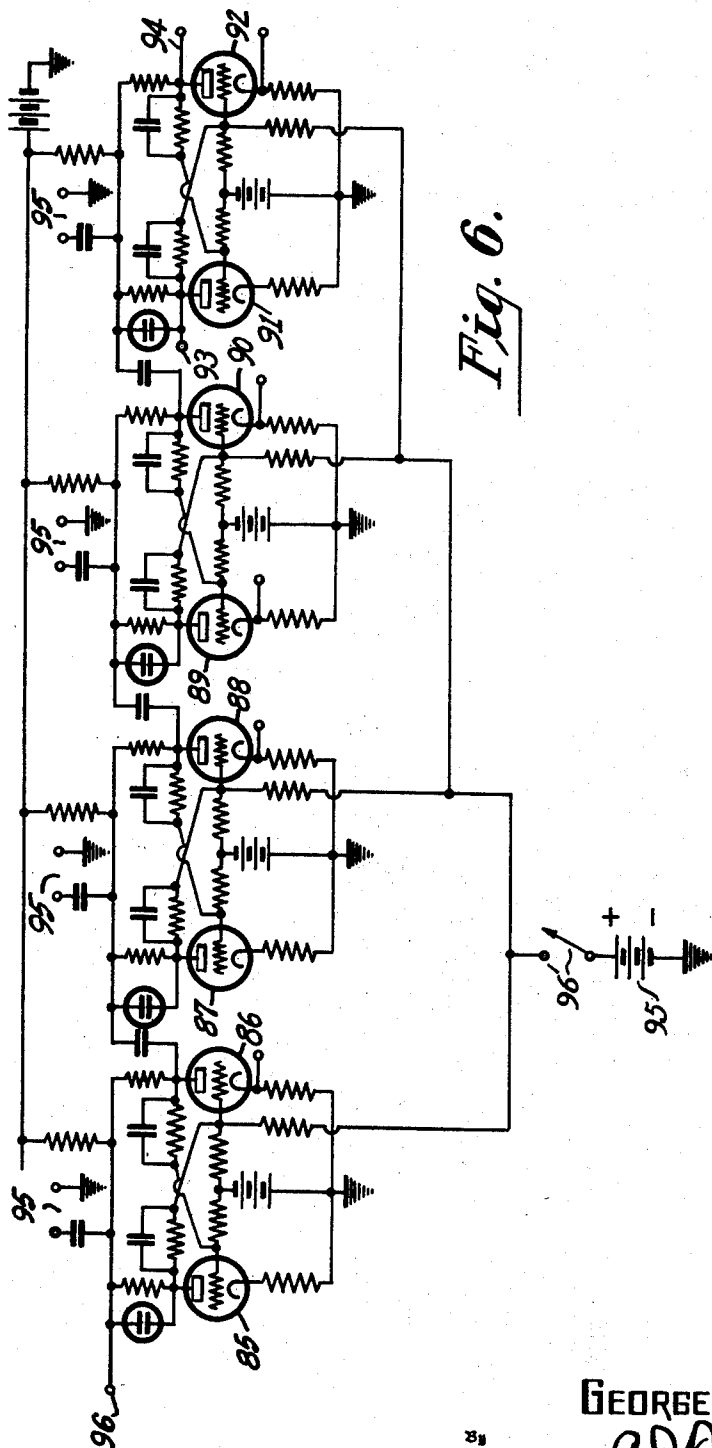
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COMPUTING DEVICE

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UNITED STATES PATENT OFFICE

2,435,840

COMPUTING DEVICE

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Application December 28, 1943, Serial No. 515,887

6 Claims. (Cl. 235-61)

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This invention relates to computing devices such as are utilized to generate a desired function of two variables, and has for its principal object the provision of an improved computing device and method of operation whereby such a function may be derived by simple control operations without the necessity of involved mathematical computations.

The present invention is similar in many respects to that of a Flory and Morton copending application Serial No. 517,048, filed January 5, 1944, which operates to generate a function expressed in terms of a plurality of variables.

