

July 16, 1946.

J. A. RAJCHMAN

2,404,250

COMPUTING SYSTEM

Filed Jan. 22, 1944

3 Sheets-Sheet 1

Fig. 1.

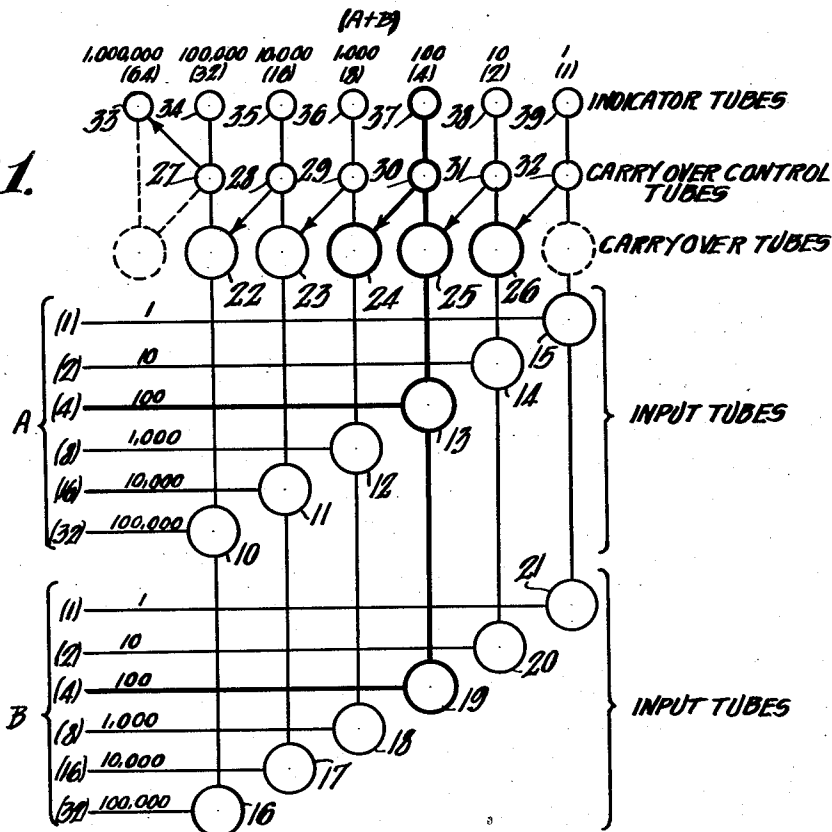
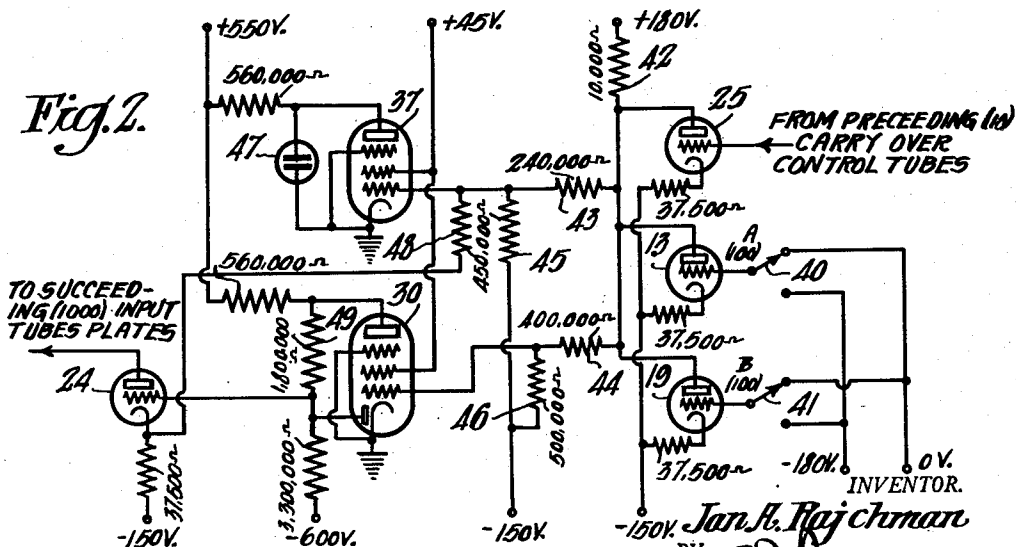


Fig. 2.



