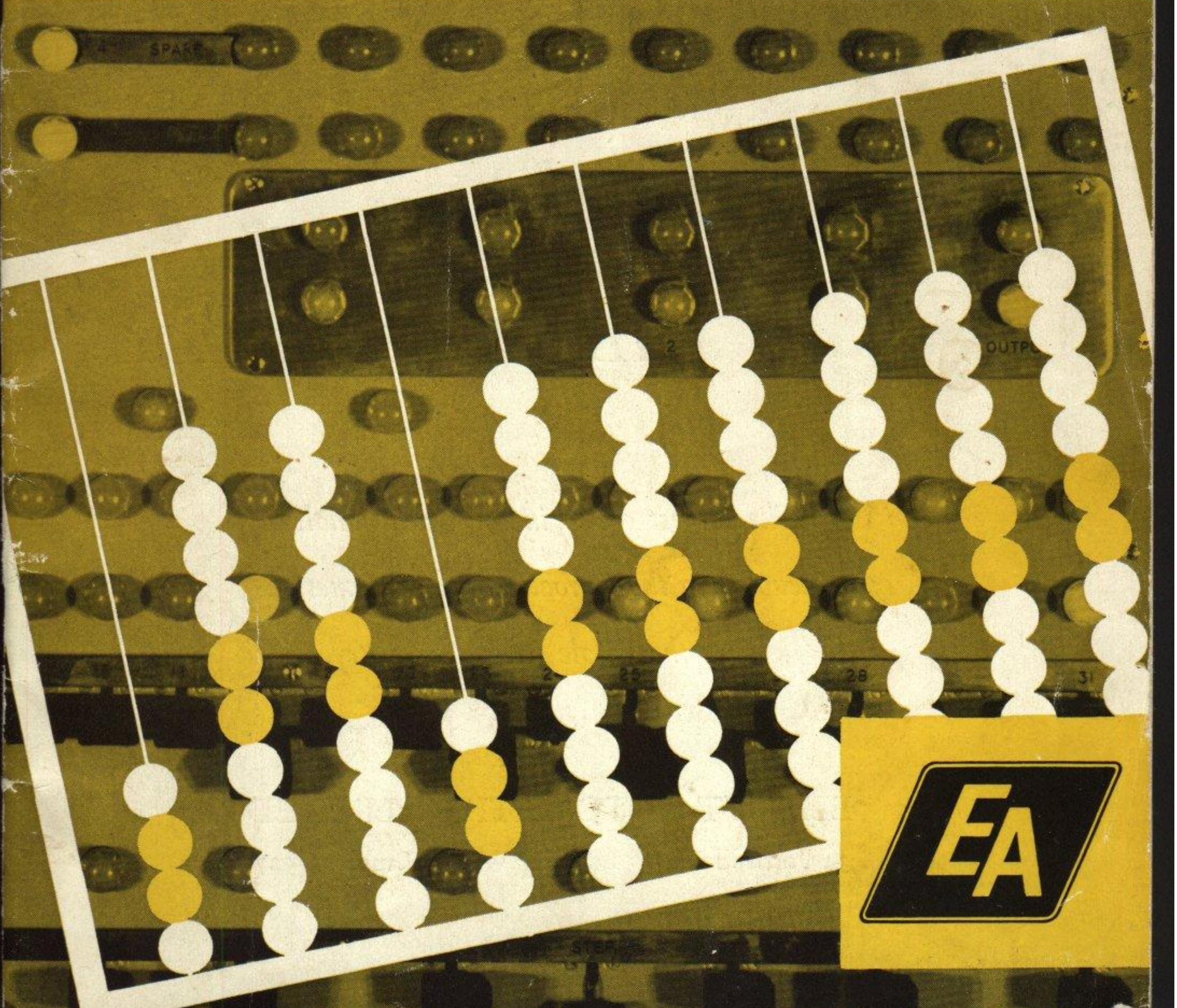
THE A.B.C. OF 'ELECTRONIC BRAINS'



The A.B.C. of 'Electronic Brains'

A series of six talks broadcast
in the External Service of the BBC

by
LEON BAGRIT
DEPUTY CHAIRMAN AND MANAGING DIRECTOR
OF ELLIOTT-AUTOMATION LIMITED

This Edition of "The ABC of 'Electronic Brains'" is produced with the co-operation of the British Broadcasting Corporation, whose assistance and permission to reproduce illustrations and diagrams is gratefully acknowledged.

ELLIOTT-AUTOMATION LIMITED
34 Portland Place, London W.1.

FOREWORD

I was happy to accept the BBC's invitation to broadcast a series of talks on electronic computers, because it is my passionate belief that these modern miracles will have a profound effect on the life of every human being. It is the duty of all of us to acquire at least a sufficient understanding of the gifts made to us by our very talented scientists so that their application will achieve the maximum benefit, not to a few inhabitants of the so-called advanced nations, but to all mankind.

I have, of course, had much advice from my technical colleagues and I gratefully acknowledge their unstinted help given with commendable patience. I have attempted to act as an interpreter and have given extremely simple explanations of the technical profundities; as a layman I could not do otherwise. I hope that other laymen will find what I have written of some value.

I expect that from a truly scientific point of view I have in places over-simplified the subject, but this I believe to be both necessary and desirable when writing or talking about science to a lay audience. Although much detail is omitted, I hope I have not distorted the broad picture.

Leon Bagrit.

The author, Mr. Leon Bagrit, is Deputy Chairman and Managing Director of Elliott-Automation Ltd.

INTRODUCTION

This booklet is entitled ' The ABC of Electronic Brains' and it is a good start to enquire why we have used the word ' Brain ' to describe what is after all no more than a man-made machine.

The fact is that these machines—computers—can and do arrive at results which a human being arrives at only by using his brains, and in many cases the highly ingenious and rapid computer may often do even better than the human mind. Computers are more ' single-minded ' in solving logical processes and can therefore be organized to perform jobs where a systematic form of thinking or logic, which can be laid down beforehand, has to be followed. However, the answer produced by a computer at the end of any operation must depend, and can only depend, on the information which is fed into the machine from an outside source.

So we can say with truth that although computers perform operations similar to those of the human mind we have no proof that they are artificial copies of a human brain. This is rather like saying that a loudspeaker performs similarly to a human voice but is not a copy of the human throat and mouth.

One of the reasons why computers are so often referred to as ' electronic brains ' is that some of the mechanics of the human mind seem to be like many of the processes which are in fact incorporated in the machines. Although they did not originate as copies of the human mind, it was striking to find how similar were some of the actual logical processes. Some of the circuit diagrams produced by early pioneers were found by their medical friends to show a great similarity to the nerve connections in the human brain.

MECHANIZATION AND AUTOMATION

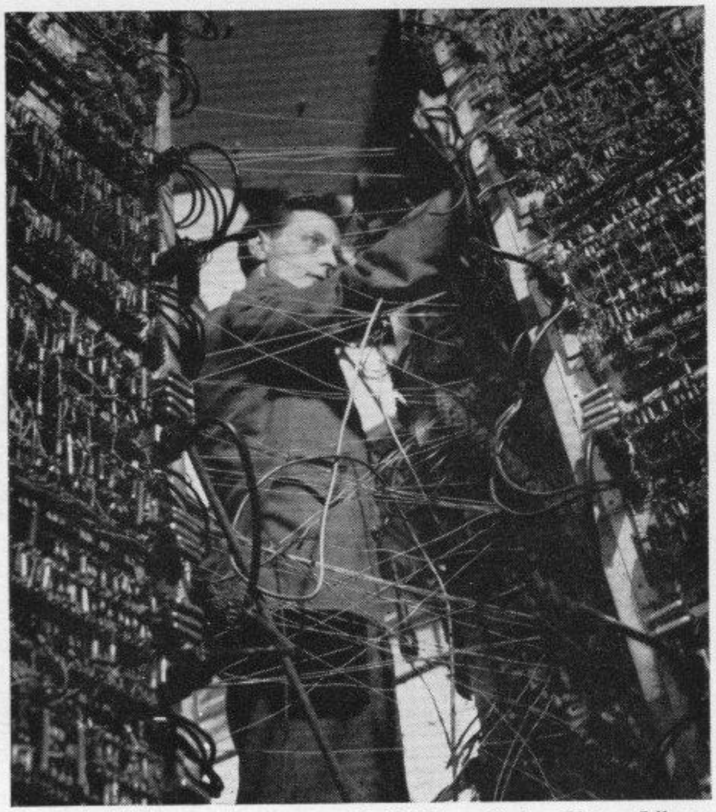
One of the factors missing in mechanization is a thinking element, a ' brain ' which can adjust the actions of a machine to varying conditions. It is just here that computers can be of the greatest importance. They can be given instructions and thereby enabled to take charge of all kinds of processes leading to greatly increased working efficiency and speed. This ability is nowadays called automation.

Let me make this clear by human analogy. Mere mechanization is muscular action, that is to say, our limbs can move without our having to use our brains. It is only when our brain controls our movements that these can be adjusted to changes in outside circumstances, and it is precisely this element of control which the modern electronic computer introduces.

Most ' electronic brains ' are used for the purpose of making calculations of various kinds and I should like to explain why they are important and what they can do.

WHAT IS A COMPUTER?

A computer is obviously a machine that computes, and since the two verbs ' compute ' and ' calculate ' have the same meaning we ask why computers are so much more important than their predecessors, calculators. I am sure you will have seen some of these predecessors such as an abacus, an adding machine or a desk calculating machine. All these are mechanical and not electronic devices for performing arithmetical operations and all require detailed manipulation by a human being whilst they are making calculations. Although they are wonderful examples of the inventiveness of the human mind and, in their day, were developments of the highest importance, they are as much unlike a modern computer as a horse and cart is unlike a racing car.



Radio Times Hulton Picture Library

A 'historic' computer picture taken in 1955

The novelty of electronic computers compared with their forerunners lies in three fundamental properties; they are fast; they do not require detailed manipulation by a human being, and they can choose which of several different operations are the right ones to make in given circumstances. All this implies that they can carry out a very long calculation with complex choices without human interventions and do it very quickly.