The principle employed in generating arbitrary functions of two variables such as are required to determine time of flight, gun elevation and the like consists basically of determining the value of the function and its rate of change with respect to the two variables at a number of discrete points and interpolating between these points. In accordance with the present invention, matrices are used for evaluating the required quantities, and the fundamental elements containing the matrices for generating impulse number trains representing the necessary quantities are cathode-ray tubes, similar to the monoscope utilized in television technique.

The monoscope consists of an electron gun, deflection means and a special screen or target which is connected to an external signal lead. These elements are enclosed in an evacuated envelope. Information is recorded on the special screen in the form of fine lines of carbon or the like, having a different secondary electron emission rate from the screen background which may consist of aluminum or an equivalent material. As the electron beam sweeps across the screen, a current pulse due to the change in secondary electron emission is generated each time a line is crossed. Pulses formed in this way are amplified and applied to a totalizing device.

The screen may be similar to a sheet of cross section paper in that it is divided into squares or areas so that the horizontal rows represent one set of factors of terms and at least one term of the function. Information is recorded in the squares in the form of lines representing binary numbers. Two types of lines are used, a narrow line for digit zero (0) and a wide line for digit one

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(1). The width of the electron beam is made just small enough to resolve the wide lines. Consequently, the output pulses are of the same width but differ in amplitude, a large amplitude representing 1 and a small amplitude representing 0. When the electron beam sweeps across such a group of lines, potentials representative of a series of digits are developed.

Thus, to obtain one set of values of the function, the beam is deflected vertically to the horizontal row of successive areas on which are recorded values of the function for the selected value of one variable (i. e., y). For this step, it is arranged that the vertical deflection is linear and that V_0 — YV_1 volts are applied to the vertical deflecting electrodes, V_0 being the voltage required to deflect the beam from the center to the bottom of the matrix pattern and V_1 the voltage required to move the beam one row vertically. The beam is then deflected horizontally to scan the row of areas on which are recorded the selected set of values of the function.

The signals from the selected row of screen areas are in the form of potentials representative of the successive digits of the binary numbers recorded on that particular row. These potentials are amplified and then divided into stepping pulses (one for each digital position) and impulses corresponding to the digital positions where 1 appears in the recorded numbers. The stepping pulses are utilized to control the operation of a totalizer wherein the desired value of the function is established, the pulses corresponding to the digit 1 being utilized as a multiplier or merely added to the sum then in the totalizer as required to establish the function. As herein-after explained, a desired number of zeros may be recorded preceding or following certain of the matrix numbers for facilitating these operations of the totalizer.

Important objects of the invention are to provide means for generating a function having certain factors of some of its terms and one of its terms recorded in a single row on a matrix, to provide means for deriving different values of the function from different rows of the matrix and to provide means for selectively establishing each value of the function in a totalizer.

The invention will be better understood from

the accompanying drawings considered in connection with the following description, and its scope is indicated by the accompanying claims.

Referring to the drawings:

Fig. 1 is a block diagram of the entire computing system,

Figs. 2 and 2a show details of the monoscope screen or target on which the different values of each set are recorded in different horizontal rows,

Fig. 3 is a wiring diagram of the control circuits of the computer,

Fig. 4 is a wiring diagram of the circuit by which signals derived from the monoscope screen are separated into stepping pulses and pulses corresponding to each digital position on which a digit 1 is recorded,

Fig. 5 is a wiring diagram of the two right hand units of the totalizer, and

Fig. 6 illustrates four units of the set-up devices utilized to select a predetermined row of monoscope screen values and to establish the value by which other values are multiplied in the totalizer.

In considering the various figures, it should be understood that all the signals derived from the monoscope screen are supplied through a single lead to the amplifying and separating circuit of Fig. 4, that the stepping pulses derived from this circuit are applied to each A unit of the totalizer to advance the number in the totalizer one digital position to the left, that the pulses representing the digit 1 are fed into the first of the totalizer to be added to the number, if any, already in the totalizer, and that, at certain stages of the operation, the number in the totalizer is fed into the transfer units T for multiplying it by a number previously established in the X set-up unit.