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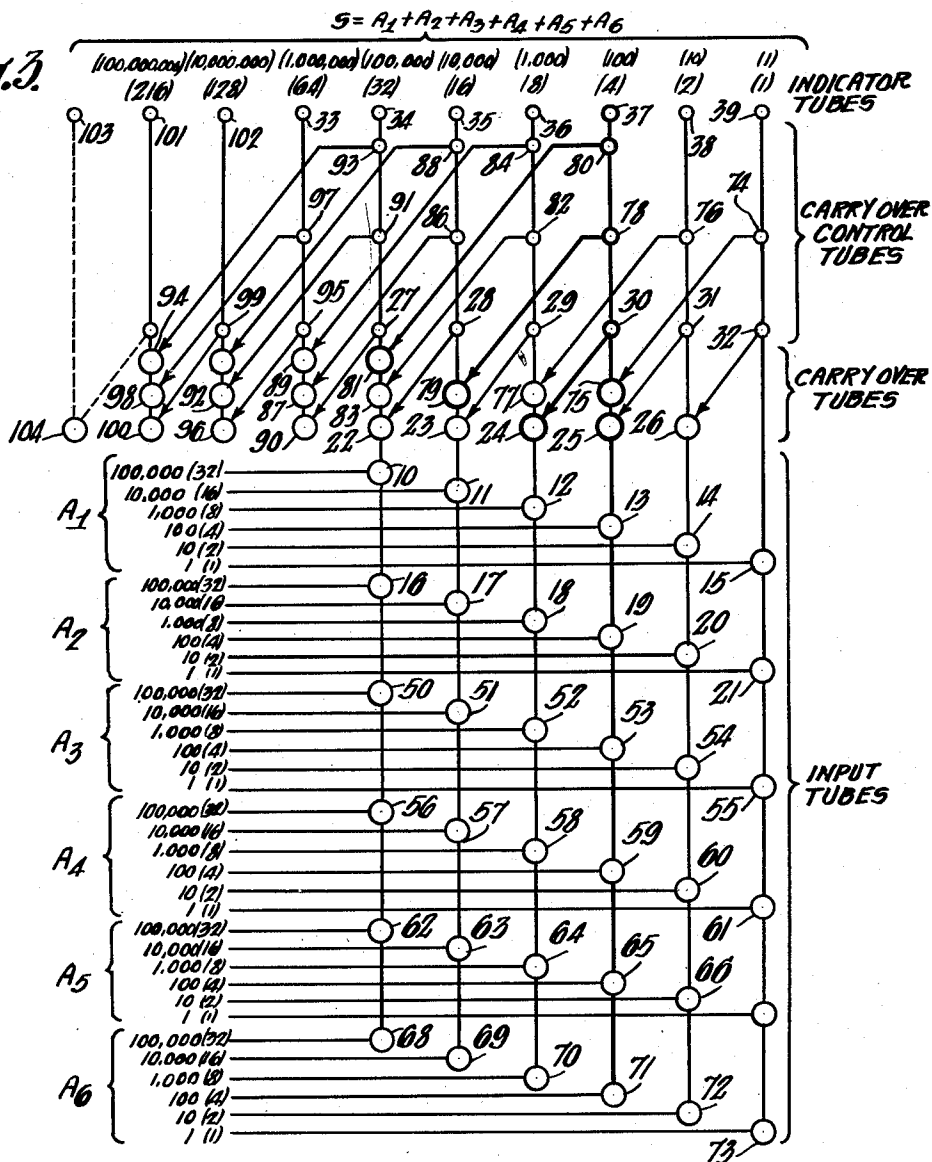
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Fig. 3



INVENTOR.
Jan. A. Rajchman
BY
CD Tucka
ATTORNEY.

July 16, 1946.

