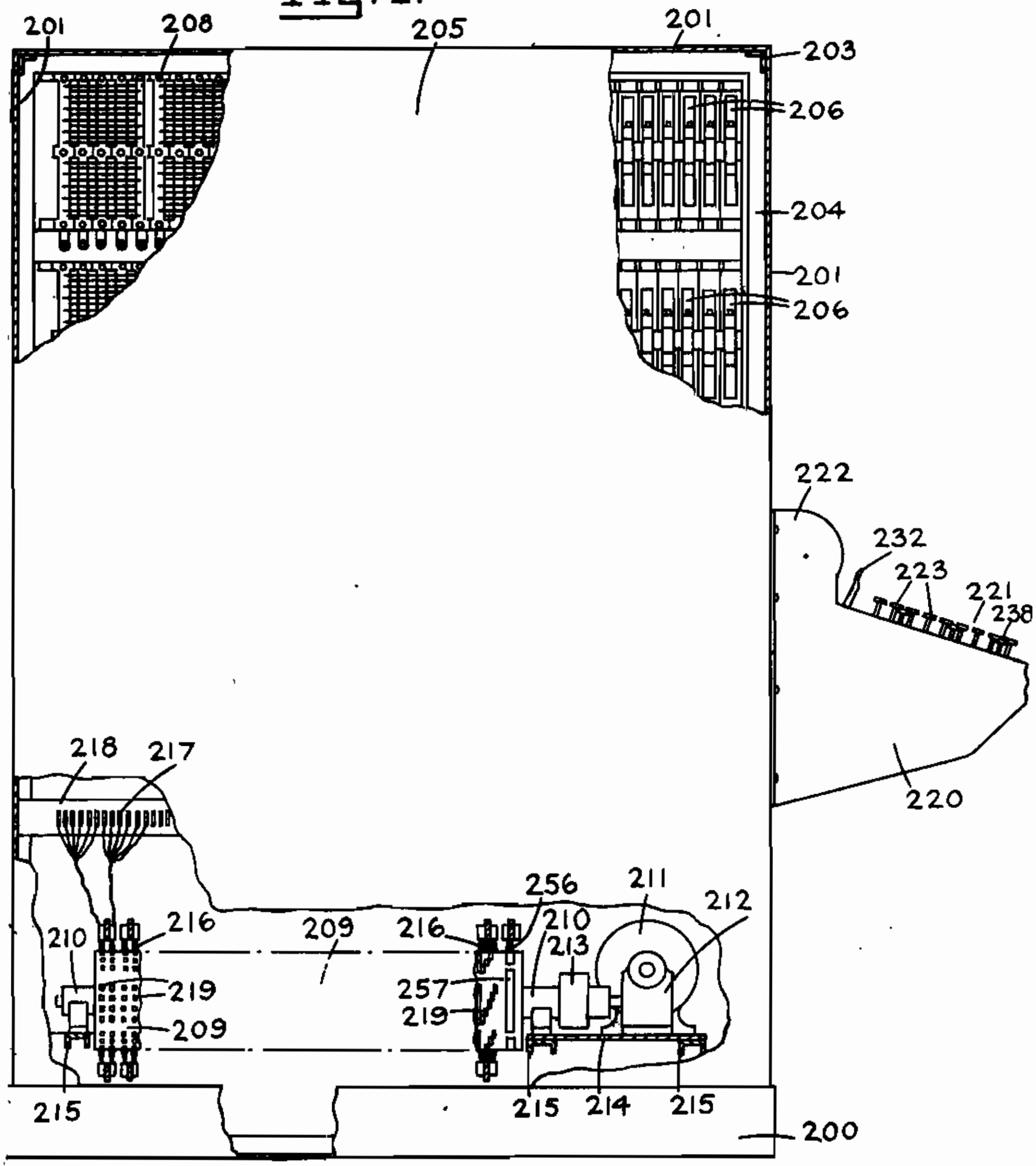
PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832
39 Sheets-Sheet 1

Fig. 1.



PUBLISHED

JUNE 8, 1943.

BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets–Sheet 2

Fig. 2.

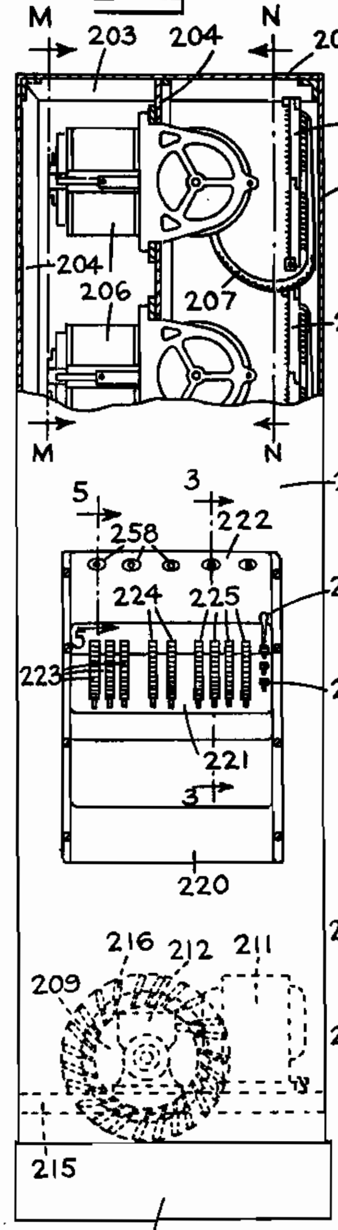


Fig. 2A.

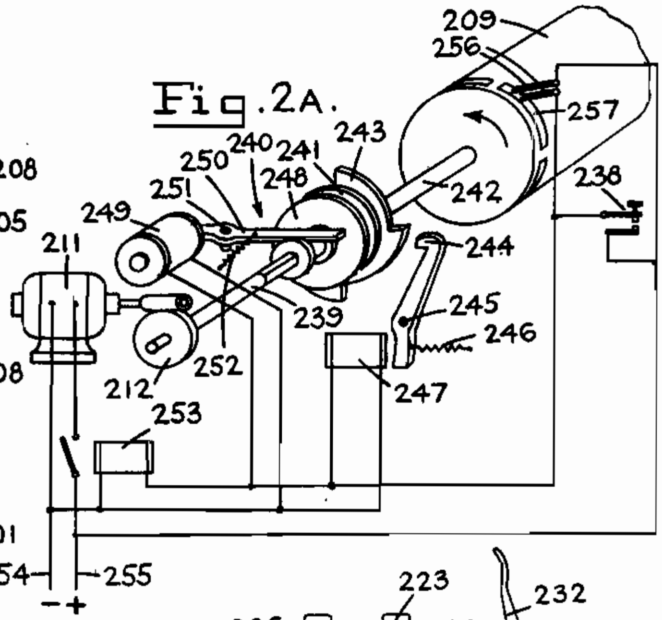


Fig. 4.

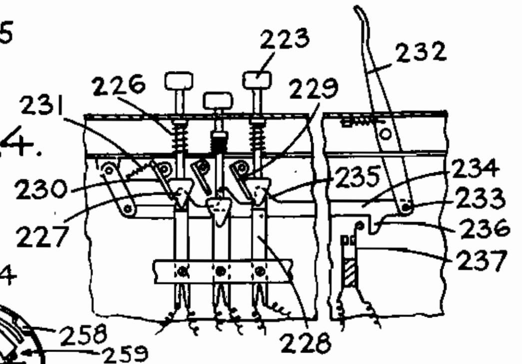
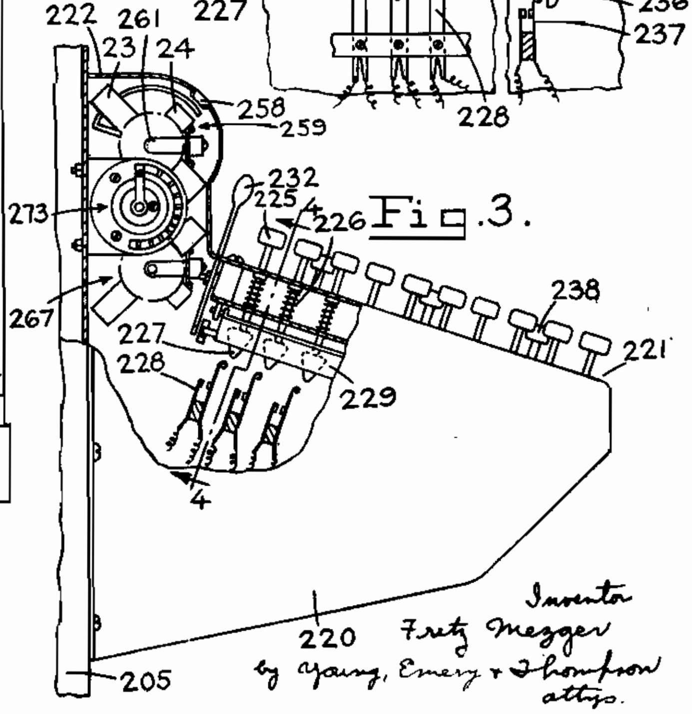


Fig. 3.



Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832
39 Sheets–Sheet 3

Fig. 5.

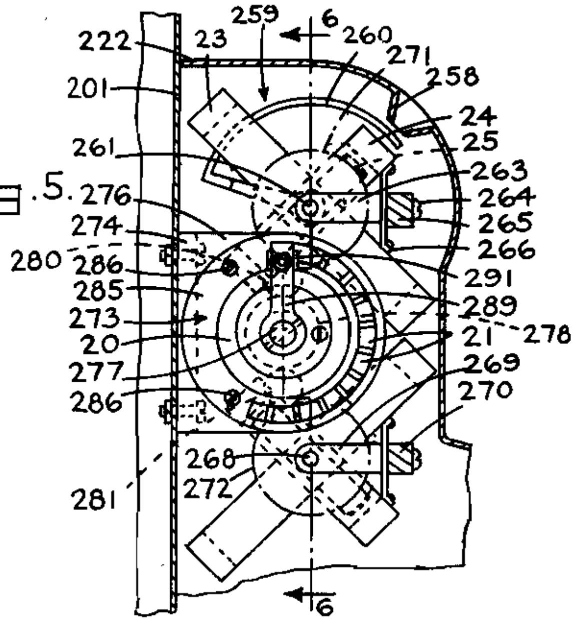
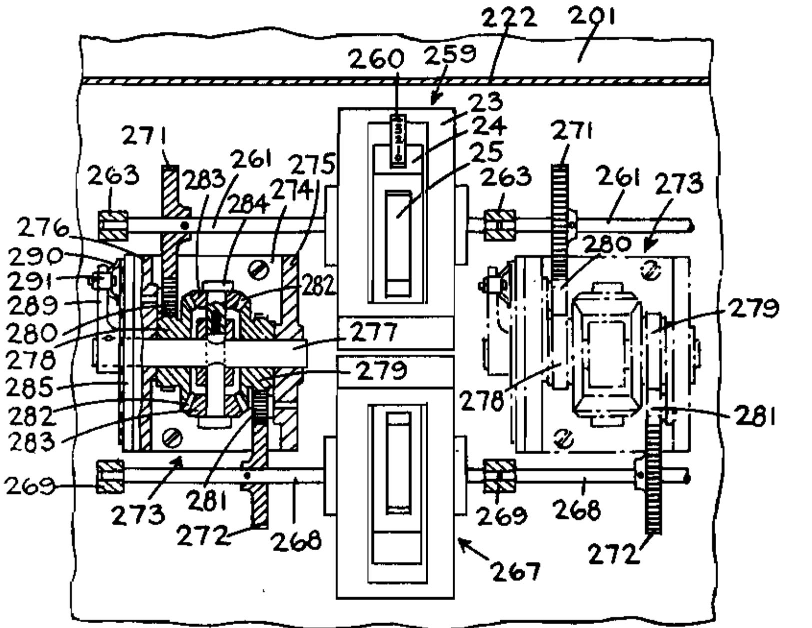


Fig. 6.



Fritz Mezger Inventor
by Young, Emery & Thompson
attys.

PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER

PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832
39 Sheets-Sheet 4

Fig. 7.

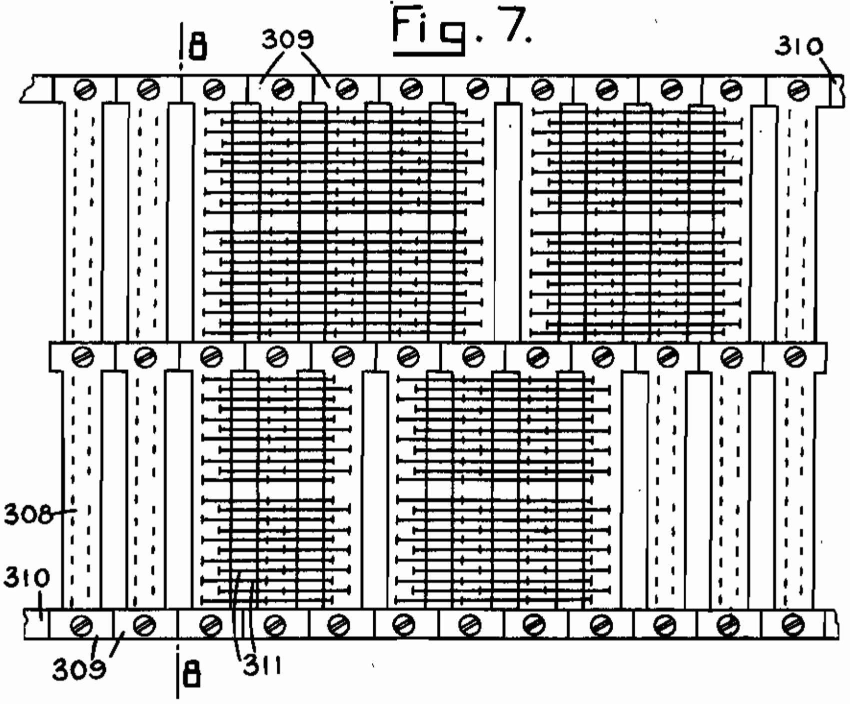
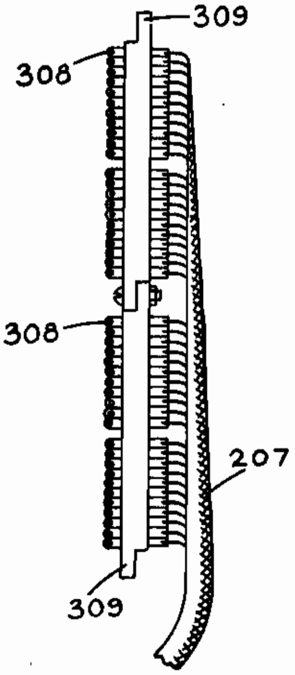


Fig. 8.



Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

PUBLISHED

JUNE 8, 1943.

BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24 1938

Serial No.
209,832

39 Sheets-Sheet 5

Fig. 9.

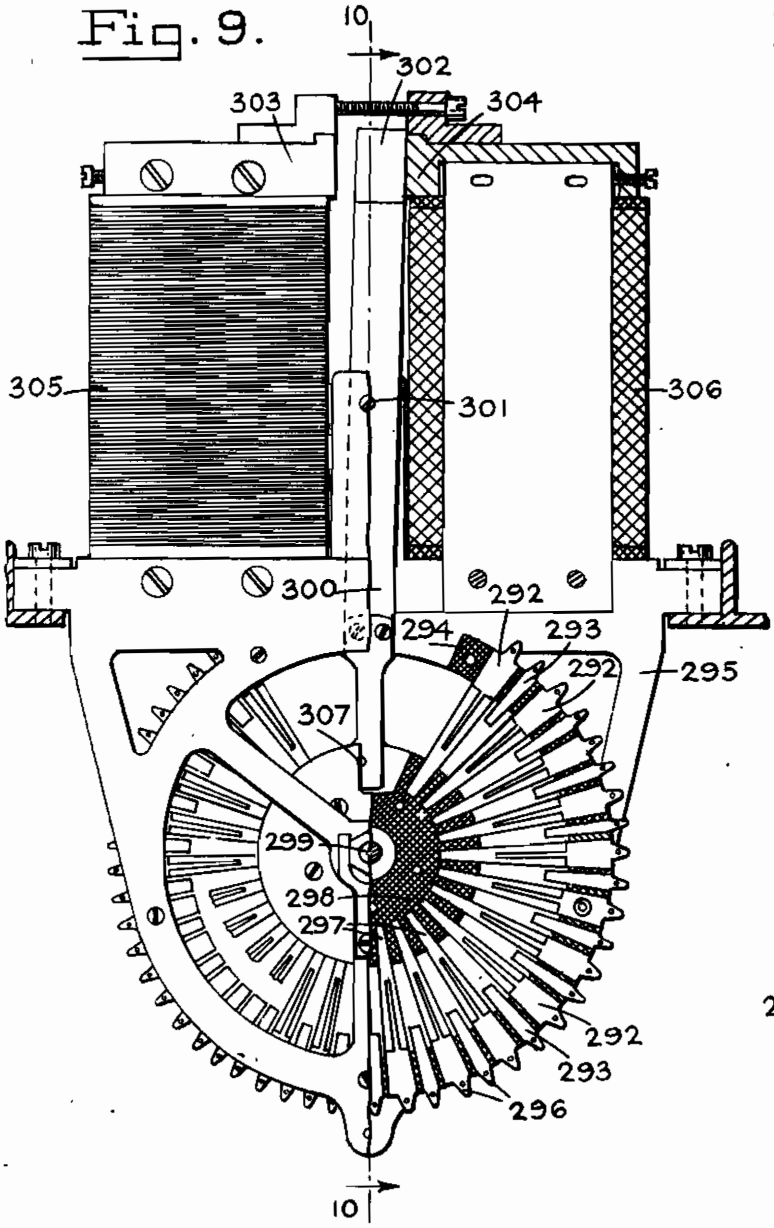
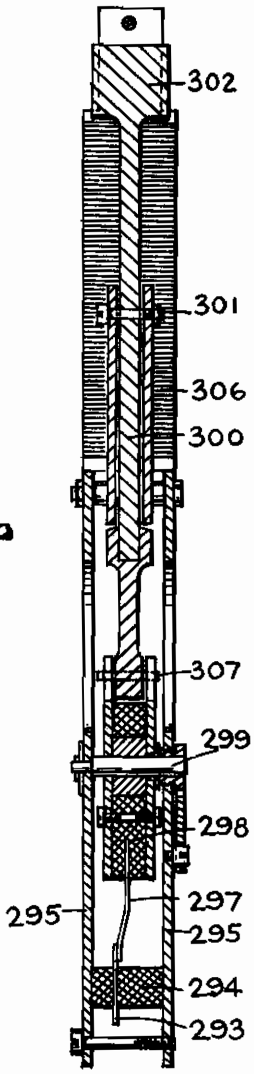


Fig. 10.



Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

PUBLISHED

JUNE 8, 1943.

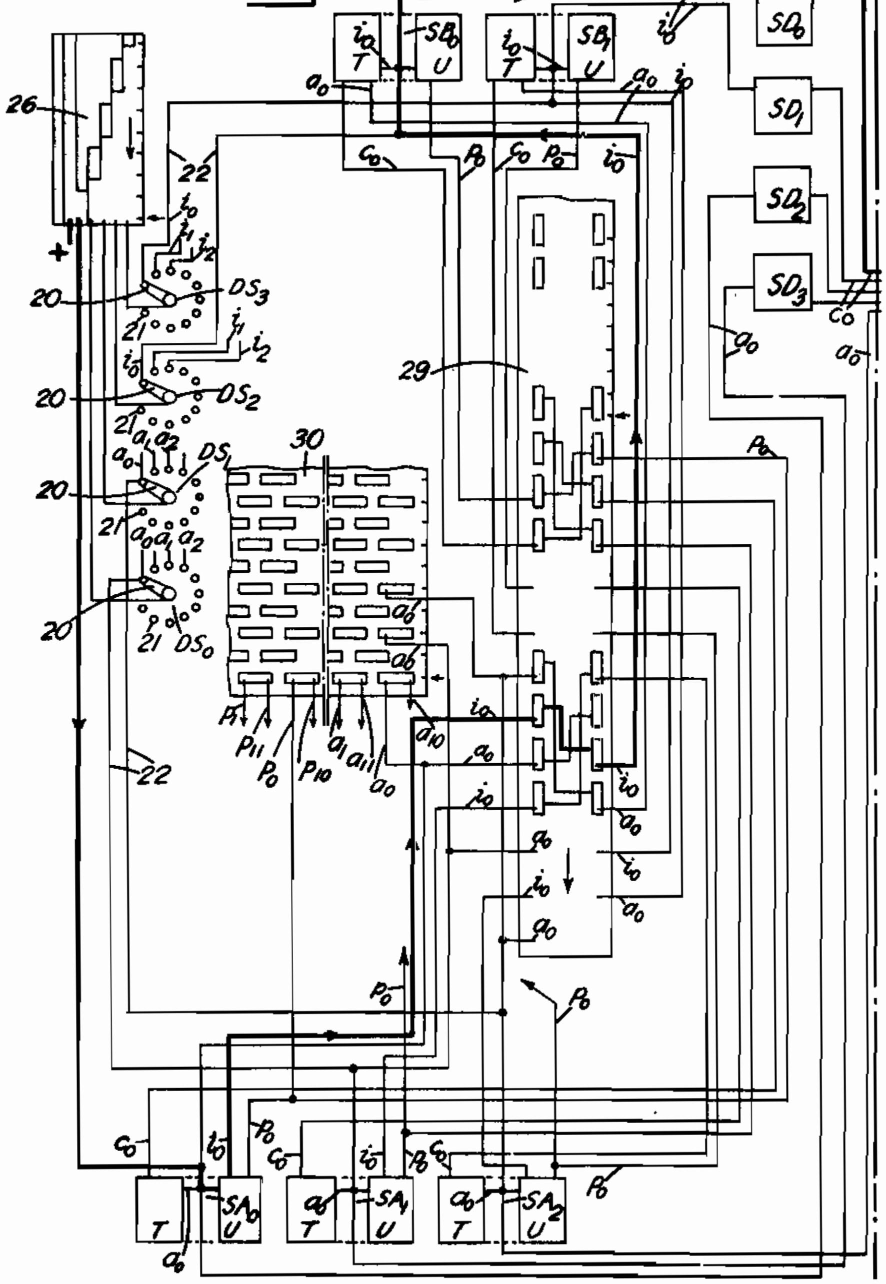
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No. 209,832

39 Sheets-Sheet 6

Fig. 11A.



Inventor
Fritz Mezger
by Young, Emery + Thompson
attys.

PUBLISHED

JUNE 8, 1943.

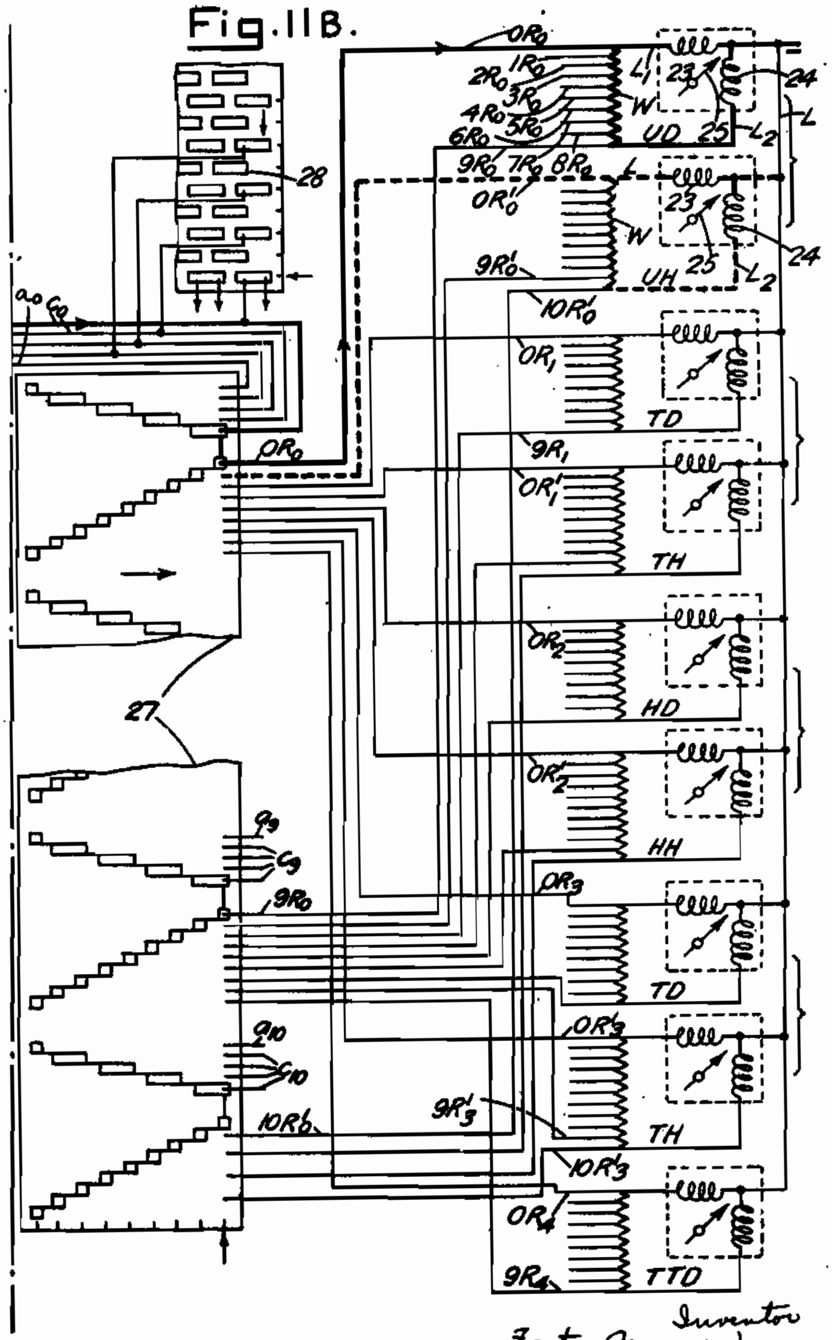
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets-Sheet 7

Fig. 11B.



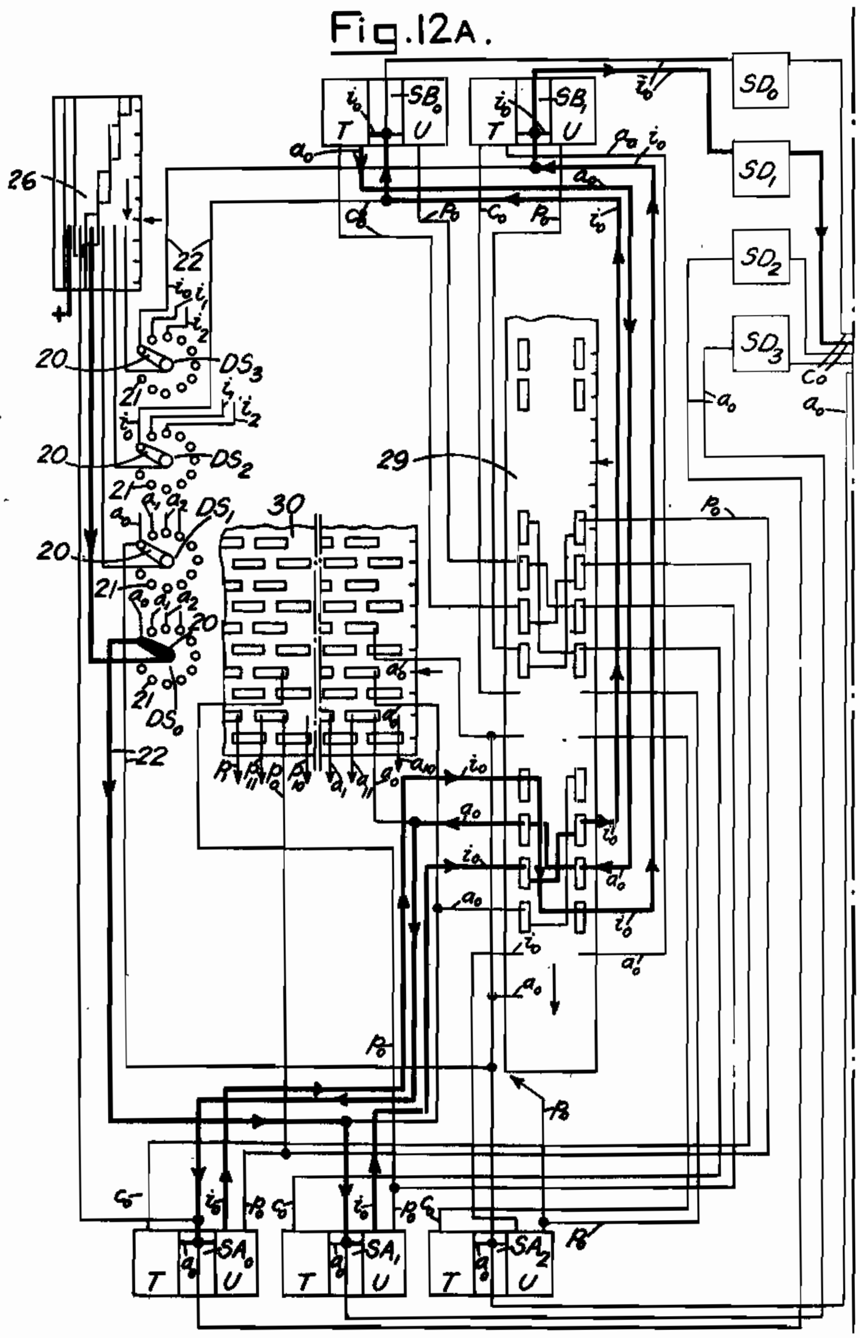
Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832
39 Sheets-Sheet 8

Fig. 12A.