If the function to be generated is

$$f(yx) = f_0(y) + a(y) \cdot x + b(y) x^2 + c(y) x^3,$$

the number $f_0(y)$ and the coefficients $a(y)$, $b(y)$ and $c(y)$ are recorded along the y th line of the screen so that they are read from left to right as c , b , a and f_0 . The value of the variable y is used to select the y (th) row of the screen areas and the value x is used as a multiplier in the totalizer. The same procedure is followed with respect to all the other horizontal rows of values recorded on the screen.

The computer of Fig. 1 includes a cathode ray device 10 which is provided with an electron gun 13 for forming a beam of electrons, a pair of electrodes 14 for deflecting the beam in a vertical direction, a pair of electrodes 15 for deflecting the beam in a horizontal direction, and a screen or target 16 upon the horizontal rows of areas of which are recorded successively values of c , b , a and f , there being one row of areas for each set of values of these quantities. Secondary electrons emitted by the target 16 are collected by the coating 16' which is maintained slightly positive with respect to the target 16 as is customary in the operation of cathode ray devices.

The vertical deflecting system of the cathode ray device 10 includes a switch SV having three leads. Through one of these leads, pulses are supplied to the switch from an impulse generator. Through another of these leads, these pulses are applied to the y set-up unit which may be of a well known trigger circuit type for adding to the number set up in it and to an amplifier-rectifier-capacitor unit 60—61—62 for deflecting the beam to a horizontal screen row of areas predetermined

by the number set up in the y set-up unit. When the number in the unit reaches zero, a resulting positive pulse is transmitted from one lead of a trigger circuit unit of the set-up device to the switch through its other lead for interrupting the transmission of pulses and stopping the vertical deflection at the selected row of areas.

A negative pulse produced at another lead of such trigger circuit unit by clearing of the coarse y set-up device is also utilized to initiate operation of the horizontal deflection system 11 and, through a switch 12, the positive pulse similarly generated is utilized to activate the amplifier and separation channel 17. The stepping pulses delivered from this channel are supplied through a lead 19 to each A unit of the totalizer AB. The pulses representing the digit 1 are supplied to the right hand A unit of the totalizer through a lead 20.

As hereinafter explained in connection with Fig. 5, the number established in the x set-up unit is transmitted to the totalizer as a result of a stepping pulse on lead 19 only when a potential representative of the digit 1 is transmitted from the totalizer through the lead 21 and an amplifier 22 to the transfer units T. The totalizer units A are trigger circuit units of a well known type which includes two cross-connected electron discharge tubes, only one of which conducts current at any given time. Transfer of current from one to the other of these tubes is effected by the application of a negative pulse to the common anode resistor terminal or symmetrical point of the two tubes or to the control grid of the particular tube that happens to be conducting when the negative pulse is applied.

The totalizer units B are similar to the A units with the exception that the grid resistances of the two tubes of each unit are made unequal so that the application of a negative pulse to the grid of the tube having the highest grid resistance causes current to be transferred to the other tube of the unit only for a very short time, after which it is automatically returned to the tube having the higher grid resistance. These B units are connected between the A units for carrying over a digit 1 from a lower to the next higher digital position. Thus the unit B₁ carries over ones from the unit A₁ to the unit A₂, the unit B₂ carries over ones from the unit A₂ to the unit A₃, etc. The delay circuit in the lead 20 is for the purpose of so timing the digit pulses on lead 20 from the amplifier separator that they do not interfere with the pulses applied to the A units through the transfer units T.

Assuming that (1) the y and x values corresponding to a particular horizontal line of screen areas have been established in the y and x set-up units, and (2) the electron beam has been vertically deflected to this line, all as previously indicated, the operation of the system is apparent from the following tabulation. In this tabulation, the first column shows the successive operational steps by which the selected value of the function is transferred to the totalizer. The fourth column shows the transfers of the digit 1 through the lead 20. The third column shows the transfers of x through the transfer elements T. The second column shows the stepping pulses through the lead 19. The fifth column shows the number in the totalizer A units which represent successive digital positions of the number, lowest digital position being at the right (A).

For the purpose of this sample calculation, it

is assumed that the different values are expressed in the binary numerical system and that $x=10$, $f_0=1011$, $a=101$, $b=110$, and $c=11$. A pulse on any lead is indicated by 1 and the absence of a pulse on any lead is indicated by 0.