J. A. RAJCHMAN

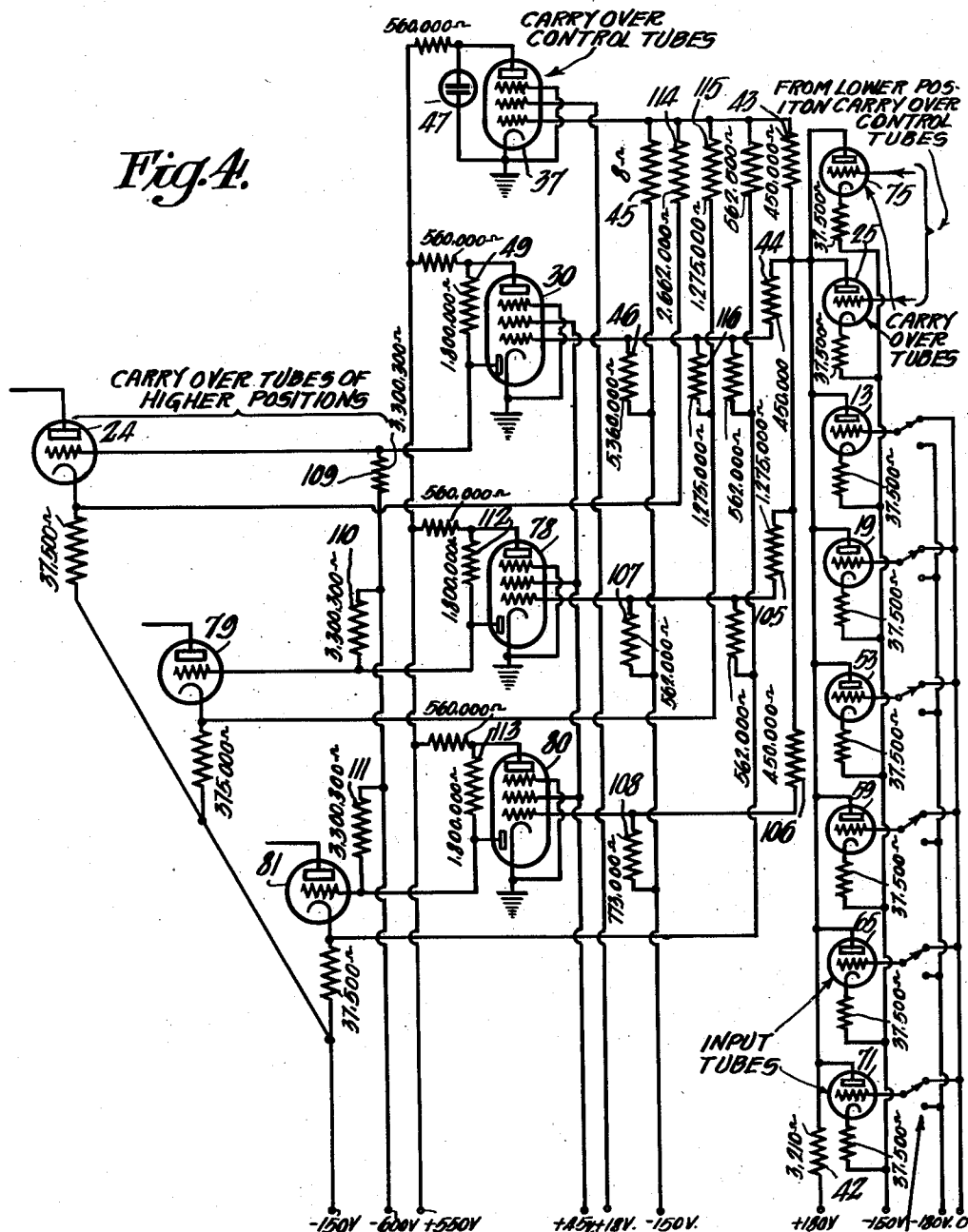
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Fig. 4.



SWITCHES CORRESPONDING TO SAME POSITIONS IN ALL TERMS OF SUM INVENTOR.

Jan. A. Rajchman

BY

CD Ruska

ATTORNEY

UNITED STATES PATENT OFFICE

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COMPUTING SYSTEM

Jan A. Rajchman, Princeton, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application January 22, 1944, Serial No. 519,299

6 Claims. (Cl. 235-61)

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This invention relates to computing systems of a type disclosed in a copending application Serial No. 511,729 filed Nov. 25, 1943. It has for its principal object the provision of an improved computing circuit and method of operation whereby the sum of a plurality of numbers is readily derived. The two inventions are distinguished from one another in that the present invention is directed to the problem of addition, whereas the invention of the copending application is directed to the problem of multiplication. Certain features are common to both inventions. The broader claims appear in the copending application, the claims of the present application being directed more particularly to the features which make possible the addition of two or more numbers.

All the computations are performed in terms of numbers. The present computing device is therefore of the numerical type, as contrasted with devices using continuously variable physical quantities, such as voltage, current or phase, as variable of computation. The whole computation is made in the binary system of numeration so that any number is expressed as a sum of powers of two in which the coefficients of the terms are zero or one. These are the only two digits of the binary system.

In this system, a number is expressed thus:

A=a_n2ⁿ+a_{n-1}2ⁿ⁻¹+...+a_k2^k+...+a₀

where the coefficients a_k are either one or zero. The numbers can be written in the usual digital representation as shown for the first seventeen numbers in the following table:

0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111
16	10000

For any number the first digit from the right, or first "digital position," signifies whether there is a 1=2⁰ in the number or not, the second digital place whether there is a 2=2¹ or not, the third

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whether there is a 4=2² or not, the fourth whether there is an 8=2³ or not, etc.