Fritz Mezger Inventor
by Young, Emery & Thompson attys.

PUBLISHED

JUNE 8, 1943.

BY A. P. C.

F. MEZGER

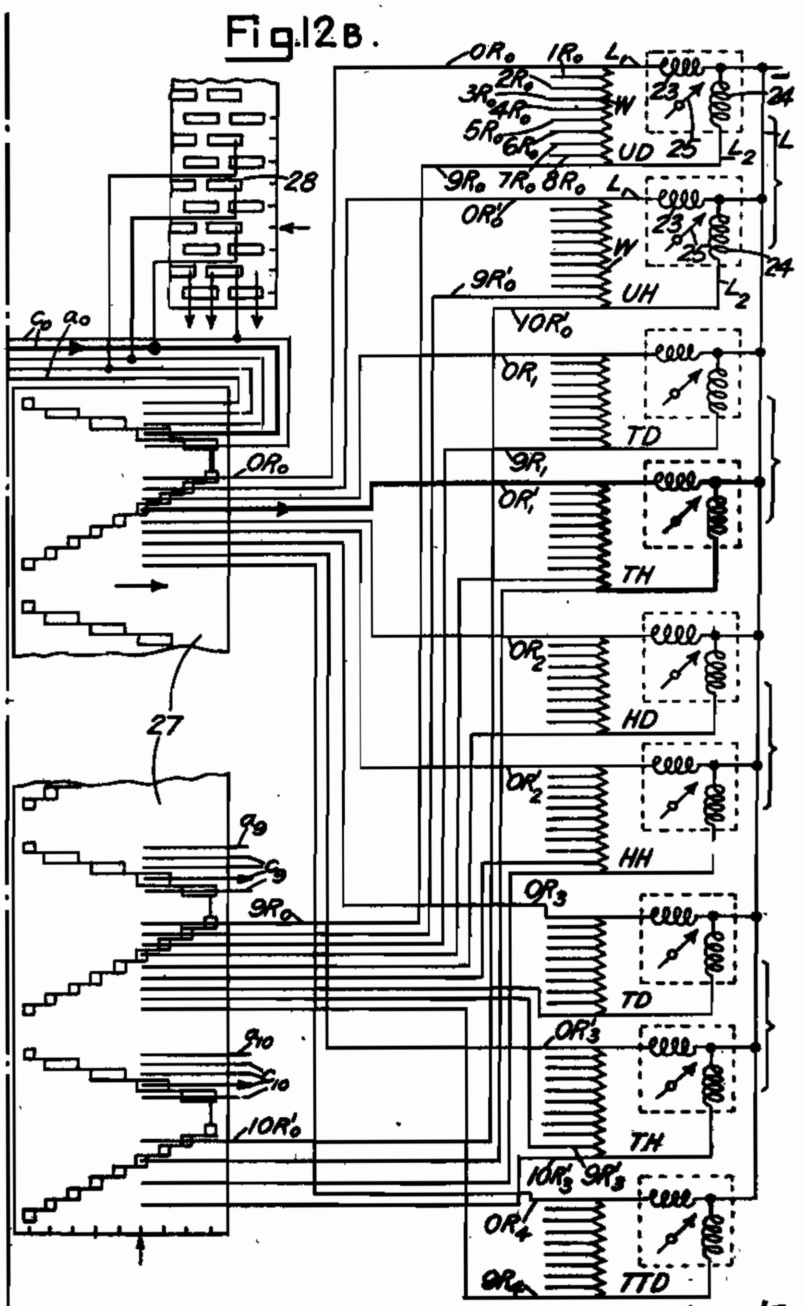
PROCESS AND DEVICE FOR ELECTRICAL CALCULATION

Filed May 24, 1938

Serial No. 209,832

39 Sheets-Sheet 9

Fig.12B.



Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

PUBLISHED

JUNE 8, 1943.

BY A. P. C.

F. MEZGER

PROCESS AND DEVICE FOR ELECTRICAL CALCULATION

Filed May 24, 1938

Serial No. 209,832

39 Sheets-Sheet 10

Fig. 13.

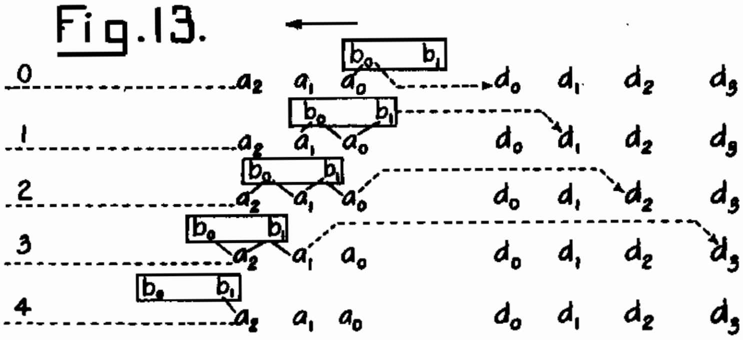


Fig. 14.

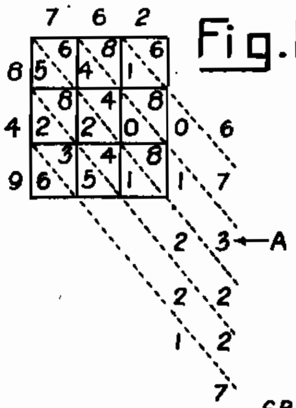


Fig. 15.

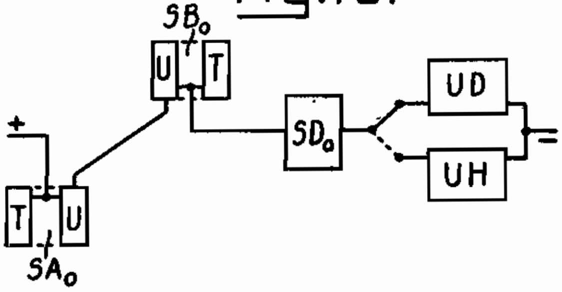


Fig. 16.

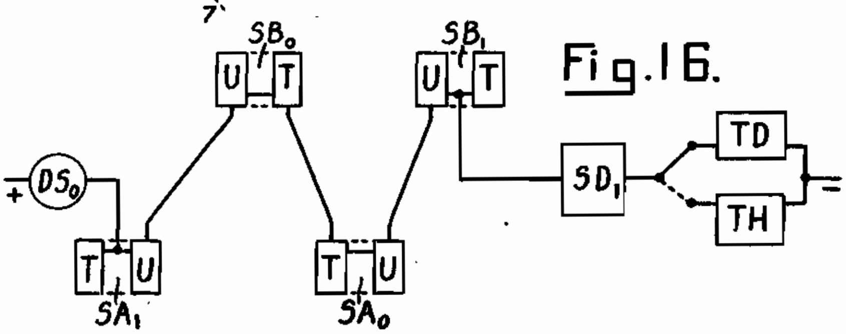
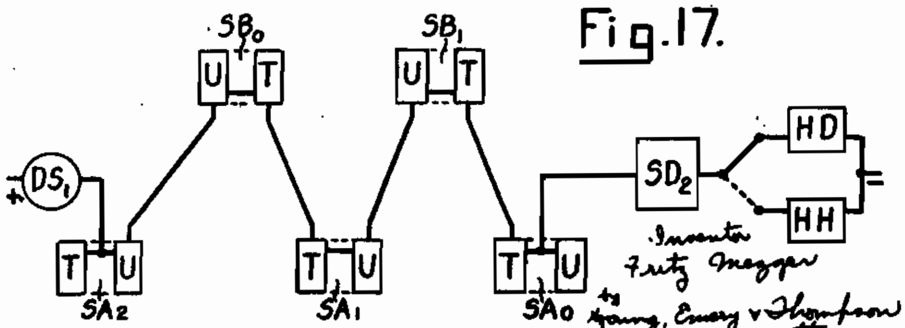


Fig. 17.



Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

PUBLISHED

JUNE 8, 1943.

BY A. P. C.

F. MEZGER

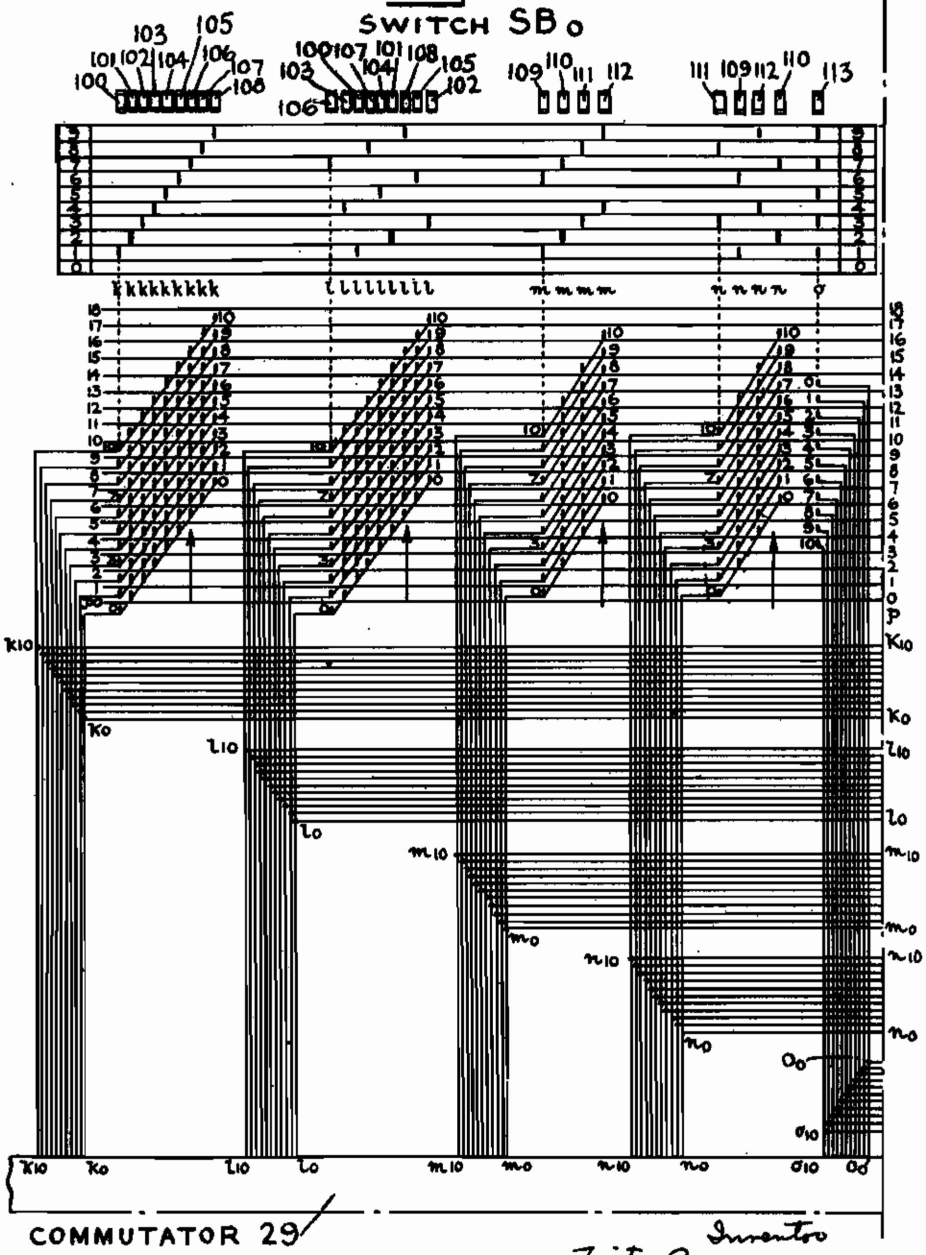
PROCESS AND DEVICE FOR ELECTRICAL CALCULATION

Filed May 24, 1938

Serial No. 209,832

39 Sheets-Sheet 11

Fig. 18 A.



Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

PUBLISHED

JUNE 8, 1943.

BY A. P. C.

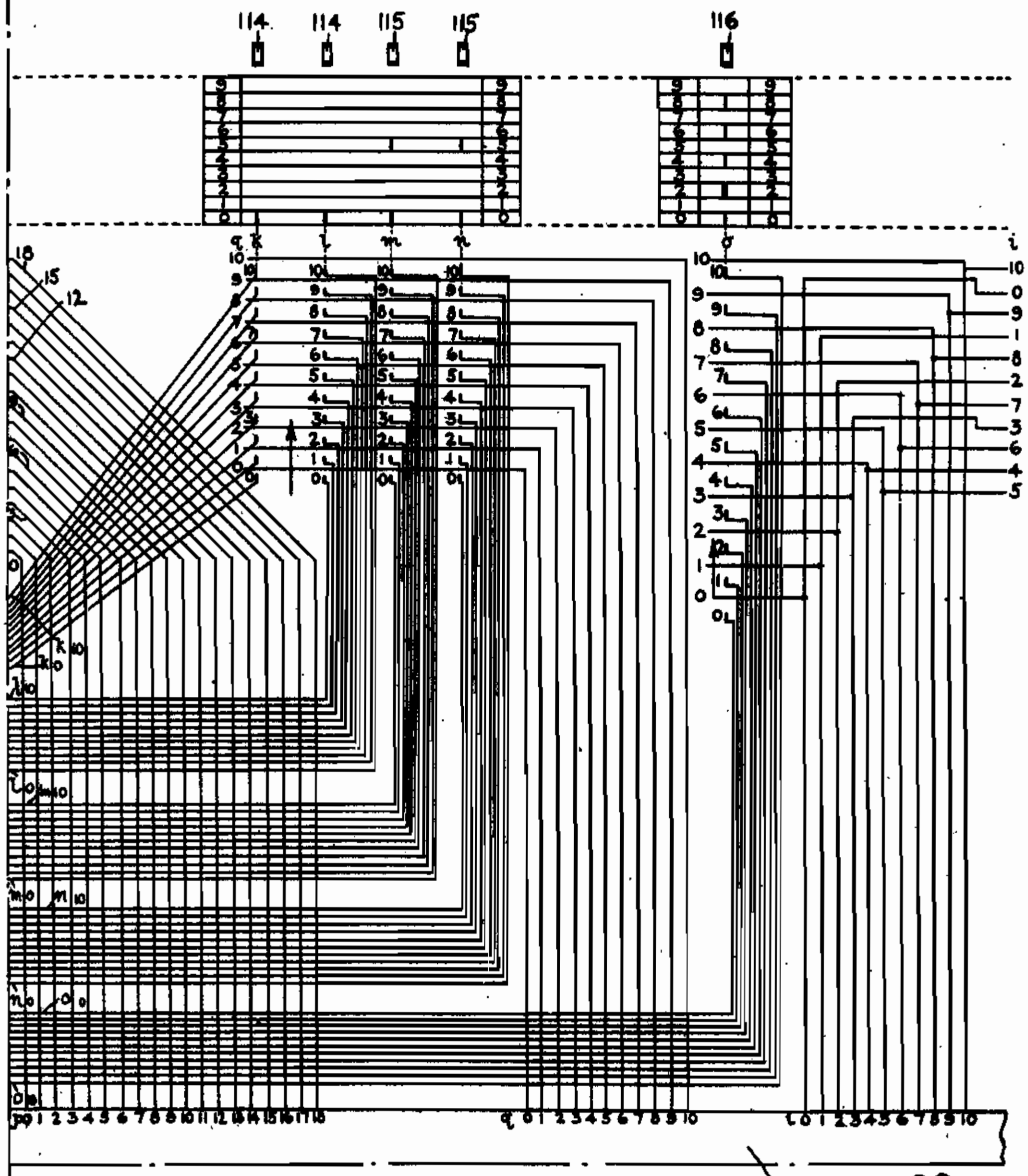
F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets—Sheet 12

Fig. 18 B.

SWITCH SBo



Inventor:
Fritz Mezger
By Young Emery & Thompson
Attorneys

PUBLISHED

JUNE 8, 1943.

BY A. P. C.

F. MEZGER

PROCESS AND DEVICE FOR ELECTRICAL CALCULATION

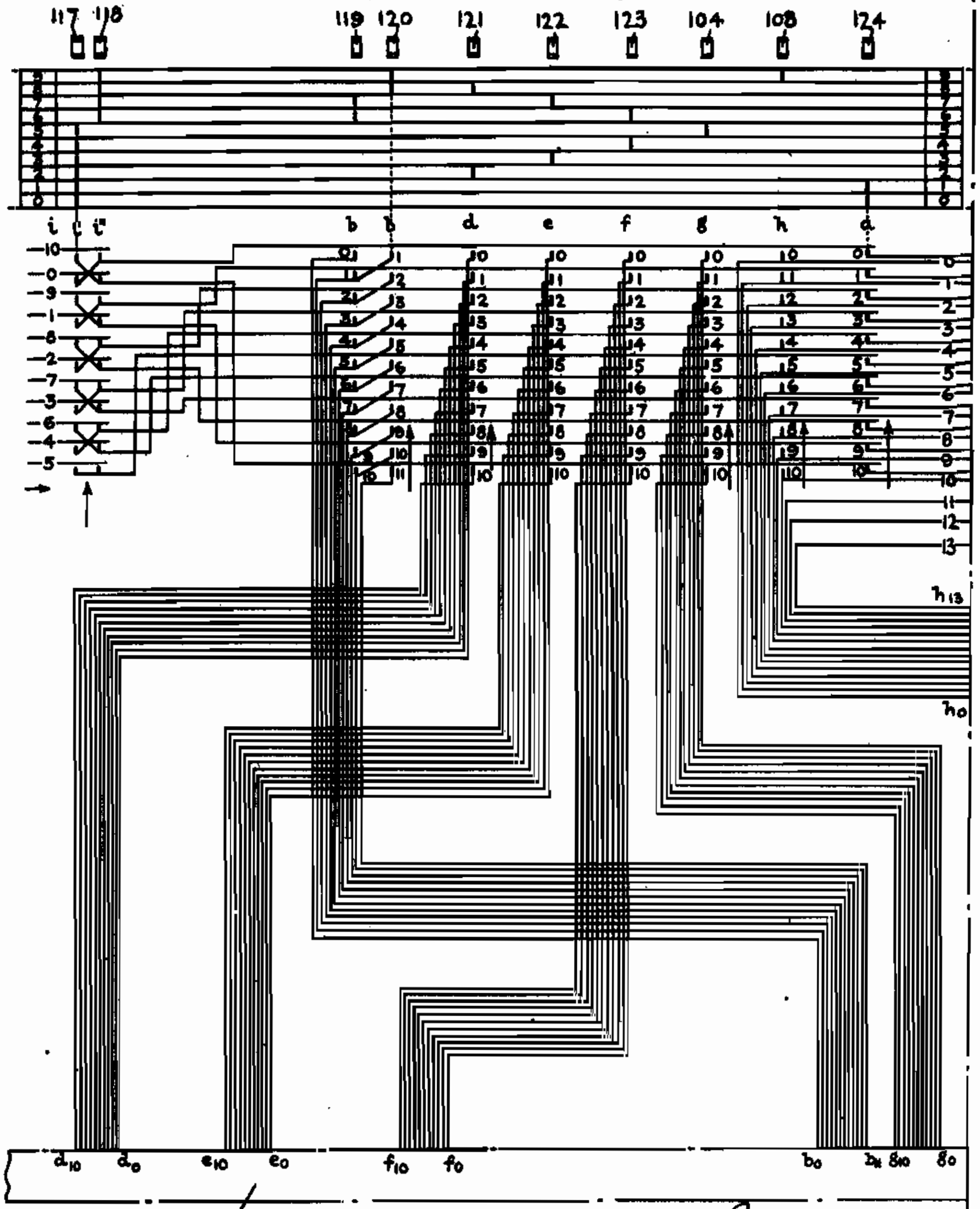
Filed May 24, 1938

Serial No. 209,832

39 Sheets-Sheet 13

Fig. 18 C.

SWITCH SBo



COMMUTATOR 29

Inventor:
Fritz Mezger
By Young Emery & Thompson
Attorneys

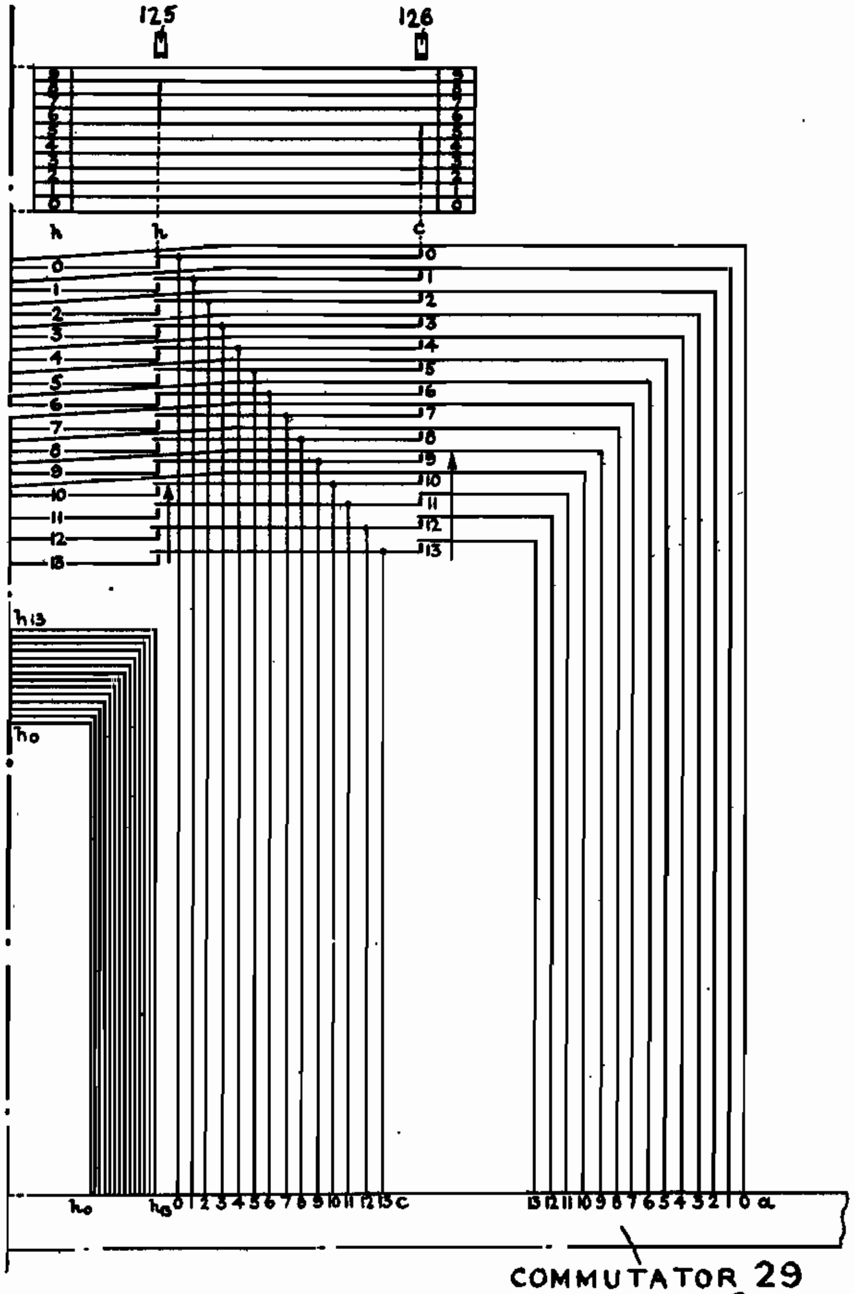
PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets-Sheet 14

Fig. 18 D.
SWITCH SBo



COMMUTATOR 29

Inventor:
Fritz Mezger
By Young Emery & Thompson
attorneys

PUBLISHED

JUNE 8, 1943.

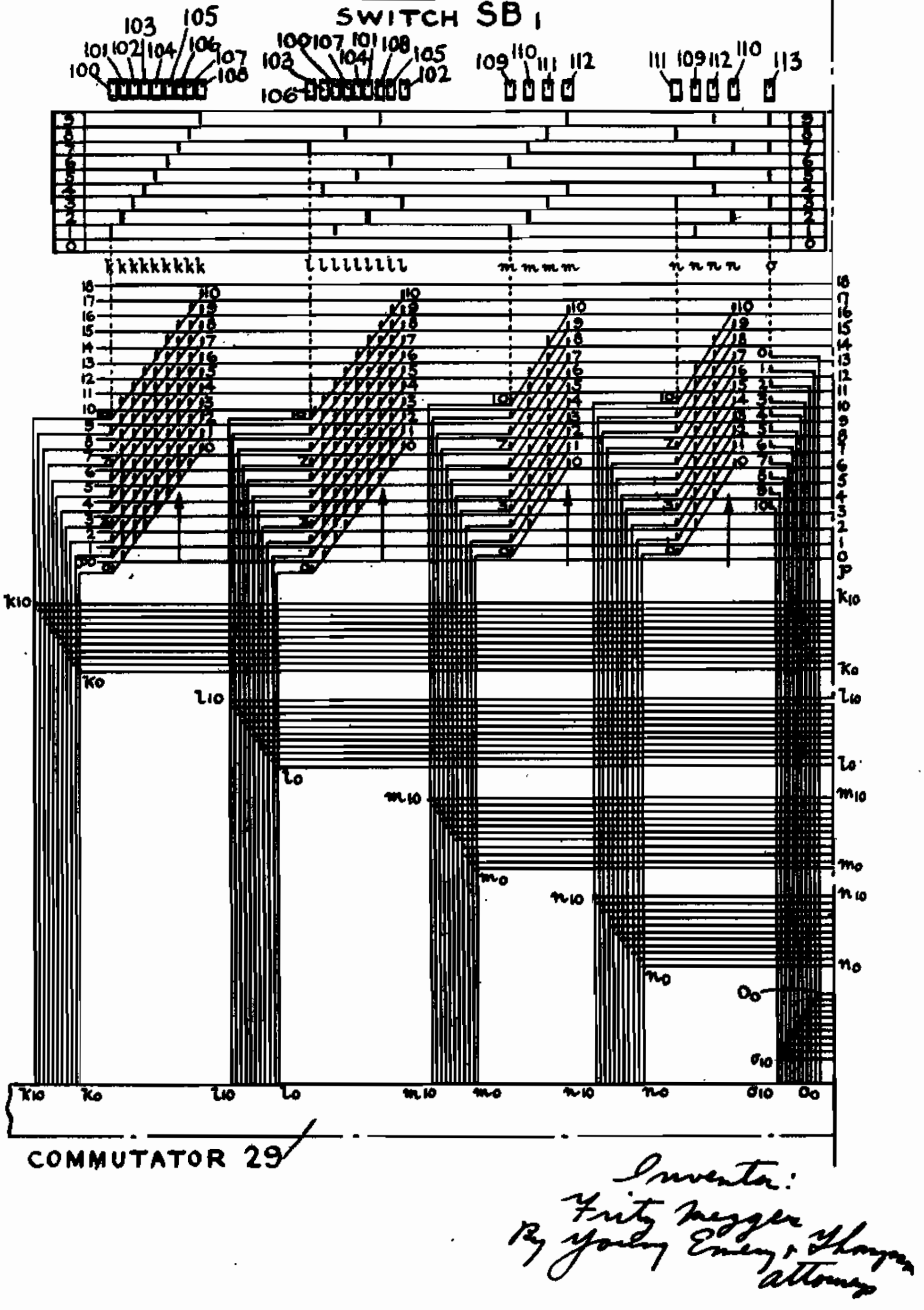
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets–Sheet 15

Fig. 19A.



