CALCULATING MECHANISMS

CALCULATING is the computing of a result by multiplication, division, addition or subtraction. IBM calcultors all use counters of some type to accumulate the results. As stated in an earlier section, a counter is actually only capable of adding; subtraction is actually accomplished by adding complements. Multiplication and division must also be accomplished by adding.

TYPE 602A CALCULATING PUNCH METHOD OF CALCULATION

Arithmetic Principles of Multiplication

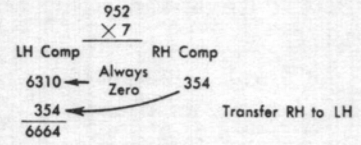
A review of the principles and theory of mental multiplication at this time will establish a foundation upon which the explanation of the machine method can be based.

Multiplication is normally a process of multiplying one digit by another. For example, assume the following multiplication is to be done manually:

$$\begin{array}{r} 9\ 5\ 2 \\ \times\ 7 \\ \hline 6\ 6\ 6\ 4 \end{array}$$

The multiplication is actually accomplished by multiplying 7 times 2, 7 x 50, and 7 x 900, and adding the results. The addition of the results is accomplished after each multiplication step. This is done by a process of left and right-hand components. As a result of the multiplication of 7 x 2 the result has two components. The right-hand component is a 4 and the left-hand component is a one. The right-hand component is written down and the left-hand component is remembered or jotted down to be added to the right-hand component of the next digit. This procedure is repeated until multiplication is completed.

The addition of the left and right-hand components need not take place until after the multiplication is complete. The left-hand component of the first digit is always in the tens position, or in other words, offset one position. Similarly all left-hand components are offset one position to the left. We can, therefore, place a zero in the units position of the left-hand components. The same problem which was worked by the normal manual method above, is worked below by adding left and right-hand components after multiplication is completed.



This method is adaptable to machine operation and is used in the Type 601 and 602 Calculating Punches. The left-hand components are directed to a counter and the right-hand components are directed to another counter. On the next cycle, the right-hand components are transferred to the left-hand components counter. Thus the product is accumulated in the left-hand components counter.

The 602A uses a modification of the left and right-hand components method explained above. A saving of time, which is very desirable, would result if the left and right-hand components could both be placed in the same counter during the same cycle. A study of previous sections shows that a counter is capable of accumulating a nine during any one cycle. Therefore, if the right and left-hand components total nine, it is conceivable that they could both be entered into the same counter during one cycle.

The table shown in Figure 307 is a multiplication table showing all possible combinations. It is possible that, for any digit used as a multiplier, the largest right-hand component will be added to the largest left-hand component. From the table the highest components for any multiplier can be determined quickly. The chart shows that 1, 2, and 5 are the only multipliers whose maximum left and right-hand components do not total more than nine.

Multiplicand \ Multiplier	1	2	3	4	5	6	7	8	9
1	1	2	3	4	5	6	7	8	9
2	2	4	6	8	10	12	14	16	18
3	3	6	9	12	15	18	21	24	27
4	4	8	12	16	20	24	28	32	36
5	5	10	15	20	25	30	35	40	45
6	6	12	18	24	30	36	42	48	54
7	7	14	21	28	35	42	49	56	63
8	8	16	24	32	40	48	56	64	72
9	9	18	27	36	45	54	63	72	81

Figure 307. Multiplication Table

The following is an example of multiplication entering both left and right-hand components during a single cycle:

7 4 5	multiplicand
× 5	multiplier
5 0 5	RH comp.
3 2 2	LH comp.
3 7 2 5	product

All multipliers must be broken down into combinations of 1, 2, and 5 if the above method is used. For example, if the multiplier is 7, the multiplicand will be multiplied by 5 and by 2 and the products totalled. The result will be the same as if the multiplicand had been multiplied by 7 originally. Algebra takes advantage of this fact as shown by the examples below:

$$5x + 2x = 7x$$

In this case, x is the multiplicand and the multipliers are 2, 5, and 7. This can be proven by substituting a value for x. Assume that $x = 6$; then substituting in the equation it becomes:

$$5(6) + 2(6) = 7(6)$$
$$30 + 12 = 42$$

Formation of a Multiplier

The information given is now sufficient to determine how a multiplier will be formed. The table in Figure 308 shows the combination used by the machine to form the actual multiplier digit. Note that in addition to a X1, X2, and X5, the machine also uses a X10. The X10 is merely a X1 with a shift of one position. The formation of the machine multiplier for a 4 and a 9 follows the rules established above if it is in the units position. However, if a 4 or 9 is encountered in any other position of the multiplier, the machine multiplier deviates from the standard. This is done to save machine cycles and time.