6. $x^2c+xb+a$ is multiplied by x and at the same time f is added to the total, giving the desired number, $f(xy)=x^3c+x^2b+xa+f$.

It will be noted that the essential computing sequence at the totalizer is always: stepping pulse

Operating Steps	Lead 19 Stepping Pulse	Lead 21 Transfer	Lead 20 Digit 1 from tube	No. in Totalizer	Remarks
1-----	1	0	1	000000000 000000000 000000001	
2-----	1	0	1	000000010 000000010 000000011	$=c$
3-----	7			011000000	initial stepping pulses to adjust totalizer
4-----	1	0	1	110000000 110000000 110000001	
5-----	1	1	1	100000010 100000100 100000101	stepped 1 place 10 added 1 added
6-----	1	1	0	000001010 000001100 000001100	$cx+b$
7-----	6			110000000	initial stepping pulses
8-----	1	1	0	100000000 100000010 100000010	
9-----	1	1	1	000000100 000000110 000000111	
10-----	1	0	0	000001110 000001110 000001110	
11-----	1	0	1	000001100 000001100 000001101	cx^2+bx+a
12-----	5			111010000	initial stepping pulses
13-----	1	1	0	110100000 110100010 110100010	
14-----	1	1	1	101000010 101000010 101000011	
15-----	1	1	0	010000110 010001000 010001000	
16-----	1	0	1	100010000 100010000 100010001	
17-----	1	1	1	000100010 000100010 000100010	$cx^3+bx^2+ax+f_0$

It will be noted that the operation involves the following steps:

1. x is set up in multiplicand of multiplier unit.

2. Beam is deflected vertically by the y value to the desired horizontal row containing c , b , a and f_0 .

3. c is fed to totalizer unit through the lead 20.

4. c is multiplied by x by being fed to the transfer tubes (from B_{11} and amplifier 22) as a result of being stepped along by stepping pulses of b . (Note the actual number b is preceded by enough stepping pulses to adjust totalizer to bring c to the proper position.) At the same time, b is added to the product, the digit 1 pulses being delayed so that each digit 1 arrives just after the stepping and multiplication of the corresponding binary place has occurred. This yields $xc+b$.

5. $xc+b$ is multiplied by x and at the same time a is added to the total (similar to 4) yielding $x^2c+xb+a$.

on lead 19 followed by transfer pulse on lead 21, followed by digit 1 pulse on lead 20. In any particular case, the transferred digit may be 0 and there will be no pulse on lead 21 or the digit on lead 20 may be 0 and there will be no pulse on lead 20, but the timing is always the same.

Figs. 2 and 2a show front elevational and sectional views of the screen 16. The details of the screen have been explained above.

The details of the manner in which these various steps are produced will be readily understood from a consideration of the wiring diagram of Fig. 3, wherein the various parts are enclosed by dotted lines and are generally indicated by reference characters applied to these dotted enclosures. In this figure, DV is the vertical deflection generator. G is an impulse generator from which pulses are applied to the vertical deflection generator DV for moving the electron beam vertically and to a y set-up unit S for reducing to zero a y number previously established in the set-up unit. SV is a switch which ter-

minates the supply of impulses from the generator G when the number established in the unit S is reduced to zero. DH is the horizontal deflection generator for moving the electron beam to scan the selected horizontal areas. 12 is the switch through which the amplifying and separating channel between the monoscope screen or target 16 and the totalizer A—B is controlled.

The complete vertical deflection system includes the switch SV (comprising the trigger circuit tubes 54 and 55) and a control tube 56. Positive pulses are applied from the generator G through a capacitor 58 to the control grid of the tube 56 which is capable of delivering negative pulses to the y set-up device and to the deflection generator DV only when the tube 54 is conducting and a positive potential drop exists in the cathode resistor 59 of the tube 54.