PUBLISHED

JUNE 8, 1943.

BY A. P. C.

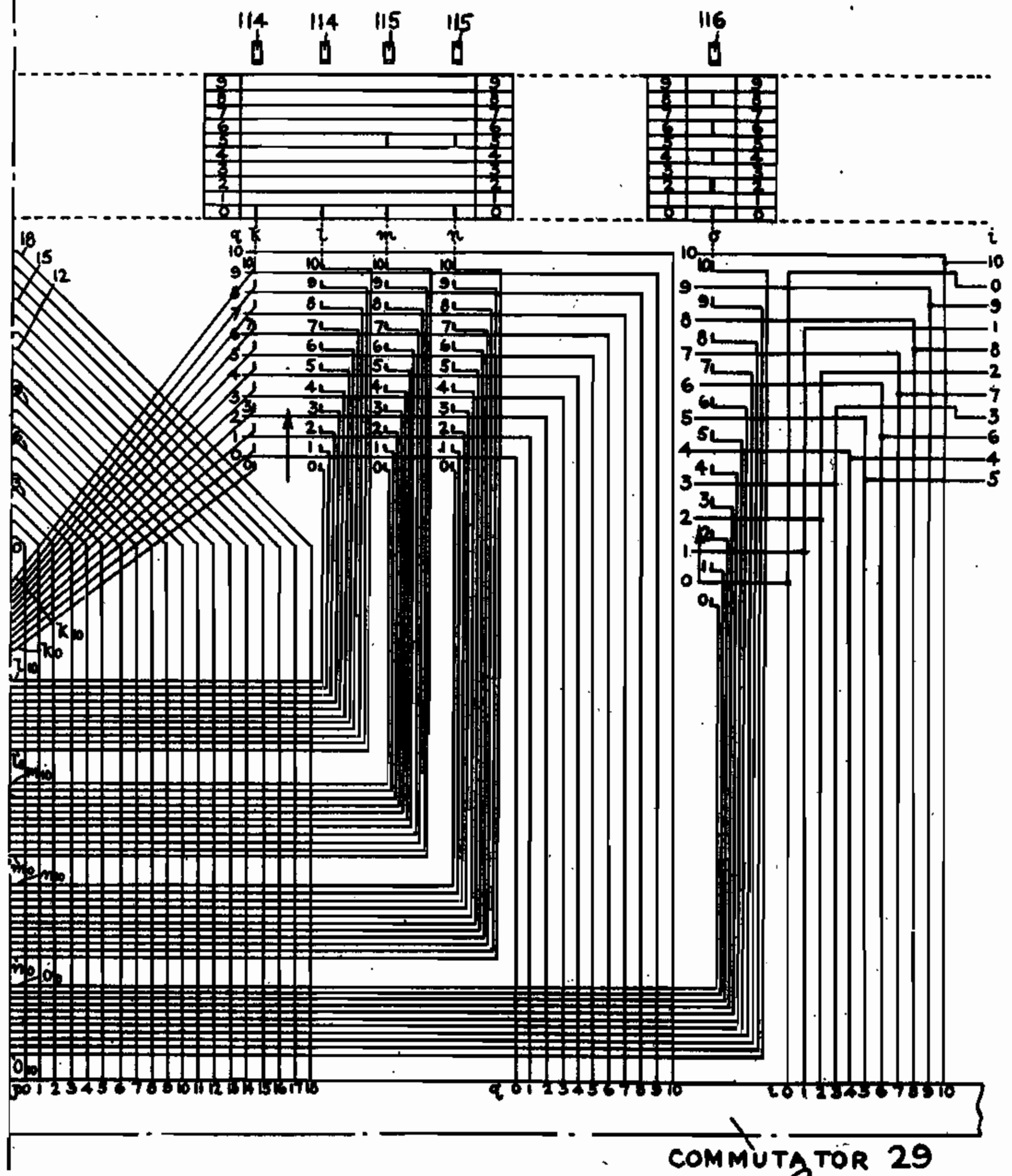
F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets-Sheet 16

Fig. 19 B.

SWITCH SB1



COMMUTATOR 29

Inventor:
Fritz Mezger
By Young, Emery & Thompson
Attorneys

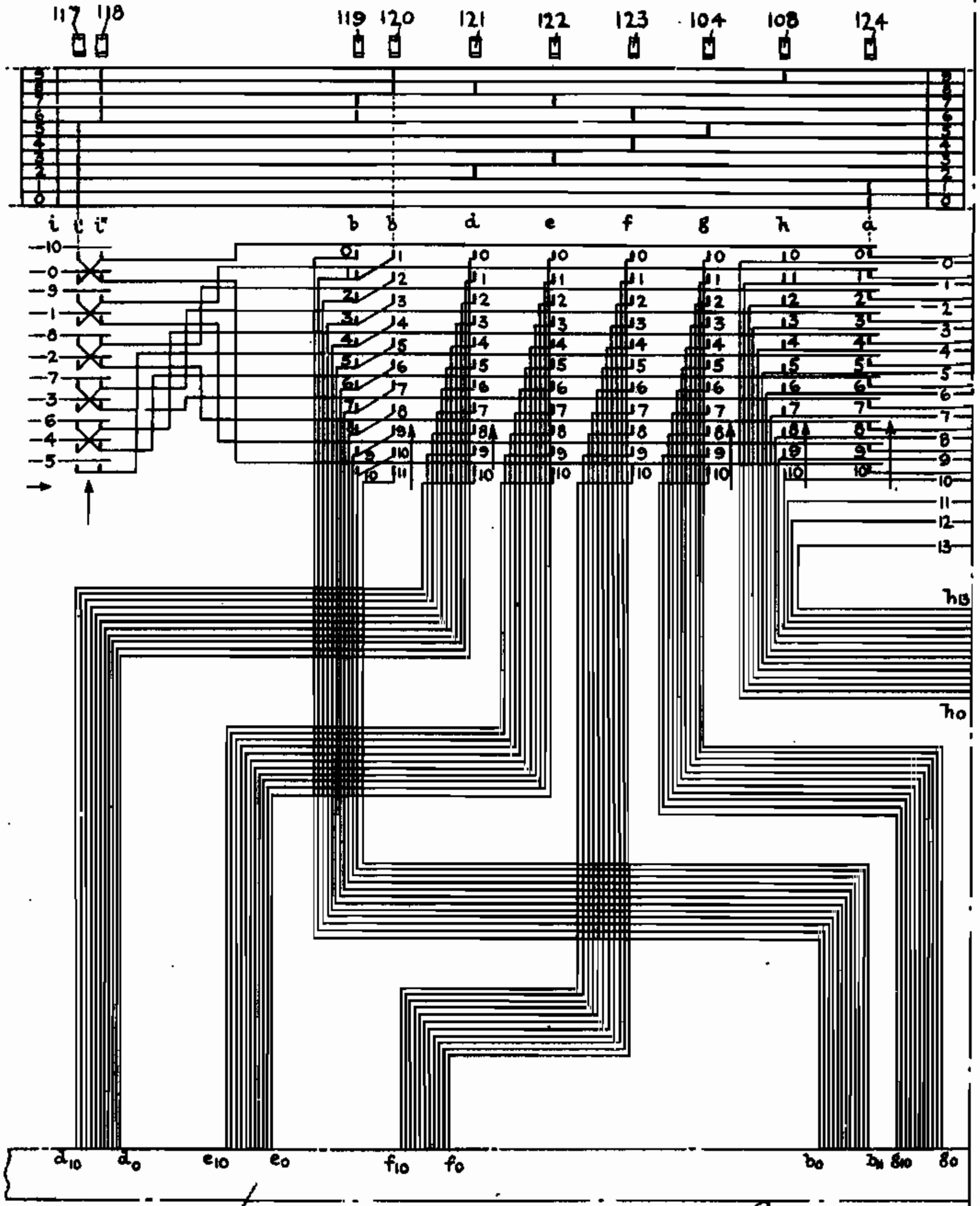
PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

Fig. 19 C.

SWITCH SB1



COMMUTATOR 29

Inventor:
Fritz Mezger
By Young, Emery & Thompson
Attorneys

PUBLISHED

JUNE 8, 1943.

BY A. P. C.

F. MEZGER

PROCESS AND DEVICE FOR ELECTRICAL CALCULATION

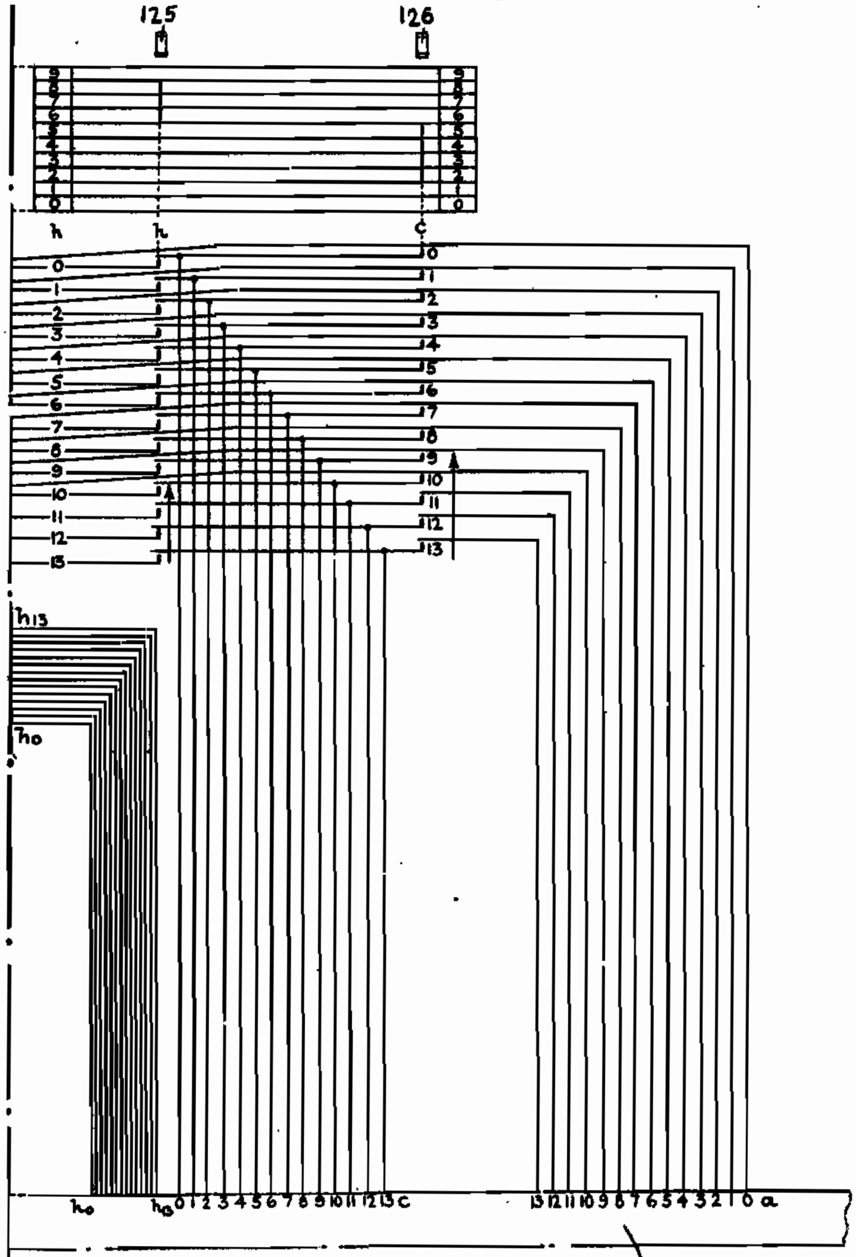
Filed May 24, 1938

Serial No. 209,832

39 Sheets-Sheet 18

Fig. 19 D.

SWITCH SB_1



COMMUTATOR 29

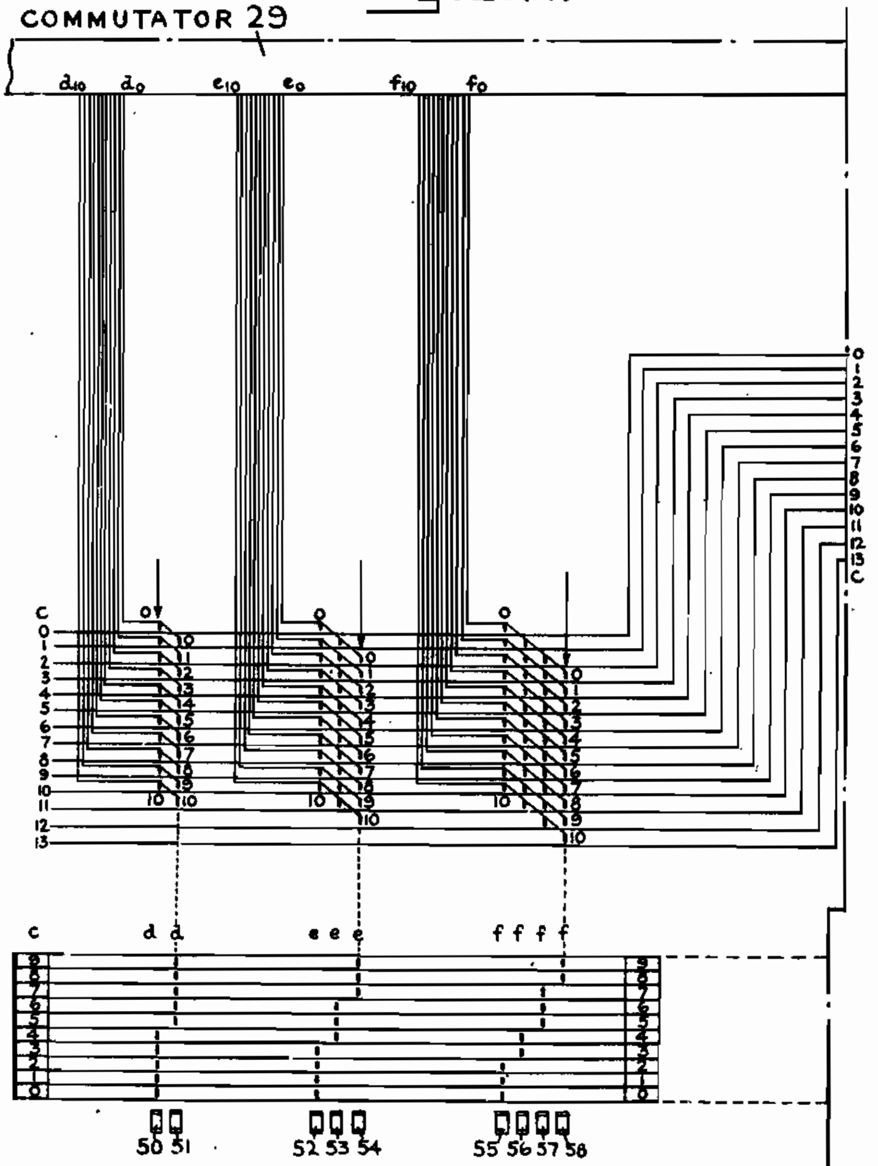
Inventor:
Fritz Mezger
By Young, Emery & Thompson
Attorneys

PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832
39 Sheets-Sheet 19

Fig. 20A.



SWITCH SA0

Inventor:
Fritz Mezger
By Young, Emery & Thompson
Attorneys

PUBLISHED

JUNE 8, 1943.

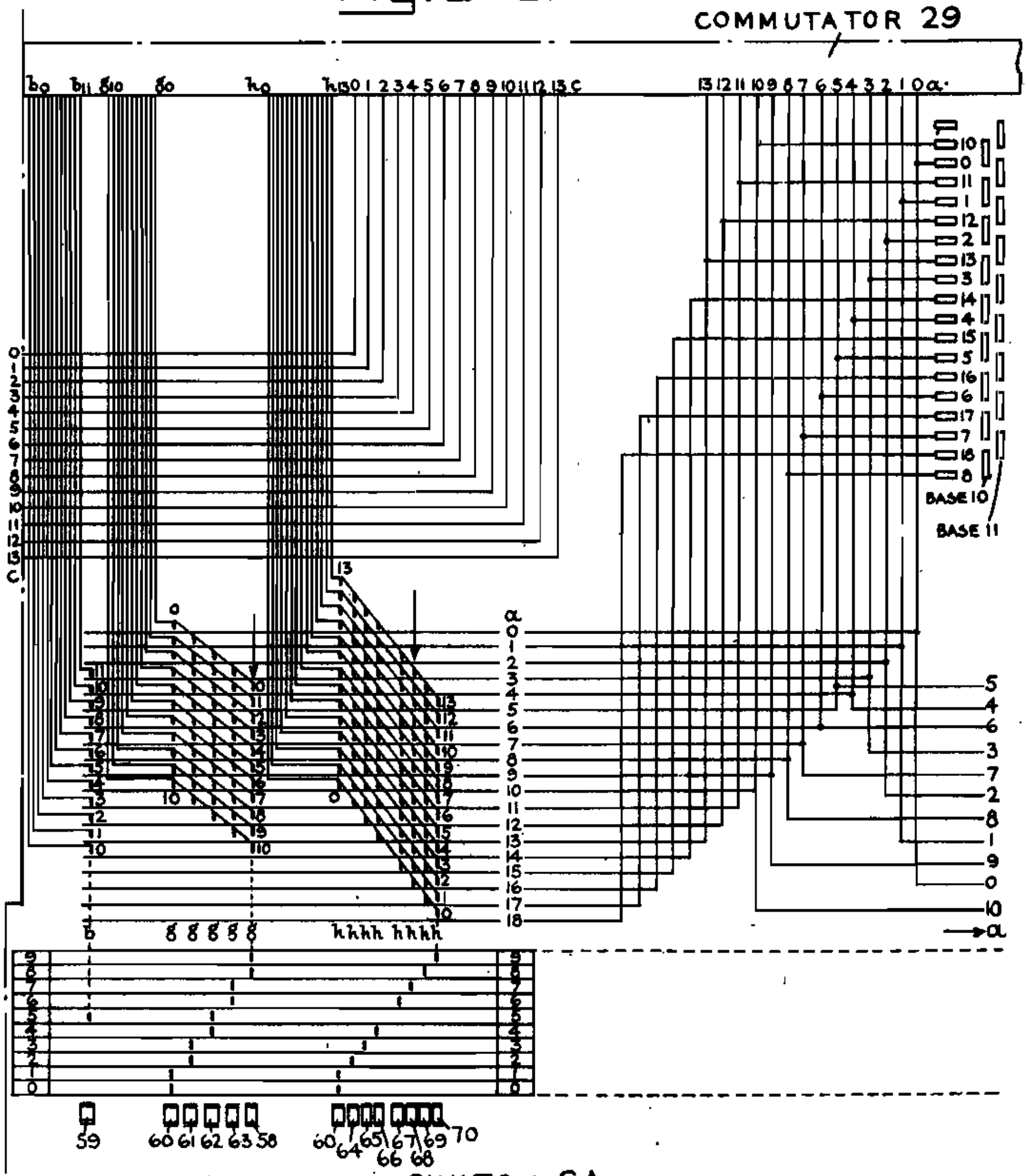
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets-Sheet 20

Fig. 20 B.



Inventor:
Fritz Mezger
By Young Emery & Thompson
Attorneys

PUBLISHED

JUNE 8, 1943.

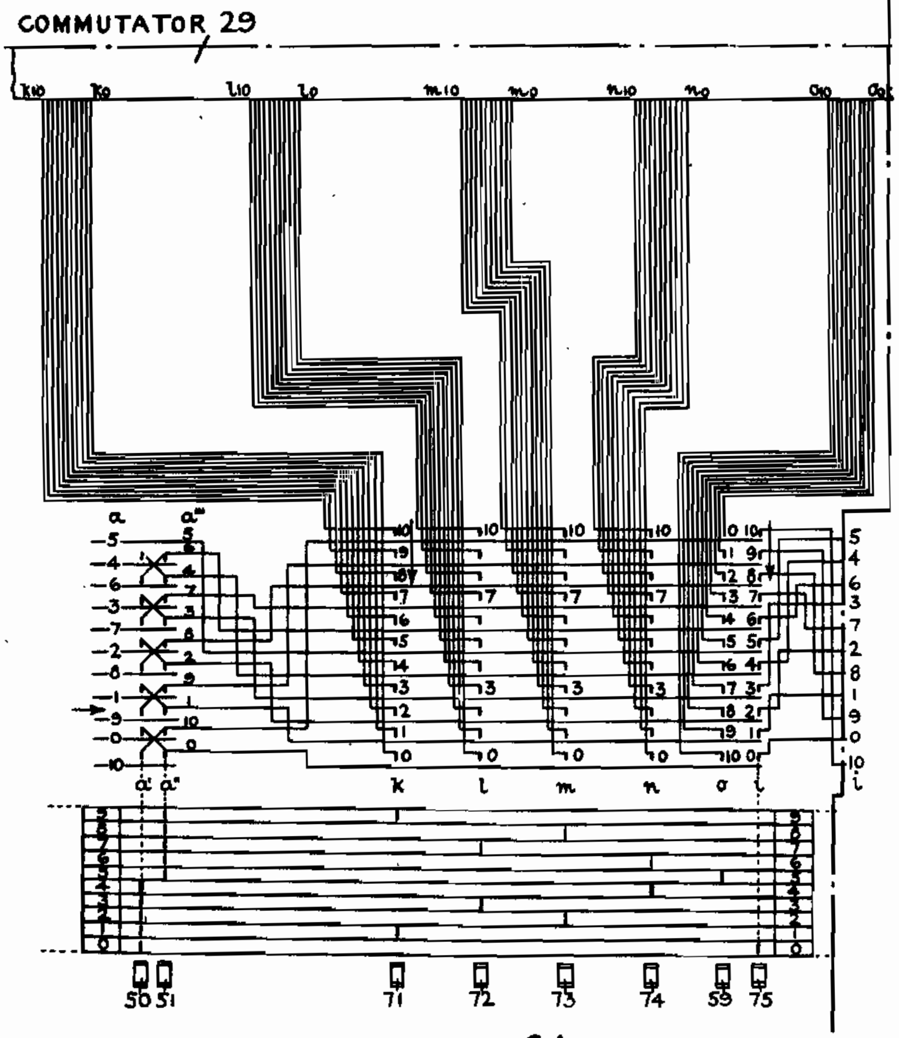
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets-Sheet 21

Fig. 20C.



SWITCH SA0

Inventor:
Fritz Mezger
By Young, Emery & Thompson
attorneys

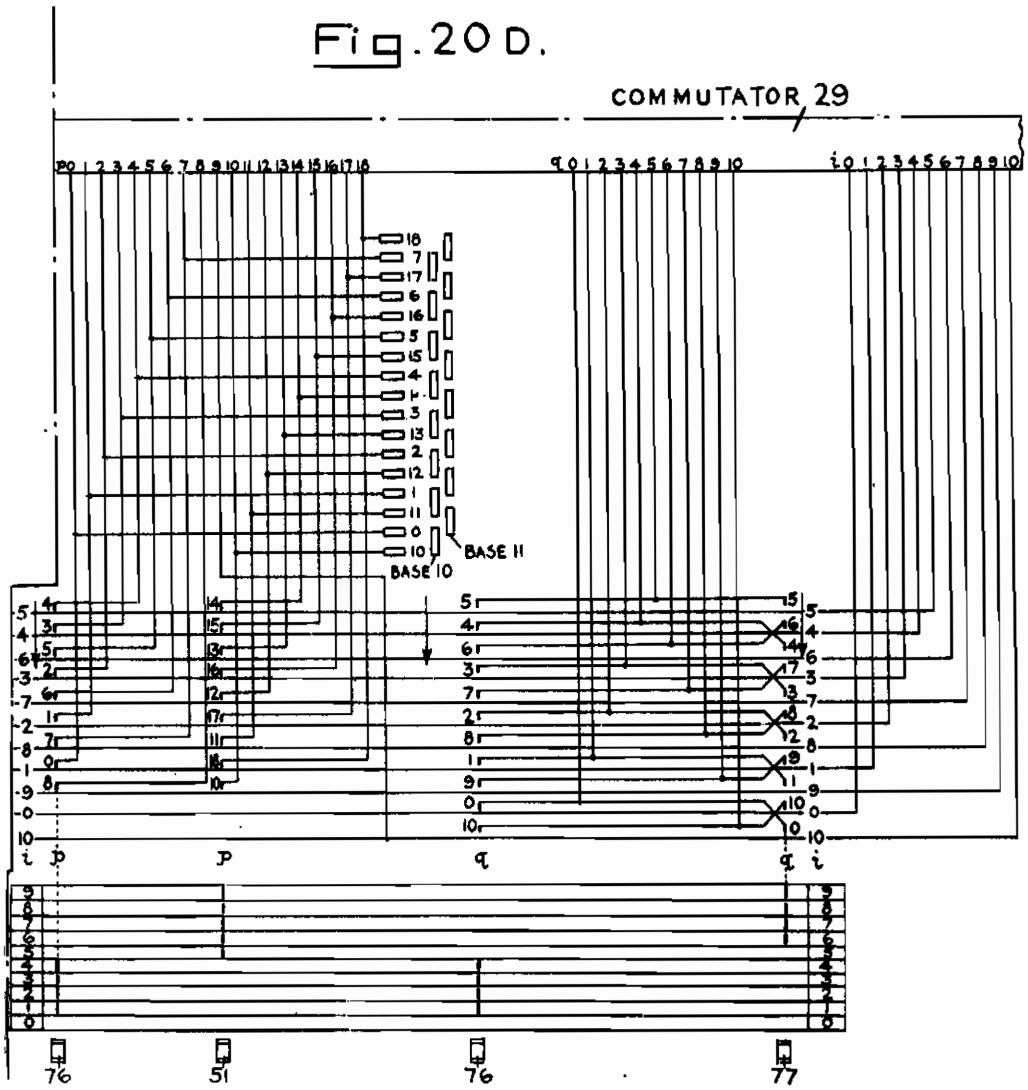
PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets-Sheet 22

Fig. 20 D.



SWITCH SAo

Inventor:
Fritz Mezger
By Young, Emery & Thompson
Attorneys

PUBLISHED

JUNE 8, 1943.