Moreover, electronic computers are general purpose machines. By this I mean that the same machine can be changed very simply from one job to another. Never before has mankind had such a powerful tool available.

WHAT CAN COMPUTERS DO?

You can make a computer do anything that you can express as a series of arithmetical operations. Apart from the obviously arithmetical work like pay calculations, which I explain in detail further on, there is much work which can be put into a mathematical form although at first sight it may not appear to have anything to do with arithmetic. A simple example of such work would be the sorting of names of people into alphabetical order. By coding the letters of the alphabet with numbers, we turn the job into one where we in fact ask the computer to decide which is the lowest coded number, which the next lowest, and so on.

In our modern society the number of calculations to be made is vast. Examples of commercial jobs involving calculations which come to mind are control of stock or inventory; sending invoices for goods sold, and paying wages. In wages the easiest part of the calculation is the multiplication of the number of hours worked by the rate of pay per hour. But the matter is rarely so simple. One has to add bonuses for good work and for output; one has to deduct the money put aside for pensions, for membership of sports clubs, and for other reasons which may vary from man to man; a man may have to be paid at different rates for different jobs and he may earn special bonuses for exceptional work. Furthermore, to manage and control a large organization, the amount paid in wages has to be split between each department, and indeed for costing purposes, between each job.

Another thing which is useful to know is the number of pound notes, ten shilling notes, and of each denomination of coin (and this applies in all currencies) so that you have the right quantity of each to put in the individual envelopes which you use for paying your employees. Human brains and ingenuity are certainly able to do this kind of job but in order that continuous accuracy is achieved, speed must be reduced. However, a computer will not only make all the calculation to arrive at the pay of each individual, but will make entries in the books of accounts of the organization and will do this at high speed and do it accurately. The result in the form of a payslip (Fig. 1) will look like this:

BLANK COMPANY LIMITED — STAFF PAYSLIP

NAME	CLOCK NO.	WEEK ENDING DATE	TAX WEEK	TAX CODE NO.	TAX BASIS	BASIC HOURS PAID	OVERTIME
A. N. OTHER.	23680	29 1 60	43	39		44.00	10.15
1	2	3	4	5	6	7	8

GROSS WAGE	±TAXABLE ADDITIONS OR DEDUCTIONS	GROSS PAY TO DATE	TAX OR REFUND THIS WEEK	TAX PAID TO DATE	NATIONAL INSURANCE
13 10 9		545 0 4	1 15 0	66 10 0	9/11
9	10	11	12	13	14

PENSION CONT.	NATIONAL SAVINGS	OTHER DEDUCTIONS	±NON-TAXABLE PAY ADJUSTMENTS	TOTAL DEDUCTIONS	NET WAGE
0 10 6	0 15 0	0 0 3	0 0 0	3 10 8	10 0 1
15	16	17	18	19	20

Fig. 1

Let me give you an example of the relative speeds of humans and computers when they are doing simple addition sums.

If you or I add up two numbers of six figures it will take us not less than five seconds. Most electronic computers can do over ten thousand of these sums every second. This starts to give you some idea of the phenomenal speed of these machines. Of course speed of calculation does not matter very much if you have to add up or multiply or subtract only a few numbers, but the moment you are dealing with vast quantities of data or information, the speed at which you can do these sums is of paramount importance.

The great speed which the computer now puts at the disposal of the scientist and engineer has made possible a large number of technological advances which would otherwise not have taken place. Atomic energy is one example. In order to arrive at the answers necessary before an atomic power station can be built, the number of computations necessary would previously have taken several men a hundred years. With a computer a few men can do the work in a matter of months. This tremendous saving has made it possible for atomic energy to become the practical proposition which it now is. Let me repeat that, without computers the development of atomic power stations would have been quite impossible.

Space travel is another example. This achievement which man has taken out of science-fiction and made real is the direct consequence of the computer's ability to make high-speed calculations. Not only must a mass of computation be carried out before we can design and produce the rockets and spaceships, but to navigate them is another complex problem solvable only by electronic computers.

And this is only the beginning of the age of computers. A new world is opening up—a world based upon the electronic speed of computation—a world in which we can foresee the time when the drudgery of clerical labour will be eliminated. ' Electronic brains ' will be used not only for clerical work but to control manufacturing processes. The introduction of the brain element into manufacturing is likely to increase the productivity per man to such an extent that we can look forward to an era where there should be a plentiful supply of goods and a reduction in the hours necessary to produce them. The less industrialized countries will benefit from a flow of goods at prices they can better afford to pay. In short, the computer will open up an age of leisure coupled with plenty. Moreover, and this is of the utmost importance, there will be new work to be done. New industries and new kinds of jobs will arise because of this revolutionary ability of computers to calculate and control.

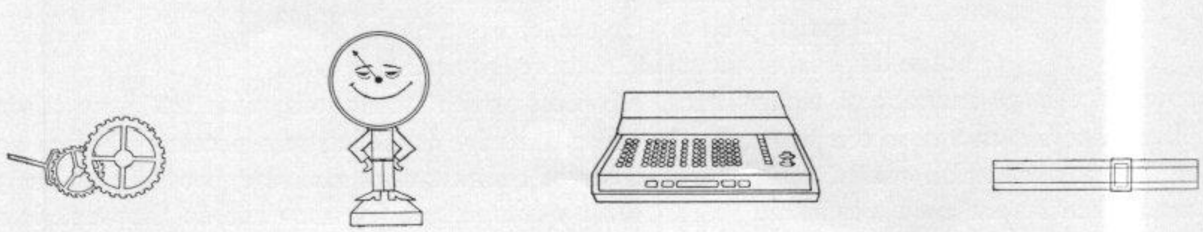
Perhaps you are thinking ' Will this advance lead to unemployment? ' Let me say that a recent survey on the subject could not reveal one person who had no work because a computer had been used.

DIGITAL AND ANALOGUE COMPUTERS

There are two kinds of computers, analogue and digital. Digital computers operate on numbers which are represented by separate pulses of electricity; analogue computers operate on continuously variable currents and voltages which represent the quantities.

It is not easy to grasp at once the difference between a digital and an analogue device, but perhaps the following non-electronic examples, and a glance at the illustration (Fig. 2) that follows them, will help.

1. A clock in which the position of the hands is controlled by distinct mechanical impulses from the escapement mechanism can be said to be a DIGITAL device.
2. A weighing machine in which the pointer can take up any position, not a series of separated positions, is ANALOGUE.
3. A simple key-operated adding machine is DIGITAL.
4. A slide rule is ANALOGUE.



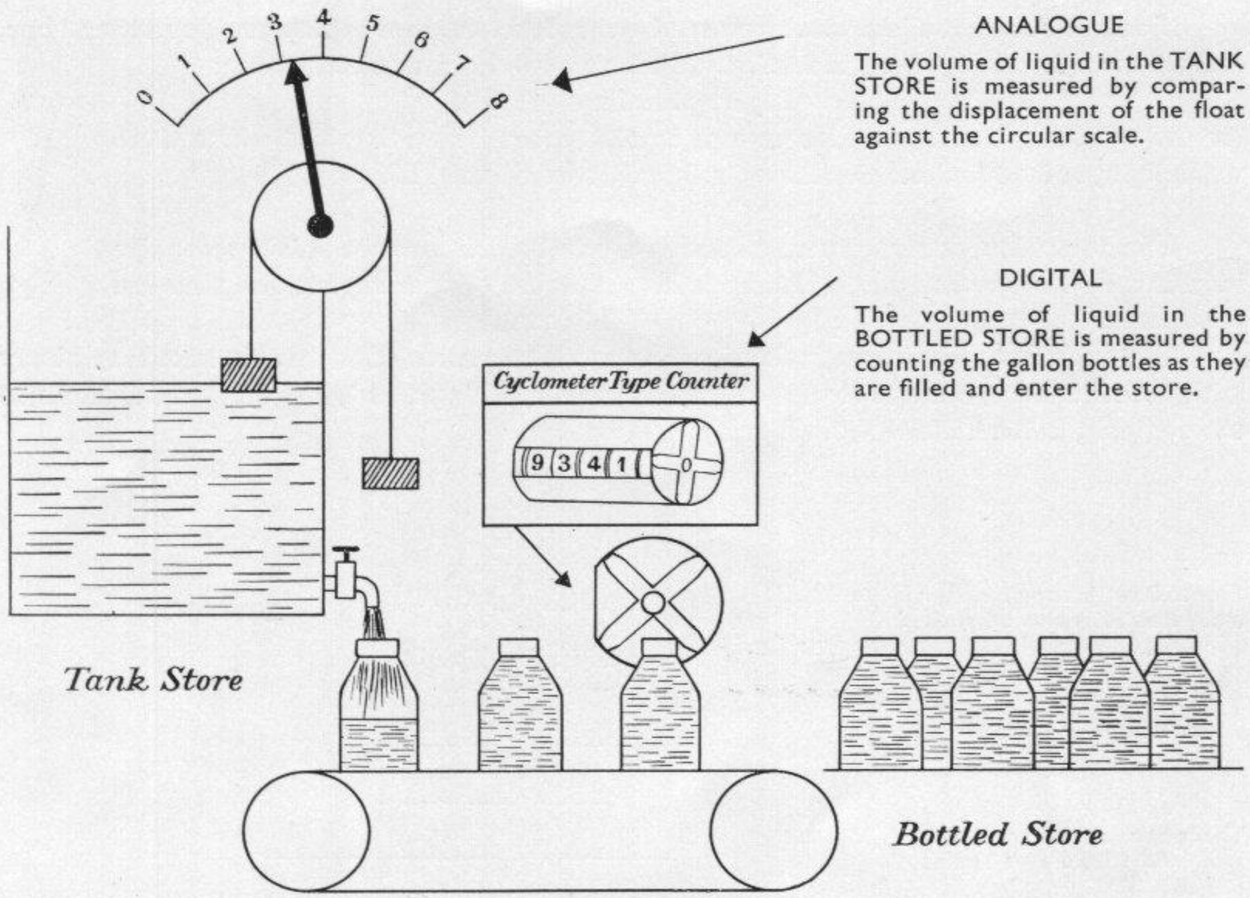


Fig. 2

HOW DOES A DIGITAL COMPUTER WORK?