Assume a multiplier of 54352. The first multiply cycle is a X + 5 operation with a shift of 4 (50000) and is determined by the 5 in the high order, or fifth position. The next multiplier is determined by the 4 in the fourth position. The machine will select a 5 as the multiplier digit with a shift of 3 (5000). However, since the 4 is not in the units position, the X-1 multiplier which would be expected at this time to correct the multiplier to a 4 is not selected. Instead, the machine tests the next, or third position for the next multiplier digit. However, the multiplier developed up to this point is 55000 which is greater by one, in the fourth position, than the actual multiplier. To correct the multiplier, the complement of the remaining digits is subtracted. The remaining digits are 352 and their complements are 648. If 648 is subtracted from 55000, the result is 54352 which is the correct multiplier. Therefore, when the third position is tested, it is read as a 6 and the product subtracted to correct the partial product.

A general rule governing the selection of multipliers for 4's and 9's not in the units position is as follows: When a multiplier of 4 is encountered, multiply by 5 and for all remaining positions multiply by the complement and reverse the sign (+ or −); when a multiplier of 9 is encountered, multiply by 10 and for all remaining positions multiply by the complement and reverse the sign.

The complete multiplier for the number assumed (54352) is formed in Figure 309. The first multiplier encountered is a +5 with a shift of 4 or +50000.

Actual Multiplier	Machine Multiplier	
1	Times 1 (written X + 1)	
2	X + 2	
3	X + 5, X − 2	
4	X + 5, X − 1	In the units position. X + 5 in all other positions
5	X + 5	
6	X + 5, X + 1	
7	X + 5, X + 2	
8	X + 10, X − 2	
9	X + 10, X − 1	In the units position. X + 10 in all others

Figure 308. Machine Multiplier Selection Table

64
54 | 35 | 2

1st	Multiplier	+ 50000
2nd	"	+ 5000
3rd	"	− 500
4th	"	− 100
5th	"	− 50
6th	"	+ 2
		54352 Total Multiplier

Figure 309. Multiplier Formation

The second multiplier is a 4 which will be a machine multiplier of +5 with a shift of 3 because it is not in the units position. However, the machine recognizes the 4 and for each multiplier henceforth; until it encounters another 4 or a 9, it will operate on a complement basis and reverse the sign. The next multiplier is a 3 but will be recognized as a 6 which is the 9's complement of 3. Also instead of adding it will subtract the product because the sign was changed from plus to minus. The machine multipliers for a 6 in this case are a X-5 and X-1. The next multiplier is a 5 but it appears as a 4. As a result it is treated as a −5 with a shift of one (−50). However, this will again reverse the sign and return the multipliers to true figures. Therefore the next multiplier is a +2 with no shift.

68
69 | 32

1st	Multiplier	+ 5000
2nd	"	+ 1000
3rd	"	+ 1000
4th	"	− 50
5th	"	− 10
6th	"	− 10
7th	"	+ 2
		6932 Total

Figure 310. Multiplier Formation

Figure 310 shows the formation of another multiplier. The difference between the formation of this multiplier and the one previously explained is that the sign is not reversed a second time and complement figures are used throughout the remaining multipliers. Note that the complement of the units position multiplier is based on 10 instead of 9.

COUNTER OPERATION DURING MULTIPLICATION

X1 Operation

A X1 operation is the same as straight accumulation, and will be considered first. The ratchet type counter is a complements counter, as pointed out in the section on counters. Figure 311 is a counter chart showing the counter operation for a multiplicand of 5902 and a multiplier of 1. There are no left-hand components and the highest right-hand component possible is a 9. Therefore, since the counter is capable of accumulating a maximum of 9, it becomes the same operation as straight accumulation. On a plus operation, all positions are started at 9 time by a *hot 9* Impulse. To enter a component, an impulse is

MC					5	9	0	2
MP							+	1
RHC	0	0	0	0	5	9	0	2
LHC	0	0	0	0	0	0	0	0
9	9	9	9	9	9	9	9	9
8	0	0	0	0	0	9	0	0
7	1	1	1	1	1	9	1	1
6	2	2	2	2	2	9	2	2
5	3	3	3	3	$\boxed{3}$	9	3	3
4	4	4	4	4	3	9	4	4
3	5	5	5	5	3	9	5	5
2	6	6	6	6	3	9	6	$\boxed{6}$
1	7	7	7	7	3	9	7	6
0	8	8	8	8	3	9	8	6
11	c 8	c 8	c 8	c 8	c 3	9	c 8	c 6
12	8	8	8	8	3	9	8	6
13	9	9	9	9	4	0	9	7
14								
15								
16								

Figure 311. Counter Operation for an X + 1 Multiplier

directed to the stop magnet at the digit time corresponding to the digit to be entered. If a digit impulse is not received, the counter will be stopped at zero time by an impulse which is directed to all positions. Carry is affected in the normal manner through the 9-10 brush at 12-time but the counter is stopped by an electrical impulse to all stop magnets at 13-time.