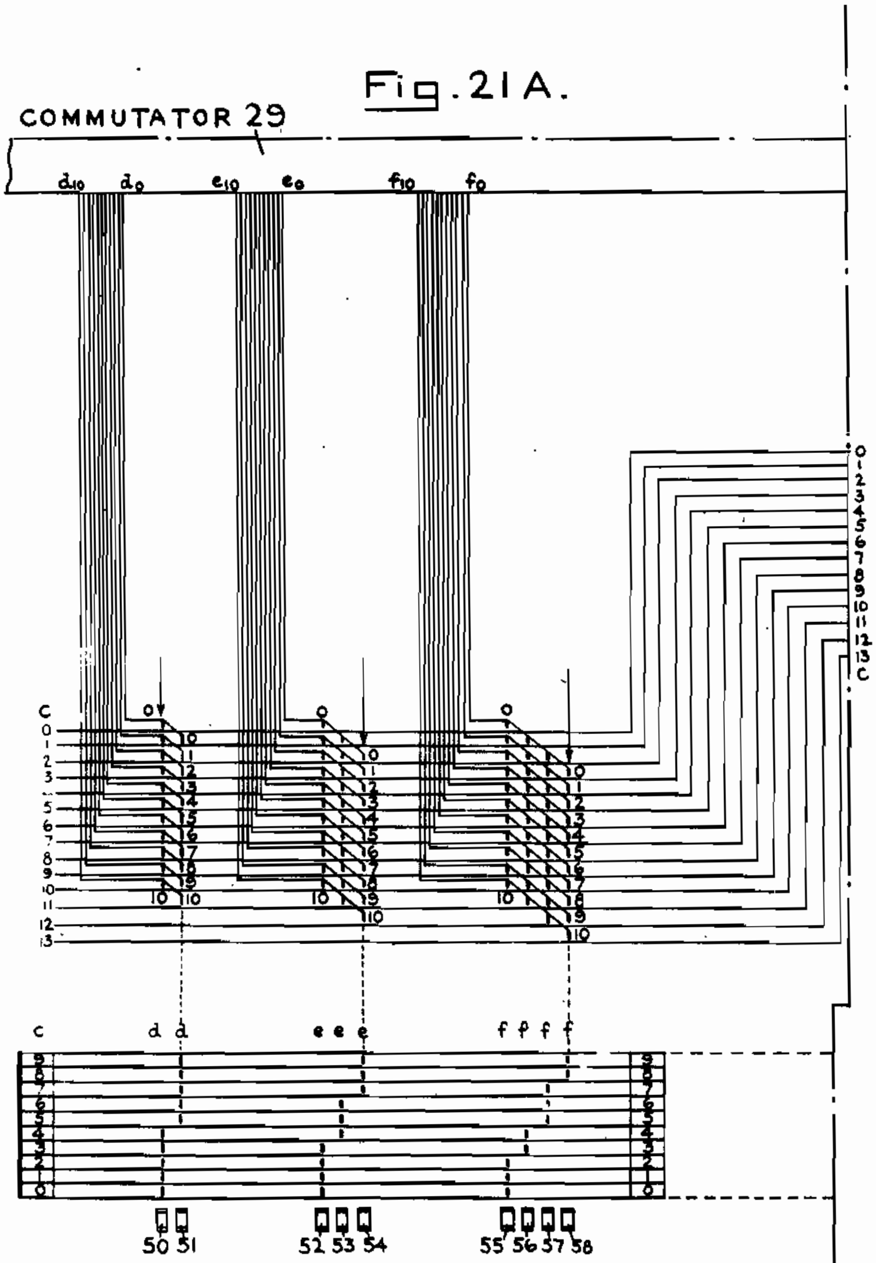
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets-Sheet 23

Fig. 21A.



Inventor:
Fritz Mezger
By Young, Emery & Thompson
Attorneys

PUBLISHED

JUNE 8, 1943.

BY A. P. C.

F. MEZGER

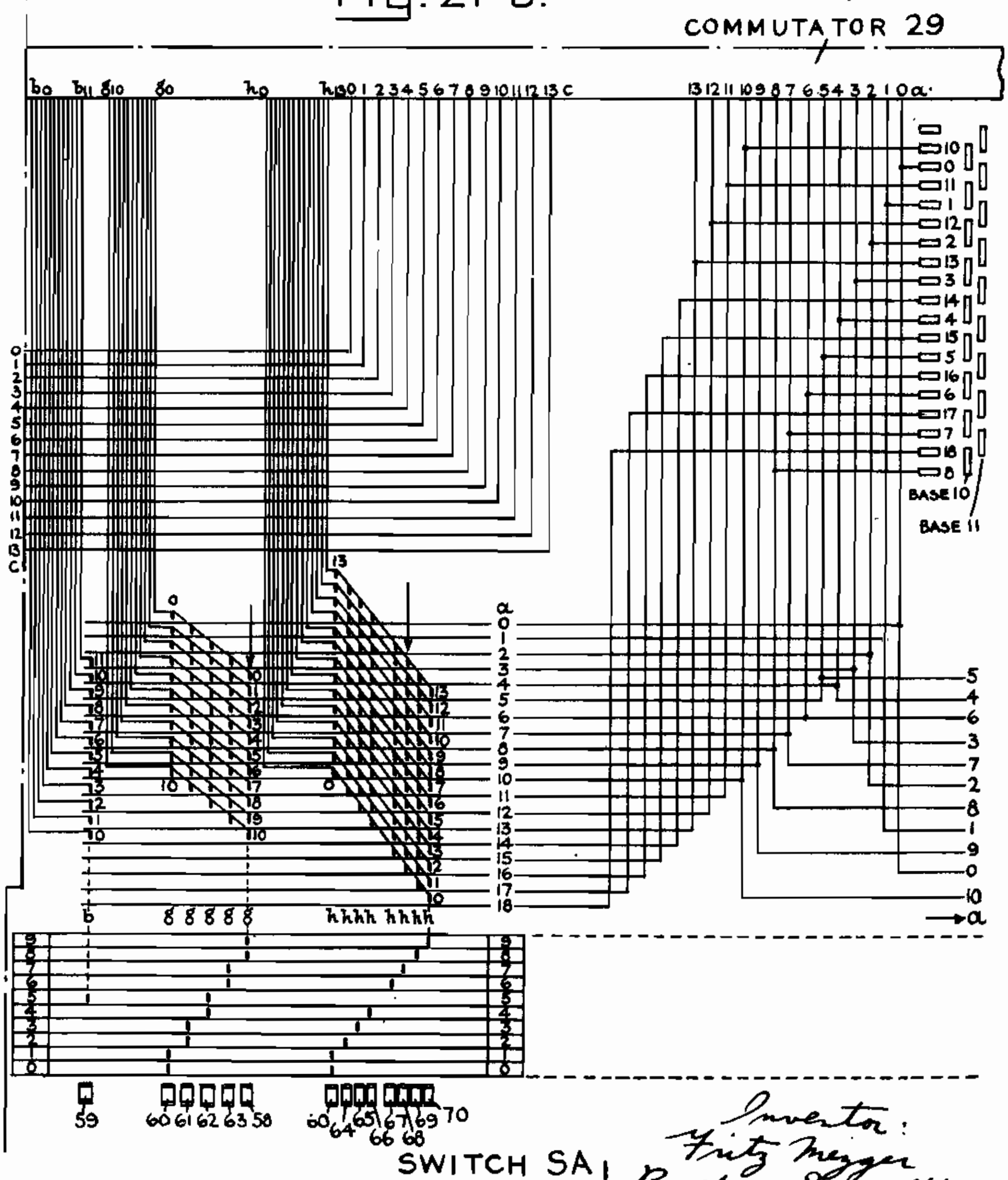
PROCESS AND DEVICE FOR ELECTRICAL CALCULATION

Filed May 24, 1938

Serial No. 209,832

39 Sheets-Sheet 24

Fig. 21 B.



Inventor:
Fritz Mezger
By Young, Emery & Thompson
Attorneys

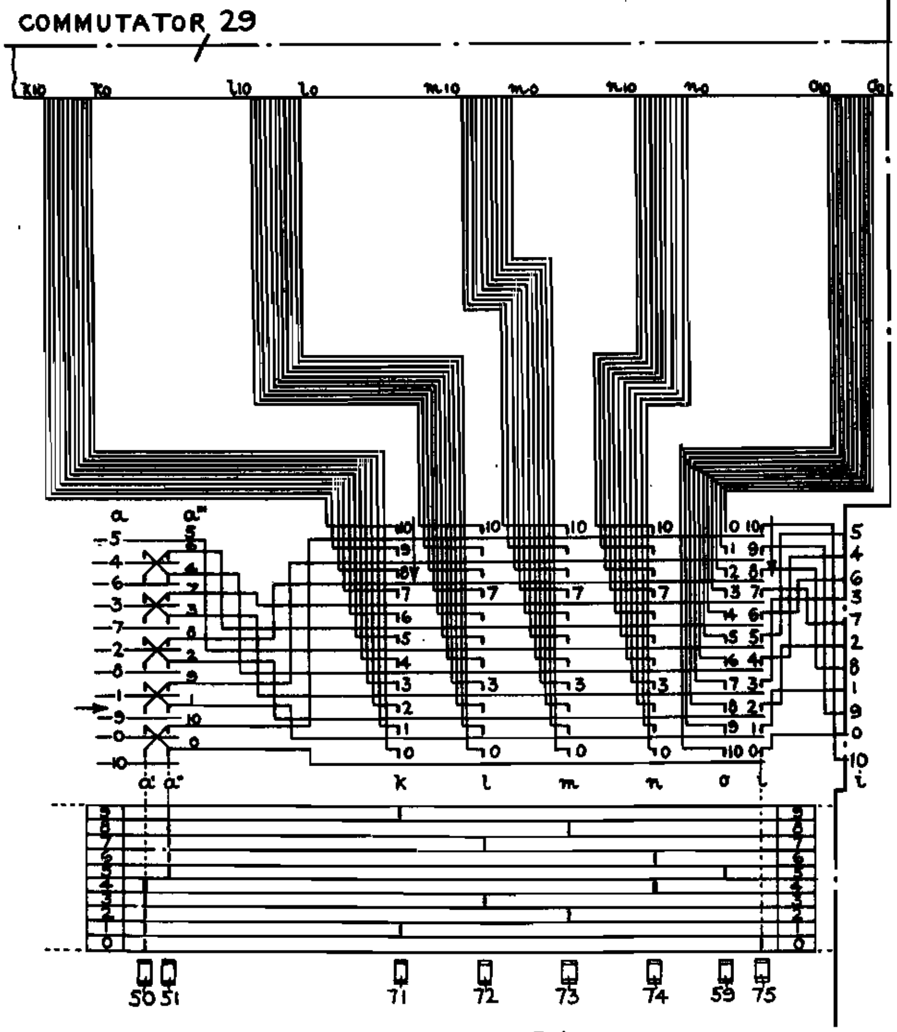
PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets-Sheet 25

Fig. 21 C.



SWITCH SA1

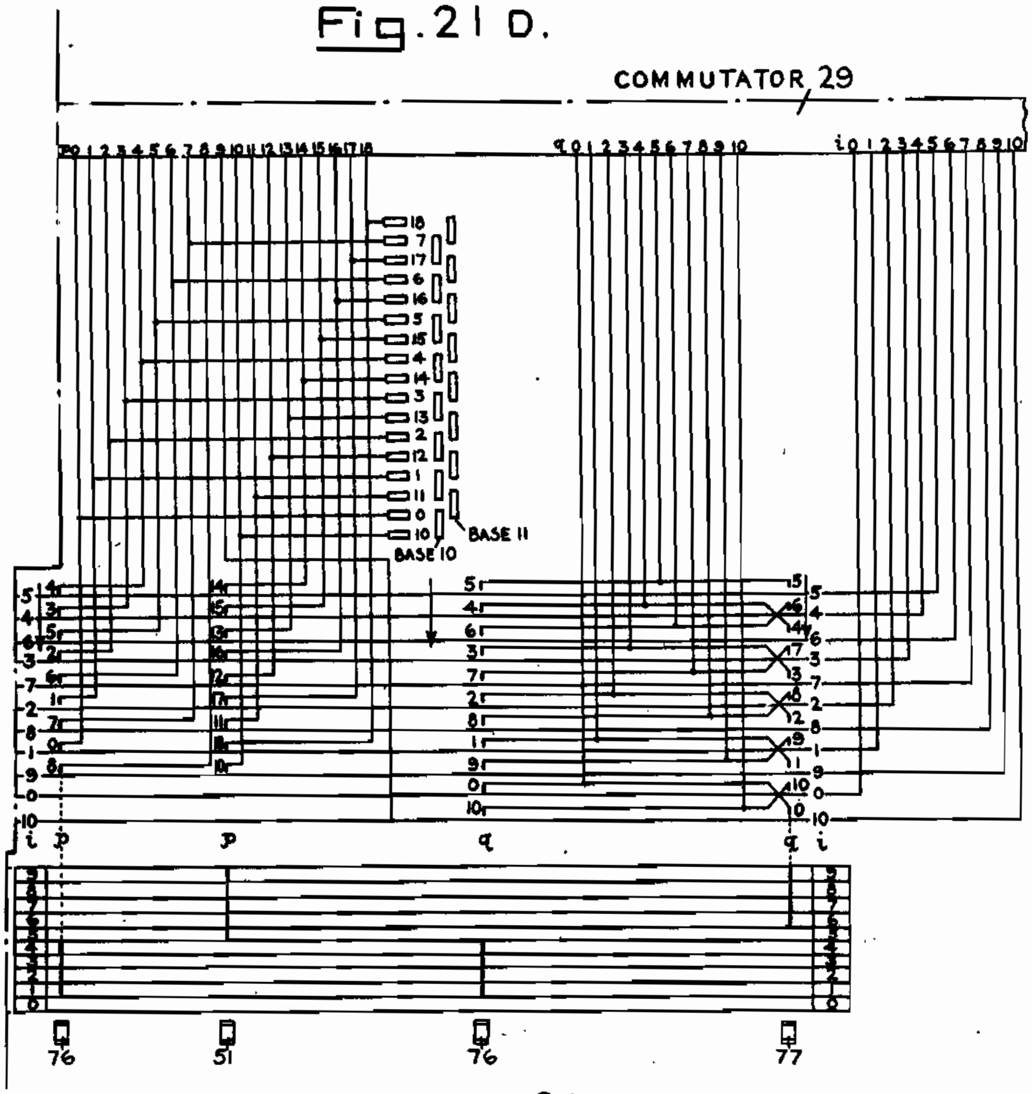
Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832
39 Sheets-Sheet 26

Fig. 21 D.



SWITCH SA1

Inventor
Fritz Mezger
by Young, Emery & Thompson

PUBLISHED

JUNE 8, 1943.

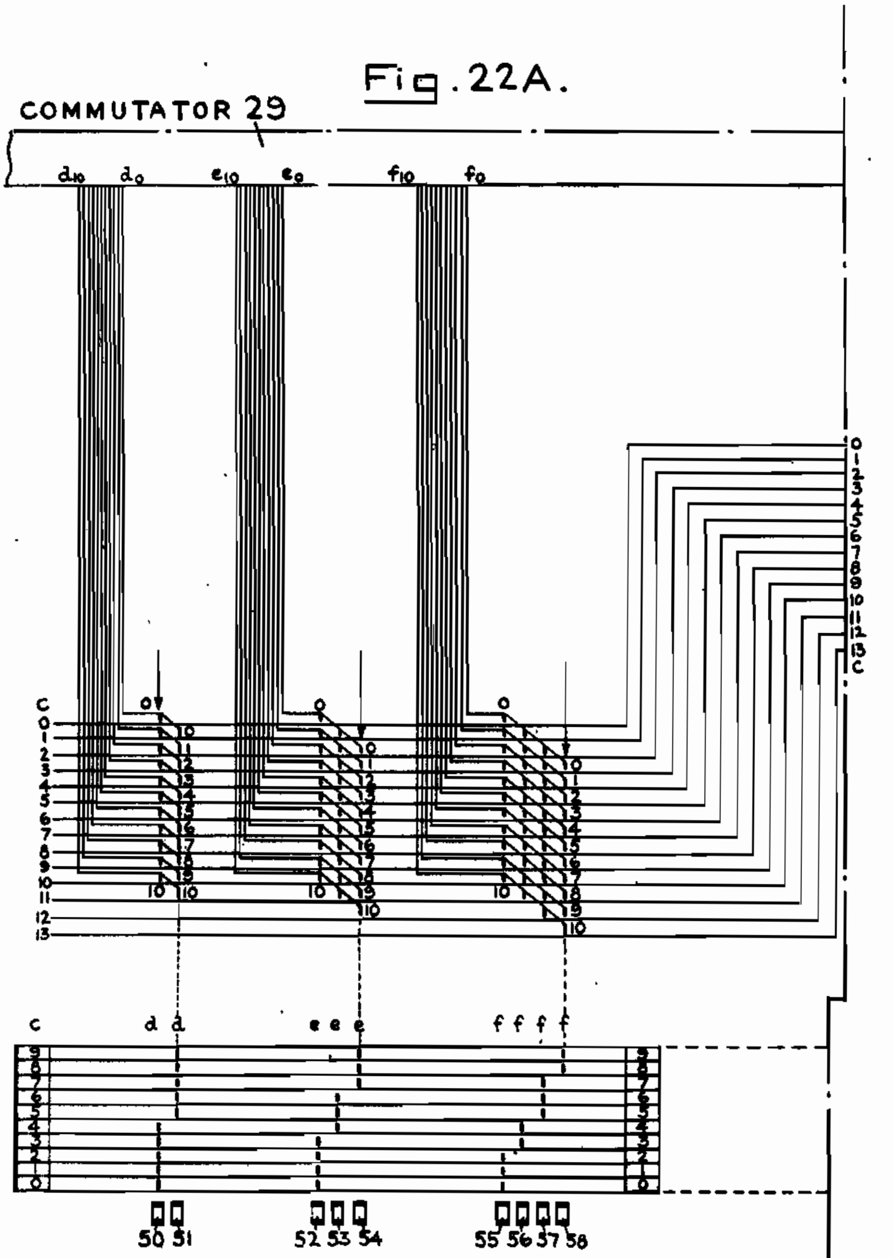
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets-Sheet 27

Fig. 22A.



Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

PUBLISHED

JUNE 8, 1943.

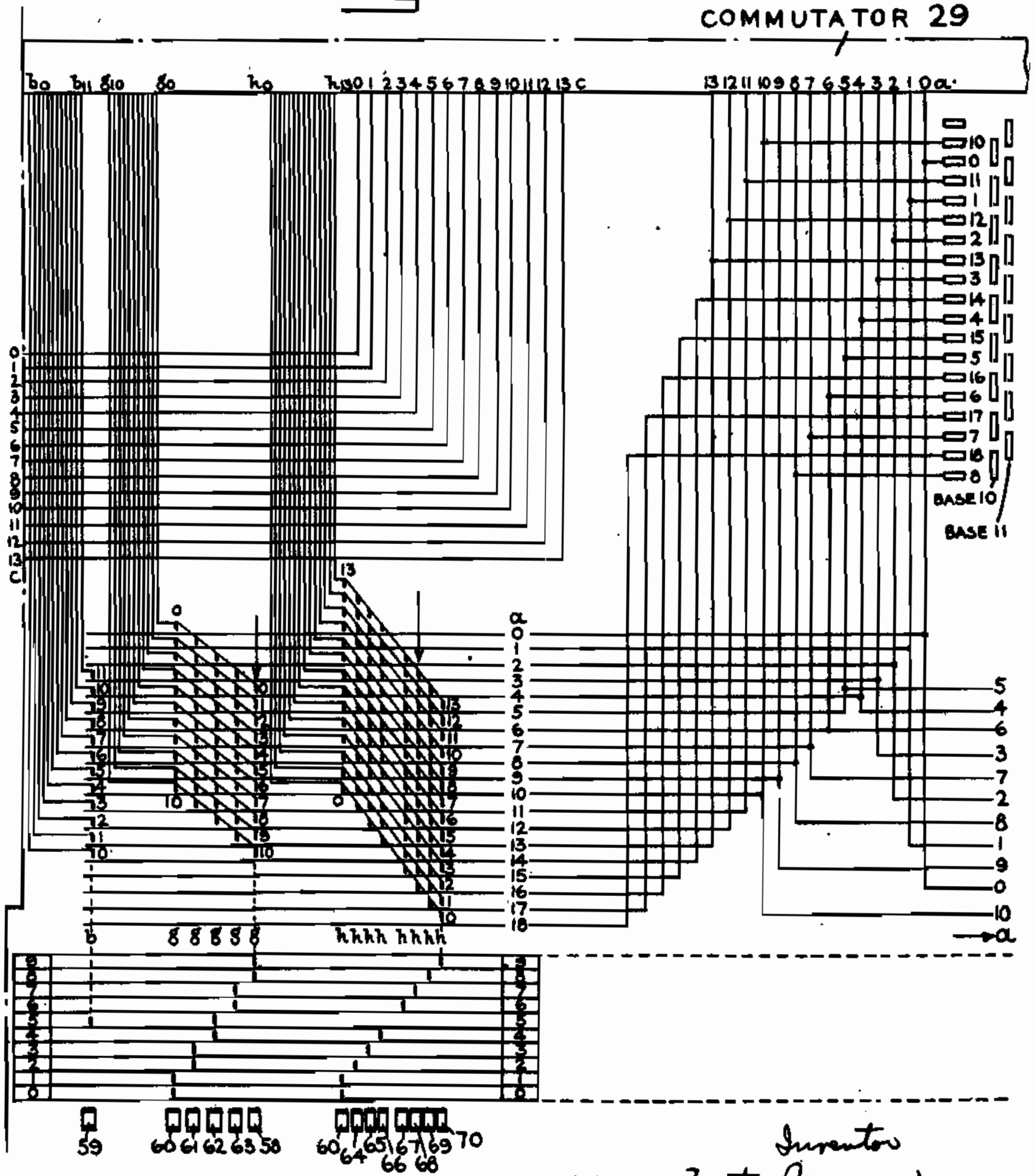
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets-Sheet 28

Fig. 22 B.



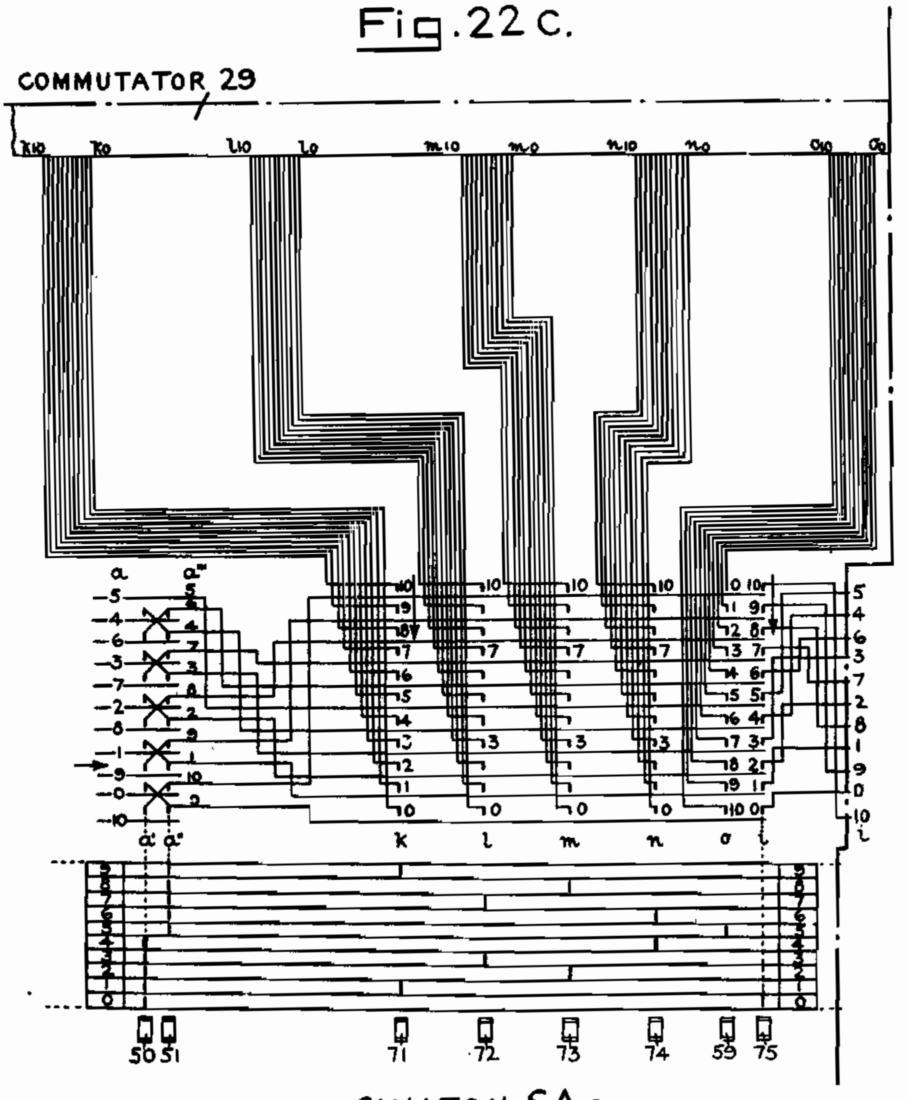
Inventor
Fritz Mezger
by Young, Emery & Thompson
attys

PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No. 209,832
39 Sheets-Sheet 29

Fig. 22 C.



SWITCH SA2

Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

PUBLISHED

JUNE 8, 1943.

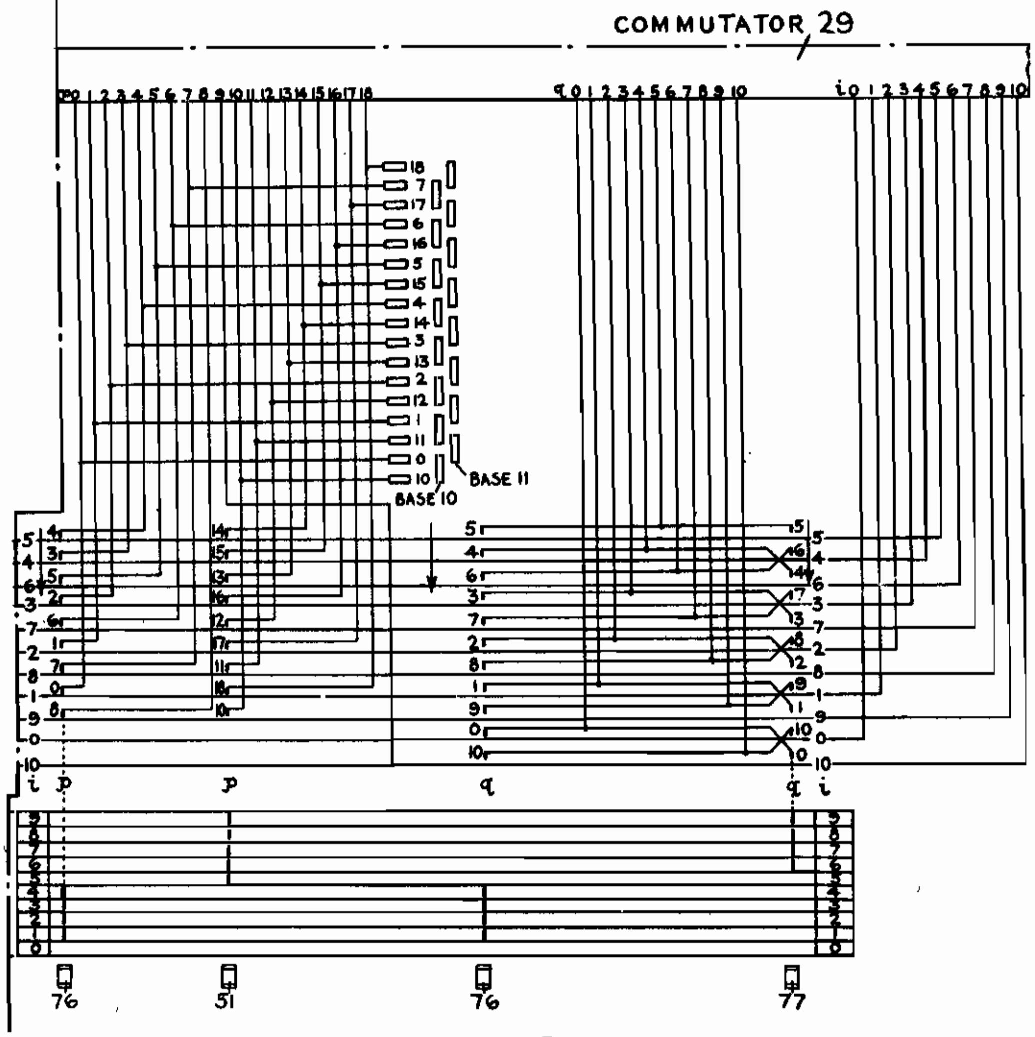
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets-Sheet 30

Fig. 22 D.