Strangely enough, the most important thing in a computer is the wire. Every number which the machine deals with is transmitted along some of the wires inside it. The first thing I want to explain is how numbers can be sent along a wire.

When you switch on an electric light you send a continuous flow of electricity through the wire to the bulb which remains lit until you switch it off. Suppose I could see the light and you wished to signal to me a particular number; you could do this by switching the light on and off. You might flash the light on and off as many times as necessary so that when I received the signal I could count the number of flashes. But if the number were a large one you would take a very long time to make the full number of flashes. Therefore, to speed up the operations we should try to devise a system of abbreviation, or a code. This is precisely what the computer designers have succeeded in doing.

The code used is somewhat like the morse code where a dash and a dot are the only two symbols used because they are so easily recognized. Suppose you and I agreed that a dot meant ONE, and a dash simply meant that you left a blank space, we should have a simple and useful code. If you link up the idea of a code with the rhythmic tickings of a clock you will find that what I am going to explain is easier to understand.

If on the first tick of the clock you send a signal, on the second tick you do not send one, and on the third tick you again send one, then you would in fact be flashing:

Light. No light. Light.

At the receiving end I would turn this into a record by writing '1' where there was a light, and '0' where there was no light. It would read like this:

1 0 1

If in our code this represented a specific figure I would now be able to recognize it. Actually, as we shall see, 101 stands for the figure '5' amongst those who use computers.

This code has the advantage that it corresponds to a form of arithmetic known as binary arithmetic. Binary, because it uses only two symbols, '0' and '1', instead of the more usual ten symbols, 1.2.3.4.5.6.7.8.9.0. (Fig. 3)

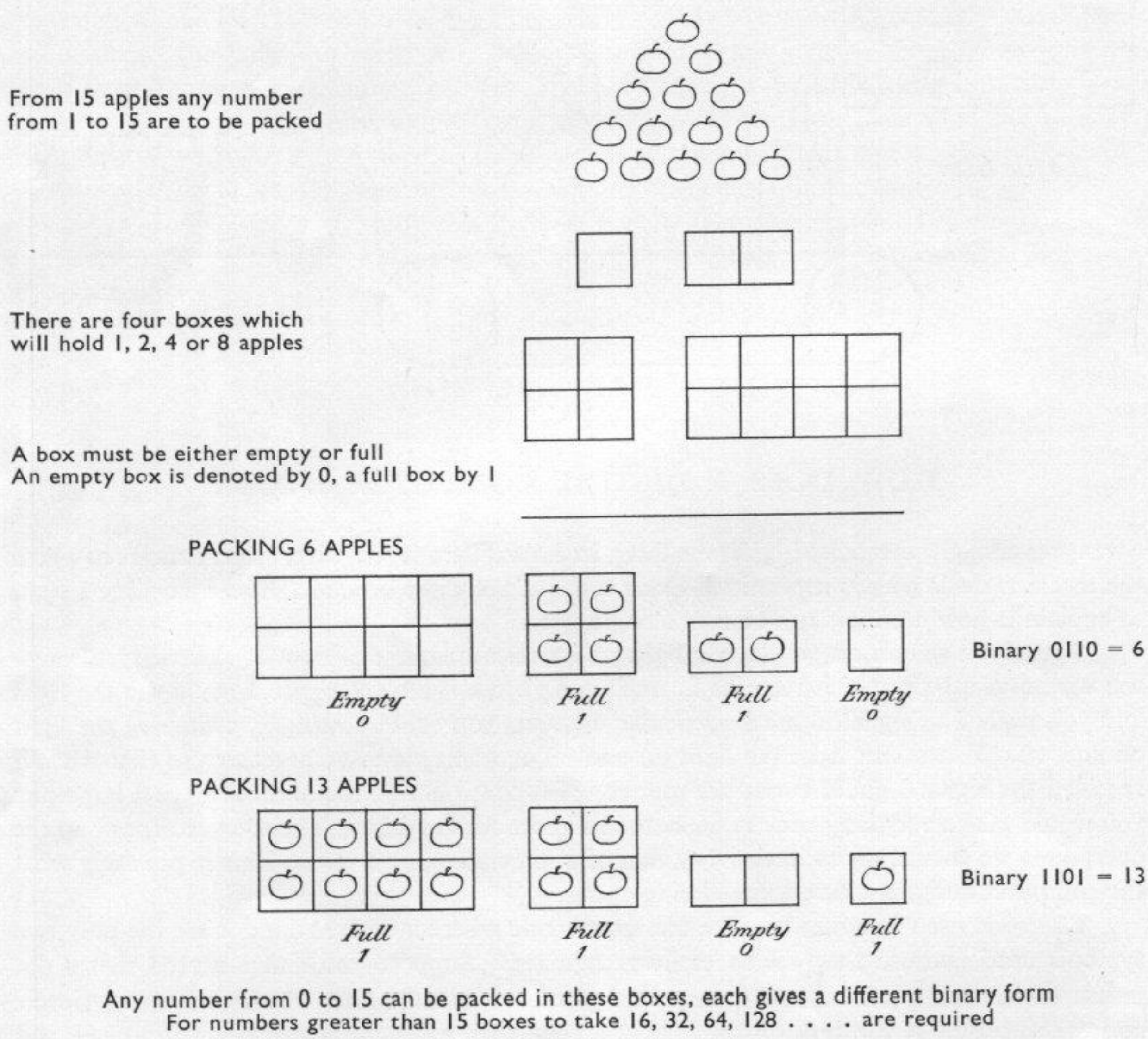
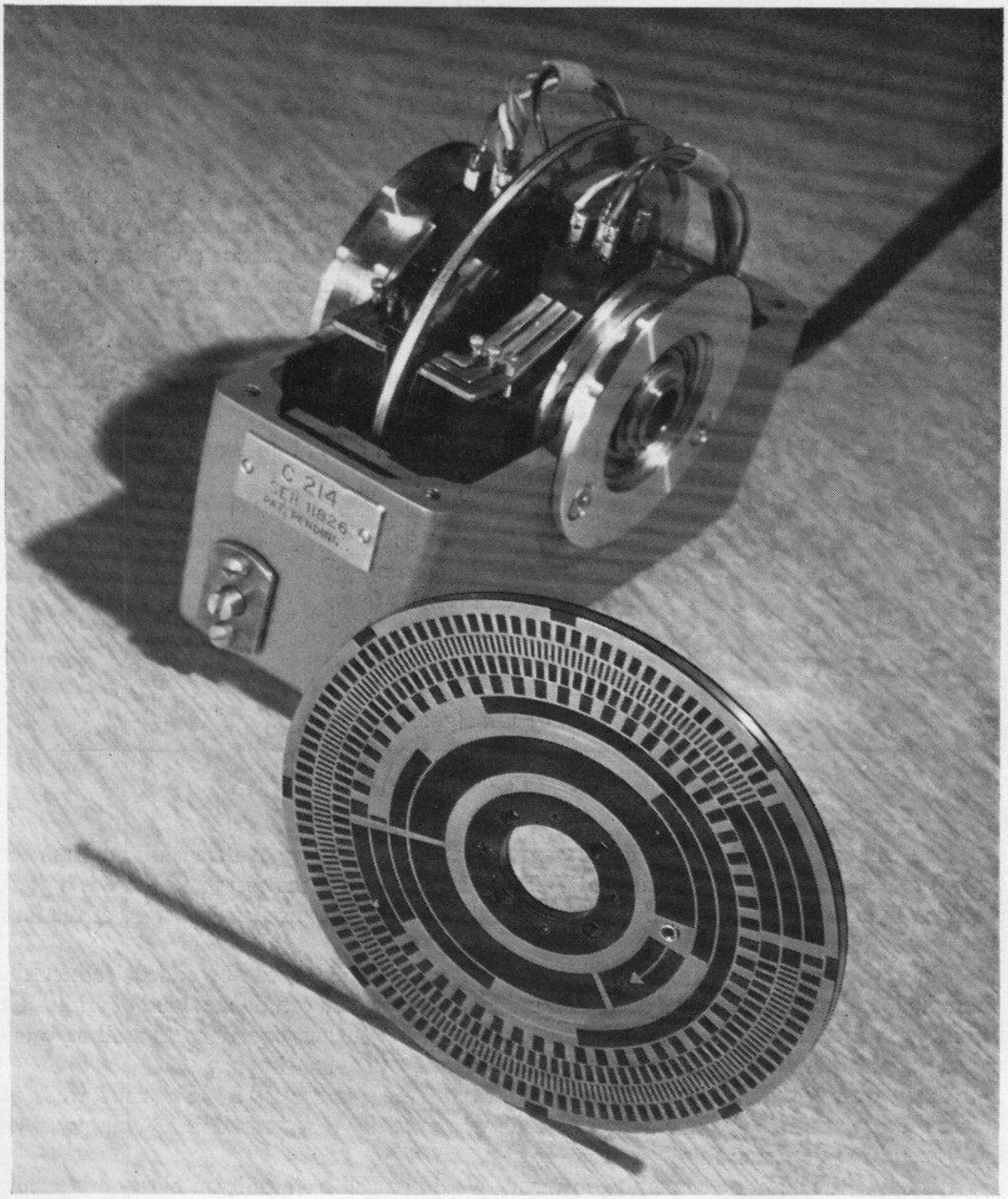


Fig. 3



Elliott Brothers (London) Ltd.

This Analogue to Digital Converter has a coded disc which enables a measurement of quantity to be converted into a number which can be printed as a record of measurement at a particular moment in time.

To return to the concept of our ticking clock for one moment—let us arbitrarily decide that we will never use more than 32 ticks in any one number. The largest number we could then transmit would be:

1111,1111,1111,1111,1111,1111,1111,1111.

This number expressed in our decimal language is:

4,294,967,295.