Figure 312 shows the same problem with a X-1 multiplier. Note that it is precisely the same as a plus operation of a Type 402 counter.

X2 Operation

A X2 operation requires that the cycle be divided into two parts: one for the entry of the right-hand components; another for the entry of the left-hand components. It must be divided so that an 8 can be entered as a right-hand component. Since a counter turns through one cycle point for each digit added, the start and stop impulses must be arranged so that the counter may rotate for 8 cycle points during one portion of the cycle. This is done by arranging the internal automatic start and stop impulses 8 cycle points apart. Figure 313 shows the automatic start and stop shots for a plus operation and the time they occur. This figure assumes no right-hand components and there are, therefore, no impulses to the stop mag-

MC					5	9	0	2
MP							—	1
RHC	0	0	0	0	5	9	0	2
LHC	0	0	0	0	0	0	0	0
9	9	9	9	9	9	9	9	9
8	9	9	9	9	9	0	9	9
7	9	9	9	9	9	1	9	9
6	9	9	9	9	9	2	9	9
5	9	9	9	9	9	3	9	9
4	9	9	9	9	0	4	9	9
3	9	9	9	9	1	5	9	9
2	9	9	9	9	2	6	9	9
1	9	9	9	9	3	7	9	0
0	9	9	9	9	4	8	9	1
11	9	9	9	9	t 4	t 8	9	t 1
12	9	9	9	9	4	8	9	1
13	0	0	0	0	5	9	0	2
14								
15								
16								

Figure 312. *Counter Operation for an X −1 Multiplier*

nets until 1 time. The counter wheels turned through 8 cycle points, so it is possible to add or subtract an 8. The counters contain a 7 when stopped at 1 time.

MC								
MP								
RHC								
LHC								
9	9	9	9	9	9	9	9	9
8	0	0	0	0	0	0	0	0
7	1	1	1	1	1	1	1	1
6	2	2	2	2	2	2	2	2
5	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4
3	5	5	5	5	5	5	5	5
2	6	6	6	6	6	6	6	6
1	7	7	7	7	7	7	7	7
0	7	7	7	7	7	7	7	7
11	t 8	t 8	t 8	t 8	t 8	t 8	t 8	t 8
12	8	8	8	8	8	8	8	8
13	9	9	9	9	9	9	9	9
14								
15								
16								

Figure 313. *Counter Charts of Automatic Impulses for an X 2 Multiplier*

MC						6	5	4
MP							+	2
RHC	0	0	0	0	0	2	0	8
LHC	0	0	0	0	1	1	0	0
9	9	9	9	9	9	9	9	9
8	0	0	0	0	0	0	0	9
7	1	1	1	1	1	1	1	9
6	2	2	2	2	2	2	2	9
5	3	3	3	3	3	3	3	9
4	4	4	4	4	4	4	4	9
3	5	5	5	5	5	5	5	9
2	6	6	6	6	6	5	6	9
1	7	7	7	7	7	5	7	9
0	7	7	7	7	7	5	7	9
11	t 8	t 8	t 8	t 8	t 7	t 5	t 8	t 0
12	8	8	8	8	7	5	8	0
13	9	9	9	9	8	6	9	1
14								
15								
16								

Figure 314. *Counter Operation for an X + 2 Multiplier*

The counters are started again at zero time for the purpose of entering left-hand components. The stop magnets will all receive an impulse to stop at 11 time since a one is the highest left-hand component possible on an X2 operation.

All counters will carry in the example shown because all counters went from 9 to 0, and as a result all will contain 9's to indicate nothing has been accumulated.

Figures 314 and 315 show an X +2 and an X−2 operation. A counter wheel is either caused to rotate a given number of cycle points or remain stationary a given number of cycle points to accumulate a given digit. To accumulate during a plus operation, it is necessary to *prevent* the counter from rotating.

Figure 314 shows the counter operation for a multiplier of +2 and a multiplicand of 654. The units position has a right-hand component of 8 to be placed in it. The stop magnet must be impulsed at 9 time so that the counter wheel does not turn at all. This is necessary because the counter must be *prevented* from turning during 8 cycle points and there are only 8 cycle points between 9 time and 1 time. Previously the impulses have been available at the time corresponding to the digit accumulated. However, this is not true in this type of multiplication process. The circuit network supplies the impulse to the stop magnet the desired number of cycle points before the internal stop impulses.