SWITCH SA2

Inventor
Fritz Mezger
by Young, Emery & Thompson
attys

PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832
39 Sheets-Sheet 31

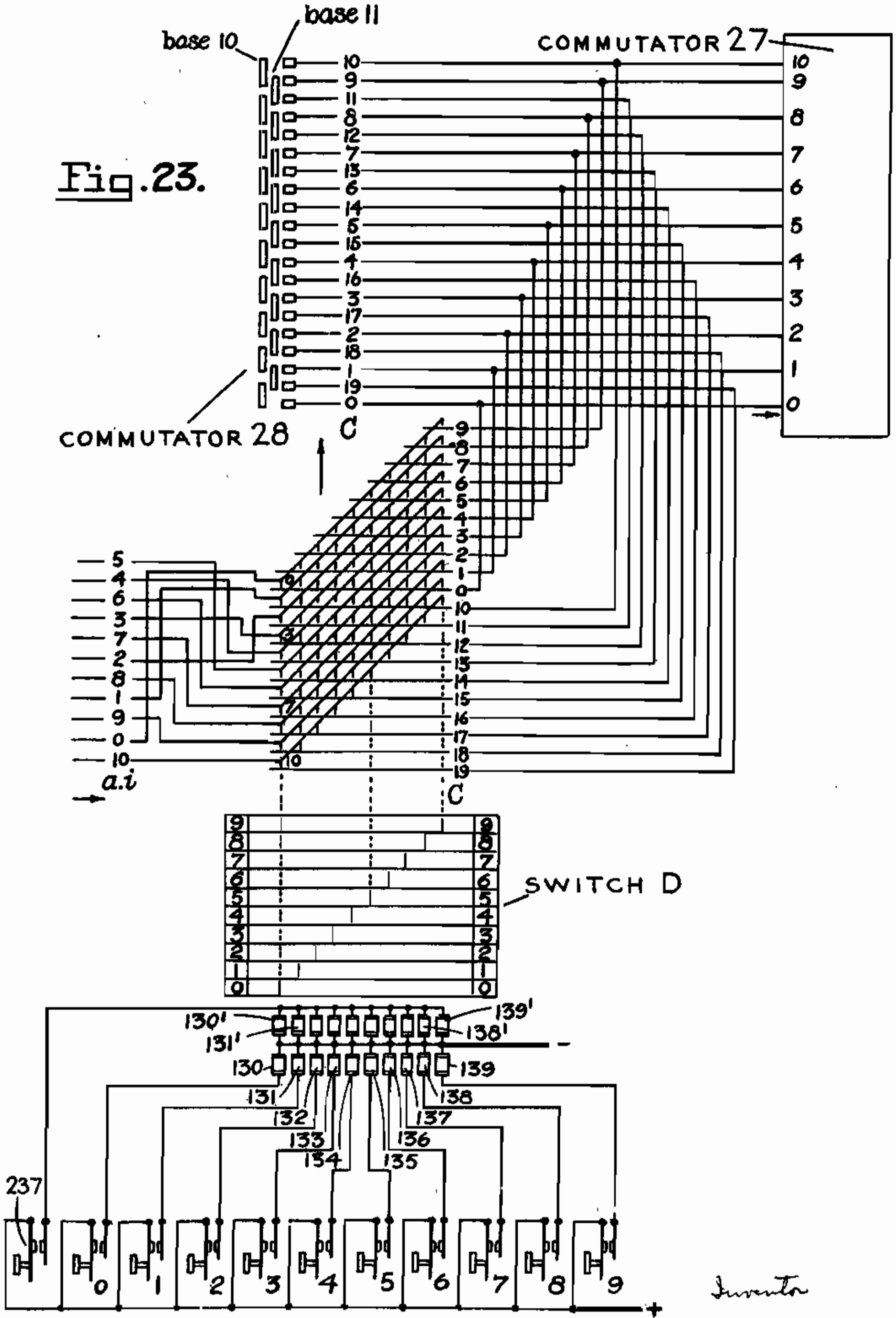


Fig. 23.

Inventor
Fritz Mezger
by Young, Emery & Thompson attys.

PUBLISHED

JUNE 8, 1943.

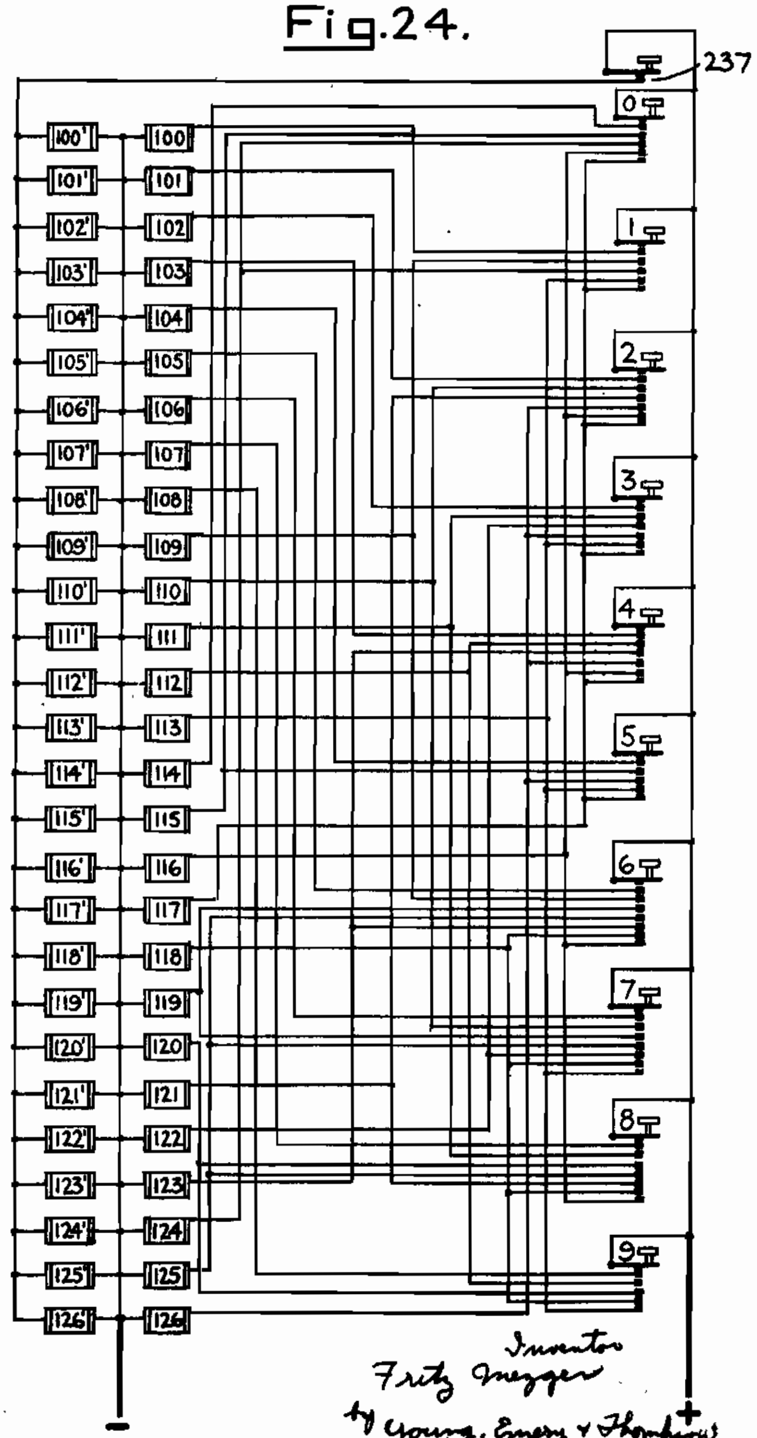
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets-Sheet 32

Fig. 24.



Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

PUBLISHED

JUNE 8, 1943.

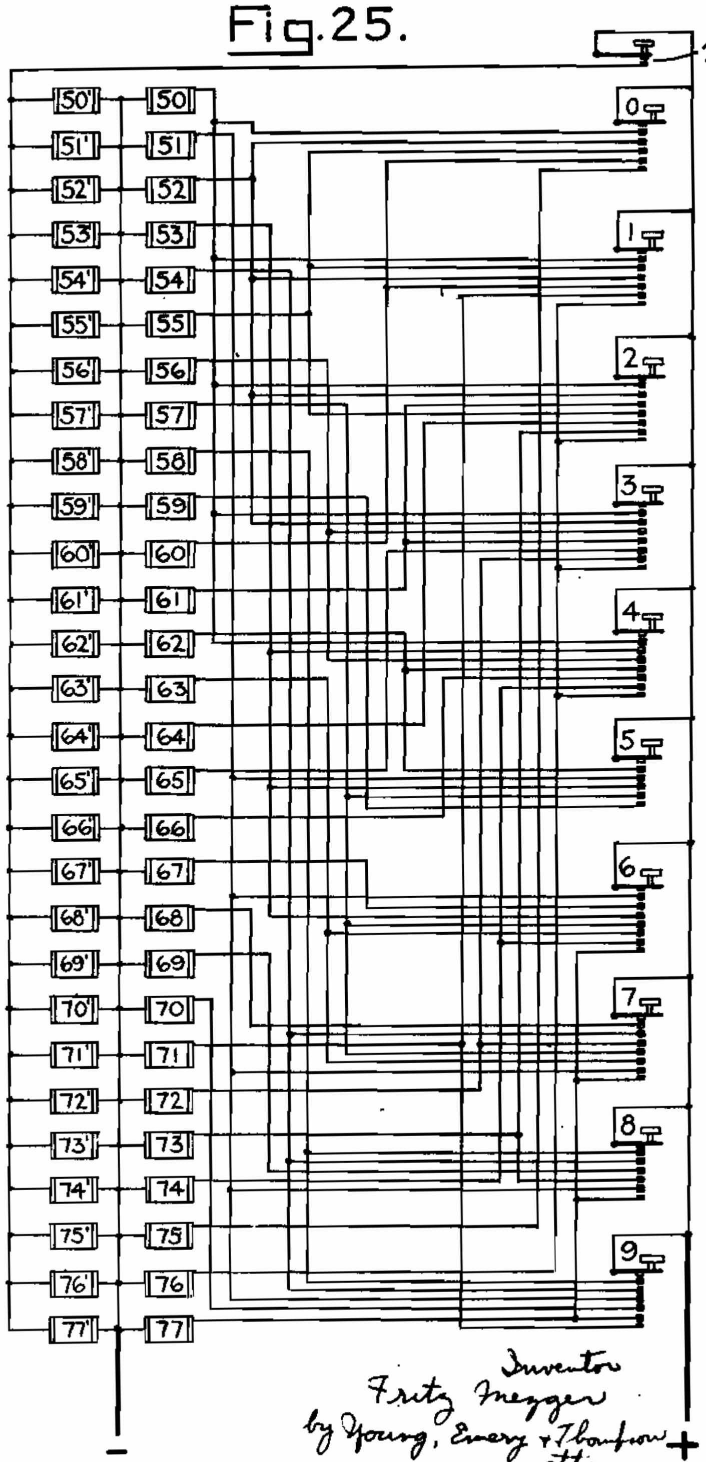
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

39 Sheets-Sheet 33

Fig. 25.



Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832
39 Sheets-Sheet 34

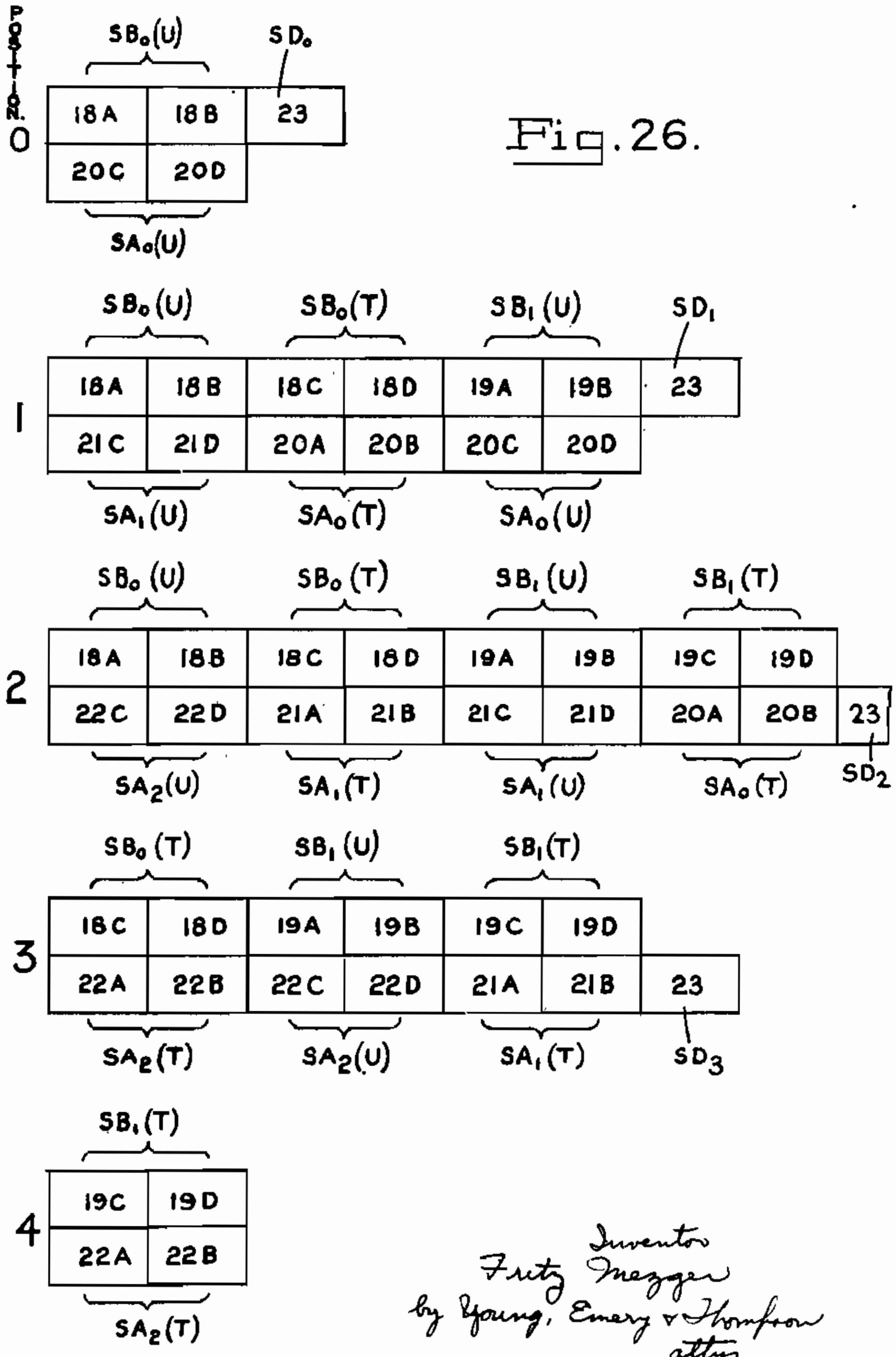


Fig. 26.

Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

PUBLISHED

JUNE 8, 1943.

BY A. P. C.

F. MEZGER

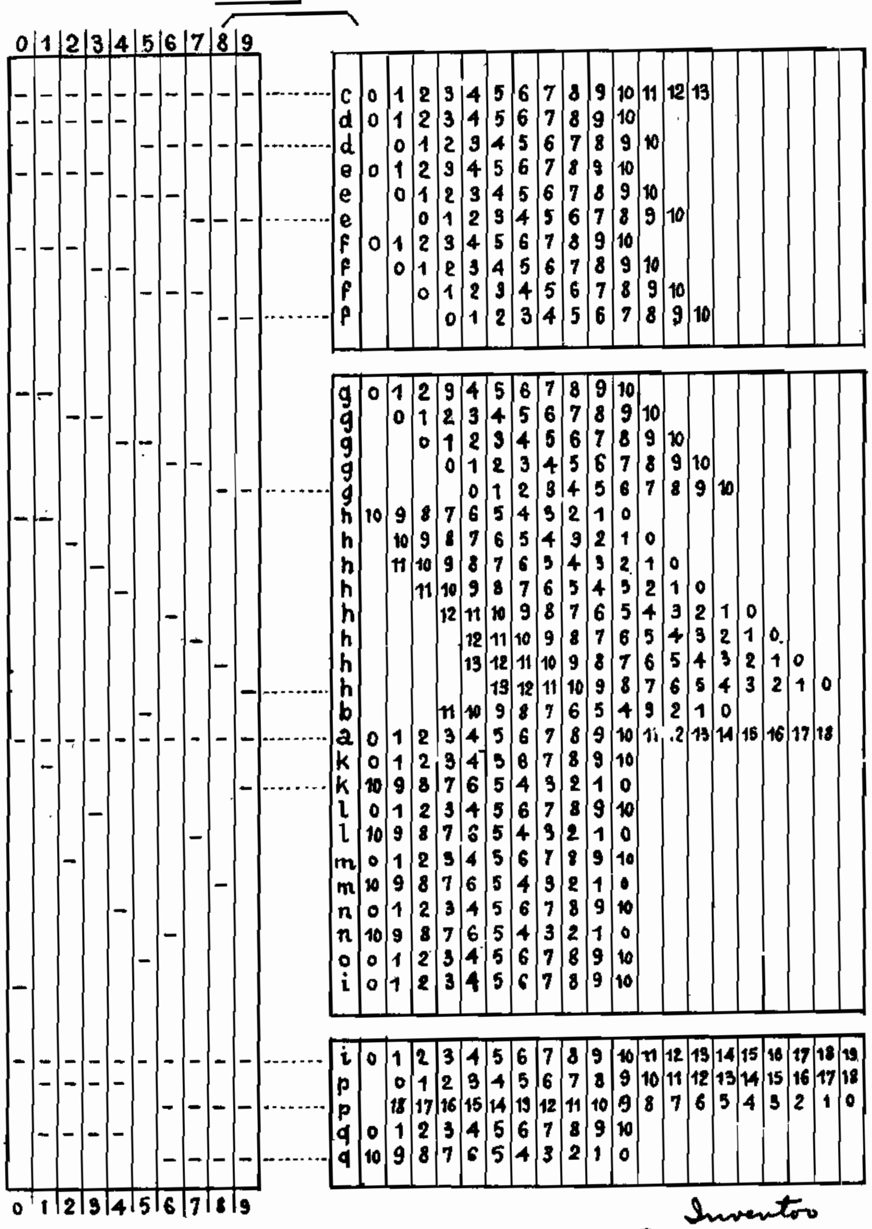
PROCESS AND DEVICE FOR ELECTRICAL CALCULATION

Filed May 24, 1938

Serial No. 209,832

39 Sheets-Sheet 35

Fig. 27.



Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

PUBLISHED

JUNE 8, 1943.

BY A. P. C.

F. MEZGER

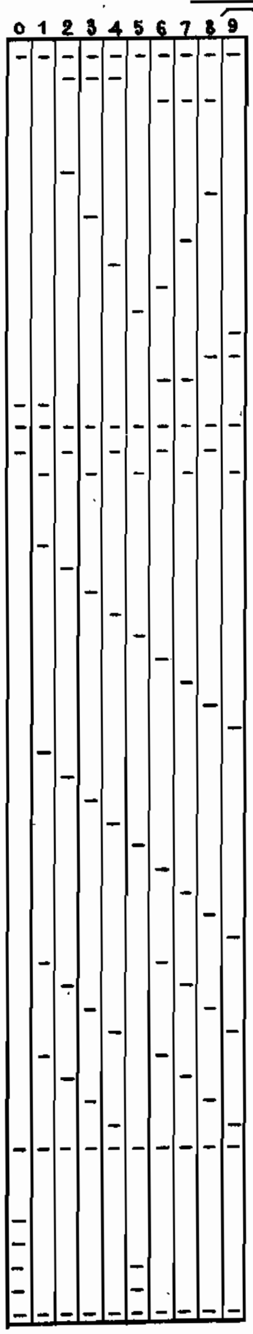
PROCESS AND DEVICE FOR ELECTRICAL CALCULATION

Filed May 24, 1938

Serial No. 209,832

39 Sheets-Sheet 36

Fig. 28.



c	0	1	2	3	4	5	6	7	8	9	10	11	12	13					
a	0	1	2	3	4	5	6	7	8	9	10	11	12	13					
h	0	1	2	3	4	5	6	7	8	9	10	11	12	13					

d	0	1	2	3	4	5	6	7	8	9	10								
d	10	9	8	7	6	5	4	3	2	1	0								
e	0	1	2	3	4	5	6	7	8	9	10								
e	10	9	8	7	6	5	4	3	2	1	0								
f	0	1	2	3	4	5	6	7	8	9	10								
f	10	9	8	7	6	5	4	3	2	1	0								
g	0	1	2	3	4	5	6	7	8	9	10								
h	10	9	8	7	6	5	4	3	2	1	0								
b	10	9	8	7	6	5	4	3	2	1	0								
b	11	10	9	8	7	6	5	4	3	2	1								
a	0	1	2	3	4	5	6	7	8	9	10								
i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
o	0	1	2	3	4	5	6	7	8	9	10								
o						0	1	2	3	4	5	6	7	8	9	10			

k	0	1	2	3	4	5	6	7	8	9	10								
k		0	1	2	3	4	5	6	7	8	9	10							
k			0	1	2	3	4	5	6	7	8	9	10						
k				0	1	2	3	4	5	6	7	8	9	10					
k					0	1	2	3	4	5	6	7	8	9	10				
k						0	1	2	3	4	5	6	7	8	9	10			
k							0	1	2	3	4	5	6	7	8	9	10		
k								0	1	2	3	4	5	6	7	8	9	10	
k									0	1	2	3	4	5	6	7	8	9	10
l			0	1	2	3	4	5	6	7	8	9	10						
l						0	1	2	3	4	5	6	7	8	9	10			
l									0	1	2	3	4	5	6	7	8	9	10
l		0	1	2	3	4	5	6	7	8	9	10							
l					0	1	2	3	4	5	6	7	8	9	10				
l								0	1	2	3	4	5	6	7	8	9	10	
l	0	1	2	3	4	5	6	7	8	9	10								
l				0	1	2	3	4	5	6	7	8	9	10					
l							0	1	2	3	4	5	6	7	8	9	10		
m		0	1	2	3	4	5	6	7	8	9	10							
m				0	1	2	3	4	5	6	7	8	9	10					
m						0	1	2	3	4	5	6	7	8	9	10			
m								0	1	2	3	4	5	6	7	8	9	10	
n				0	1	2	3	4	5	6	7	8	9	10					
n								0	1	2	3	4	5	6	7	8	9	10	
n		0	1	2	3	4	5	6	7	8	9	10							
n						0	1	2	3	4	5	6	7	8	9	10			
p	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

k	0	1	2	3	4	5	6	7	8	9	10								
l	0	1	2	3	4	5	6	7	8	9	10								
m	0	1	2	3	4	5	6	7	8	9	10								
n	0	1	2	3	4	5	6	7	8	9	10								
q	0	1	2	3	4	5	6	7	8	9	10								

Inventor
Fritz Mezger
by Young, Emery & Thompson
atty.

PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No. 209,832
39 Sheets-Sheet 37

Fig. 29.

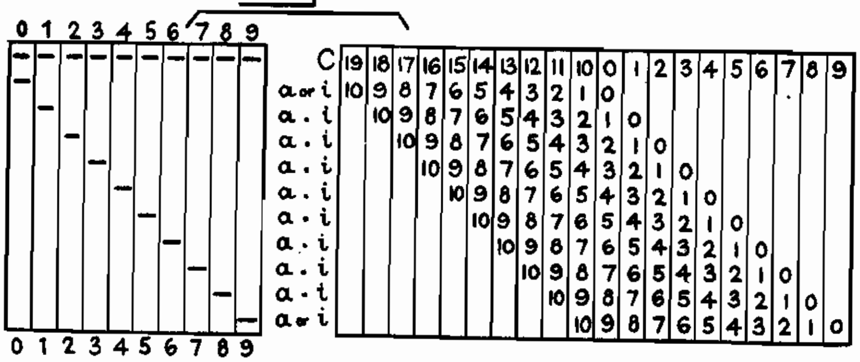
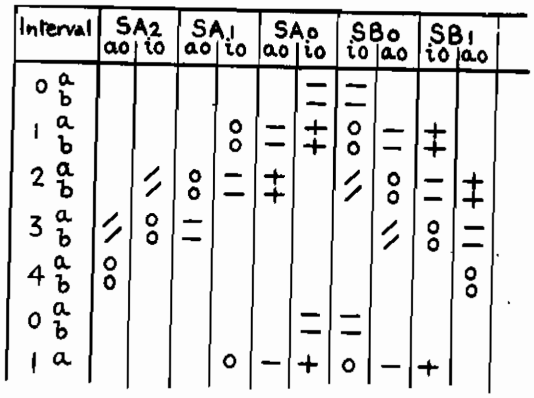


Fig. 30.



Fritz Mezger Inventor
by Young, Emery & Thompson attys.

PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832
39 Sheets-Sheet 38

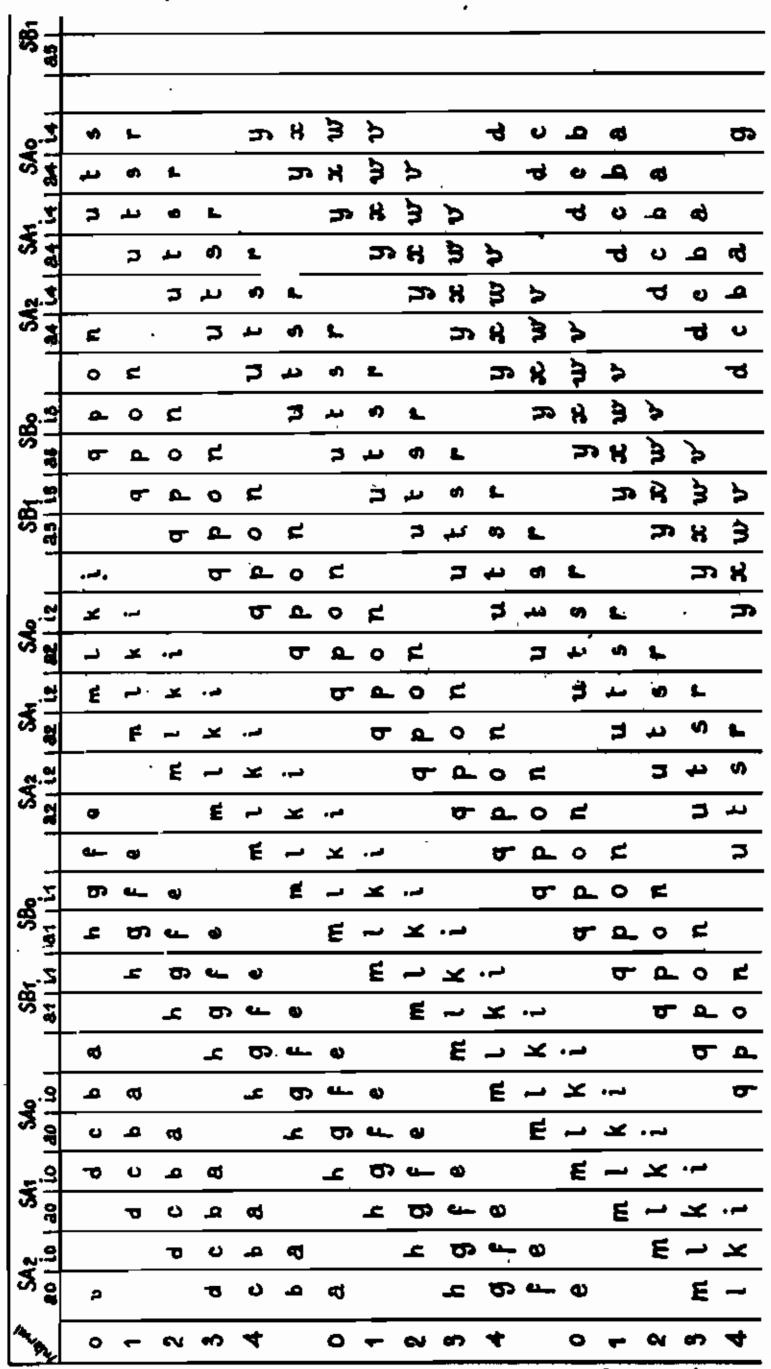


Fig. 31A.

Fritz Mezger Inventor
by Young, Emery & Thompson
attys.

PUBLISHED
JUNE 8, 1943.
BY A. P. C.