It is obvious that fractions and fractional numbers can be expressed in the binary system in a manner similar to the decimal fractions by using a "binal point" analogous to the "decimal point." A table of a few fractions would be:

0	.0000
1/8	.0001
1/8	.0010
1/8	.0011
1/4	.0100
1/8	.0101
3/8	.0110
1/2	.0111
1/2	.1000
1/8	.1001
5/8	.1010
1/2	.1011
3/4	.1100
1/2	.1101
7/8	.1110
1/2	.1111
1	1.0000
1 1/8	1.0001
1 1/8	1.0010

1327/64 1101.011011

For any number the first digit from the right of the binal point signifies whether there is a 1/2=2⁻¹ in the number or not, the second whether there is a 1/4=2⁻², the third whether there is a 1/8=2⁻³ or not, etc.

This system of numeration was chosen because most electronic computations are more easily performed in it than in any other system. This unusual method of expressing numbers does not involve any practical difficulty so long as the input and output of the computing device are converted automatically to control some physical apparatus, such as an anti-aircraft fire control system. Under such conditions, no ciphering or deciphering to or from the decimal numeration is involved.

All the operation is made in a direct system in which the binary number is expressed by a system of as many potentials as there are digits in it, each potential having one of two definite values V₁ and V₂ corresponding respectively to the digits zero and one. All these potentials exist simultaneously on a system of conductors each carrying a potential corresponding to one digit of the number. Thus, for example, to express the first seventeen numbers, five conductors would be required. The number 9 would be expressed by

the following excitation of the five conductors: $V_1V_2V_3V_4V_5$, since it can be written as 01001. In a computing device, two or more such systems of potentials are combined and a new system of potentials is derived from them. The result of the computation is the stationary final value of these output potentials and depends only on the stationary value of the input potentials, regardless of the manner in which they were reached. A sudden change in one or more input digits will, after short transients, cause the output potentials to reach their correct stationary values, so that the operation of the direct computing device may be considered as "continuous." It does not involve any trigger elements with inherently stable states or any other "holding" devices, nor does it necessitate any definite sequence, timing, or clearing pulses. Therefore, it is not a counter of any sort and does not involve impulses. It is basically the fastest type of numerical device, since no time is wasted in the proper sequencing of operations.

As pointed out above, in the direct binary system of computation with fixed constraints, the output potentials or currents are in direct relation to the input potentials so that for each place or digit of the inputs and outputs there must be provided a conductor.

The sum of two binary numbers $A=10111$ and $B=10110$ ($A=23$ and $B=22$ in the decimal numeration) can be made as is done in the usual elementary arithmetic.

1 11	carry over	
10111	A	23
+ 10110	B	+22
101101	A+B	45

This addition proceeds by adding successively the digits of A and B of the same digital position from right to left, taking into account the "carry over" number which results when the sum of the digits in any digital position is equal to two or more. Thus in the above example, the operation can be followed by starting from the right and saying successively: one and zero equal one, write one; one and one equal two, write zero, and carry over one; one, one and one equal three, write one and carry over one; one, zero and zero equal one, write one; etc.

More generally the sum of any number of numbers can be made as is done in the usual decimal arithmetic, provided the "carry over" digits are properly taken into account. For example the sum S of six numbers $A_1A_2A_3A_4A_5$ and A_6

$$S=A_1+A_2+A_3+A_4+A_5+A_6$$

can be calculated by writing the numbers in a column and adding as usual. The following example illustrates the procedure:

	1 1	} carry over digits
	1111 1	
A ₁ -----	100101	37
A ₂ -----	001101	13
A ₃ -----	101111	47
A ₄ -----	010101	21
A ₅ -----	101110	46
A ₆ -----	100111	39
Total-----	11001011	203

This addition proceeds by adding successively the digits of $A_1A_2 \dots A_6$ of the same digital position from right to left, taking into account the "carry over" digits which occur when the sum

in any column has an odd number of pairs, an odd number of groups of four or an odd number of groups of eight. Thus in the above example the operation can be followed by starting from the right column and going through all columns successively as follows: five ones, write one, carry over one two columns to the left (since there is one group of four in five and one is odd); three ones, write one, carry over one to the next column to the left (since there is a pair in three); eight ones, write zero and carry over one three columns to the left (since there is one group of eight in eight); three, write one and carry over one to the next column; two, write zero and carry over one to the next column and one two columns to the left, one write one, and finally one write one. This procedure may be summarized by stating that the digits of any one digital position and digits carried over from preceding digital positions to that particular position are added, that is to say the number of ones is merely counted. Then the result of that count is expressed in the binary system, and its lowest digit determines the corresponding digit of the sum, its next digit determines the carry over to the next digital position, its further next digit determines the carry over to the further next digital position, etc. Of course, the expression of a number in the binary system is obtained by determining whether the number of units in it is odd or even for the lowest digital position, whether the number of pairs of units in it is odd or even for the next position, the number of groups of four is odd or even for the further next position, etc.