Figure 314 also shows the right-hand component of 2 being entered. Note that the impulse is available 2 cycle points before 1 time. If a 4 and a 6 are to be entered as right-hand components, the impulses will be directed to their stop magnets 4 and 6 cycle points before the stop impulses.

The above figure shows that in positions which have a left-hand component of 1 to be accumulated, the start and stop magnets are impulsed simultaneously to prevent the counters from turning.

The carry takes place in the usual manner and the counter value of the amount accumulated in the counter is 998691. This is the complement of 001308 which is the correct product.

Figure 315 shows the counter operation for the same problem with a minus sign. In a minus operation it is necessary to cause the counter wheel to *turn* the desired number of cycle points. The amount is accumulated as a true figure on a minus operation.

X5 Operation

The cycle is divided into two parts for an X5 operation as on an X2 operation, for the entry of left and right-hand components. However, the division is made at a different point in the cycle to accommodate different maximum components. The largest right-hand component is a 5 while the largest left-hand component is a 4.

The cycle is divided to provide 5 cycle points in the first half to accumulate a right-hand component of 5. Four cycle points are used in the second half of the cycle to provide the cycle points necessary to accumulate a 4.

Figures 316 and 317 show the counter operation of an X +5 and an X −5 with a multiplicand of 947.

The control circuits and multiplying network circuits will not be studied at this time, but will be studied with the machine in which they are used.

Arithmetic Principles of Division

The objective of a division operation is to find the quotient of a dividend and a divisor. The quotient is

MC						6	5	4
MP							−	2
RHC	0	0	0	0	0	2	0	8
LHC	0	0	0	0	1	1	0	0
9	9	9	9	9	9	9	9	9
8	9	9	9	9	9	9	9	0
7	9	9	9	9	9	9	9	1
6	9	9	9	9	9	9	9	2
5	9	9	9	9	9	9	9	3
4	9	9	9	9	9	9	9	4
3	9	9	9	9	9	9	9	5
2	9	9	9	9	9	0	9	6
1	9	9	9	9	9	1	9	7
0	9	9	9	9	9	1	9	7
11	9	9	9	9	t0	t2	9	t7
12	9	9	9	9	0	2	9	7
13	0	0	0	0	1	3	0	8
14								
15								
16								

Figure 315. Counter Operation for an X − 2 Multiplier

MC						9	4	7
MP							+	5
RHC	0	0	0	0	0	5	0	5
LHC	0	0	0	0	4	2	3	0
9	9	9	9	9	9	9	9	9
8	0	0	0	0	0	9	0	9
7	1	1	1	1	1	9	1	9
6	2	2	2	2	2	9	2	9
5	3	3	3	3	3	9	3	9
4	4	4	4	4	4	9	4	9
3	4	4	4	4	4	9	4	9
2	5	5	5	5	4	0	5	0
1	6	6	6	6	4	1	5	1
0	7	7	7	7	4	1	5	2
11	t8	t8	t8	t8	t4	t1	t5	t3
12	8	8	8	8	4	1	5	3
13	9	9	9	9	5	2	6	4
14								
15								
16								

Figure 316. Counter Operation for an X + 5 Multiplier

MC						9	4	7
MP							—	5
RHC	0	0	0	0	0	5	0	5
LHC	0	0	0	0	4	2	3	0
9	9	9	9	9	9	9	9	9
8	9	9	9	9	9	0	9	0
7	9	9	9	9	9	1	9	1
6	9	9	9	9	9	2	9	2
5	9	9	9	9	9	3	9	3
4	9	9	9	9	9	4	9	4
3	9	9	9	9	9	4	9	4
2	9	9	9	9	0	4	9	4
1	9	9	9	9	1	4	0	4
0	9	9	9	9	2	5	1	4
11	9	9	9	9	t 3	t 6	t 2	t 4
12	9	9	9	9	3	6	2	4
13	0	0	0	0	4	7	3	5
14								
15								
16								

Figure 317. Counter Operation for an X − 5 Multiplier

the largest quantity by which the divisor can be multiplied to produce a product which is not greater than the dividend.

It is difficult to multiply mentally by factors which are larger than 10 and it is usually done by decimal steps. The process is actually one of selecting various multipliers, using them to multiply the divisor, and then reducing the dividend by the amount of the product. This process is continued until the dividend has been reduced to zero or left with a remainder less than the divisor. Figure 318 is an example of manual long division.

The machine accomplishes division in a manner very similar to manual long division. The divisor is compared to the dividend and a multiplier is selected.

```
               2342 Quotient
Divisor 295)691054 Dividend
           -590
            1010
           -885
             1255
           -1180
              754
            -590
              164 Remainder
```

Figure 318. Example of Manual Long Division

The divisor is then multiplied by the multiplier selected and the product subtracted from the dividend counter. The divisor is then compared to the remainder in the dividend counter to select another multiplier or quotient digit. This operation is repeated until the remainder is zero or less than the divisor.