F. MEZGER
PROCESS AND DEVICE FOR
ELECTRICAL CALCULATION
Filed May 24, 1938

Serial No.
209,832

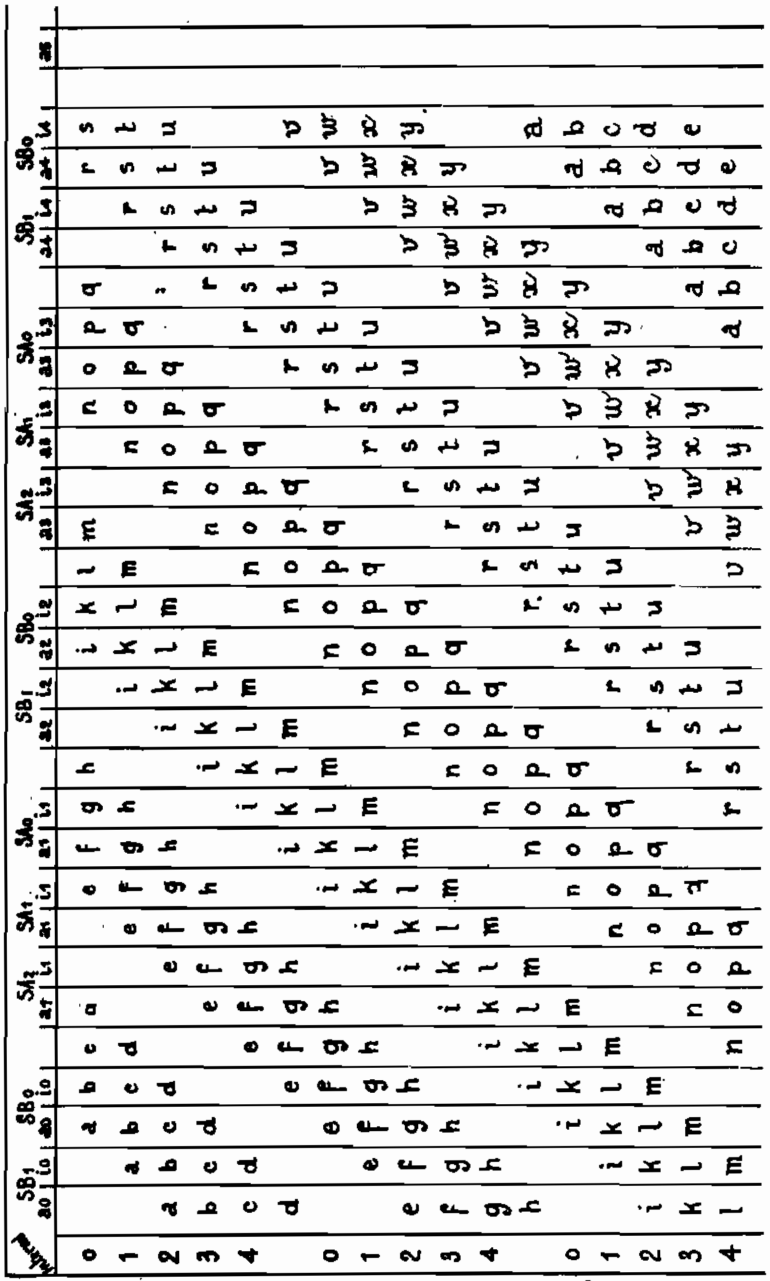


Fig. 31B.

Inventor
Fritz Mezger
by Young, Emery & Thompson
attys.

Published June 8, 1943

Serial No. 209,832

ALIEN PROPERTY CUSTODIAN

PROCESS AND DEVICE FOR ELECTRICAL CALCULATION

Fritz Mezger, Paris, France; vested in the Alien Property Custodian

Application filed May 24, 1938

This invention relates to calculating apparatus and has for its object to provide an apparatus which performs multiplication in a novel manner.

Multiplication is effected mentally by multiplying one factor, the multiplicand, by each digit of the other factor, the multiplier, to obtain a series of partial products and finally adding these partial products together. Each operation in the process consists in the calculation of the multidenominational partial product which is the product of the multiplicand by a single digit of the multiplier. The product of a multiplicand digit and a multiplier digit comprises, in general, a two figure number, and it is therefore the practice to multiply a multiplicand digit by a multiplier digit, to add, to the units digit of the product, the tens digit of the product of the next lower multiplicand digit and the same multiplier digit and to carry forward the tens digit of the first-mentioned product together with the tens digit, if any, resulting from the addition of the units digit of that product to the tens digit of the second mentioned product. The digits of the various interdigital products calculated during the process are thus not written down. Multiplying machines of the partial product kind constructed hitherto operate in substantially the above method with the modification that two partial products are obtained at each operation, one consisting of the units digits and the other of the tens digits of the products of each digit of the multiplicand by a single digit of the multiplier. The summation of the partial products proceeds concurrently with their calculation, the two partial products resulting from one operation being either formed consecutively and added in a single counter or formed simultaneously and added in separate counters to provide two partial products which are subsequently added together.

A method of performing multiplications mentally is, however, known in which all the digits of the various interdigital products are written down. This method is shown in diagrammatic form in Figure 14 of the accompanying drawings, the table showing by way of example the multiplication of 762 by 948. The factor 762 is written along the top side of a rectangle while the factor 948 is written from the bottom upwards along the left-hand side of the rectangle. The rectangle is divided into squares as shown, so that there is one square for each pair of digits taken one from each factor. Each square is divided diagonally by the dotted lines as shown and in it is written the product of the digit vertically above it and the digit horizontally to its left. The units digit is written above the diagonal of the square, the tens digit is written below the diagonal of the square. The digits are then added diagonally, starting from the top right-hand corner and adding together all the digits lying between two diagonal lines. If the sum of the digits added together is more than 9, the tens digit is written in the next diagonal space and is added in with the digits in that space. In the example shown, the product is 722376.

Considering the diagonal space A on the table of Figure 14, the sum 23 which is obtained is the sum of the units digit of 7×8, the tens digit of 6×8, the units digit of 6×4, the tens digit of 2×4, the units digit of 2×9 and one unit transferred from the previous summation. It will be noted that this summation is a summation of units and tens digits, alternately, of interdigital products plus a transferred unit. It should also be noticed that the first summation involves the units digits of both factors, the second summation involves the units and tens digits of both factors, the next two summations involve all the digits of both factors, the fifth summation involves the tens and hundreds digits of both factors and the last involves the hundreds digits of both factors.

The method of multiplication just described comprises two stages, the first being the calculation and writing down of all the various interdigital products needed and the second stage consists in the diagonal summation of the digits of these products and comprises a separate summing operation for each diagonal row of digits. The present invention provides calculating mechanism which operates generally in accordance with the above method but which combines the two stages and performs a sequence of operations each of which consists in the calculation of all the product digits shown in a diagonal row in the above table and their summation as a single operation. A diagrammatic representation of the process is obtained if one of the factors (948) is considered to be stationary while the other factor (762), written backwardly as 267, is moved towards the left step by step into successive positions designated 0, 1, 2, etc. in Figure 13 of the accompanying drawings, each position corresponding to a stage in the process. In each position the product digits are summed as indicated by arrows in the example for position 1 which follows:

```
   2   6   7
 ------------
   ↗  ↘  ↗
 ------------
 9   4   8
```

The units digits of the products indicated by the arrows ↗ are calculated and the tens digits of the products indicated by the arrows ↘ are also calculated and these tens and units digits are added together and to the digit, if any, carried from the previous summation to give a digit of the final result. The complete operation may be set out in the following manner:

Position	Partial products in which are retained only— The tens	The units		Result
0		8×2	6	6
		4×2	8	
1	2×8...	....	1	
		8×6	8	
			(1)7	7
		Transfer	1	
2....	....			
		9×2	8	
	2×4...	....	0	
		4×6	4	
	6×8...	....	4	
		8×7	6	
			(2)3	
		Transfer	2	
3				
	2×9...	....	1	
		9×6	4	
	6×4...	....	2	
		4×7	8	
	7×8...	....	5	
			(2)2	2
		Transfer	2	
4				
	6×9...	....	5	
		9×7	3	
	7×4...	....	2	
			(1)2	2
		Transfer	1	
5				
	7×9....	....	6	
			7	7

In accordance with the present invention any tens or higher digit resulting from the formation in a particular operation in the process is ignored in doing the summation and only the units digit of the sum is calculated. Special provision is made for determining the tens digit resulting from any summation and for including it in the next summation. This provision is based upon the following considerations:

If any number in the decadal notation is expressed in a notation having the base G and the units digit of the number to the base G is subtracted in accordance with the notation to the base G from the units digit of the decadal number, a difference will be obtained which is constant for the decade in which that number occurs. Subtraction in accordance with a base G merely differs from subtraction in the decadal system in that when a larger digit is to be subtracted from a smaller digit the number G is added instead of 10 to give a positive result digit. It is preferable that the numbers 10 and G should have no common factors. In particular, if G is 11 the units digit of the result of subtracting from the original number in the decadal system the same number re-expressed in the hendecadal system to the base 11 will be the tens digit of the original number. The truth of this can be seen from the consideration that the conversion to the hendecadal system involves the reduction of the units digit of the amount by as many units as the value of the tens digit of the number expressed in the decadal system. For example, 17 is re-written on the hendecadal system as 16 and the difference is 1 which is the value of the tens digit. 30 is rewritten as 28 and the difference 30—28 on the hendacadal system, is 3 which amount is the tens digit of the original amount. It should be noted that the difference can be obtained by subtracting the units digits one from the other and without any regard to the tens digits, which need not be calculated. For example, in the case of the last example 0+11—8=3.

A relationship between the difference and the tens digit of the original amount also exists for notations on other bases, although the relationship is not a direct one, as it is on the base 11 can be used provided that the largest sum that can be formed in any operation does not exceed 109, when the difference will be equal to the digit 10 on the hendecadal notation. If the largest sum that may occur exceeds 109, it is necessary to use an auxiliary notation on a larger base than 11 to permit of the difference being greater than 10. For example, the notation to the base 13 allows of a difference as great as 12 in that notation, 12 being, of course, a single digit in the notation to the base 13. The following table gives the different decades in the notations on the bases 9, 11 and 13.

Decadal regions	Differences between the units digit in the system on the base 10 and on the base— 9	11	13
0– 9	0	0	0
10– 19	8	1	3
20– 29...	...7..	...2..	...6.
30– 39	6	3	9
40– 49	5	4	12
50– 59...	...4..	...5..	...2
60– 69	3	6	5
70– 79	2	7	8
80– 89...	...1..	...8..	..11
90– 99		9	1
190–109		10	4
110–119...	......	......	...7
120–129			10

According to the present invention there is provided a calculating mechanism for multiplying two factors together in a succession of stages to obtain a single result digit in a normal notation, comprising means operable to calculate, at each stage, the digits of interdigital products pertaining to that stage and to sum said product digits in the normal notation and in also a special notation so as to obtain the units digits of the sum alone in each case, means for obtaining, at each stage, the difference between the two said digits, obtained at that stage and for adding into the sum obtained in the next stage a digit corresponding to said difference and equal to the tens digit of the sum obtained in the normal notation in the previous stage.

The present invention further provides an electrical system for performing multiplication in accordance with the method previously described.

A further feature of the invention consists in the provision of apparatus for evaluating expressions of the general form $D+/-AB=R$ and which comprises means for including in the sum formed at each stage the appropriate digit of the term D.

An electrical calculating system in accordance with this invention will now be described by way of example only with reference to the accompanying drawings in which:

Figures 1 and 2 are side and front views respectively of the machine, parts of the casing being broken away to show the internal construction. The parts shown broken away in the upper right and left hand corners of Figure 1 correspond respectively to sections on the lines M—M and N—N in Figure 2.

Figure 2A is a circuit diagram showing the method of controlling an electric motor driving a commutator forming part of the machine.

Figure 3 is a section through the keyboard along the line 3—3 in Figure 2.

Figure 4 is a section along the line 4—4 in Figure 3.

Figure 5 is a section along the line 5—5 in Figure 2 and shows one of the indicators of the result register.

Figure 6 is a vertical section through the result indicator along the line 6—6 in Figure 5.

Figure 7 is an enlarged view of the connection frame which is seen in the upper left hand corner of Figure 1.

Figure 8 is a section along the line 8—8 in Figure 7.

Figure 9 is a side view of an electromagnetically operated multi-contact switch unit a large number of which are used in the construction of the machine.

Figure 10 is a section along the line 10—10 in Figure 9.

Figures 11A and 11B constitute a diagram showing the various parts of the apparatus in a diagrammatic manner and typical electrical connections between them. The connections established during one stage of the operation of the machine are shown in full lines. This figure does not constitute a circuit diagram.

Figures 12A and 12B constitute a similar diagram of Figures 11A and 11B but show the connections established at another stage of the operation.

Figure 13 is a diagram illustrating successive stages of a multiplying operation.

Figure 14 shows the method of multiplication already referred to.

Figures 15, 16 and 17 are diagrams showing respectively the different series of switches pertaining to the calculation of the units, tens and hundreds denominations of the result.

Figures 18A, 18B, 18C, 18D, 19A, 19B, 19C, 19D, 20A, 20B, 20C, 20D, 21A, 21B, 21C, 21D, 22A, 22B, 22C, 22D and 23 are circuit diagrams for the switches and show how the switches co-operate to perform calculations.

Figure 24 is a circuit diagram showing the method of operating the electromagnets controlling the switches shown in Figures 18A, 18B, 18C, 18D, 19A, 19B, 19C and 19D.

Figure 25 is a similar circuit diagram showing the method of operating the electromagnets controlling the switches shown in Figures 20A, 20B, 20C, 20D, 21A, 21B, 21C, 21D, 22A, 22B, 22C and 22D.

Figure 26 is a diagram showing how Figures 18, 19, 20, 21A, B, C and D and Figure 23 may be pieced together to trace continuous circuits during different stages in the operation of the machine.

Figures 27, 28 and 29 are connection tables for three kinds of switches by which the factors are set up in the machine and which control multiplying and subtracting operations.

Figures 30, 31A and 31B are connection tables relating to the commutating means for establishing these series of switches.

The general arrangement of a machine constructed according to the invention is shown in Figures 1 and 2. The machine stands upon a base **200**, the front, top and back of the casing being formed by metal sheets **201** joined at the corners by angle irons **203**. A number of frames **204** run round the interior of the casing and serve to support the side walls **205** and the members accommodated in the interior of the machine.

Mounted on the frames **204** in the upper part of the casing are a large number of electromagnetically operated multiple-contact switches **206**, whence depart bundles of wires **207** (Figure 2) terminating at connection frames **208** situated at the same height. The construction of the switches and connection frames will be further described hereinafter. In the lower part of the casing is housed a commutation cylinder **209** the shaft of which is carried in bearings **210**. The commutation cylinder **209** is driven by an electric motor **211** through a reducing gear **212** and a combined electromagnetically operated clutch and stop device **213**. The commutation cylinder together with the motor, reducing gear, clutch and stop device are mounted on a platform **214** supported by rails **215**. A number of rows of contact brushes **216** are disposed around the commutation cylinder **209** and are joined individually to the blades **217** of a connection frame **218** arranged above the commutation cylinder. The commutation cylinder is of the usual construction and comprises a large number of insulated contact segments **219** the arrangement and interconnection of which will be described hereinafter.

A bracket **220** projects from the front of the casing and carries the keyboard **221** and the result register **222**. The machine here described by way of example is arranged to evaluate expressions of the general form $D-AB=R$, the factors A and B having three and two digits respectively and the term D four digits. Consequently the keyboard **221**, details of which are shown on a larger scale in Figures 3 and 4, comprises three rows of keys **223** for the factor A, each row containing ten keys numbered individually from 0 to 9, two similar rows **224** for the factor B and four similar rows **225** for the term D. As shown in Figures 3 and 4 the keys are raised resiliently by springs **226** and at their lower ends carry cam members **227** whereby contact pairs **228** are closed when the key is depressed. All the keys **225** relating to the term D close single contact pairs as shown in Figure 3, but the keys **223** and **224** relating to the factors A and B close multiple contacts in a similar manner. The number of contacts closed by each key will appear from the subsequent description. After being depressed the keys are prevented from rising by locking plates **229** pivoted at **230** and urged by the springs **231** against the cam members **227**. It is thus possible, by depressing the appropriate keys in the different rows (one per row) to set up the factors A and B and the term D. After the calculation has been effected the keys are released by a release key or trigger 232 which is pivoted at 233 to a bar 234 having projections 235 which are adapted to engage the plates 229 to push them aside and release the keys when the trigger is operated. The closing of the contact pairs 228 energises the operating magnets of the corresponding switches 208 to establish the connections corresponding to the introduction of the digits interventing in the calculation. When the calculation has been completed, operation of the trigger 232 releases the keys as already described and also, by means of a projection 236 on the bar 234, temporarily closes a contact pair 237 whereby resetting magnets of the switches are energised and the switches are returned to their starting positions.

The keyboard also carries a switch 238 for starting the electric motor 211. For the performance of each calculation the commutation cylinder 209 must be turned through a quarter of a revolution, and Figure 2A shows diagrammatically the arrangements provided for this purpose. The commutation cylinder 209 is driven from the shaft 239 of the reducing gear 212 through a magnetically operated clutch and stop device indicated generally by the reference 240. The driven plate 241 of the clutch is fixed to the commutator shaft 242 and is provided with fcur equally spaced projections 243 adapted to be engaged by a stop member 244 pivoted at 245 and urged into engagement with the projections by a spring 246. The part of the stop member projecting below the pivot 245 is formed as an armature for an electromagnet 247 whereby the stop member may be disengaged from the projections 243. The driving plate 248 of the clutch is held in engagement with the driven plate 241 by an electromagnet 249 acting through a lever 250 pivoted at 251 and provided with a pull-off spring 252. Clutch and stop mechanisms suitable for the present purpose are already well known and Figure 2A is intended to be regarded simply as a conventional diagram for the purpose of explaining the operation. 253 indicates the magnet of a relay for closing the circuit of the motor 211 from the supply leads 254 and 255. The windings of the magnets 247, 249 and 253 are connected in parallel, one connection being made to the supply lead 254 and the other to one of a pair of brushes 256 co-operating with segments 257 on the surface of the commutation cylinder. Each segment extends over practically a quarter of the circumference of the cylinder and the arrangement is such that the leading brush runs off a segment as a projection 243 of the stop mechanism approaches the stop member 244. The other brush 256 is connected to the supply lead 255, and the switch 238 for starting the operation is connected between the two brushes. In the operative position the commutation cylinder is stopped in a position in which one of the brushes 256 rests on the insulating portion of the cylinder. If the switch 238 is now closed, the magnets 247, 249 and 253 are energised so that the stop member 244 is retracted, the clutch plates 241, 248 are brought into engagement and the motor circuit is completed. The motor 211 therefore starts and drives the commutation cylinder so that both brushes 256 run on to one of the segments. If the switch 238 is now allowed to open, the motor continues to drive the commutation cylinder until the leading brush 258 runs off the segment 257. The circuit of the magnets 247, 249 and 253 is thereby interrupted, so that the stop member 244 is released and engages with one of the projections 243 to stop the rotation of the commutation cylinder. At the same time the clutch is disengaged and the motor circuit is interrupted so that the motor runs freely until its momentum is exhausted and it comes to rest.

The result register is situated above the keyboard 221 and comprises five windows 258 for the five digits of the result. Figures 5 and 6 show the construction on a larger scale. For each denomination of the result there is provided an indicator 259 comprising a sector-shaped scale 260 secured to an iron rotor 25 mounted on a shaft 261 and arranged at the centre of two coils 23, 24 at right angles to one another. The shafts 261 of the various indicators are carried in bearings 263 attached by screws 264 to a rail 265 running from side to side of the bracket 220. The coils 23, 24 are also fixed to the rail 265 by connecting strips 266. The scale 260 of each indicator has inscribed on its external face the ten characteristic decadal digits 0 to 9 and corresponds to one denomination of the result. These result indicators are shown diagrammatically on the right hand side of Figure 11B, UD being the units decadal indicator, TD the tens decadal indicator and so on to TTD which is the ten thousands decadal indicator. As will be seen from Figure 11B, one end of the coils 23 is connected to one end of the coils 24 and to the negative current supply lead L of the machine. The other ends of the coils 23 and 24 are connected by leads L_1 and L_2 respectively to the ends of resistances W which are provided with ten tapping points to which are connected the ten result leads on the decedal system designated 0R to 9R. The suffix 0, 1, 2, 3 or 4 indicates the denomination to which the leads pertain, 0 indicating the units denomination, 1 the tens denomination, etc. When the machine is operated, one of the result leads 0R to 9R of each of the decadal indicators is rendered alive so that a resultant magnetic field is produced by the coils 23, 24 whose direction is determined by the ratio of the magnetising currents of the two coils and is thus independent of variations in the voltage at which the apparatus is supplied with current. The current will branch through the resistance W and the lines L_1 and L_2, and the ratio of the intensities of the currents in the two leads will vary in accordance with which of the result leads 0R to 9R is included in the circuit. Thus, the rotor 25 will take up a position determined by which result lead is included in the circuit and corresponding to a result digit which appears in the window 258. The indicators are not provided with return springs, so that each rotor will remain in any position to which it is moved when its windings are energised, after those windings have been de-energised. In other words, each indicator moves from one indicating position to the next and does not return to zero unless the digit to be indicated in zero.

The machine here described by way of example uses the hendecadal system as the auxiliary base in order to obtain the correct carrying from one denomination to the next according to the principle already explained. For this purpose the result register also comprises for each denomination except the highest (there being then no carrying to be effected) a second result indicator represented generally by the reference 267. The construction of the hendecadal indicators 267 is similar to that of the decadal indicators 259 except that no scale 260 is required. The shafts 268 are carried in bearings 268 fixed to a rail 270 similar to the rail 265. The hendecadal indicators are shown diagrammatically on the right hand side of Figure 11B, UH being the units hendecadal indicator, TH the tens hendecadal indicator and so on to the thousands hendecadal indicator. The coils 23 and 24 of the hendecadal indicators are joined by leads L_1 and L_2 to the ends of resistances W which are provided with eleven tapping points to which are connected the eleven result leads on the hendecadal system designated OR′ to 10R′. The suffix 0, 1, 2 or 3 again indicates the denomination to which the leads pertain. The hendecadal indicators operate in the same way as the decadal indicators except that they may take up any one of eleven positions and in passing from lower to higher digit positions rotate in an anticlockwise direction instead of a clockwise direction.

As already explained, the transfer or carrying from one denomination to the next is determined by the difference between the results obtained on the decadal and hendecadal systems. For this purpose the two indicators 259, 267 pertaining to each denomination except the highest jointly control by gear wheels 271, 272 respectively a differential switch mechanism generally indicated by the refernece 273.

Each differential switch comprises a base 274 with side portions 275, 276 carrying a shaft 277. Loosely mounted on the shaft 277 are gear wheels 278, 279 meshing respectively with idler gear wheels 280, 281 meshing with the gear wheels 271, 272. The gear wheels 278, 279 are also provided with bevel teeth 282 meshing with planetary bevel pinions 283 mounted loosely on a cross shaft 284 made in two halves screwed together. A disc of insulating material 285 is secured to the side portion 276 by screws 286 and carries an inner contact ring 20 and an outer concentric row of contact segments 21. An arm 289 is fixed to the shaft 277 and to its outer end is secured a contact bridge piece 290 by means of a stirrup 291. Wiring connections to be described later are made to the contact ring 20 and to the contact segments 21. During the operation of the machine the decadal and hendecadal indicators pertaining to a denomination of the result are energised successively. Supposing that both indicators are originally in the zero position, the shaft 261 of the decadal indicator is first turned to the position corresponding to the particular digit of the result, while the shaft 268 of the hendecadal indicator remains stationary. During this period the gear wheel 278 is turned by the gear wheel 271 and the shaft 277 is turned by the planetary pinions 283 so that the contact bridge piece 290 moves over a number of contact segments 21 equal to the said digit. The shaft 261 then remains stationary while the shaft 268 is turned to the position corresponding to the particular digit of the result in the hendecadal system. During this period the gear wheel 279 is turned by the gear wheel 272 and the shaft 277 is turned by the planetary pinions 283 so that the contact bridge piece 290 moves back over a number of contact segments equal to the said hendecadal digit. The contact bridge piece 290 therefore finally comes to rest on a contact segment 21 corresponding to the difference between the digits in the decadal and hendecadal systems. The same final position will, of course, be arrived at when either or both indicators start from a position other than zero. The gearing ratios between the driving wheels 271, 272 and the gear wheels 278, 279 are preferably selected so as to compensate the difference in rotation of the shafts of the decadal and hendecadal indicators. The four differential switches are shown diagrammatically on the right hand side of Figure 11A, DS_0, DS_1, DS_2 and DS_3 being respectively the switches driven by the indicators of the units, tens, hundreds and thousands denominations.

The digits of the term D and of the factors A and B of the expression $D-AB=R$ will be designated $d_0, d_1, d_2 \ldots a_0, a_1, a_2 \ldots$ and $b_0, b_1, b_2, \ldots$ respectively, the suffixed numerals indicating the denominational value of each digit, 0 indicating the units denomination, 1 the tens denomination and so on. Each digit is entered by a separate switch which is adjustable into any one of ten positions by the ten keys of the corresponding row of the keyboard 221, so that each position corresponds to a different digit. The switches for the term D will be designated SD0, SD1, SD2, etc. The switches for the factor A will be designated SA0, SA1, etc. and the switches for the factor B, SB0, SB1, etc. Each of these switches is a multi-contact switch built up from a number of similar electromagnetically controlled units and makes a different predetermined set of connections for each position. The construction of the switch units and the manner in which they are grouped together to form a switch SA, SB or SD, using these designations generically, will be described more, fully hereinafter.

The apparatus also comprises a commutator, already referred to by the reference numeral 209, which turns continuously while a calculation is being effected and connects the switches together in different series at each stage in the operation. Each series comprises switches SA and SB arranged alternately and followed by one of the switches SD. The switches which are connected in series at any stage depend upon the factor digits which are involved at that stage and this series of switches provides a series of circuits corresponding to all possible results at that stage and terminating in ten result leads; if the calculation is proceeding on the decadal notation, and 11 result leads if the calculation is proceeding on the hendecadal notation. The setting of the switches selects uniquely one of these circuits so that one of the result leads is alive. At each stage a result digit is calculated first on the decadal notation and then on the hendecadal notation. The connection of the result leads to the indicating devices of the result register has already been described with reference to Figures 5, 6 and 11B. The latter figure is a continuation towards the right of Figure 11A.

The indicators are connected in circuit in turn by the commutator 27 as will be described later, starting with the units decadal indicator UD followed by the units hendecadal indicator UH, the tens decadal indicator TD, the tens hendecadal indicator TH and so on up to the ten thousands decadal indicator TTD. Thus at each stage the appropriate decadal indicator is energised and will indicate a digit of the result. This digit is the units digit of the sum and is in the decadal notation. The hendecadal indicator for the same denomination is then energised and indicates a digit which is the units digit of the same sum when expressed in the hendecadal notation. By means of the differential switches DS_0, DS_1, etc. the two indicators of each pair jointly control the addition into the sum formed at the next stage of the tens digit of the sum formed at the stage in which they are set. The contacts 21 of each differential switch are permanently connected to lines **22** leading to the first switch of the series of switches established in the next stage of the operations and so as to determine through which of eleven arrival lines of this first switch the circuit is to be completed. Only the first of these arrival wires has been shown in Figure 11A. The effect of this selection of an arrival line will be apparent from the description which is to be given later.

The commutator **26** in the left hand upper corner of Figure 11A moves in the direction of the arrow, and in the first stage of the calculation makes a connection from the positive pole of the source of current to the arrival line a_0 of the switch SA_0, which is the first switch of the series for calculating the units denomination of the result. Thereafter it connects the positive pole of the source of current successively to the contacts **20** of the differential switches DS_0, DS_1, DS_2 and DS_3 as the different series of switches are established for the calculation of the higher denominations of the result.

In order that the indicating devices should operate correctly the load on the rotors must be very small, and instead of driving the differential switches directly as described, it may, therefore, be preferred to employ the rotors merely as relays to control follow-up servo-motors, in the manner well-known in ships-compasses and like remote indicating devices, and these motors may control the differential switch mechanism.