This arithmetical process is performed by the computing circuit of the present invention.

Important features of the present invention are (1) a plurality of input tubes (one for each digital position of the numbers to be added) each connected to operate as a cathode follower so that it is either non-conductive or conducts a standard unit (about 4 ma.) of current, (2) a plurality of carry overtubes (for transferring units of current from lower digital positions to a higher digital position) each connected in the same manner as the input tubes, (3) a plurality of carry over control tubes, (4) a resistance network so interconnecting the input, carry over control and carry over tubes as to ensure that the digits one are carried over to the proper higher digital positions, and (5) means for registering or indicating in their proper order the various digits of the resulting sum.

The input tubes for any given digital position of the numbers to be added are connected in parallel with one another and, through a common resistor, to a source of plate potential. Also connected in parallel with each digital position group of input tubes and supplied with plate voltage through the same common resistor are whatever carry over tubes that are required to transfer digits one to this digital position from lower digital positions. To the control grids of the input tubes are applied either -180 (when the corresponding digit is zero) or zero voltage (when the corresponding digit is one). The tubes conduct current only when the zero voltage is applied to their grids. Each conducting input tube is utilized to represent a digit one and each non-conducting tube is utilized to represent a digit zero.

As the parallel-connected input tubes and the parallel-connected carry over tubes, if any, for

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a given digital position become conducting one after another, the plate voltage of all these tubes is reduced by discrete steps because all the tubes draw current through the same plate resistor. This voltage reduction in discrete steps is utilized to control the conductivity of the indicator tube and the carry over control tubes for this given digital position. The carry over control tubes, in turn, control the carry over tubes by which digits are transferred to high digital positions. Adjacent the resistors and leads interconnecting these various tubes are legends indicating suitable values which may be utilized in assembling and operating the circuit.

In the operation of the circuit, the indicator and carry over control tubes are conducting when no input or carry over tube corresponding to the given digital position is conducting. When one of the parallel-connected input and carry over tubes is conducting the indicator tube is biased off so that an indication for that digital position is produced. When two of the parallel-connected tubes are conducting, the first carry over control tube is biased off, a carry over tube in the next higher digital position is made conducting, and a potential applied from the cathode of this carry over tube biases off the indicator tube. Further steps in the operation are hereinafter explained in detail. At this point, however, it should be noted that (1) the conductivity of the indicator tube for the given digital position is controlled jointly by the parallel-connected tubes and by the higher digital position carry over tubes and (2) the carry over control tubes each include a diode element which enables the grid of the corresponding carry over tube to assume a predetermined voltage.

The invention will be better understood from the following description considered in connection with the accompanying drawings and its scope is indicated by the appended claims.

Referring to the drawings:

Figure 1 is a diagrammatic representation of a computing circuit arranged in accordance with the invention for adding two numbers (A and B) of six digital positions, circles being used to indicate the electron discharge devices involved in the various connections.

Figure 2 is a wiring diagram of a part of the circuit of Fig. 1, and

Figures 3 and 4 are similar to Figs. 1 and 2 with the exception that the circuit is so extended as to add six numbers each having six digital positions.

Upon detailed consideration of the circuits of Figs. 1 to 4, it becomes obvious that these circuits are readily extended to deal with any desired number of numbers having any number of digital positions.

The circuit of Fig. 1 includes one group of input tubes 10 to 15 to which are applied potentials representative of the various digits of a number A and another group of input tubes 16 to 21 to which are applied potentials representative of the various digits of a number B. In each of these groups, the lowest digital position is at the top and highest digital position is at the bottom. This is indicated by the binary numbers placed above the various input leads. When zero voltage is applied to one of these input leads, the digital position which it represents contains a one. When -180 volts are applied to an input lead, the digital position which it represents contains a zero. Switches 40 and 41 (Fig. 2), another computing circuit or any other suitable

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means may be utilized to apply these digital representative potentials to the input leads.