One basic difference between the machine operation and the manual operation is the selection of a multiplier. In a manual operation as many of the divisor digits as practical on the high order end are compared to the dividend to be sure that the remainder does not go negative. If the multiplier selected is too large it is erased and another one selected. However, the machine is limited to the quotient digits which can be selected because each is to be a multiplier of the divisor, and the machine is only capable of multiplying by 1, 2, or 5. Therefore, the quotient selected will often be too large, causing the remainder to go negative. However, the circuits are so arranged that computations are carried on just as well with a negative remainder as with a positive one. The sign of the quotient is changed and the product added rather than subtracted.

A quotient is selected by comparing only the high order digit of the divisor to the high order digit of the existing dividend. The circuit network for quotient selection is designed to select quotients according to the table in Figure 319. The table is arbitrarily arranged to provide the fewest number of cycles to calculate a quotient.

	Dividend High Order Digit								
Divisor High Order Digit	1	2	3	4	5	6	7	8	9
1	1	2	2	2	5	5	5	5	5
2	.5	1	1	2	2	2	2	2	5
3	.5	.5	1	1	2	2	2	2	2
4	.2	.5	1	1	1	1	2	2	2
5	.2	.5	.5	1	1	1	1	2	2
6	.2	.5	.5	.5	1	1	1	1	1
7	.2	.2	.5	.5	.5	1	1	1	1
8	.2	.2	.5	.5	.5	1	1	1	1
9	.2	.2	.5	.5	.5	.5	1	1	1

Figure 319. Quotient Selection Table

Figure 320 shows the machine method of division. The divisor is placed in a storage unit because it does not change; the dividend is placed in a counter because it must be reduced. As a result of the first test for a quotient, a two is selected (see chart in Figure 319). The two is then used as a multiplier to multiply the divisor and has a shift of four. The product is then subtracted from the dividend leaving, in this case, a dividend of 298490, and its sign is still plus. The high order position of the new dividend or remainder is now compared to the high order position of the divisor to select the next quotient. A quotient of one is selected. When the machine recognized that the original high order position had been reduced to zero, it stepped down to test the next position and also reduced the multiplier shift to three. The dividend is now reduced by the product of the new quotient factor and the divisor. As a result, the high order position and the next high order position are both reduced to zero. The machine recognizes this and steps down two positions to test the one and also reduces the multiplier shift to a shift of one. The quotient factor selected is five-tenths (.5), and it has a shift of one. The fact that it is a tenths factor is the same as a right shift of 1 and the resultant is a quotient factor of 5 with no shift.

```
        shift of four          Formation of
divisor    20000                    the
  297 | 6238490 dividend         Quotient
      -  594                     + 20000
         298490                  +  1000
         297000                       + 5
         001490                    21005
           1485
           0005 remainder
```

Figure 320. Formation of a Quotient — Machine Method

The dividend is reduced, as a result of the 5 multiplier, to a remainder of 5. The machine recognizes that this is less than the divisor and is still positive and it ends the divide operation.

Figure 321 is another example of machine division. However, in the case shown the dividend goes negative on three occasions, which causes the product to be *added* to the dividend and the quotient factor *subtracted*. Note also that until the high order factor is reduced to zero, there is *no change* in *shift*.

```
                     Quotient
                     Formation
297 | 7958690        + 20000
    - 5940000        + 10000
    + 2018690         - 5000
    - 2970000         + 2000
    - 0951310          - 200
    + 1485000            - 5
    +  533690            + 2
    -  594000            - 1
    -  060310
    +   59400        + 20000   - 5000
    -  000910        + 10000   -  200
    +    1485        +  2000      - 5
    +     575            + 2      - 1
    -     594        + 32002   - 5206
    -     019        -  5206
    +     297          26796 Quotient
    +     278
```

Figure 321. Quotient Formation

604 ELECTRONIC CALCULATOR METHOD OF CALCULATION

THE ARITHMETIC PRINCIPLES used in the Electronic Calculator are much simpler than those of the Calculating Punch. This is possible because of its tremendous speed, which is due to a lack of mechanical devices. The Type 604 uses an electronic counter of the type studied in Accumulating Mechanisms. The electronic counter consists of a group of triggers which operate on a modified binary system. These counters accumulate as a result of a series of pulses and each pulse increases the amount in the counter by one. The normal operating frequency of the pulses in the Type 604 Electronic Calculator is 50kc. Therefore, each pulse requires .00002 seconds, or 20 micro-seconds. There are 25 pulses in an electronic cycle which compare to the 360° found in electro-mechanical machines. An add cycle then would require 25 pulses, .0005 seconds, or 500 micro-seconds.