Each switch SA or SB consists essentially of two parts which are adjustable together. One part of the switch may be termed the tens part and is indicated by the reference T and the other the units part and is indicated by the reference U. The tens part of each switch SA and the tens part of the switch SB preceding it in the series are electrically connected together during the operation of the machine and co-operate, while the units part of each switch SA is electrically connected to and co-operates with the units part of the switch SB which follows it in the series. Each pair comprising the tens part of a switch SB followed by the tens part of a switch SA serves to calculate the tens digit of the product of the two digits represented by the setting of the two switches and to add this digit to the sum of the digits calculated by the pairs of switch parts earlier in the sequence of switches. Each pair comprising the units part of a switch SA followed by the units part of a switch SB serves in similar manner to calculate the units digit of the product of the digits represented by the setting of the switches. The switches are built up from a number of electromagnetically operated units of the kind shown in Figures 9 and 10. Each unit comprises a ring of fixed contacts **292**, **293** mounted on a segment of insulating material **294** fixed to the frame **295**. The contacts **292** are wider than the contacts **293** and are arranged alternately therewith. Each contact **292**, **293** is provided with a tab **298** for making soldered connections to the wiring. A ring of moving contacts **297** are embedded in a disc **298** of insulating material mounted on a spindle **299** supported in bearings in the frame **295**. Each movable contact **297** is in the form of a split blade of the same width as the fixed contacts **292**. The disc **298** carrying the movable contacts is driven in reciprocatory rotation about its spindle **299** by one end of a lever **300** pivoted to the frame at **301** and forming at its other end a movable armature **302** placed between the poles **303**, **304** of two electromagnets **305** and **306**. When the magnet **305** is energised the lever **300** is moved in an anticlockwise direction and by means of a pin **307** in its lower end moves the insulating disc **298** in a clockwise direction so that one part of the split movable contacts **297** moves off the wide fixed contact **292** on to the adjacent narrow fixed contact **293**. Each wide contact **292** is thus electrically connected to the adjacent narrow contact **293**. The excitation of the other electromagnet **308** conversely returns all the moving contacts to the position shown in Figure 9. These electromagnetically operated units are mounted in the casing as indicated at **206** in Figures 1 and 2 and from the tabs **296** wires of the bundle **207** lead to connection frames **208**, shown on a larger scale in Figures 7 and 8, where they are connected to metal blades **308** embedded in insulating bars **309** fixed to transverse rails **310**. The blades **308** of the various bars **309** are aligned in the transverse direction of the bars so that these blades may be connected by wires **311** to carry out the connections presently to be described.

Figures 18A, 18B, 18C and 18D show one of the switches SB. Figure 18B is a continuation to the right of Figure 18A, these two figures completing the units part of the switch. Similarly, Figure 18D is a continuation towards the right of Figure 18C and these two figures together form the tens part of the switch. The table labelled "Switch B" which extends across the top of these figures indicates the digital settings of the switch for which particular contacts will be closed. Where a dash appears in a horizontal column of the table the contacts vertically in line with that dash will be closed, in the direction of the adjacent arrow, when the switch is set to register the digit at the end of the horizontal column. For example, if the switch is set to record 4, then in the part of the switch shown in Figure 18A the fourth row of k contacts, the second row of l contacts, the fourth row of m contacts and the third row of n contacts will all be closed. Similar remarks apply to the contact shown in Figures 18B, 18C and 18D.

Each of these rows of contacts is constituted by a group of the contact pairs **292**, **293** of an electromagnetically operated switch unit shown in Figures 9 and 10, and the operating electromagnets are indicated diagrammatically above the tables vertically above the contacts which they operate. For example, referring to the nine rows of contacts marked k in Figure 18A, each row comprises eleven contact pairs numbered **0** to **10**, and is on a different switch unit. The closing magnets of these nine units are shown vertically above the corresponding rows and are marked **100**, **101**, **102** . . . **108**. When the switch is set to register a digit from 1 to 9 inclusive one of these magnets is energised, as indicated by the dash in the horizontal column pertaining to that digit, so that the disc **298** (Figure 9) of the corresponding switch unit is rotated and the contact pairs **292**, **293** of the group are connected together. In Figure 18A there are also nine rows of contacts marked l, and as the registration of digits from 1 to 9 inclusive also in this case only involves the closing of one row of contacts at a time, each of these rows may be paired with one of the rows k so that the same magnet closes the contacts of both rows. Thus, for example, the first row of contacts k and the third row of contacts l are both closed when the digit 1 is set up and may therefore both be mounted in the same switch unit so as to be closed by the same magnet **100**. For convenience, in Figure 18A the magnets **100** to **108** have been repeated above the rows of contacts l. In the case of the four rows of contacts m, it will be seen that each row is closed when two digits are set up, for example the first row is closed when the digits 1 to 6 are set up, and to avoid the formation of back circuits in the magnet wiring system, which will be described presently, such rows can only be paired with other rows which are closed when the same two digits are set up. The first row of m contacts is therefore paired with the second row of n contacts and all these contacts mounted on the same switch unit and operated by the same magnet **109**. The remaining rows of contacts on Figures 18A, B, C and D are allocated to different switch units according to the same principle as may readily be followed by reference to the table and the numbering of the operating magnets.

Figure 24 shows how the operating magnets pertaining to the switch SB are controlled by the keyboard. **100** to **126** inclusive are the closing magnets shown in Figures 18A, 18B, 18C and 18D, and **100'** to **126'** inclusive are the corresponding magnets for returning the switch units to the open position. One terminal lead of each magnet is permanently connected to the negative current supply line, and the other terminal lead of each of the opening magnets **100'** to **126'** inclusive is connected to a common line leading to one of the contacts of the contact pair **231** operated by the trigger **232** (see Figure 4). The other contact of the pair **231** is connected to the positive current supply line. Operation of the trigger **232** therefore releases all the keys which have been depressed, as already described, and also energises all the magnets **100'** to **126'** to return the switch units to the open circuit position. The closing magnets **100** to **126** inclusive are controlled by the keys **0** to **9** which are one of the rows of keys **224** shown in Figure 2. The other row of keys **224** controls an identical system of magnets pertaining to the other switch SB. When a key is depressed all the contacts shown in a group below it are connected together. When the key **0** is depressed to register the digit 0 in the switch SB under consideration it will be seen from the tables of Figures 18A, 18B, 18C and 18D that the following magnets have to be energised: **114**, **115**, **116**, **117** and **124**. For this purpose one contact controlled by the key **0** is connected to the positive current supply line and the other five are each connected to one of the magnets named. In a similar manner, inspection of the tables of Figures 18A, 18B, 18C and 18D shows that when the key **1** is depressed the following magnets have to be energised: **100**, **109**, **113**, **117** and **124**, and it will be seen from Figure 24 that the key **1** controls six contacts one of which is connected to the positive current supply line and the other five to the five magnets last named. The remaining keys **2** to **9** inclusive control sets of contacts connected up to the magnets according to the same principle.

Figures 20A, 20B, 20C and 20D show one of the switches SA. Figure 20B is a continuation to the right of Figure 20A, these two figures completing the tens part of the switch, and Figure 20D is a continuation to the right of Figure 20C, these two figures together forming the units part of the switch. The switches SA are built up from a number of electromagnetically operated switch units in the manner already described for the switches SB, so that further description of this construction is considered unnecessary. The switches SA are closed by magnets **50** to **77** inclusive and opened by magnets **50'** to **77'** inclusive, and Figure 25 shows the connections of these magnets to the contacts operated by the keys **0** to **9** of one of the rows **223** of Figure 2. Each row of keys **223** controls an identical switch SA by means of a magnet system as shown in Figure 25.

Figure 23 shows one of the switches SD, which is composed of ten of the electromagnetically operated switch units each having eleven contact pairs. As shown by the table labelled "Switch D" one of these units is operated for each digit registered. The magnets for closing the switch contacts are shown below the table and are denoted by the references **130** to **139** inclusive. References **130'** to **139'** indicate the corresponding magnets for returning the switches to the open position. One lead of each of the magnets is connected to the negative current supply line, and the other lead of each of the opening magnets is connected to one contact of the contact pair **231** which is closed by the trigger **232** (Figure 4). The other contact of the pair **231**, and one contact of each of the contact pairs closed by the keys **0** to **9** inclusive are connected to the positive current supply line. The other contact of each of the pairs controlled by the keys is connected to the closing magnet to be controlled by that key. The keys **0** to **9** are one of the rows of keys **225** shown in Figure 2. The other rows of keys control identical switches SD in the same manner.

It was previously pointed out that the method of multiplication can be indicated diagrammatically by assuming that one factor, with its digits in inverted order, is moved relatively to the other factor. Five positions in such a movement are shown in Figure 13. In each position each digit of the factor B is multiplied by the digit of a factor A to its left to obtain a units digit and by a digit of the factor A to its right to obtain a tens digit. Thus the first three stages of the operation are as follows:

Position **0**, the product of the units digit b_0 of the factor B_0 by the units digit a_0 of the factor A is obtained and subtracted from the units digit d_0 of the factor D.

Position **1**, the sum of the units digits of the product of b_0 and a_1, the tens digit of the product of b_0 and a_0 and the units digit of the product of b_1 and a_0 is subtracted from the digit d_1.

Position **2**, the sum of the units digit of the product of a_2 and b_0, the tens digit of b_0 and a_1, the units digit of a_1 and b_1 and the tens digit of b_1 and a_0 is subtracted from the digit d_2 of factor D.

Figure 15 shows the order in which the switches are connected in circuit by a commutator presently to be described for the stage of the operation corresponding to position **0** in Figure 13. At this stage only the units parts U of the switches SA_0 and SB_0 and the switch SD_0 are connected in circuit. On the left-hand side the positive pole of a source of supply is connected to an arrival lead of the switch SA_0. The departure lines of the switch SD_0 are connected firstly to the decadal indicator UD of the units denomination of the result register and then to the hendecadal indicator UH of the units denomination. During the first part of this stage of the operation notation-controlling commutators to be described are in the decadal position while during the second part they are in the hendecadal position. As will be clear from the following description the switches SA_0 and SB_0 will determine the units digit of the product of the units digits of the two factors and this units product digit will be subtracted from the units digit of the factor D by the switch SD_0.

This circuit will lead to one of the lines $0R_0$ to $9R_0$ of Figure 11B and as already explained the units decadal indicator UD will move to a position corresponding to the units digit of the result. In the second part of the first part of the operation the notation-controlling commutators will have shifted so that a similar circuit will be completed to energise the units hendecadal indicator UH in accordance with the units digit result in the hendecadal notation. The differential "carrying" switch DS_0 (Figure 16) operated by these two indicators will thus be adjusted in accordance with the difference between the units digits in the two notations, and will, as previously described, select one of a number of leads. These leads are permanently connected to the arrival leads of the switch SA_1, which is the first switch of the series of switches established to calculate the digit of the tens denomination of the result as shown in Figure 16. In this second stage in the operations, corresponding to position 1 of Figure 13, the series of switches comprises the units part of the switch SA_1, the switches SB_0 and SA_0, the units part of the switch SB_1 and the switch SD_1. Circuits are established through these switches, including the differential "carrying" switch DS_0 of the units denomination, to adjust first the tens decadal (TD) and then the tens hendecadal (TH) indicator.

The series of switches established in the third stage of the operation are shown in Figure 17 and are similar so that they need not be described. After a circuit has been completed through the highest switch SA provided in the machine (SA_2), a series of switches will be established in the next stage starting with a switch SB_0 and terminating with the switch SA_0 and one of the switches SD. The number of switches in sequence then progressively diminishes until in the final stage the sequence consists in the highest switch SB followed by the highest switch SA. In connection with the last sentence it should be noted that it is possible, for reasons which will be explained, to employ one fewer switch SD than there are denominations in the result; which accounts for the fact that the last sequence of switches consist of the highest switch SB and the highest switch SA only.

Figure 26 is a key diagram showing how Figures 18A to 23 inclusive may be pieced together to complete the electrical circuits corresponding to the five positions of Figure 13. In the position O only Figures 18A, 18B, 20C, 20D and 23 are involved and should be arranged in the order shown so that the circuits may be traced from one sheet to the next. This arrangement corresponds to Figure 15 except that the tens part of the switches SA_0 and SB_0, which are not involved in the circuits, have been omitted. The arrangements for positions 1 and 2 similarly correspond to Figures 16 and 17.

Before describing the circuits in detail, the principle on which a pair of switch parts operates will be described generally.

Taking first the case of the units part of a switch SA followed by the units part of a switch SB, these two switch parts have to add to a digit *s*, determined by the earlier switches in the sequence, the units digit of the product of the digit *a* which the switch SA is set to represent, and the digit *b* which the switch SB is set to represent. Using the hendecadal notation there are 11 possible values for *s* and 10 possible values for *a* and *b*. There are therefore 1,100 possible computations, but there are only 20 possible results, since the largest product digit is 9 and the largest value of *s* is 10, so that the possible results are 0–19 inclusive. There are 11 arrival leads to the units part of the switch *SA*, each of these leads corresponding to a different value of *s*. The appropriate lead is rendered alive by circuits completed from the earlier switches in the series while the other leads are dead. Each of these leads has 10 branches, each branch corresponding to a different value of *a*. The switch SA serves to make a connection in each branch corresponding to the definite value of *a* which the switch is set to register, there being one of such branches in each of the eleven sets. The switch also breaks the other branches corresponding to other values of *a*, so that a connection can be established through the arrival lead which is alive to the connected branch which is associated with the digit for which the switch SA is set. The 110 branches extend from the switch SA to the related switch SB. Each branch is provided with 10 secondary branches inside the switch SB, each of the secondary branches relating to each one of the primary branches being allocated to a different value of *b*. The switch SB is provided with contacts for completing connections in all the secondary branches corresponding to the value of *b* for which the switch is set, there being one of such branches in each of the 110 secondary sets. The switch SB interrupts the secondary branches corresponding to all other values of *b*. Since each secondary branch in a group corresponds to a different value of *b*, only one branch in a group will be alive and the secondary branch in the group will continue the circuit through the primary branch which is alive. This circuit will correspond to the computation $s+ab$ where *s*, *a* and *b* have definite values and will therefore have a definite result value depending upon the values of the factors. Each of the secondary branches is connected permanently to one of 20 result wires allocated to the different results from 0 to 19. If the calculation is proceeding on the decadal system, the result wires corresponding to 10–18 are connected respectively to the result wires corresponding to 0–8, since only the units digit of the result is required, so that the result 10 corresponds to the result 0 and so on. If the calculation is proceeding on the hendecadal notation the result wires corresponding to 11–19 are connected respectively to the result wires corresponding to 0–8 since the units digit of 11 when expressed in the hendecadal notation is 0 and the units digit of 12 is 1 and so on. A connection is thus completed from the arrival wire to one of 11 departure wires, which are the result wires corresponding to 0 to 10, corresponding to the required result. This departure wire is in turn connected to the arrival wire of the next switch part in the series which would normally be the tens part of the switch SB.

The connections for the tens switch part of SB followed by tens switch part SA will be substantially the same, but the manner in which the various secondary branches are connected to the result wires will be different, since the tens digit of the product must be taken into account instead of the units digit. Further, the switch SB controls the contacts in the primary branches, while the switch SA controls the contacts in the secondary branches, since the switch SB precedes the switch SA in series at this point of the series of switches.

To summarize the above each switch SA would be connected to the units part of one switch SB by 110 primary branches from its units part and to the tens part of another switch SB by 110 primary branches from its tens part and thus would have 220 primary branches, that is connections to switches SB. Each switch SA would have also 11 arrival leads and 11 departure leads. Further each switch SA would have 110 contacts in its units parts and 1100 contacts in its tens parts or 1210 contacts in all. Each switch SB would also have 11 arrival and 11 departure leads 220 primary branches and 1210 contacts, 1100 in its units part and 110 in its tens part.

In practice it is possible, as will be described next, to modify the theoretical circuits described above so as to reduce the total number of contacts required in each switch. The effect of these modifications is to reduce the total number of contacts in each switch SA to 381, 253 in the tens part and 128 in the units part, and the number of contacts in the switch SB to 490, 352 in the units part and 138 in the tens part. It will be noted that the decrease in the number of contacts in one part of each switch is accompanied by an increase in the other part of that switch but the total number of contacts is greatly reduced. The number of primary branches is drastically reduced but the modifications necessitate additional connections between the switches which, with the remaining primary branches, result in a total of 199 connections from each switch to the preceding and following switch in the series.

The modifications will now be explained with reference to Figures 18A, 18B, 20C and 20D, which should be arranged as shown at position 0 in Figure 26, and show the circuits for the units part of the switch SB_0 and the units part of the switch SA_0. As already explained, the contacts shown in Figures 20C and 20D are in the switch SA_0, and the table labelled "Switch A" indicates the digital settings of the switch for which particular contacts will be closed. Similarly the contacts in Figures 18A, 18B are in the switch SB_0, and the table labelled "Switch B" shows which contacts are closed in any particular setting of the switch.

The arrival wires are shown at a and correspond to the digits 0–10 as indicated in the lower left-hand corner of Figure 20C. The departure wires are shown at i in the upper right-hand corner of Figure 18B, and the digital values corresponding to them are indicated.

If the digit a is zero, the units digit of the product ab is also zero, so that the arrival wires a can be connected directly to the corresponding departure wires i by means of the contacts i_0 to i_{10} which are closed when the switch SA_0 is set to record 0. Under these conditions, the contacts a'_0 to a'_{10} are also closed, so that the circuit may extend from the line a_0 to the line i_0 from the line a_1 to the line i_1 and so on. The primary and secondary branches for the value $a=0$ can thus be omitted.

When the value of a is 1, the switch SA_0 will close contacts k_0 to k_{10}, and the contacts a'_0 to a'_{10}, so that the circuits will extend over a group of lines k which constitute the primary branches. Each of these primary branches can be connected by 9 pairs of contacts to any one of 9 lines p_0 to p_{18}, the contacts being arranged systematically. The line k_0 corresponds to the computation $0+1x$, the line k_3 to the computation $3+1x$ and so on. Thus, the line k_0 must be connected to one of the result lines p_0 to p_8 which correspond to the results 1–9, the line k_3 must be connected to one of the lines p_3 to p_{11} which correspond to the results 4–12, and so on. Which of these various contacts are closed, as the result of the setting of the switch SB_0 that has been made, is indicated by the dashes in the table "Switch B," and the arrangement is such that each of the lines k_0 to k_{10} is connected to the appropriate one of the lines p_0 to p_{18}. Thus, when the switch SA_0 is set to register 1 and the switch SB_0 set to register a significant digit and with one of the leads a only alive, a unique circuit will be established through one of the lines a'''_0 to a'''_{10}, one of the lines k_0 to k_{10} and one of the lines p_0 to p_{18}. Similar primary branches comprising the lines m, l and n are provided for the digital values 2, 3 and 4 of a respectively. In connection with the branches m and n, a simplification is possible owing to the fact that the products of the digits 2 and 4 must have the values 2, 4, 6, 8 so that only four pairs of contacts are needed to connect each of the lines m and n to the appropriate lines p. Thus, the contacts which connect the line m_0 to the line p_1 to give the result 2 are closed both when the digital value of b is 1 and when it is 6, since the units digit of the product 2×1 and of the product 2×6 is 2 in both cases.

The manner in which circuits are established when the digit a is 6, 7, 8 or 9 is based upon the following considerations. If the units digit of a product ab is y, the units digit of the product $(10-a)b$ is $10-y$. The truth of this can be shown by the following demonstration. Let x be the tens digit of the product ab so that $ab=10x+y$ then $(10-a)b=10b-ab=10b-(10x+y)=10(b-x-1)+(10-y)$. Thus the tens digit of the product $(10-a)b$ is $(b-x-1)$ and the units digit is $10-y$. In other words the units digit of the product of two digits is the complement of the units digit of the product of the complement of one of those two digits multiplied by the other digit. Further, the sum of the complements of the two digits is equal to the difference between 20 and the sum of the two digits. Thus $(10-s)+(10-y)=20-(s+y)$.

The digit 9 is the complement of 1, the digit 8 is the complement of 2, the digit 7 is the complement of 3 and the digit 6 is the complement of 4. With the present circuits the same connections between the lines a''' and k are established both for 1 and 9. The lines 1 are connected to the lines a''' both for the digits 3 and 7. The lines m and n are used in the same manner for the digits 2 and 8 and for the digits 4 and 6 respectively.

Thus when the switch SA_0 is set to register 6, 7, 8 or 9, it will establish the same circuit connections from the lines a''' to the lines p as when it is set to register 4, 3, 2 or 1 respectively and these connections will serve to complete a circuit corresponding to the complement of the units digit of the product instead of that corresponding to the units digit of the product. Further when the switch SA_0 is set to represent 6, 7, 8 or 9, it will close the contacts a'' and connect the lines a to the lines a''' in inverted order so that the line a''' which is alive corresponds to the complement of the digit represented by the line a which is alive. Thus the complement of the digit s will be added to the complement of the units digit y of the result and the line p which is alive will correspond to the difference between 20 and the required result digit.

The lines p are connected to the departure lines i by means of two groups of contacts p of the switch SA_0. The left-hand group of contacts p_0 to p_8 are closed when the switch SA is set to record 1, 2, 3 or 4 and serve to connect the lines p_0 to p_8 to the lines i_1 to i_9 respectively. The lines p_0 to p_8 correspond to the digits 1 to 9 of the result and are therefore connected directly to the required lines i. The line p_9 which corresponds to 10 is permanently connected to the line i_{10} since the result 10 is always equal to 10 whether it is the true number or the complement of the true number.

When the result is a complement, the line p_{18}, will correspond to the complementary result 19 and therefore to the true result 20—19=1. The contacts p_{18} of the righthand group p_{10} to p_{18} serve therefore to connect the line p_{18} to the line i_1. This right-hand group of contacts p_{10} to p_{18} is closed when the switch SA_0 is set for 6, 7, 8 or 9. The other lines p_{10} to p_{17} are similarly connected so that the complementary result represented by the energised line p_{10} to p_{18} is converted into a true result represented by an energised line i_1 to i_{10}.

The above is explained as to how the units digit required is arrived at when the sum $(s+ab)$ is 10 or less. If the sum is more than 10 and is a true amount, one of the lines p_{10} to p_{18} will be alive and this line must be connected to the appropriate line p_0 to p_8 so as to complete the circuit through the proper departure line i_1 to i_9. For this purpose a commutator is provided which is shown to the right of the lines p in Figure 20D and comprises a plurality of segments designated 0 to 8 and 10 to 18 connected each to the corresponding line p_0 to p_8 and p_{10} to p_{18} and two rows of bridging contacts labelled "base 10" and "base 11". The bridging contacts labelled "base 10" bridge the contacts when the calculation is proceeding on the decadal notation and serve to connect the line p_{10} corresponding to the result 11 to the line p_0 corresponding to the result 1 and so on. When the calculation is proceeding on the hendecadal notation the bridging contacts labelled "base 11" bridge the contacts 0 to 18 and connect the line p_{11} corresponding to 12 to the line p_0 corresponding to 1 and so on. Thus the result computed by the switch parts SA_0 and SB_0 under consideration will be expressed in the decadal or the hendecadal notation and carried forward to the next pair of switch parts. The same commutator serves to make the proper connections when the result is a complement of a sum more than 10 but in this case the connections will arrive through one of the lines p_0 to p_8 and will leave through one of the lines p_{10} to p_{18} instead of vice versa. It will be appreciated that only one of these two groups of lines p can be connected to the group of lines i so that only one circuit can be completed.

In the above description it was assumed that the digit b was a significant digit. If the digit b is 0 the setting of the switch SB_0 causes the contacts k, l, m and n opposite the left-hand part of the table headed Switch B to be closed so as to connect whichever of the lines k, l, m or n, that is alive to a line q. The effect of this connection is that when the digit a is not 0, each arrival line a is connected to the line q for the same digit. If the digit a is 1, 2, 3 or 4, the left-hand group of contacts q_0 to q_{10} of the switch SA_0 will be closed and will connect the lines q_0 to q_{10} each to the corresponding line i_0 to i_{10} so that each line a will be connected to the corresponding line i, which is correct since the product ab is zero. If the digit a is 6, 7, 8 or 9, the setting of the switch SA_0 will connect the lines a to the lines a''' in inverted order so that the lines a will be connected to the lines q in inverted order also. In view of this the switch SA_0 is arranged to close the right-hand group of contacts q_0 to q_{10} when the digit a is 6, 7, 8 or 9 so as to invert the connections between the lines q and the lines i and correct inversion between the lines a and the lines a'''.

If the digit a is even and the digit b is 5, their units product is necessarily zero. The switch SB_0 is therefore arranged to close the contacts m_0 to m_{10} and n_0 to n_{10} when it is set to record 5. Since one or other of the two groups of lines m and n is included in the circuit when the digit a is even, this will have the result of connecting lines a to the lines q whenever the digit a is even and the digit b is 5. The case where the digit a is odd and the digit b is 5 is taken care of by the contacts k and l of the switch SB_0 in the manner previously described.

Finally, when the digit a is 5 the units digit of the product will be 0 if the digit b is even and 5 if the digit b is odd. When the switch SA_0 is set for 5 it closes the contacts O_0 to O_{10} to establish circuit through a group of lines O which can be connected to the lines p in the proper manner on the closure in Figure 18A of a group of contacts O_0 to O_{10} of the switch SB_0. These contacts are closed whenever the digit b is odd. It will be noted that the contacts a'' are closed when the switch SA_0 is set for 5 so that the result obtained is a complementary result. It is therefore converted into the true result in the same way as when the digit a is 6, 7, 8 or 9. When the digit b is even, a group of contacts O_0 to O_{10} of the switch SB_0 (Figure 18B) is closed and serve to connect the lines O_0 to O_{10} to the lines i_0 to i_{10} in the proper manner, allowance being made for the fact that the contacts a'' are closed so that each line a is connected to the corresponding line i.

The construction of all the switches SA is the same and the construction of all the switches SB is the same, so that the explanation just given in connection with Figures 18A, 18B, 20C and 20D serves also for the co-operation of the units parts of the switches SA_1, SB_0 and SA_0, SB_1 which occur in position 1 and involve Figures 18A, 18B, 21C, 21D and 19A, 19B, 20C and 20D respectively, for the co-operation of the units parts of the switches SA_2, SB_0 and SA_1, SB_1 which occur in position 2 and involve Figures 18A, 18B, 22C, 22D and 19A, 19B, 21C and 21D respectively, and for the cooperation of the units parts of the switches SA_2, SB_1 which occurs in position 3 and involves Figures 19A, 19B, 22C and 22D. In other words, Figures 18A and 19A are identical as are also Figures 18B and 19B; 20C, 21C and 22C; 20D, 21D and 22D.

Turning now to the case when the tens part of a switch SB is followed by the tens part of a switch SA, and taking as an example the co-operation of the tens part of the switch SB_0 with the tens part of the switch SA_0, which occurs in position 1 and involves Figures 18C, 18D, 20A and 20B arranged in the order shown in Figure 26, position 1, the current will arrive by a wire i (Figure 18C) of the switch SB_0 and depart by a wire a

of the switch SA_0. If the digit b is 0 or 1, the tens digit of the product ab will necessarily be 0 and therefore the sum of the tens digit of the product ab and the digit s introduced through the wire i will be equal to the digit s. Thus the switch SB_0 is arranged to close its contacts a_0 to a_{10} when it is set to represent 0 or 1 and to connect the lines i directly to the lines a in the normal order.

When the digit b is 2, 3 or 4 the switch SB_0 will connect the lines i to groups of lines d, e, or f respectively. The switeh SA_0 will connect the appropriate group of lines d, e or f to lines c of which there are 14. These lines return to the switch SB_0 and are connected by the switch SB_0 to lines a_0 to a_{13} by the contacts c_0 to c_{13}. These lines correspond to the results from 0 to 13 in value and the lines a_{10} to a_{13} are connected, in accordance with the hendecadal or the decadal notation and by the commutator indicated below them, to the lines a_0 to a_3 in the same manner as was previously described with reference to Figures 18A, 18B, 20C and 20D. The circuits are similar to those described with reference to Figures 18A, 18B, 20C and 20D for the digits 1 to 4 except that they are arranged to effect the addition of the tens digit of the product to the digit introduced from the earlier switches instead of units digit of the product.