The mathematicians' way of passing from the long binary number to the large decimal number is to calculate in powers of 2 instead of powers of 10. By this I mean that, reading from right to left, instead of one, ten, hundred, etc., a binary number is made up of one, two, four, eight, etc. This is shown in the following illustration (Fig. 4) in which we have used a symbol like 2^5 to represent $2 \times 2 \times 2 \times 2 \times 2$.

Because

1111,1111,1111,1111,1111,1111,1111,1111 in Binary

equals

$2^{31} + 2^{30} + 2^{29}$ . . . . and so on to . . . $2^2 + 2 + 1$

or

4,294,967,295 in Decimal

We can code all integers from

0 to 4,294,967,295

with

32

On or Off signals

Fig. 4

You will see again from this illustration that with 32 ticks we can transmit any number from 0 to over four thousand million. This is a large range of numbers and there is a great economy in using binary because we need to send only 32 flashes or signals instead of the four thousand million.

Binary numbers, that is, those composed only of 0's and 1's can be added, subtracted, multiplied, and divided just like decimal numbers. In fact, you can do any kind of arithmetic in binary such as square roots, sines, and cosines, simultaneous equations as well as commercial calculations. The rules are different but actually they are simpler.

When we say that 101 in binary stands for the same number as '5' in decimal, we have done no more than change our units as we do when we say that 'two dozen' and 'twenty-four' stand for the same number. (Fig. 5)

Although the computer operates in binary we do not all have to learn binary arithmetic because quite automatically the computer will translate decimal, sterling, rupees and annas, feet and inches, or indeed any kind of units into binary arithmetic for its own internal use, and then will convert its binary answers back into the kind of units we want.

You can now start to see how important the wire is in a computer because by dividing the time in the machine into rhythmic beats or intervals like the ticking of our clock, you can, on

DECIMAL Based on Powers of TEN	BINARY Based on Powers of TWO
1205 means	10010110101 means
1 thousand + 2 hundreds + 0 tens + 5	$1.2^{10}+0.2^{9}+0.2^{8}+1.2^{7}+0.2^{6}+1.2^{5}+1.2^{4}+0.2^{3}+1.2^{2}+0.2^{1}+1$
or	or
$1 \times 1000 + 2 \times 100 + 0 \times 10 + 5$	$2^{10} + 2^{7} + 2^{5} + 2^{4} + 2^{2} + 1$
or	or
$1.10^{3} + 2.10^{2} + 0.10^{1} + 5$	$1024 + 128 + 32 + 16 + 4 + 1$
	or
	1205

BINARY ADDITION

TABLE		EXAMPLE	
$0 + 0 = 0$	$1 + 1 = 0$ and 1 to carry	101101	$32 + 8 + 4 + 1 = 45$
$0 + 1 = 1$		11101	$16 + 8 + 4 + 1 = 29$
$1 + 0 = 1$	$1 + 1 + 1 = 1$ and 1 to carry	1001010	$64 + 8 + 2 = 74$

BINARY MULTIPLICATION

TABLE	EXAMPLE	
$0 \times 0 = 0$	1001	$8 + 1 = 9$
$0 \times 1 = 0$	101	× $4 + 1 = 5$
$1 \times 0 = 0$	1001	
$1 \times 1 = 1$	0000	
	1001	
	101101	$32 + 8 + 4 + 1 = 45$

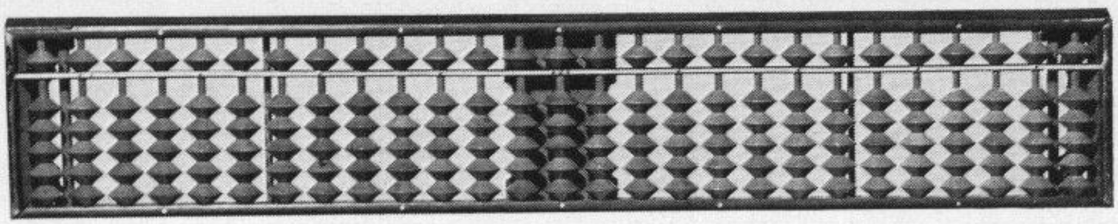
Fig. 5

any one tick, either decide to send a signal or decide not to send one. The intervals of time during which there either is a signal or not, are ticked off inside the computer by a kind of electronic clock.

Now we come to the reason why electronic computers operate so quickly. Electronic components like valves and transistors can tick, or, to be more formal, I would say they can generate pulses, at rates like a million a second. An electronic computer is mainly a machine for processing or handling pulses, and it works fast because it deals with the pulses so very quickly.

ELECTRICAL AND MECHANICAL PULSES

So far we have been dealing with millions of pulses a second and perhaps it all sounds very revolutionary and strange, until we recall that the older machines which help mankind to make calculations also use pulses. The earliest is the Abacus. In this very old device numbers are represented by beads on a wire. Like the computer it is a pulse processing device but the pulses are supplied not electrically but by a human hand or foot pushing the bead. Simple adding machines represent numbers by the position of a gear wheel which has ten teeth, one for each of the digits. In the early machines they were operated by levers and keys moved by a human finger; again pulse processing, but mechanical pulses. Then came desk calculating machines able to multiply and divide as well as add and subtract. The essential innovation was their ability to deal with all the digits of a number at the same time.



Japanese Abacus

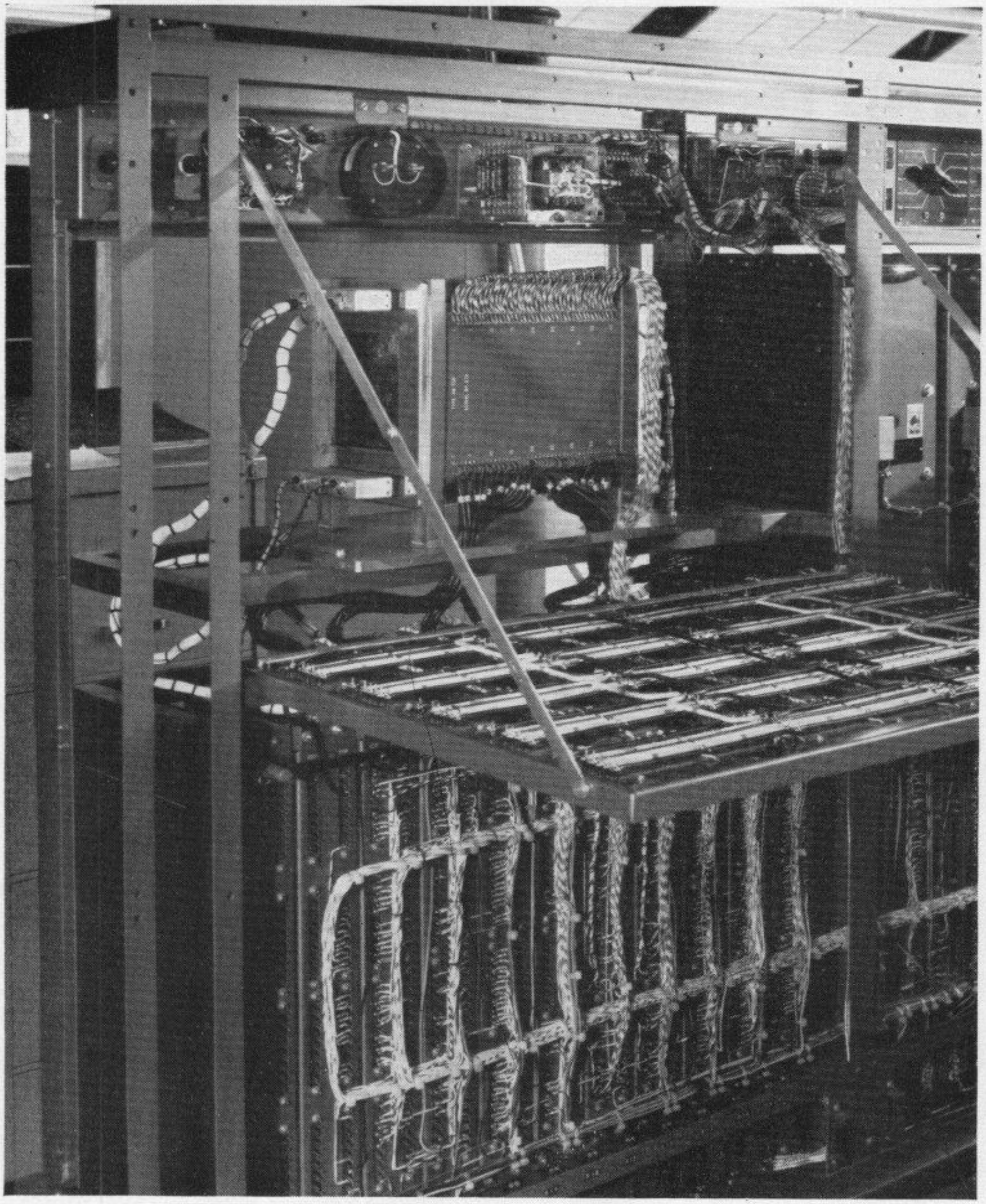
After these desk calculating machines came punched card machines which used the electric relay for calculating. The relay in its first use was the means of moving levers by an electric current, and in this case it was the movement of the levers which made the calculations.

This history shows that the use of pulses for numbers is not new; what is new is the use of electronic pulses. To generate a mechanical pulse something solid has to be moved, such as a bead in an abacus, or a wheel, or a lever. To move something solid requires mechanical effort; moreover, this effort cannot be supplied in really rapid bursts. But because electronic pulses are not solid they require no mechanical effort and can be supplied at tremendously rapid speeds. And so once again we come to the reasons for the high speed at which electronic computers operate.

A COMPUTER'S MEMORY

Naturally, as well as sending pulses down lengths of wire, we need to store the information contained in them so that it is not lost. In other words, we have to ' remember ' numbers in what we call a ' memory '.

You must keep in mind that we are storing only 0's and 1's. We may do this on a magnetic drum or disk in a rather similar way to that used for recording music. The surface of the drum is sprayed with a coating of material which can easily be magnetized, and one of the most remarkable things is the ability to magnetize separate and tiny portions of this coating. (Fig. 6)



Elliott Brothers (London) Ltd.