Electronic Calculator Method of Multiplication

The components method of calculation used in other machines is used as a time saving device, but, as stated above, the speed of calculation of the electronic counter makes it unnecessary in the Electronic Calculator. The method used in the electronic system is much more straightforward and simple. If 125 is to be multiplied by 5 the machine merely adds 125 five times. Basically this calculation would require 5 cycles or .0025 seconds.

A sample multiplication is shown graphically in Figure 322. The multiplicand is placed in a storage unit because it does not change. The multiplier is placed in a special storage unit so that it can send information from any position to a special single position counter. The multiplier storage unit has a capacity of 5 digits. Therefore, it will accommodate a 5 digit multiplier.

In essence the multiplicand storage unit instructs the product counter of the number to be added. The multiplier storage unit, in conjunction with the single position counter, instructs the product counter how many times the multiplicand should be added and the column shift necessary.

All multiplication and division operations automatically begin in a column shift of 5. The high order position of the multiplier is tested to determine how many times the multiplicand is to be added in the counter in CS-5 (column shift of 5). Any digit found in the high order position of the multiplier is placed in the single position counter in 10's complement form. The entry of a digit in the single position counter signals the machine to begin multiplying. In the case shown in Figure 322 when the 5th position is tested, a zero is found and no multiplication takes place. The machine did require a cycle, however, to make the test. The product counter remains at zero. The test cycle finding a zero in the multiplier causes a shift from column shift 5 to column shift 4.

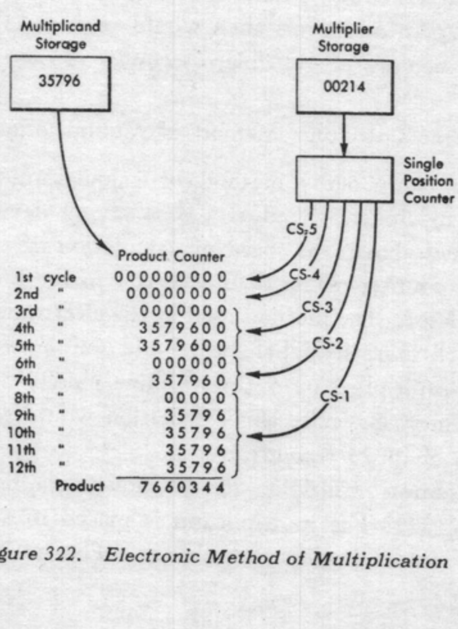


Figure 322. Electronic Method of Multiplication

On the second cycle, the 4th position is tested because a CS-4 is indicated. Again, finding a zero, a step down to CS-3 is provided.

A third cycle results in testing the 3rd position since a CS-3 is now indicated, but this time a 2 is encountered. As a result an 8, which is the 10's complement of 2, is entered into the single position counter. The product counter has not accumulated as yet because all cycles have been test cycles and the partial product is still zero. However, the entry now of a significant digit into the single position counter allows the multiplicand to be accumulated in the product counter in CS-3 during the next cycle. During the next cycle, the multiplicand is added once into the product counter, and a 1 is added in the single position counter. The single position counter now contains a 9 which permits multiplication to continue and a CS-3 is still indicated. On the next cycle, the multiplicand is again added into the product counter in CS-3 and another 1 added to the single position counter. The single position counter now contains a zero. Ordinarily a counter which passes from 9 to 0 causes a carry. However, the impulse resulting in this case instructs the machine to end multiply. It also results in a step down from CS-3 to CS-2. On the next cycle the second position of the multiplier is tested, and a 9 is placed in the single position counter. One cycle of accumulation is made as a result.

This procedure is carried on until the single position counter goes to zero while a CS-1 is indicated. The machine recognizes this as the end of the multiplication and ends the multiply operation.

The entire multiplication operation required 12 cycles. The time required is .0005 x 12 or .006 seconds.

Electronic Calculator Method of Division

A division operation requires that the dividend be reduced to a zero value or have a positive remainder which is less than the divisor. In the electronic calculator, the dividend is placed in the counter and the divisor subtracted from it until it is reduced to meet the requirement of division as stated above. The dividend is placed in the counter in 9's complement form and will remain a complement as long as it remains positive.

The divisor is placed in a storage unit, so that it may instruct the dividend counter of the amount to be subtracted.

The quotient factors are placed in the same special storage unit used to store the multiplier in a multiplication operation. The electronic storage unit used is a series of triggers arranged in a manner similar to the electronic counter, but with no provision for carrying.