Assuming the tube 56 to be conducting, the negative pulses supplied through the tube 56 function to subtract from the count set up in the y set-up device and at the same time (through the amplifier 60 and rectifier 61) to increase the charge of a capacitor 62. As the charge of this capacitor increases, the voltage between the vertical deflectors 14 is increased and the beam is moved to the line of areas containing the pertinent information. Then the y counter clears and thereby transmits a positive impulse to the control grid of the tube 55, thus transferring current from the tube 54 to the tube 55 and biasing off the control tube 56. The vertical deflection system is restored to its initial condition by the application of a positive pulse to the lead 63.

The horizontal deflection generator DH is an ordinary saw tooth generator sometimes used in connection with television circuits. It includes a capacitor 23, which is charged through a lead 24 and is discharged through a tube 25 in response to a negative pulse, supplied upon clearance of the y set-up unit, through a lead 94 to the control grid of a direct current amplifier 26. The cathode-anode potential of the tube 26 is normally such that it conducts sufficient current to maintain the tube 25 at cut-off. The application of a negative pulse to the grid of the tube 26 cuts off its current. This makes the grid of the tube 25 more positive, thereby discharging the capacitor 23 and producing a very rapid initial deflection of the beam to the start position. After the negative pulse applied to the grid of the tube 26 subsides, the tube 25 assumes its normal cut-off condition. Thereafter charging of the capacitor 23 results in a gradual rise of the potential at the upper plate of the capacitor 23. The resulting change in potential is applied through a coupling capacitor 27 to the single-ended push-pull amplifier stage 28—29, and thence to the horizontal deflecting electrodes 15 of the cathode ray device 10, thus deflecting the beams along the selected row of screen areas on which the pertinent data is recorded.

At the same time that a negative pulse is applied to the horizontal deflection generator DH, a positive pulse is also applied through the lead 93 to the control grid of the left hand tube 31 of the switch 12, thereby producing in the cathode resistor 52 of this tube a positive potential drop which neutralizes the negative potential of a battery 53 connected in a control lead of the amplifying and separating channel and permitting signals to pass through this circuit to the totalizer A—B. How the negative and positive control pulses are produced by the y set-up device S is

explained in connection with Figure 6 which is a wiring diagram of the device S.

The amplifying and separating circuit of Fig. 4 (element 17 of Fig. 1) includes an input terminal 64 which is connected to the screen 18 and a switching terminal 65 which is connected to the terminal of the y counter through the switch 12. The operation of the switching signal to prevent operation of the circuit until the y set-up device has cleared (turned to zero), is obvious from the previous explanation.

When the y counter has cleared, the area containing the pertinent data is scanned and the resulting signals are applied through the lead 64 to the control electrode of an amplifier 66 and are further amplified by the amplifiers 67 and 68. From the output of the amplifier 68, the signals are supplied to two paths, one of which includes a limiter unit 69 and a shaping unit 70 for producing the stepping pulses and the other of which includes an amplifier unit 71, a clipper unit 72 and a shaping unit 73 for providing the counting pulses which represent the digits 1 of the recorded data. The character of the signal pulses at each stage of their progress through the circuits is shown above the circuits and is readily understood in view of the fact (previously explained) that each pulse represents a digital position in a binary number, the high amplitude pulses represent the digit 1 and the low amplitude pulses represent the digit 0. The stepping pulses appearing at the output terminal 19 are applied to the A units of the totalizer and the counting pulses appearing at the terminal 20 are delivered to the right hand A unit of the totalizer, as previously explained.

Fig. 5 illustrates the wiring of two units of the transfer and two units of the totalizer A—B.

At this point, it should be understood (1) that the trigger circuit units of the switches SV and 12 (Fig. 3) are of the type in which only one of the cross-connected tubes is conducting at a time and current is switched from one tube to the other by the application of a negative pulse either to the grid of the conducting tube or to the upper terminals of the anode resistors of the two tubes, (2) that the y and x set-up units include similar trigger circuit units which are connected in cascade as indicated in Fig. 6, (3) that the units A of the totalizer A—B include a number of trigger circuit units, and (4) that the units B of the totalizer are similar to those of the units A with the exception that they are of the slide-back type, i. e., the grid resistance of the right hand tube is made higher than that of the left hand tube so that a negative pulse applied to the grid of the right hand tube transfers current to the left hand tube after a slight delay and only for a very short time, after which current is automatically returned to the right hand tube. These various set-up circuits are more fully disclosed and claimed in my copending application Serial No. 473,146, filed January 21, 1943, now Patent No. 2,404,047.