The condition of the two groups of input tubes 10 to 15 and 16 to 21 is determined by the digits of the two numbers to be added. Each of these tubes is conducting a standard amount of current of about 4 ma. when a potential (0 v.) representative of the digit one is applied to its control grid and is biased off when a potential (-180 v.) representative of the digit zero is applied to its control grid. These standard unit currents are supplied through a common resistor 42 and are determined by the fact that each of the tubes is connected to operate as a cathode follower. Under these conditions, the anode potential of all the input tubes decreases by a standard amount for each tube that is made to conduct the standard units of 4 ma. and each of the tubes may be considered as representing a digit one or a digit zero.

For converting these various digits into a binary number which is the sum of the two numbers, a group of carry over tubes 22 to 26 and a group of carry over control tubes 27 to 32 are provided. The resulting sum is registered or indicated by a group of indicators 33 to 38 which may include a neon lamp or the like. The manner in which these results are accomplished will be more easily understood in connection with Fig. 2.

Fig. 2 shows the details of that part of the circuit which appears in the heavy lines of Fig. 1. It will be noted that the input tubes 13 and 19 are connected to the same terminal of the resistor 42 as the carry over tube 25 which has its control grid connected to the carry over control tube 31 for applying a positive potential when a one is to be transferred from the second digital position to the third digital position which is represented by the input tubes 13 and 19. All the carry over tubes 22 to 26, like the input tubes 10 to 21, are of the cathode follower type so connected as to conduct a standard unit (4 ma.) of current.

It is apparent that the potential at the lower terminal of the resistor 42 is reduced by a predetermined amount when one of the tubes 25, 13 or 19 takes current, by twice this amount when two of these tubes take current and by three times this amount when all three of these tubes take current. These different voltages are applied through the resistors 43 and 44 to the first or control grids of the indicator tube 37 and the carry over control tube 30. Potential is applied also to these grids from a -150 v. lead through resistors 45 and 46. To the second or screen grids of the tubes 30 and 37, potential is applied from a +45 v. lead.

Connected in shunt to the tube 37 is a neon tube 47 for indicating when this tube is not conducting (a condition existing when a digit zero is in the third digital position of the sum of the two numbers being added).

The carry over tube 24 of the fourth digital position has the upper end of its cathode resistor connected through a resistor 48 to the first or control grid of the indicator tube 37. The control grid of the tube 24 is connected to the diode element of the tube 30 and through a resistor 49 to the anode of the tube 30 so that the tube 24 conducts current only when the tube 30 is biased off. The purpose of the diode element of the tube 30 is to establish at the grid of the carry over tube 24 a predetermined potential which is intermediate those of the +550 v. and -600 v. leads when

the tube 30 becomes non-conducting and no plate current is drawn through its anode resistor by the tube.

The manner in which the circuit operates to convert the digits established by the tubes 25, 13 and 19 into a binary number is indicated by the following tabulation:

Input tubes conducting	Tube 30	Tube 37	Tube 24	Sum
None	On	On	Off	0
1	On	Off	Off	100
2	Off	On	On	1,000
3	Off	Off	On	1,100

From this tabulation, it is evident that the tubes 30 and 37 are conducting and the tube 24 is biased off when none of the tubes 25, 13 and 19 is conducting. When one of the tubes 25, 13 or 19 is conducting, the potential at the lower end of the resistor 42 is reduced sufficiently to bias off the tube 37 thereby lighting the lamp 47 and indicating a digit one in the third digital position of the binary number. When two of the tubes 25, 13 or 19 are conducting, the potential at the lower end of the resistor 42 is reduced sufficiently to bias off the tube 30. This has two results. It makes the tube 24 conducting so that a digit one is carried over to the fourth digital position. When the tube 24 conducts, a positive potential is applied to the control grid of the tube 37 so that this tube takes current and the lamp 47 is extinguished. When all of the tubes 25, 13 and 19 conduct the potential at the lower end of the resistor is sufficiently negative to bias off both tubes 30 and 37 so that the carry over tube 24 remains conducting and the lamp 47 is lighted. Under these conditions, a binary number of 1100 is established in the part of the circuit detailed in Fig. 2. How the complete sum of two numbers represented by potential applied to all the input leads is established is readily understood from the foregoing explanation.

Figs. 3 and 4 illustrate how the circuit of Figs. 1 and 2 may be extended to produce the sum of six numbers each having six digital positions, the same reference numerals being applied to corresponding parts of all the figures.