In the National-Elliott 803 Computer the 'memory' is a ferrite core matrix which has a capacity of over 4,000 words occupying a space of less than one cubit foot.

THE BBC AND ITS WORLD-WIDE SERVICES

The series of talks upon which this booklet is based was first broadcast in the BBC's General Overseas Service. Keeping listeners throughout the world informed of scientific and industrial achievement is part of the purpose of the BBC's External Services which are heard throughout the world in English and thirty-eight other languages for some eighty-five hours per day.

Thirty-nine high power short-wave transmitters broadcast news and programmes direct to an audience of many millions, while radio organizations in over fifty countries rebroadcast selected BBC programmes, thus bringing them to an even wider audience. Every week some one thousand news bulletins are broadcast overseas, and throughout the years the BBC's news services have become accepted in Britain and every part of the world as setting a standard of reliability and impartiality.

The General Overseas Service is the BBC's World Service in English serving a world wide audience, and is designed not only for those who have English as their mother tongue, certain programmes being specially tailored to the interests of those for whom English is a second language. Broadcasting as it does for twenty-two and a half hours a day it is the biggest short-wave radio service in the world. As well as broadcasting the best of the programmes produced for the audiences in Britain itself, the General Overseas Service also prepares a wide range of programmes for its own use. Talks, discussions, and feature programmes keep its world wide audience in touch with thought and opinion in Britain, reflect scientific and industrial achievement, and examine the social, economic, and industrial problems which are being faced in various parts of the world. Music, drama, sport, and variety all play their part in this service.

In addition to the General Overseas Service and special broadcasts in English to the Commonwealth, the BBC also broadcasts to countries in Europe and throughout the world in the languages which can be found at the bottom of this page.

News bulletins prepared for special language services include all the main items of world news in a form consistent with the bulletins broadcast in Britain, and are varied only for matters of local interest. Programmes other than news are designed to meet the special interests of their particular audiences and, in addition to reflecting the important aspects of British life and thought, they give emphasis to subjects and problems related to the country or area concerned.

WRITE TO THE BBC . . .

The BBC welcomes correspondence from overseas listeners, and letters are valued both as an indication of an interest taken in the BBC and as a source of programme material. Correspondence can be conducted in any language and we are grateful for any comments or suggestions for programmes that you may like to make. Letters should be addressed to BBC EXTERNAL SERVICES, BUSH HOUSE, LONDON, W.C.2. ENGLAND.

PUBLICATIONS

London Calling is the weekly programme bulletin of the BBC's Overseas Services designed for listeners throughout the world to the BBC's short-wave transmissions. Distributed by air-mail, it contains advance details of programmes and wave-lengths for a week and notes on the major broadcasts.

London Calling Europe is the weekly programme bulletin of the European Services of the BBC containing advance details of broadcasts in English and other languages and texts of English by Radio lessons. A special edition for French-speaking listeners contains additional texts of English by Radio lessons with explanations in French.

Hier Spricht London is a weekly magazine in German containing advance details of a week's broadcasts in the BBC's European Service in English and German. These include the English by Radio lessons and the texts of some of the lessons are also published.

Details of prices and subscription terms of the above publications can be obtained from BBC PUBLICATIONS, 35 MARYLEBONE HIGH STREET, LONDON, W.1, ENGLAND.

The External Services of the BBC broadcast throughout the world in the following languages: Albanian, Arabic, Bengali, Bulgarian, Burmese, Cantonese, Czech, Finnish, French, German, Greek, Hausa, Hebrew, Hindi, Hungarian, Indonesian, Italian, Japanese, Kuoyu, Malay, Maltese, Persian, Polish, Portuguese, Rumanian, Russian, Serbo-Croat, Sinhalese, Slovak, Slovene, Somali, Spanish, Swahili, Tamil, Turkish, Urdu, and Vietnamese.

THE BRITISH BROADCASTING CORPORATION

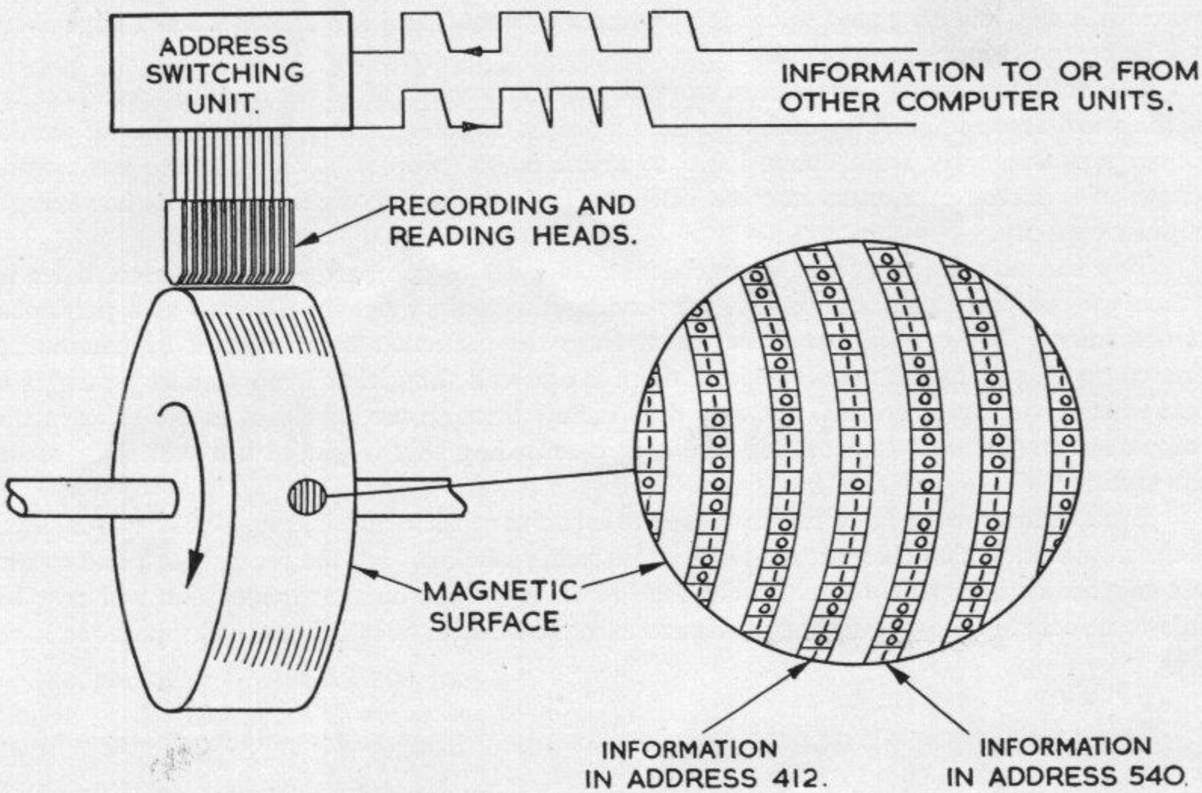


Fig. 6

To do this the drum must revolve under what is called a magnetizing head which records 0's and 1's on the surface. We can place several heads next to each other and use different parts of the drum for different numbers. So small are the separate areas which can be magnetized that we can store 150 0's or 1's in every inch of every track. The head is not only able to record the 0's and 1's but it can be used for reading back the pulses later. The magnetism on the surface is retained virtually for ever, and of course that is why the drum is a storage or memory device.

Other devices for storing numbers in computers are nickel or mercury delay lines, magnetic cores, and magnetic tapes. Each has its own special properties but the functional characteristic of a memory is common to all. Magnetic tapes are virtually infinite in capacity since different tapes can be placed on the driving mechanism. Most computers used for business calculations are equipped with a number of magnetic tape units which feed information to, and receive information from the computer's internal memory.

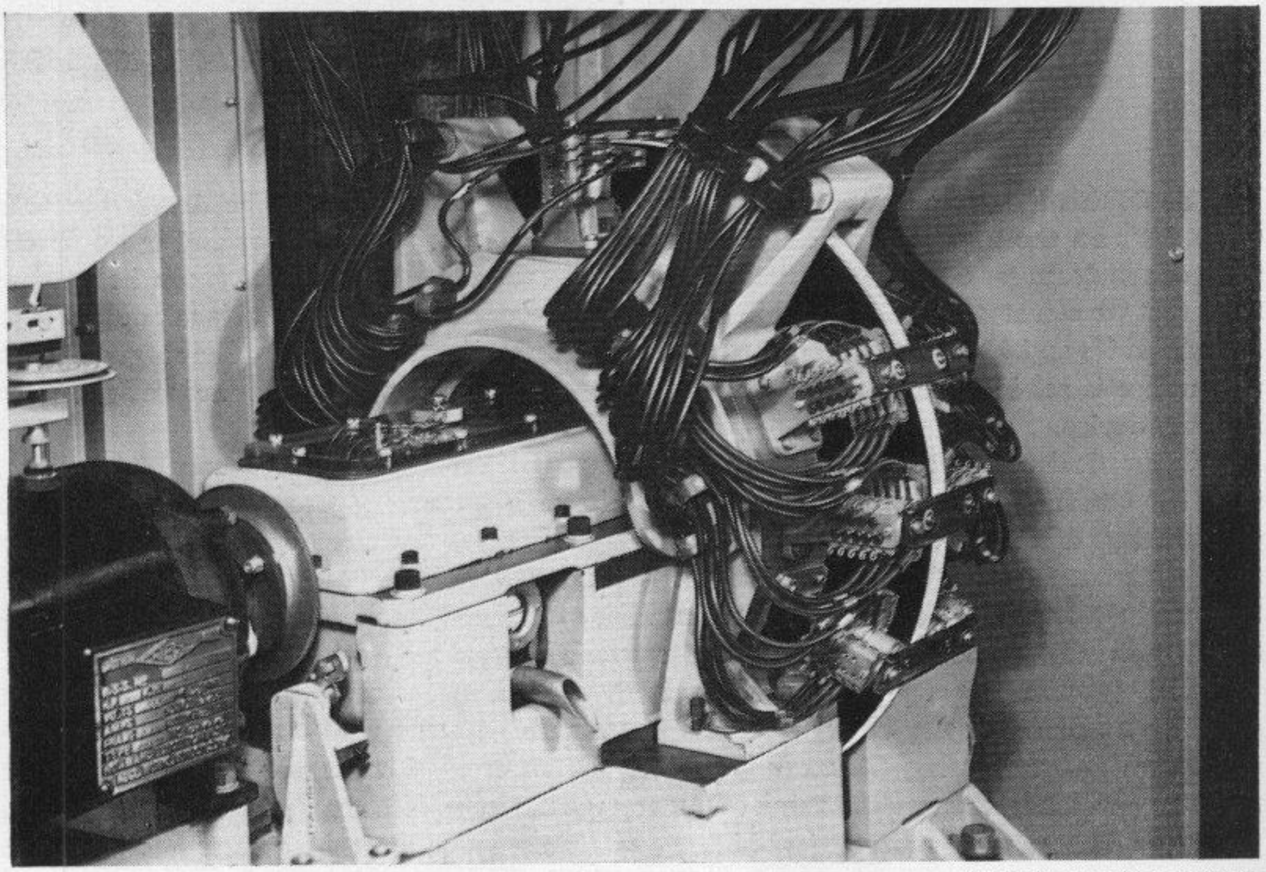
The essential property of the memory is that it is a means of converting the pattern of pulses or no-pulses of the binary numbers flowing through the wire into magnetism or no-magnetism and so storing them. If we use 0 for an area which is not magnetized and 1 for an area which is, then we can think of our storage device as directly storing binary numbers.