When the digit b is 5, the switch SB_0 connects the lines i to lines g which are connected by the switch SA_0 to lines a_0 to a_{14} in the appropriate manner and these lines are connected to the departure lines a_0 to a_{10} through the notation-changing commutator or directly in the manner described previously. If the switch SB_0 is set for 9, the contacts i'' will be closed instead of contacts i' and the lines i will be connected in the switch in the complementary manner instead of the direct manner. The switch SB_0 will also close its contacts h_0 to h_{10} so as to connect the lines h to the lines i and the lines h will be systematically connected to the lines a_0 to a_{18} in accordance with the values of the tens digits of the various products but the connections will be so made as to allow for the fact that the lines i are connected in a complementary manner. For example, the line h_0 which is connected to the line i_{10} will be connected to the line a_{10} and not the line a_0 when the switch SA_0 is set for 0. The contacts h of the switch SA_0 are arranged to give the complement of the tens digit and this digit is added to the complement of the digit introduced by the lines i; the complementary is then reconverted back to its proper form.

The circuits established when the digit b is 6, 7 or 8 are based upon the following considerations. If b_1 and b_2 are complementary digits, x is the tens digit of the product $b_1 \times a_1$, y is the tens digit of the product $b_2 \times a_1$ and z is the tens digit of the product $9a_1$ then $x+y=z$. For example, if 2 and 8 are the complementary digits b_1 and b_2 and a_1 is 7; x will equal 1, since twice 7 is 14; y will equal 5, since $8 \times 7=56$; z will equal 6, since $9 \times 7=63$. $1+5=6$. When the digit b is 6, 7 or 8, the contacts i'' of the switch SB_0 are closed so that the circuit established will correspond to s where s is the digit corresponding to the energised line i. In addition the circuit will include one of the lines d, e or f corresponding to the complement of the digit which the switch SB_0 is set to represent. Thus, if the switch SB_0 is set to represent b_1 and the switch SA_0 is set to represent a_1, the circuit established will correspond to a_1, b_2 where b_2 is the complement of b_1. The required result is $s+x$ but the circuits established will correspond to $-s+y$. The circuit will include the lines c_0 and c_{13} which are connected by the row of contacts h of the switch SB_0 (Figure 18D). This row of contacts h are closed when the switch is set to record 6, 7 or 8. The circuits continue in exactly the same way as when the switch SB_0 was set to represent 9 except that instead of the line corresponding to the complement of s, or to $-s$, being rendered alive by being connected to the alive line i, the line h corresponding to $(-s+y)$ is rendered alive by being connected to the alive line c. As previously explained the contacts h of the switch SA_0 serve to select the lines corresponding to the complement of the tens digit of 9 times the digit for which the switch SA_0 is set. Since the switch SA_0 is set to represent the digit a_1 the circuit completed will correspond to $(-s+y-z)$ where z is the tens digit of the product $9a_1$ as before. Now $y-z=-x$ so that the connection corresponds to $-s-x$ or $-(s+x)$. As previously explained the contacts h of the switch SA_0 correct for the fact that the result is in a complementary form so that the circuit selected is the correct one namely that corresponding to $(s+x)$.

Finally, when the switch SA_0 is set to register 5, special circuits are completed when the switch SB_0 is set for 6, 7, 8 or 9. These circuits are completed through the group of wires b and need no special explanation.

The explanation just given in connection with Figures 18C, 18D, 20A and 20B serves also for the cooperation of the tens parts of the switch SB_0, SA_1 and SB_1, SA_0 which occur in position **2** and involves Figures 18C, 18D, 21A, 21B and 19C, 19D, 20A and 20B respectively, for the co-operation of the tens parts of the switches SB_0, SA_2 and SB_1, SA_1 which occur in position **3** and involve Figures 18C, 18D, 22A, 22B and 19C, 19D, 21A and 21B respectively, and for the co-operation of the tens parts of the switches SB_1, SA_2 which occurs in position **4** and involves Figures 19C, 19D, 22A and 22B. In other words, Figures 18C and 19C are identical as are also Figures 18D, 19D; 20A, 21A and 22A; 20B, 21B and 22B.

A complete connection table for the switches SA is shown in Figure 27 while Figure 28 is a similar table for the switches SB. In these tables each lead is designated by a letter which is shown to the left of the table and a figure. It will be noted that the tables are divided into groups and connections are made by the switch between the leads occurring in a vertical column in each group of the table but not between the leads in two different groups of the table. Whether or not a connection is made between a pair of leads occurring in the same table depends upon the setting of the switch and is indicated by the dashes in the left-hand part of the table. This part of the table is divided into ten vertical columns corresponding to the ten possible positions of the switch. If a dash occurs in a column opposite a horizontal line of leads in the right-hand part, a connection can be made to any of those leads. Two leads occurring in a vertical column will be connected together in a particular setting of the switch if dashes occur opposite both those leads in the column corresponding to that setting of the switch. For example, in position **3** of the switch SA, the leads c_0, d_0 and e_0 (Figure 4) are connected together, the leads c_1, d_1, e_1 and f_0 are connected together, the leads c_2, d_2, e_2 and f_1 are connected together and so on. In position **4**, on the other hand, the leads c_0 and d_0 will be connected together, the leads c_1, d_1, e_0 and f_0

will be connected together and so on. It will be noted that many of the leads are duplicated. This is of course merely diagrammatic in order that the connections established in the various positions may be made apparent. For example, the leads e_0 to e_{10} are shown 3 times. This is because in the positions 0, 1, 2, and 3 they have to be connected respectively to the lines c_0 to c_{10}, in the positions 4, 5 and 6, they have to be connected to the lines c_1 to c_{11}, and in the positions 6, 7, 8 and 9, they have to be connected to the lines c_2 to c_{12}. These three different schemes of connections have been shown by repeating the line three times in different relative positions to the lines c and by providing dashes in the appropriate columns to the left of the table.

One method of materialising these tables will be explained as applied to group 1 of Figure 27. In this method each designation comprising the letter d, e or f and a number shown in the table denotes a pair of contacts connected between the line having the same designation and the line c_0 to c_{13} at the head of the column containing the designation. Thus, there are two sets of eleven contacts d_0 to d_{10}. One set connects the line d_0 to the line c_0 and so on, and the other the line d_0 to line c_1 and so on. The first set are closed for the positions 0 to 4 of the switch and the second set for the positions 5 to 10. In the same way there are three groups of contacts e_0 to e_{10} and four groups of contacts f_0 to f_{10}. This is the method of showing the contacts adopted in Figures 18A to 22D inclusive but is not the only method or necessarily the best method.

The system of connections shown in Figures 27 and 28 produce exactly the same results as those shown in Figures 18A to 22D inclusive but are not absolutely identical. The principal difference is that in Figures 18A to 22D the contacts a' and a'' are provided for the purpose of obtaining the complement of the digit introduced whereas in Figure 27 the same result is obtained by providing two alternative methods of connection between the lines a and k, a and l, a and m, a and n. One of these methods of connection is a direct method and the other is an inverted method. The effect of the connections shown in Figure 27 is that instead of providing the contacts a' and a'' there will be provided duplicate contacts k, l, m and n for connecting the corresponding wires to the wires in an inverted manner instead of a direct manner. It will be noted that the arrangements shown in Figure 20C result in an economy since only two sets of contacts are required instead of four. In a similar manner the contacts i and i' of Figure 18C replace the alternative connections d, e, and f shown in Figure 28.

The 98 leads of each switch SA denoted in Figure 27 by the reference letters a to h, excluding the leads a_{14} to a_{10} which are internal leads, are connected to the correspondingly lettered leads of the switch SB as shown in Figure 28. The 101 leads of the same switch SA denoted in Figure 27 by the reference letters i to q, but excluding the leads i_{16} to i_{10} which are internal leads, are connected to the corresponding lettered leads of another switch SB. These connections are effected by means of a commutator so as to connect the switches together in a different ordered series at each stage of the calculation. The arrangement of this commutator, shown at 29 in Figure 11A, will be described later.

The wiring for each of the switches SD is shown in Figure 23. The switch receives current from the line a or the line i which is alive and corresponds to the units digit of the sum of all the units and tens product digits which are summed at a particular stage of the computation. The function of the switch SD is to subtract this digit from the digit which is registered by the setting of the switch. The switch closes a group of eleven contacts in each of its positions so as to connect each line a or i to one of ten lines c_0 to c_{10} corresponding to the difference between the two digits if the digit recorded by the switch SD is the larger. For example, if the switch is set to record 5 and the alive line a or i represents 3, the circuit will be completed through the line labelled a_3 or i_3, the diagonal line labelled 3 and the line c_2. If the digit represented by the switch SD is the smaller, it is necessary to subtract the digit represented by the line a or i from ten plus the digit represented by the setting of the switch if the calculation is proceeding on the decadal notation and from eleven plus the digit represented by the setting of the switch if the calculation is proceeding on the hendecadal notation. There are thus two possible values of the result digit under the latter condition and the circuit continues from the line a or i through one of the lines c_{10} to c_{10} and hence through the notation-controlling commutator and either through the segments marked base 10 or the segments marked base 11 to the lines c_0 to c_9. For example, if the switch SD is set for 5 and the digit to be subtracted is 7 the circuit will include the line a_7, the diagonal line labelled 7, the line c_{11} and then either the line c_8 or the line c_9. The first case corresponds 10+5−7 on the decadal notation and the second case to 11+5−7 on the hendecadal notation.

The connection table for the switches SD is shown in Figure 29. The switches SD are connected as follows. The leads i_0 to i_{10} of the switch SD_0 (Figure 11A) are permanently connected respectively to the corresponding leads i_0 to i_{10} of the switches SB_0. The switch SD_1 is connected in the same way to the switch SB_1 and so on up to the switch SD_n, the switch SB_n being the switch for the highest denomination of the factor B. The leads a_0 to a_{10} of the switch $SD_{(n+1)}$ are permanently connected to the corresponding leads of the switch SA_0, the switch $SD_{(n+2)}$ is connected to the switch SA_1 and so on.

As already explained, Figure 26 is a key diagram showing the order in which Figures 18A to 23 inclusive are arranged to enable circuits to be traced through in the five positions 0 to 4, and the circuits established by the switches for a numerical example 7538−(48×62)=4562 will now be indicated:

Position 0a (decadal notation)

Current enters 20C by a_0, a'''_{10}, m_{10} (SA_0=8) to 18A, p_{13} (SB=2) through 18B to 20D, i_8 (SA_0=8) through 18B to 23, c_2 (SD_0=8), result ---------------------------------- 2

Position 0b (hendecadal notation)

The circuit in this position is unchanged, result ---------------------------------- 2

Position 1a

Current enters 21C by a_0, n_0 (SA_0=4) to 18A, p_7 (SB_0=2) through 18B to 21D, i_8 (SA_1=4) through 18B to 18C, d_8 (SB_0=2) to 20A, c_9 (SA_0=8) through 20B to 18D, a_9 (SB_0=2) through 20B to 20C, a'''_1, m_1 (SA_0=8) to 18A, p_2 (SB_1=6) to 20D through notation-changing commutator to p_{12}, i_7 (SA_0=8) through 18B to 23, c_{13} (SD_1=3) through notation-changing commutator to c_6, result--- 6

Position 1b

The circuit in this position is the same as for position 1*a* up to the first notation-changing commutator (on Figure 20D) which makes a connection to p_{13}, i_8 ($SA_0=8$) through 19B to 23, c_{12} ($SD_1=3$) through notation-changing commutator to c_8, result................ 8

Position 2a

Current enters 22C by a_2, a'''_2, i_2 ($SA_2=0$) through 22D and 18B to 18C, d_2 ($SB_0=2$) to 21A, C_2 ($SA_1=4$) through 21B to 18D, a_2 ($SB_0=2$) through 21B to 21C a'''_2, n_2 ($SA_1=4$) to 19A, p_5 ($SB_1=6$) through 19B to 21D, i_8 ($SA_1=4$) through 19B to 19C, f_4 ($SB_1=6$) to 20A, c_7 ($SA_0=8$) through 20B to 19D, h_7 ($SB_1=6$) through 19C and 19D to 20B, a_{10} ($SA_0=8$) to 23, c_{14} ($SD_2=5$) through notation-changing commutator to c_5, result 5

Position 2b

The circuit in this position is the same as for position 2*a* up to the notation-changing commutator in Figure 23 which makes a connection to c_6, result.......................... 6

Position 3a

Current enters 18C by i_1, d_1 ($SB_0=2$) to 22A, c_1 ($SA_2=0$) through 22B to 18D, a_1 ($SB_0=2$) through 22B to 22C, a'''_1 ($SA_2=0$) to 22D, i_1 ($SA_2=0$) through 19B to 19C, f_9 ($SB_1=6$) to 21A, c_{10}, ($SA_1=4$) to 19D, h_{10} ($SB_1=6$) through 19C and 19D to 21B, a_3 ($SA_1=4$) to 23, c_4 ($SD_3=7$), result...................... 4

Position 3b

The circuit in this position is the same as for position 3*a*, result......................... 4

Position 4 (decadal only)

Current enters 19C by i_0, f_0 ($SB_1=6$) to 22A, c_0 ($SA_2=0$) through 22B to 19D, h_0 ($SB_1=6$) through 19C and 19D to 22B, a_{10} ($SA_2=0$) through notation-changing commutator to a_0, result................................ 0

The commutator 209 (Figure 1) which controls the various connections in accordance with the stage of the operation rotates continuously through a quarter revolution for each calculation to perform the following functions:

(1) To establish the different series of switches appropriate to each stage of the calculation in turn by connecting the various leads of each switch to the corresponding leads of two other switches on either side of it in the series.

(2) For the first stage it must connect the lead a_0 of the switch SA_0 to the source of current, and for the succeeding stages it must connect the single contact 20 (Figure 11A) of the appropriate differential switch DS_0, DS_1, DS_2 or DS_3 to the source of current.

(3) At each stage of the operations it must adjust the circuits first to give the result on the decadal notation and then on the hendecadal notation.

(4) Finally, it must connect the departure lines C_0 to C_{10} of each switch SD_0, SD_1 etc. to the corresponding leads of the two indicators for the corresponding denomination of the result register and these connections must first be made to the leads of the decadal indicator and then to the leads of the hendecadal indicator.

All these functions are carried out by the single complex commutator 209, but to enable the operation to be more readily followed the commutator has been divided into parts in the diagram of Figures 11A and 11B.

The commutator part 26 for carrying out the function (2) has already been described with reference to Figure 1, and commutators for carrying out the function (3) have been referred to in connection with Figures 18A to 23 inclusive. On Figures 11A and 11B all the commutators are shown diagrammatically and these figures will now be further explained.

On the right hand side of Figure 11B are the indicators of the result register which, as already described, co-operate in pairs to actuate the differential switches DS_0 to DS_3 shown on the left hand side of Figure 11A. These differential switches co-operate with the commutator 26 in the upper left hand corner of Figure 11A to connect the positive pole of the source of current to the appropriate input lead of the first switch of each series. The switches SA_0, SA_1 and SA_2 are grouped together at the bottom of Figure 11A and are each represented by two rectangles, for the units and tens parts respectively, joined by an arrival line a_0. These lines a_0 are selected as typical of the eleven arrival lines a_0 to a_{10} of the switches SA. In a similar manner the switches SB_0 and SB_1 are represented at the top of Figure 11A by pairs of rectangles joined by typical arrival lines i_0.

The switches SD_0, SD_1, SD_2 and SD_3 are shown as rectangles arranged in a vertical group in the upper right hand corner of Figure 11A. In the first stage of the operations the switch SB_0 is followed by the switch SD_0 (see Figure 15) and this is indicated by the typical line i_0 connecting the switch SB_0 to the switch SD_0. In the second stage of the operations the switch SB_1 is followed by the switch SD_1 (see Figure 16) and this is indicated by the typical line i_0 connecting the switch SB_1 to the switch SD_1. Similarly, in the third and fourth stages the switches SA_0 and SA_1 are followed by the switches SD_2 and SD_3 respectively, and the connections are indicated by the typical lines a_0. As already explained, for the fifth stage no switch SD is required, and the typical line a_0 from the switch SA_2 is therefore shown proceeding direct to the upper part of the commutator 27 which connects this line and the typical lines C_0 from the switches SD alternately to the appropriate result lines OR_0, OR_1, OR_2, OR_3 and OR_4 of the decadal result indicators and to the appropriate result lines OR'_0, OR'_1, OR'_2 and OR'_3 of the hendecadal result indicators. The lines C_1 to C_{10} and a_1 to a_{10} from the switches SD and SA_2 proceed in a similar manner to the commutator 27 but are not completely shown. The lines C_1 to C_8 and a_1 to a_8 are omitted entirely, but the commutator ends of the lines a_9, C_9, a_{10} and C_{10} are shown.

In the first part of the first stage of the operations the commutator 27 is in the position shown in Figure 11B and connects the lines C_0 to C_9 from the switch SD_0 to the result lines OR_0 to $9R_0$ of the units decadal indicator UD in the manner shown for the lines C_0 and OR_0. Of these connections only the first indicated by a heavy line, and last are shown. For the second part of the first stage the commutator 27 is advanced one step in the direction of the arrow and then connects the lines C_0 to C_{10} from the switch SD_0 to the result lines OR'_0 to $10R'_0$ of the units hendecadal indicator UH. Of these connections only the first and the last two are shown. For effecting each of these connections a similar set of contacts has been shown on the commutator **27**, but it will appreciated that as the lines a_{10} and C_{10} have only to be connected to the hendecadal indicators, some of the contacts of the corresponding part of the commutator are redundant and could be omitted. For the first part of the second stage the commutator is advanced a further step and then connects the lines C_0 to C_9 from the switch SD_1 to the result lines OR_1 to $9R_1$ of the tens decadal indicator TD. The second part of the second stage and the subsequent stages follow in a similar manner, and it need only be pointed out that the last stage comprises only one part, in which the lines a_0 to a_9 from the switch SA_2 are connected to the result lines OR_4 to $9R_4$ of the ten thousands decadal indicator TTD.

At **28** is indicated the notation-changing commutator pertaining to the switches SD. Only part of this commutator is shown, but it will be understood that for each switch SD there is a pair of horizontal rows of contacts serving to connect the lines C_{10} to C_{19} leaving the switch to the lines C_0 to C_9 in the manner explained in connection with Figure 23.

In the first stage of the operations the units part U of the switch SA_0 has to be connected to the units part U of the switch SB_0 (see Figure 15), and this is effected by means of the commutator **29**. A typical lead i_0 is shown in heavy lines leaving the units part of the switch SA_0, passing across the commutator and joining the lead i_0 of the units part of the switch SB_0. A similar connection can also be traced between the leads p_0 of these two switches. The same connections are maintained during both parts (decadal and hendecadal) of the first stage, and in order that all the commutator parts may be arranged on a common cylinder, the contacts of the commutator **29** are made sufficiently long so that a change of connection takes place only on every other step. For the second stage, therefore, the commutator **29** advances two steps in the direction of the vertical arrow and then connects the typical lines i_0 and p_0 leaving the units part of the switch SA_1 to the lines i_0 and p_0 of the units part of the switch SB_0, also the typical lines c_0 and a_0 leaving the tens part of the switch SB_0 to the lines c_0 and a_0 of the tens part of the switch SA_0, and also the typical lines i_0 and p_0 leaving the units part of the switch SA_0 to the lines i_0 and p_0 of the units part of the switch SB_1. These connections correspond to the series of switches shown in Figure 16. For the third stage the commutator moves a further two steps and then connects the switches in a similar manner in the order shown in Figure 17. In order to simplify the diagram only two typical lines have been shown between the switches, but it will be understood that by providing a suitable number of contacts on the commutator the remaining 99 lines connecting the units parts of the switches and the remaining 96 lines connecting the tens parts of the switches may be commutated in the same way. It will be noted in this connection that the lines from each switch run in pairs to adjacent brushes on the commutator, each pair comprising a line from the tens part and a line from the units part. Thus the lines p_0 and c_0 and i_0 and a_0 are paired.

The notation-changing commutators shown separately in the group of Figures 18A to 22D are shown as the single commutator **30** in Figure 11A. Like the commutator **29**, this commutator comprises pairs of horizontal rows of contacts and rows of brushes contacting with every alternate row of contacts. The first row of brushes comprises a set connected to the lines p_0 to p_{18} leaving the units part of the switch SA_0, in the manner shown in Figure 20D, and a set connected to the lines a_0 to a_{18} leaving the tens part of the switch SA_0, in the manner shown in Figure 20B. Of the first set, only the brushes p_1, p_{11}, p_0 and p_{10} have been shown in Figure 11A, and only the connection of p_0 is shown completed, and of the second set only the brushes a_1, a_{11}, a_0 and a_{10} have been shown, and only the connection of a_0 is shown completed. In a similar manner the second and third rows of brushes comprise sets connected to the lines leaving the units and tens parts of the switches SA_1 and SA_2.

In Figures 11A and 11B the heavy line indicates a typical circuit which may be set up during the first part of the first stage (units decadal) of the operations. This circuit will be completed if the switches SA_0, SB_0 and SD_0 were all set at zero and gives the result zero. The circuit established during the hendecadal part of this stage would be the same except that the part of it to the right of the commutator **27** would follow the heavy dotted line instead of the heavy full line and would thus extend through the units hendecadal result register UH. This change is brought about by the movement of the commutator **27** through one step. The other commutators also move but make no alterations in the circuits.

Figures 12A and 12B are identical with Figures 11A and 11B except that the commutators have been moved through three steps to the tens hendecadal position. On these Figures a typical circuit has been indicated on the heavy line, the arrows on this line indicating the direction in which current flows from the positive to the negative pole. This circuit would be established if the switch DS_0 were at zero, there being no transfer from the preceding stage, and if all the switches SA_0, SA_1, SB_0, SB_1, and SD_1 were set at zero. The circuit extends through the differential switch SD_0, the units part of the switch SA_1, the units part of the switch SB_0, the tens part of the switch SB_0, the tens part of the switch SA_0, the units part of the switch SA_0, the units part of the switch SB_1, the switch SD_1 and hence through the commutator **27** to the tens hendecadal indicator TH. It will be nited that this circuit does not actually extend through the units part of the switch SB_1. This is because, as explained previously, the adjustment of the switch SB_1 has no effect on the result required if the switch SA_1 is set for 0 so that the switch SA_1 connects its arrival wire a_0 to its departure wire i_0 which is connected directly through to the wire i_0 of the switch SB_1 and the latter wire i_0 is conneced directly to the switch SD_1.

It will be appreciated that the above circuit would only be established for the particular setting of the switches mentioned. If there had been a transfer from the preceding stage of the operations, the switch DS_0 would have been in a different position and the circuit would have included a different one of the arrival wires a_0 to a_{10} of the switch SA_0. Further, if the other switches had been set for significant digits, the circuit would have passed over different connections between the switches to those shown in heavy lines.

Similar connections between the switches SA and SB may be traced on Figures 12A and 12B through the leads p_0 and c_0 of the switches and it will be noted that all these connections extend through the upper group of eight segments of the commutator **29** while the connections through the leads a_0 and i_0 extend through the lower group of eight segments of this commutator. Thus, the part of the commutator shown serves to make connections between four leads from each switch and the groups of segments will be repeated so as to deal with all the leads from each switch, each group of segments dealing with two lines from each switch. It is of no importance which two lines from the switch are related to a particular group of segments provided that one of such pair of lines is connected to the tens part of the switch and the other is connected to the units part. Each group of segments will, of course, be related to the corresponding pairs of lines from all the switches SA and SB.

The commutator is constructed in the usual manner as a rotatable cylinder of insulating material having conducting segments inset in it. The segments are disposed and connected together as shown in Figures 11A and 11B. Each lead extending to the commutator terminates in a brush bearing on the surface of the cylinder so that a circuit can be completed through it if it engages a conducting segment. The circuit through this lead will be interrupted if its brush rests on the insulating portion of the commutator. While the commutator **29** has been shown in Figures 11A and 11B as extending only in the peripheral direction, it will be understood that a number of such contact groups are as shown in Figure 1 in order to avoid the use of a commutator of unnecessarily large diameter. Actually, for the commutator **29** there are spaced round the commutation cylinder **209** in the peripheral direction four sets of eight contacts interconnected as shown in Figure 11A, the sets being separated by two blank spaces, and in the longitudinal direction of the commutator this arrangement is repeated twenty-five times. The contact groups pertaining to the commutators **26**, **27**, **28** and **30** are also of course repeated four times round the periphery of the cylinder **209**.

The arrangement of the commutator **29** is shown more generally in the connection table shown in Figures 30, 31A and 31B.

Figure 30 shows the manner in which the lines a_0 and i_0 of the five switches SA' and SB' are connected together at each stage in the operation. This figure only shows the connection for one of the **98** or **101** leads between each pair of switches but the connections for the other leads will be strictly analogous. At each stage in the operation the leads, which are indicated by the same sign in Figure 30, must be connected together for this stage. For example, for position *2b*, the lead SA_2i_0 is connected to the lead SB_0i_0, the lead SA_1a_0 is connected to the lead SB_0a_0, the lead SA_1i_0 is connected to the lead SB_1i_0 and the lead SA_0a_0 is connected to the lead SB_1a_0. Figures 31A and 31B give an extension of this table for the lead *a0* to *a4* and *i0* to *i4* of the five switches. Each column of Figure 31A corresponds to a brush connected to the lead (of the switches SA_0, SA_1, SA_2, SB_0 and SB_1) indicated at the head of the column. The letters *a*, *b*, *c* etc., correspond to the different contact segments. The top line marked position **0** indicates the position of the various contacts relatively to the brushes for the position **0** and the successive lower lines indicate how the contacts move relatively to the brushes as the commutator is rotated. In other words each letter corresponds to a single contact in Figure 31A and the repetition of the letter merely shows the various positions which those contacts assume as the commutator rotates.

Figure 31B shows the position of the relative brushes and contacts associated with other leads of the switches SA_0, SA_1, SA_2, SB_0 and SB_1 for the various positions of the commutator and it will be appreciated that each contact which is indicated by a letter in Figure 31A is connected to the contact indicated by the same letter in Figure 31B, i. e. the contact *a* (Figure 31A) is connected with the contact *a* in Figure 31B.

It will be appreciated that the switches SA, SB and SD are set initially by means of the keys **223**, **224** and **225** (Figure 2). Then as the commutator is rotated, upon operating the motor switch **238**, it will establish all the proper connections between the various switches and the result register in the proper sequence. As each system of connections is established a unique circuit will be completed through the contacts and the proper denomination of the result register and a pulse of current will pass which will adjust the appropriate result indicating device. The commutator can be thus turned at a relatively high speed.

It will be appreciated that the switches SD could equally well be connected to perform addition as subtraction (e. g. by reversing the digits on the index by which each switch SD is set) so that the machine can be made to evaluate an expression in the form of D+AB instead of D—AB. The reason for arranging the switches SD_2 so that the expression D—AB is evaluated is that it enables division to be performed. For division the dividend is set up by the switches SD as the factor D and the divisor is set up as the factor A. The required quotient is to be the factor B. The value of B is found by a process of trial and error. For this purpose a suitable value for the quotient is decided on by inspection and is set up by means of the switches SB. The machine is then operated and determines a remainder R which is the difference between the dividend and the product of the divisor and the estimated quotient. If the quotient is too large this result will be negative and the fact that it is negative will be rendered evident by the fact that the highest denomination of the result register will contain a significant digit instead of zero. This denomination is in fact only used for this purpose so that there is no point in providing a corresponding switch SD. If the result is correct the remainder must be positive and it can be determined from inspection whether this remainder is greater than the divisor, in which case the quotient digit is too small, or is less than the divisor or zero, in which case the quotient is correct. If the quotient is not correct it is modified by adjusting the switches SB and further trials are made until the correct quotient is obtained.

In order to effect multiplication, the switches SD are set at **0**. The result obtained is the complement of the true result and provision may be made for converting this complementary result into the true result by reversing the connections between the induction windings and the resistances W of the indicating mechanism. It is also possible to calculate an expression of the form AB/C by first calculating the term AB. The product AB is then set on the switches SD as the factor D and is finally divided by C by the method previously described.

The invention has been described as applied to a manually operable machine for the sake of clarity but it will be appreciated that it is not restricted to such machines as its basic principles are also applicable to machines controlled by perforated cards.

In the apparatus described above each result digit is obtained first in the decadal notation and then in the hendecadal notation. The result digit could be obtained in both notations simultaneously by duplicating all the circuits, one group of circuits being arranged for the decadal notation alone and the other for the hendecadal notation alone. This would allow of the simultaneous closure of two circuits to give the result digit in both notations, in which case the use of notation-changing commutators would be avoided and the speed of working could be doubled.

FRITZ MEZGER.