The circuit of Fig. 5 includes a number of transfer tubes 76, 77, etc., there being one such tube for each digital position of the number x. It also includes a trigger circuit unit A₁, A₂, etc., for each digital position of the number representing the generated function. Connected between the A units are the slide-back units B₁, B₂, etc., which transfer a digit 1 (from one A unit representing one digital position to another A unit representing the next higher digital position) when the lower digital A unit changes from a

binary 1 to a binary 0 condition. Potentials representative of the quantities x are applied through the leads 78, 79, etc., stepping pulses (one for each digital position) are applied through the lead 19 and pulses corresponding to the digits 1 in the number recorded on the monoscope screen are applied to the lead 20. Thus, when the right hand tube is conducting, the unit is in a binary zero condition and its indicator 80 is unlighted and, when the left hand tube is conducting, the unit is in a binary one condition and its indicator 80 is lighted.

Assuming the totalizer units A_1 and A_2 represent successive digital positions and that unit A_1 is in a binary one condition with its left hand tube conducting, the application of a negative pulse to the A_1 unit will convert the unit to a binary zero condition, thereby applying a negative pulse to the grid of the right hand tube of the slide-back unit B_1 and temporarily transferring current from its right hand tube to its left hand tube. This tube remains conducting a predetermined number of microseconds, then the conduction reverts back to the right hand tube. When this occurs, a negative pulse is transferred through the coupling capacitor 82 to the anode resistors of the unit A_2 . If this unit is in a binary zero condition, all that happens is the transfer of current to its left hand tube, thereby converting it to a binary one condition. If it is in a binary one condition, it is converted to a binary zero condition and a negative pulse is applied through a capacitor 83 to the control grid of the right hand tube of the slide-back unit B_2 , thereby temporarily transferring current to its left hand tube and upon its return applying through a capacitor 84 a negative pulse whereby a digit 1 is transferred to the A_2 unit (see Fig. 1). This process continues throughout the successively higher digital position units of the totalizer, as has been explained above. Between these transfers of potential from the leads 78, 79, etc., a negative pulse is applied through the lead 19 and the capacitors 85, 86, etc., to the grid of the left hand tube of each A unit for stepping the accumulated number to the next highest digital position.

The effect of a negative pulse applied to the lead 19 is readily understood if there be assumed to have been established in the units A_1 , A_2 , A_3 , etc., a representation of the binary number 11010. Under these conditions, the negative stepping pulse has no direct effect on the A_1 and A_3 units, which are in a binary zero condition, for the reason that the negative pulse is applied to the grids of tubes which are not conducting. The A_2 , A_4 and A_5 units, however, are in a binary one condition and the negative stepping pulse functions to convert each of these units to a binary zero condition. When this occurs, the unit B_2 functions to convert A_3 to a binary one condition, the unit B_4 functions to convert A_5 to a binary one condition and the unit B_5 functions to convert A_5 to a binary one condition. As a result, there is now established a representation of the number 110100, i. e., the number 11010 has been stepped one digital position to the left.

Fig. 6 is a wiring diagram of the y and x set-up units. As already indicated, each of these set-up units includes a plurality of trigger circuits 85—86, 87—88, 89—90, 91—92, etc. (one of each digital position in the highest value of the particular value to be established). If each of these circuits is in a binary zero condition (right hand tube conducting), the value required to clear the