You will remember that with 32 binary digits we are able to deal with any number up to 4,294,967,295. This group of 32 binary digits is the fundamental unit which our computer will process and I am going to refer to it frequently. It is therefore very useful to use one quick word for it and so I am going to call it a ' computer word ', and sometimes when I hope there will be no confusion, simply a ' word '.

Our storage device can therefore store ' computer words ' of 32 binary digits and because of the small area required for each digit in a word, it can store a very large number of words. Drum capacities vary from about 1,000 to about 60,000 words. Of course the basic word length in different computers may be different from 32 binary digits, which is, however, a popular capacity.

You can now think of the storage device as a set of compartments or pigeon holes in which we can place computer words by sending them down a wire directed at a particular compartment. We can extract these words from the particular compartment by connecting that compartment to the wire, and here there is one odd thing that I must make clear. It is that when you extract a word, not only does it flow through the wire, but it also stays in the compartment. In this, it is exactly like a tape recording that is played but still remains on the tape.

Each compartment has a number. If the capacity of the drum is, say, 10,000 words, then there would be 10,000 compartments; the first being labelled ' 1 ', the second ' 2 ', and so on. We call the number of a compartment the ' address ' of the compartment. You will now be able to understand how different words are extracted during a calculation. Suppose we have



Elliott Brothers (London) Ltd.

Magnetic disk and driving motor

stored a man's hourly rate of pay in compartment No. 412, and the number of hours he has worked in compartment No. 700, then to find his pay we must instruct the computer to multiply the word in compartment 412 by the word in compartment 700.

How this is done I will explain later. In the meantime, we must note that this 'instruction' contains two kinds of information. One, an operation like 'multiply' and the other an 'address' like 'compartment 412'.

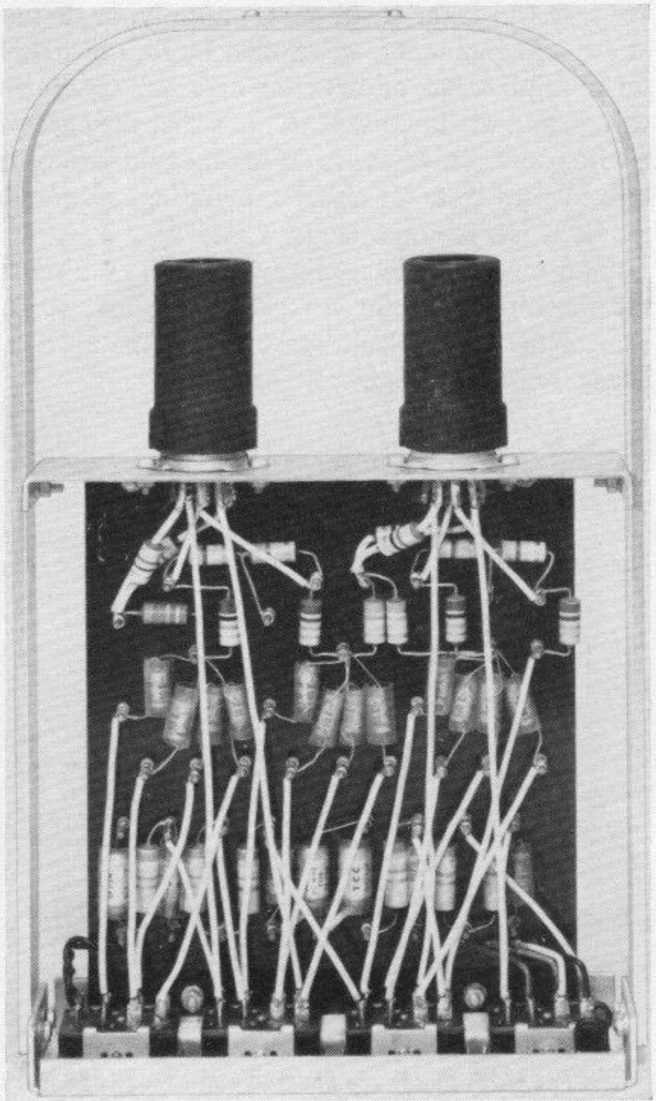
ELECTRONIC ARITHMETIC

We are now able to visualize how a computer can send numbers down a wire, store them, and recall them. Let us now see how the computer can add, subtract, multiply or divide those numbers.

This can be done by assembling valves and other components, such as resistors and condensers, so that the pulses representing binary numbers flow through this assembly. Such an assembly should be thought of as a well-defined part or section of the computer. I am going to call it a 'black box', which is a slang term of the electronic engineer, although it is really neither a box nor black, but to call it a black box does isolate it and allows us to concentrate on its function and its relationship with the rest of the equipment.

If we have two wires going into the black box we can send two numbers along these wires at the same time. The pulses will enter the box in pairs, one from each number, and on a wire coming out of the black box, the two numbers will be added together. The sum will emerge in the form of pulses of 0's and 1's.

The engineering of this black box is complex and I should have to pass into the realm of the electronic engineer to explain how he regulates the voltages and the currents in order that the addition can be made. However, you can easily obtain an insight into what goes on in the black box when I tell you the rules for adding two binary numbers together. These rules are very simple and, oddly enough, they are even simpler than the rules for adding



Elliott Brothers (London) Ltd.

'Black Box' used to add one binary digit

decimal numbers. In this system where only 0's and 1's are used, only three rules are necessary:

0 plus 0	equals	0
1 plus 0	equals	1
1 plus 1	equals	0 and carry 1

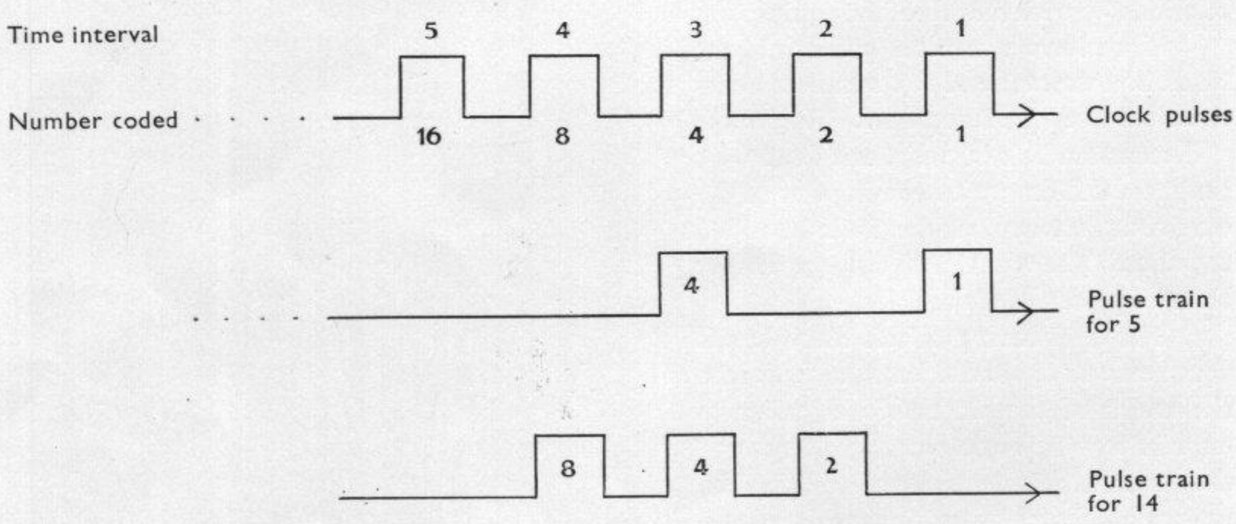
You might state these rules as:

no-pulse and no-pulse	equals	no-pulse
a pulse and no-pulse	equals	one pulse
a pulse and a pulse	equals	no-pulse and carry one pulse forward

The pulse processing carried out by a valve is a replica of the above simple binary arithmetic rules as it so happens that an electronic valve quite naturally operates in this way.

By making special connections, or circuits, as they are called, in the wires of the black box, we can make it subtract, multiply, or divide instead of add. Which circuit is to be used at any one moment is controlled by four switches—one for addition, one for subtraction, one for multiplication, and one for division. These are electronic switches made of an assembly of valves, and the important thing is that they are moved, not by a human hand, but by a pulse in a wire connected to them. What they do is to cause the two numbers which flow into the black box to pass through either the adding, subtracting, multiplying or dividing circuit, and the required job is done. (Figs. 7 and 8)

So much for electronic arithmetic. We must now enquire how we put information into the machine and how we get it out: and then, and most important, perhaps, how do we control the many black boxes that make up this machine which has to perform in complete harmony like some gigantic orchestra?