The first cycle of division always has a column shift of 5 just as it did in multiplication. The divisor, therefore, is subtracted from the dividend with a shift of 5. If the remainder is still positive, the shift will remain the same and the divisor will again be subtracted from the dividend remainder. However, if the remainder went negative, it indicates that the quotient is too large. The shift will remain the same and the divisor added to the remainder to return it to a positive value. The shift will then step down one position and the divisor subtracted again.

Figure 323 is a chart illustrating the machine operation for a specific division problem. The objective is to divide 1728 by 144. The dividend is placed in the 13 position counter provided and the divisor in a storage unit.

First Cycle. On the first cycle the divisor is subtracted from the dividend in a CS-5. As a result the dividend becomes negative. The machine recognizes that it has subtracted too much and it goes through a correction cycle.

Second Cycle. On the second, or correction cycle, the complement of the divisor is added to the dividend which returns it to its original value.

Third Cycle. The column shift is reduced to a shift of 4 and the divisor is subtracted again. Again the remainder becomes negative and another correction cycle is necessary.

Fourth Cycle. Correction cycle.

Fifth Cycle. The column shift is reduced to a shift of 3 and the divisor subtracted again. Again the remainder goes negative and another correction cycle is necessary.

Problem $\frac{1728}{144} = 12$

Cycle		Dividend	Ctr Balance	Quotient
	—	9999999998271	+	00000
		1440000		
1		9999990338271		
	Carry	11111111 1		
	—	0000001438272	−	00000
		9999998559999		
2		9999999987161		
	Carry	1111		
	—	9999999998271	+	00000
		144000		
3		9999999032271		
	Carry	111111111 1		
	—	0000000142272	−	00000
		9999999855999		
4		9999999997161		
	Carry	111		
	—	9999999998271	+	00000
		14400		
5		9999999902671		
		111111111 1		
	—	0000000012672	−	00000
		9999999985599		
6		9999999997161		
		111		
	—	9999999998271	+	00000
		1440		
7		9999999999611		
		1		
	—	9999999999711	+	00000
		1440		
8		9999999990151		
		1111111111 1		
	—	0000000001152	−	00010
		9999999998559		
9		9999999999601		
		11		
	—	9999999999711	+	00010
		144		
10	—	9999999999855	+	00010
		144		
11	—	9999999999999	+	00011
		144		
12		9999999999033		
		1111111111111		
	—	0000000000144	−	00012

Figure 323. Electronic Method of Division

Sixth Cycle. Correction cycle.

Seventh Cycle. The CS is reduced to a shift of two and the divisor subtracted from the dividend again. On this cycle the dividend remainder stayed a plus value which indicates a valid quotient factor. This permits an entry of 1 in the CS-2 position of the quotient storage unit. However, the entry will take place on the following cycle.

Eighth Cycle. The CS remains the same and the divisor is again subtracted from the dividend remainder. This time the remainder goes negative again indicating the divisor is too large to go into the remainder again. Another correction cycle is required.

Ninth Cycle. Correction cycle.

Tenth Cycle. The shift is reduced to a CS-1 and the divisor subtracted from the remainder. The remainder is still positive after the reduction which indicates a valid quotient factor, which is entered on the next cycle.

Eleventh Cycle. The shift remains the same and the divisor is subtracted from the remainder again. After the reduction, the remainder is still positive which again indicates a valid quotient factor. The one factor from the previous cycle is entered in the units position. Observation of the remainder shows that the dividend counter contains all 9's which is a zero remainder. However, the machine does not recognize this and it makes another attempt to reduce the dividend remainder.

Twelfth Cycle. The subtraction of the divisor again causes the remainder to go negative. Another 1 is entered into the units position of the quotient storage unit. The machine recognizes that the remainder has gone negative with a CS-1, and as a result it takes a correction cycle and ends division.

Thirteenth Cycle. Correction cycle.

Fourteenth Cycle. Shift out of CS-1 and end division.

This division problem required 14 cycles at .0005 seconds per cycle or .007 seconds for the entire calculation.

ELECTRONIC COMPUTERS

IBM's NEWEST CONTRIBUTIONS to the field of business management are the Electronic Computing Machines. This equipment has developed from IBM's wide experience and practical research in the use of electronics for effective management tools.

The electronic computing machines are powerful tools for management. They are a system of accounting using the latest electronic devices—magnetic tapes, magnetic drums, and electrostatic storage. These machines are designed to meet the needs of management and science for handling large amounts of data or solving complex calculating problems at electronic speed.

Data are introduced into this system from either IBM punched cards or from previously recorded magnetic tapes. Calculations can be performed on this information, and—in one operation—the results can be printed, punched in cards, or recorded on magnetic tapes. Engineers have designed a flexible system to accept a number of input and output devices as necessary for customer applications.