counter at the desired value of y , for example, is set up by applying a negative pulse to the terminals 95 of such circuits as are required to be in a binary 1 condition for insuring that a zero representation is established in the set-up device in response to the application to the terminal 96 of a number of pulses determined by the value of y . Thus if the eighth line of the target 16 is to be selected, a negative pulse is applied to the lead 95 of the trigger circuit unit 91—92. With current conduction in the left hand side of this unit and in the right hand side of the units 85—86, 87—88 and 89—90, the application of eight negative pulses to the lead 96 causes current conduction to be in the right hand sides of all the trigger circuit units, thereby producing a positive pulse at the lead 93 and a negative pulse at the lead 94. Likewise, if the seventh line of the target 16 is to be selected, a negative pulse is applied to the leads 95 of the trigger circuits 85—86 and 91—92. With current conduction in the left hand side of these two units, the application of seven pulses to the lead 96 transfers current conduction to the right hand side of the trigger circuit 91—92, producing a negative pulse at the lead 94 and a positive pulse at the lead 93. In selecting the second line of the target 16, a negative pulse is applied to the leads 95 of the trigger circuits 87—88, 89—90 and 91—92. Similarly, in selecting the sixth line of the target 16, a negative pulse is applied to the leads 95 of the trigger circuits 87—88 and 91—92. Then pulses of a number determined by the value of y are applied to the terminal 96 of the circuit 85—86 until the set-up unit is cleared and a positive pulse from the lead 93 of the last circuit 91—92 is applied to the horizontal deflection generator DH (Fig. 3) and a negative pulse is applied from the lead 94 of the circuit 91—92 to the switch SV and to the switch 12.

A battery 95 and reset switch 96 are provided for establishing a standby condition with current conduction in the right hand sides of the trigger circuit units 85—86, 87—88, 89—90 and 91—92.

The invention thus involves the provision of means (1) for deriving the products of a number of coefficients multiplied by different powers of one number, and (2) for deriving the sum of these products and another number.

I claim as my invention:

1. The combination of a member having horizontal rows upon each of which is recorded a different set of values of a first number and coefficients of different powers of a second number, means for forming an electron beam, means responsive to pulses representative of a third number for moving said beam to select one of said rows, means for moving said beam to scan said selected row and means responsive to said beam during said scanning for combining said first number with each of said coefficients multiplied by a different power of said second number.

2. In a computer for generating a function of a plurality of variables including first and second numbers, the combination of a member having horizontal rows upon each of which is recorded a different set of values determined by said first number and coefficients of different powers of said second number determined by said first number, means for forming an electron beam, means including a set-up unit in which said first number is established for moving said beam to select one of said rows, means for moving said beam to scan said selected row and means responsive to said beam during said scanning for combining

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said selected value with said selected coefficients multiplied by different powers of said second number.

3. In a computer for generating a function of two variables including first and second numbers, the combination of a member having horizontal rows upon each of which is recorded a different set of values determined by said first number and coefficients of different powers of said second number determined by said first number, means for forming an electron beam, means responsive to pulses representative of said first number for moving said beam to select one of said rows, means for moving said beam to scan said selected row, means including a set-up unit wherein said second number is established for combining said selected value and coefficients multiplied by different powers of said second number, and means for transmitting the scanned values to said combining means.

4. In a computer for generating a function of two variables including first and second numbers, the combination of a member having horizontal rows upon each of which is recorded a different set of values determined by said first number and coefficients of different powers of said second number determined by said first number, means for forming an electron beam, means responsive to pulses representative of said first number for moving said beam to select one of said rows, means for moving said beam to scan said selected row, means including a set-up unit wherein said second number is established, a totalizer and transfer means connected between said second number set-up unit and said totalizer for combining said selected value and coefficients multi-

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plied by different powers of said second number, and means for transmitting the scanned values to said totalizer.

5. In a computer for generating a function of two variables, including first and second numbers, the combination of a member having horizontal rows upon each of which is recorded a different set of values of a third number and coefficients of different powers of said second number, means for forming an electron beam, means responsive to pulses representative of said first number for moving said beam to select one of said rows, means for moving said beam to scan said selected row, means including a set-up unit wherein said second number is established, a totalizer and transfer means connected between said second number set-up unit and said totalizer, means for transmitting the scanned values to said totalizer, and means connected between said totalizer and said transfer means for combining said third number with said coefficients multiplied by different powers of said second number.

6. The combination of a member having horizontal rows upon each of which is recorded a different set of values of a first number and coefficients of different powers of a second number, means for selecting said rows, means for moving said beam to scan one part of the selected row at a relatively high speed and another part at a relatively low speed and means responsive to said beam during the relatively low speed part of said scanning for combining said first number with each of said coefficients multiplied by a different power of said second number.

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