Pulses flowing through a wire at regular time intervals are shown by the humps in the lines.
The clock pulses are emitted continuously to mark the intervals.
The middle train of pulses represents 5 (1 + 4), and the bottom train 14 (2 + 4 + 8).

Fig. 7

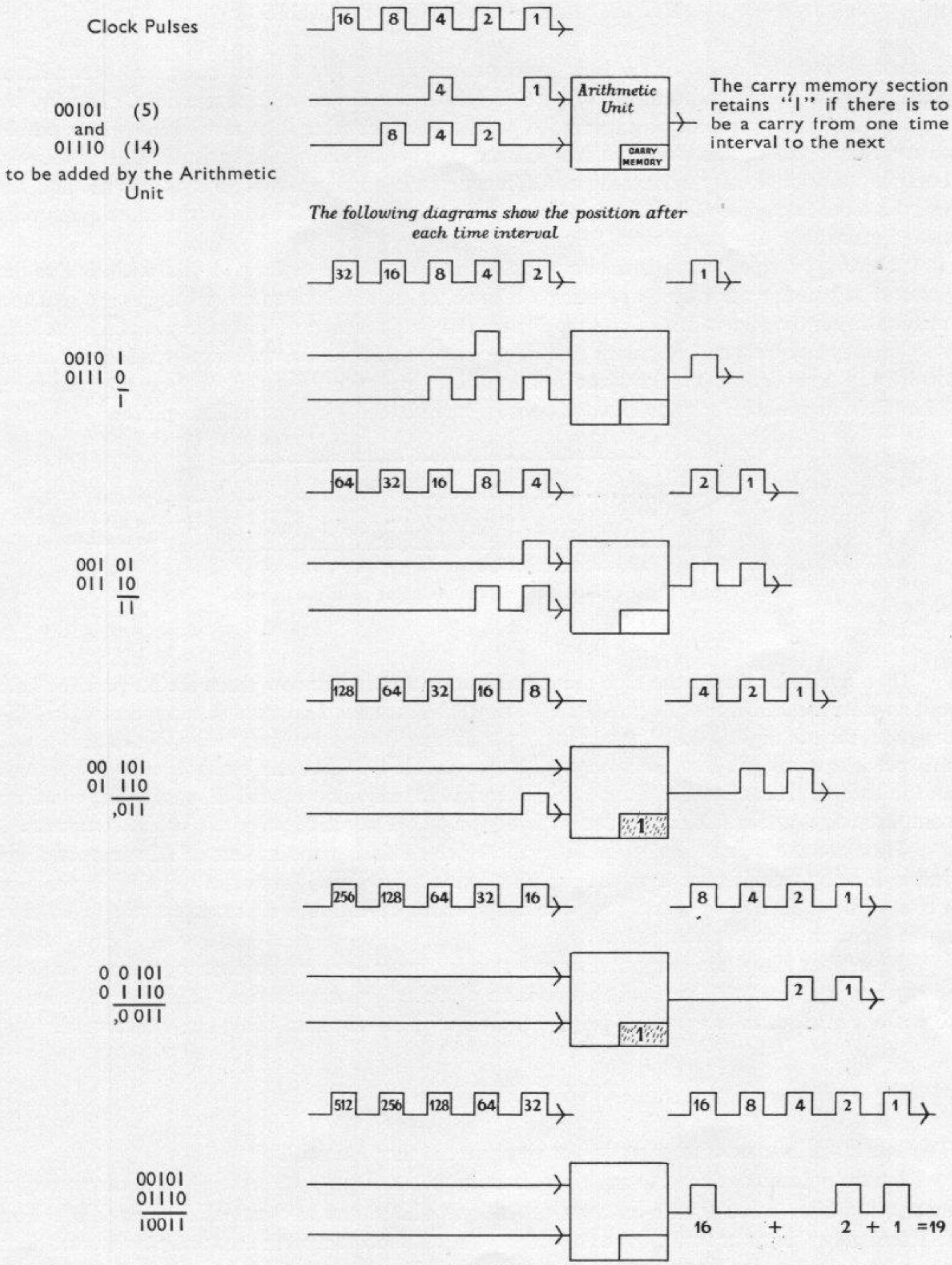
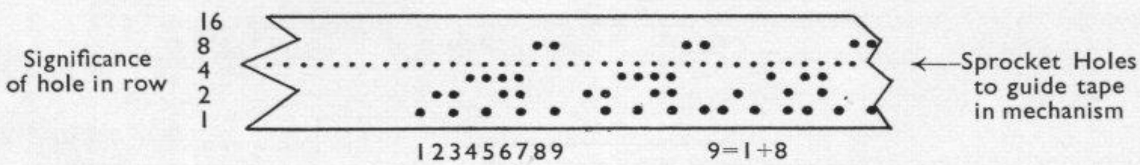

Clock Pulses
16 8 4 2 1
00101 (5)
and
01110 (14)
to be added by the Arithmetic Unit
4 1
8 4 2
Arithmetic Unit
CARRY MEMORY
The carry memory section retains "1" if there is to be a carry from one time interval to the next
The following diagrams show the position after each time interval
32 16 8 4 2
1
0010 1
0111 0
1
64 32 16 8 4
2 1
001 01
011 10
11
128 64 32 16 8
4 2 1
00 101
01 110
,011
1
256 128 64 32 16
8 4 2 1
0 0 101
0 1 110
,0 011
2 1
1
512 256 128 64 32
16 8 4 2 1
00101
01110
10011
16 + 2 + 1 =19

Fig. 8

INPUT AND OUTPUT DEVICES

Since the computer deals with pulses, our input device is a way of converting numbers written on paper into pulses and sending these along a wire to the storage or memory. Ideally, we would put ordinary pieces of paper with ordinary handwriting into a machine which would convert the handwritten numbers into binary numbers; this is not as fanciful as it sounds, because a device already exists which will convert printed characters. But as this method has not yet come into general use, I think it might be better to describe one of the more commonly used forms of input—paper tape. (Fig. 9)

This paper tape, which is about $\frac{3}{4}$-inch wide and can be as long as you wish, is like the paper tape you may have seen operating a teleprinter on which news and messages are sent and received. Across the width of the tape there is room for five holes to be punched. A hole may or may not be punched in any one of the five positions. So we can now think of hole or no-hole in a particular position, just as I explained pulse or no-pulse, or 0 or 1 in the wire. The ' hole or no-hole ' choice in the tape is, therefore, easily converted into pulses.



Paper Tape (Black dots represent holes punched in tape)

Fig. 9

The five holes across the tape are called a row, and in any row there are 32 possible hole and no-hole combinations. As you already know, this is more than enough to represent, in binary code, the ten digits 0-9. By an ingenious trick the 32 combinations are extended to 64, and this permits us to put into the computer letters of the alphabet and symbols such as commas and full stops. It is very useful to be able to handle letters and symbols. For example, when we compute wages the men's names can be included on the payslips prepared by the computer.

How are the holes actually made in the tape? This is the simplest of all the operations and is done by working the keys of a machine like a typewriter. Instead of printing, it punches a row of holes in the tape, and you will easily understand that a different pattern of holes is made for each different character.

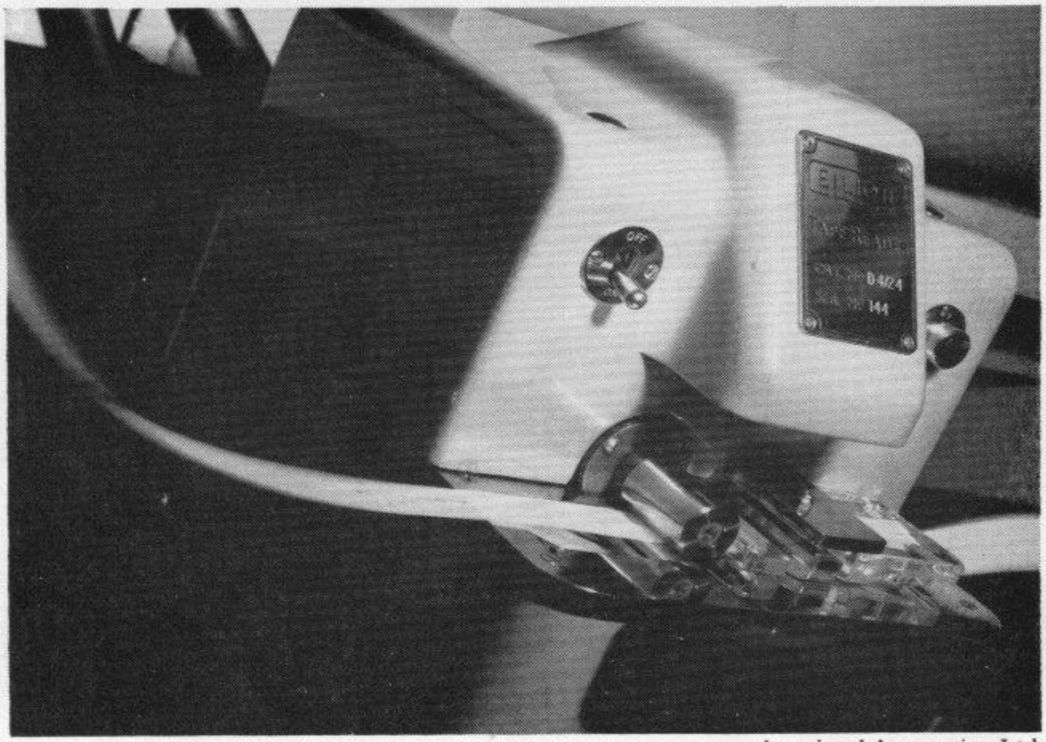
Now what about the output? Because this is simply an input in reverse, there is no need to say much about it. The final output is an electrical printing device. This can take many forms but in all cases is a page of printed material which a human being can understand.

THE CONTROL UNIT

The last black box we must have in our computer is the Control Unit.