Typical of the electronic computing systems is the Type 702, in which the principal record and file storage medium is the magnetic tape. This tape is a plastic oxide-coated tape similar to that used in tape sound recorders. Information can be stored on this tape in the form of magnetized spots with a density of 200 characters per inch. This information can be recorded or read at a speed of 75 inches per second.

The principal working storage in the machine is electrostatic storage or memory unit. This memory unit uses cathode ray tubes to store up to 10,000 characters in the form of charged spots on the face of the tubes. This memory unit is capable of storing or reading information at the rate of 23/1,000,000 of a second per character. Combined with this rapid reading or storing ability, this type of storage unit also has a highly flexible system for locating any particular characters in storage. This makes possible the rapid selection of any unit record, field, or character from storage to be used by the arithmetic and logical unit of the machine.

It is also possible to include in the system of machines additional storage in the form of magnetic drums. Each drum has a capacity of 60,000 characters, and it is possible to have from one to thirty drum storage units included in the system.

In order to understand the operation of electronic computing machines, it is necessary to first visualize the work they do.

First consider the procedure used in a standard IBM punched-card accounting system. To follow through the complete procedure of running a given report, we must start with the source documents. The first step is transferring the information to punched cards. These cards may be verified, sorted, and possibly merged with other cards. Some type of calculation may be performed, master cards selected, and other cards such as year-to-date cards merged in. At this point the cards are placed in the accounting machine and a complete report is printed along with the preparation of new year-to-date summary cards. Following this, the operator must separate from the deck certain master name cards, etc., to be returned to a file for use next month.

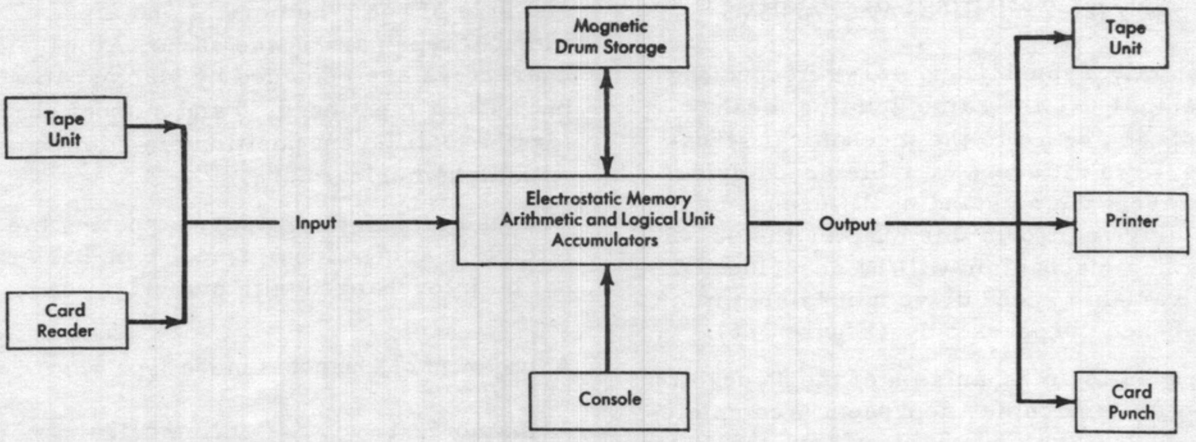


Figure 324. Type 702 Data Flow System

This is a common system that is merely a semi-mechanized system of data processing. In this system the machines did the actual work with the data punched in the card, but it was the duty of the operator to set up each machine properly, and to move the cards from one machine to the other in the proper sequence. If any situation arises requiring special handling, it is the operator who must know what to do in each particular case.

Now look at a similar application that might be applied to an electronic computing machine. It must be remembered that an electronic computing machine is more than just a machine, it is a complete high-speed automatic system for handling vast quantities of data.

The first step in the process is a detailed study of the job to be done. This includes not only the main job but also a study of each and every special case that might arise. From this, a planner will write a program for the machine, telling it, in detail, each little step to be performed. The program tells the machine where to store each piece of data, when to use it, and what operations are to be performed. It must include logical tests to be made and tell the machine what to do as a result of these tests. Once the program is established, the raw data are fed into the machine by an operator, and all other operations are performed by the machine in the proper sequence at electronic speed.

The machine takes in all the data and then can perform all the sorting, merging, calculating, etc., on just the numbers, without having to move cards as was done in the punched card system. The transfer of data from storage to the arithmetic and logical unit and back, and then to the output units is all done by high-speed electronic pulses.

By using this electronic computing system it is possible to process large amounts of data rapidly and without the possibility of human error. The machine cannot forget a portion of the processing or overlook a case that needs special handling.

Figure 324 shows a schematic layout of the Type 702 Data Processing system showing the major units and the paths for data flow between them.