It will be noted that this extended circuit includes a group of input tubes 50 to 55, 56 to 61, 62 to 67 or 68 to 73 for each additional number to be added. Since there are six input tubes 15-21-55-61-67-73, 14-20-54-60-66-72, 13-19-53-59-65-71, 12-18-52-58-64-70, 11-17-51-57-63-69 or 10-16-50-56-62-68 for each digital position of the numbers to be added, additional carry over tubes and carry over control tubes are required. Thus a carry over control tube 74 and a carry over tube 75 are required for transferring a digit one to the third digital position when four or more of the first digital position input tubes 15-21-55-61-67-73 are conducting. A carry over control tube 76 and a carry over tube 77 are required for transferring a digit one to the fourth digital when four or more of the second digital position input tubes 14-20-54-60-66-72 or three of these tubes and the carry over tube 26 are conducting.

A carry over control tube 78 and a carry over tube 79 are required to carry a digit one to the fifth digital position when four and up to eight of the tubes 75-25-13-19-53-59-65-71 are conducting and a carry over control tube 80 and a carry over tube 81 are required for transferring a digit one to the sixth digital when all of

the tubes 75-25-13-19-53-59-65-71 are conducting.

How the additional carry over control tube and carry over tube units 82-83, 84-85, 86-87, 88-89, 27-90, 91-92, 93-94, 95-96, 97-98 and 99-100 function to transfer a digit one to higher digital positions is obvious from the foregoing explanation.

Additional indicator tubes 101 and 102 are used, together with the tubes 33 to 39, to indicate the sum of the six numbers. A tenth digital position indicator tube 103 and carry over tube 104 have been indicated in dotted lines for the reason that they may be omitted since the corresponding digit is always zero. This is true because the sum of six numbers of six digits can be at most 10111010 when each of the numbers is 111111.

As shown more clearly in Fig. 4, the common anode lead of the carry over tubes 75 and 25 and the input tubes 13, 19, 53, 59, 65 and 71 is connected through resistors 105 and 106, respectively, to the first or control grids of the carry over control tubes 78 and 80 (as well as to the control grids of tubes 30 and 37). Potential is also applied to these control grids from a -150 v. lead through the resistors 107 and 108. Potential is applied from a +18 v. lead to the second or screen grid of the indicator tube 37 and from a +45 volt lead to the second control grids of the carry over control tubes 30, 78 and 80. Potential is applied to the anodes of the tubes 37, 30, 78 and 80 from a +550 volt lead. Potential is applied to the grids of the carry over tubes 24, 79 and 81 from a -600 v. lead respectively through resistors 109, 110 and 111.

The grids of the tubes 24, 79 and 81 are connected directly to the diode elements of the tubes 30, 78 and 80 and through the resistors 49, 112 and 113 to the anodes of these tubes. When the tubes 30, 78 and 80 are biased off, the corresponding diode element functions to establish a predetermined potential at the grid of the tube 24, 79 or 81. Adjacent each resistor of the circuit is a legend indicating a suitable value which may be utilized in assembling the circuit.

As in the case of Fig. 2, the input and carry over tubes are of the cathode follower type so connected that each is either cut off or draws a standard unit (about 4 ma.) of current. With these connections, the potential at the upper end of the common resistor 42 is dependent on how many of the tubes 75, 25, 13, 19, 53, 59, 65 and 71 are conducting and decreases in equal steps as one after another of the tubes become conducting.

The values of the various resistors and the applied voltages are so chosen that, when one of the tubes 75, 25, 13, 19, 53, 59, 65 or 71 is conducting, the voltage at the upper terminal of the common resistor 42 is so reduced that the tube 37 is biased off, lighting the lamp 47 and indicating a binary number of 100.

When two of these tubes are conducting, the tube 30 is biased off, the tube 24 becomes conducting thereby transferring a digit one to the next higher or fourth digital position, and a voltage applied from the cathode of the tube 24 through a resistor 114 to the first grid of the tube 37 makes this tube conductive and extinguishes the lamp 47.

When three tubes are conducting, the voltage at the upper end of the resistor 42 is reduced so that the tube 37 is again biased off and the lamp 47 is lighted. At this point, 1000 is registered at

the tube 24 and 100 is registered at the tube 37 making a binary total of 1100.

When four tubes are conducting, the voltage at the upper end of the resistor 42 is reduced further so that the tube 78 is biased off and the carry over tube 79 is made conducting. A potential applied from the cathode of the tube 79 through resistors 115 and 116 to the grids of the tubes 37 and 30 makes these tubes conducting so that the lamp 47 is extinguished and the tube 24 is biased off. A binary count of 10000 is now registered in the tube 79.

When five tubes are conducting, the tube 78 is biased off, the tube 79 is conducting and the tube 37 is biased off. Under these conditions, a binary number of 10000 is registered in the tube 79 and a binary number of 100 is registered in the tube 37 making a total of 10100.

When six tubes are conducting the tubes 30 and 78 are biased off, the tubes 24 and 79 are conducting, the tube 37 is conducting, a binary 1000 is registered in the tube 24 and a binary 10000 is registered in the tube 79. The total is now binary 11000. In this case, the tube 37 is made conducting by potentials applied from the cathodes of the tubes 24 and 79 through resistors 114 and 115 to its control grid.

When seven tubes are conducting the tubes 37, 30 and 78 are biased off, the tubes 24 and 79 are conducting, and the total binary number registered is 11100.

When all the tubes are conducting, the tube 80 is biased off, the tube 81 is conducting, the tubes 24 and 79 are biased off and the tubes 37, 30 and 78 are conducting so that a binary 100000 is registered in the tube 81.

This entire operation may be expressed in tabulation form as follows:

Tubes conducting	Tube 80	Tube 78	Tube 30	Tube 37	Tube 81	Tube 79	Tube 24	Total
None	On	On	On	On	Off	Off	Off	0
1	On	On	On	Off	Off	Off	Off	1,000
2	On	On	Off	On	Off	Off	On	1,000
3	On	On	Off	Off	Off	Off	On	1,100
4	On	Off	On	On	Off	On	Off	10,000
5	On	Off	On	Off	Off	On	Off	10,100
6	On	Off	Off	On	Off	On	On	11,000
7	On	Off	Off	Off	Off	On	On	11,100
8	Off	On	On	On	On	Off	Off	100,000

It is apparent from the foregoing description that an important feature of the carry over system is the resistive couplings controlling the potential of the grids of the carry over control and indicator tubes. This system of couplings operates in such a way that the effective number of voltage steps on any grid is equal to the number of conducting tubes 1 to 8 (to be converted to the binary system) minus the sum of the products of the carry over digits of higher digital positions by the corresponding power of two. It is evident that such effective number of voltage steps is precisely the correct binary digit.

From the circuit of Fig. 4, it is seen that the carry over tubes 24, 78 and 89 are at the same D. C. level as the input tubes 13, 19, 53, 59, 65 and 71 so that they are suitable for grouping with the input tubes of the higher digital positions. The same is true of the carry over tube 25 and the input tubes 13 and 19 of Fig. 2.

I claim as my invention:

1. An adding circuit including a separate group of tubes for each digital position of the numbers to be added, means for applying to certain of said tubes control potentials representative of the digits of the numbers to be added,

and means for applying to other of said tubes control potentials representative of digits to be transferred from lower to higher digital positions, means for establishing at the anodes of the tubes of each group a potential depending on the number of conducting tubes in that group, and means responsive to the potentials so established for indicating the sum of said numbers.

2. An adding circuit including a separate group of tubes for each digital position of the numbers to be added, means for applying to certain of said tubes control potentials representative of the digits of the numbers to be added, and means for applying to other of said tubes control potentials representative of digits to be transferred from lower to higher digital positions, means for establishing at the anodes of the tubes of each group a potential depending on the number of conducting tubes in that group, and means including a resistance network responsive to the potentials so established for indicating the sum of said numbers.

3. An adding circuit including a separate group of tubes for each digital position of the numbers to be added, means for applying to certain of said tubes control potentials representative of the digits of the numbers to be added, and means for applying to other of said tubes control potentials representative of digits to be transferred from lower to higher digital positions, means for establishing at the anodes of the tubes of each group a potential depending on the number of conducting tubes in that group, and means including a plurality of electron discharge devices controlled by the potentials so established to indicate the sum of said numbers.

4. An adding circuit including a group of input and carry over tubes, means for applying to said input tubes control potentials representative of digits of the same digital position of the numbers to be added, means for applying to said carry over tubes potentials representative of digits to be transferred to said digital position from lower digital positions, means for establishing at the anodes of said tubes potentials dependent on the number of conducting tubes in said group, and means responsive to said potentials for indicating when the number of said conducting tubes is odd.

5. An adding circuit including a group of input and carry over tubes, means for applying to said input tubes control potentials representative of digits of the same digital position of the numbers to be added, means for applying to said carry over tubes potentials representative of digits to be transferred to said digital position from lower digital positions, means for establishing at the anodes of said tubes potentials dependent on the number of conducting tubes in said group, and means responsive to said potentials for transferring digits to higher digital positions.

6. An adding circuit including a first group which has an electron discharge device for each digital position of a first number, a second group which has an electron discharge device for each digital position of a second number, means for applying to said first group of electron discharge devices potentials representative of said first number, means for applying to said second group potentials representative of said second number, and means for converting said potentials into potentials representative of the sum of said first and second numbers.

JAN A. RAJCHMAN.