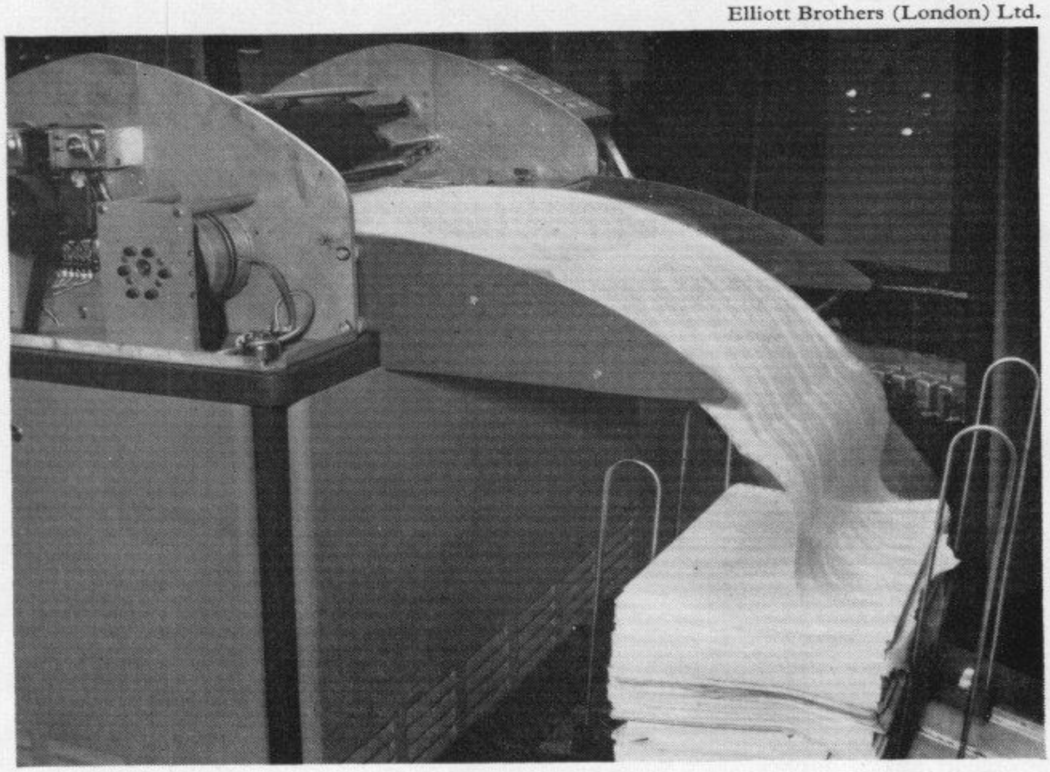
I have pointed out that, to multiply hours by rates of pay, we must give the computer an instruction like ' multiply the contents of Address 412 by the contents of Address 700 '. You will remember that our storage is a collection of numbered compartments and we assumed that hours and rates were in compartments numbered 412 and 700, which we call their addresses.

The Elliott High Speed Tape Reader reads information for computers at the speed of 1,000 characters per second.

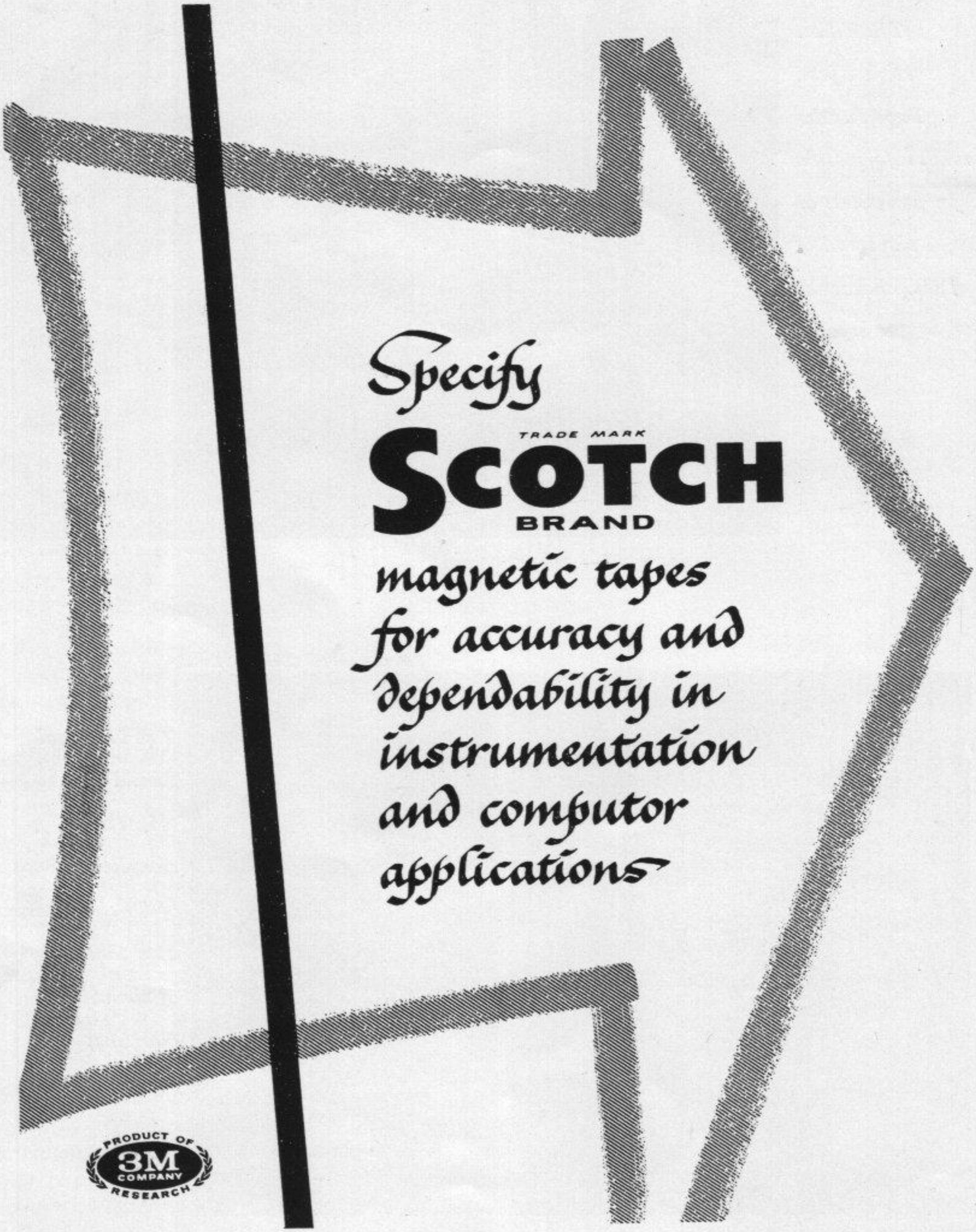


Associated Automation Ltd.

Elliott Brothers (London) Ltd.



The National Line Printer prints a complete line of 80 characters at a time at the rate of 600 lines per minute.


Specify
TRADE MARK
SCOTCH
BRAND
magnetic tapes
for accuracy and
dependability in
instrumentation
and computor
applications
PRODUCT OF
3M
COMPANY
RESEARCH

‘SCOTCH’ BRAND **INSTRUMENTATION TAPES**

Description	STANDARD		High Resolution Ext. Play	SANDWICH*		Ext. Play	HEAVY DUTY	Ext. Play
Tape Numbers	108	109	159	186	188	189	198	199
Physical Properties Colour	Red/ Brown	Red/ Brown	Dark Red	Purple	Purple	Purple	Black	Black
Backing Material	Polyester	Acetate	Polyester	Polyester	Polyester	Polyester	Polyester	Polyester
Thickness in thou								
Backing	1.45	1.42	.92	1.45	1.45	.92	1.45	.92
Coating	.55	.55	.35	.50	.35	.35	.45	.45
Protective Layer	.00	.00	.00	.05	.05	.05	.00	.00
Total	2.00	1.97	1.27	2.00	1.85	1.32	1.90	1.37
Temperature Limits for Safe Use								
Low	−40°F	−40°F	−40°F	−40°F	−40°F	−40°F	−40°F	−40°F
High	+140°F	+140°F	+140°F	+140°F	+140°F	+140°F	+250°F	+250°F
Relative Wear Ability	1.0	1.0	1.0	10.0	10.0	10.0	5	5
Magnetic Properties								
Intrinsic Coercivity (Hci) Oersteds	250	250	240	240	240	240	240	240
Retentivity (Brs) Gauss	700	700	1100	1100	1100	1100	850	850
Remanence (Flux lines/¼″ tape)	0.6	0.6	0.6	0.8	0.6	0.6	0.6	0.6
Relative Output in db at 1% distortion 15 thou Wave Length	0	0	0	+2.5	0	0	0	0
Relative Sensitivity in db 15 thou Wave Length	0	0	+1.5	+2.5	+1.5	+1.5	0	0
1 thou Wave Length	0	0	+3.5	−2.5	−2.5	−2.5	0	0
Erasing Field—Oersteds	1000	1000	800	800	800	800	1000	1000
Uniformity at 15 thou Wave Length Within a Roll	±3%	±3%	±3%	±3%	±3%	±3%	±3%	±3%
Roll to Roll	±10%	±10%	±10%	±10%	±10%	±10%	±10%	±10%

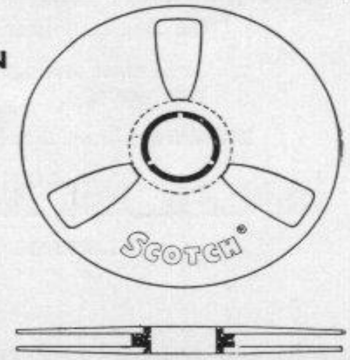
* *Exclusive* **‘SCOTCH’** *Brand*

SANDWICH INSTRUMENTATION TAPES

- No rub off or head build up
- Reduced head wear
- Improved tape life

‘SCOTCH’ BRAND PRECISION INSTRUMENTATION REEL

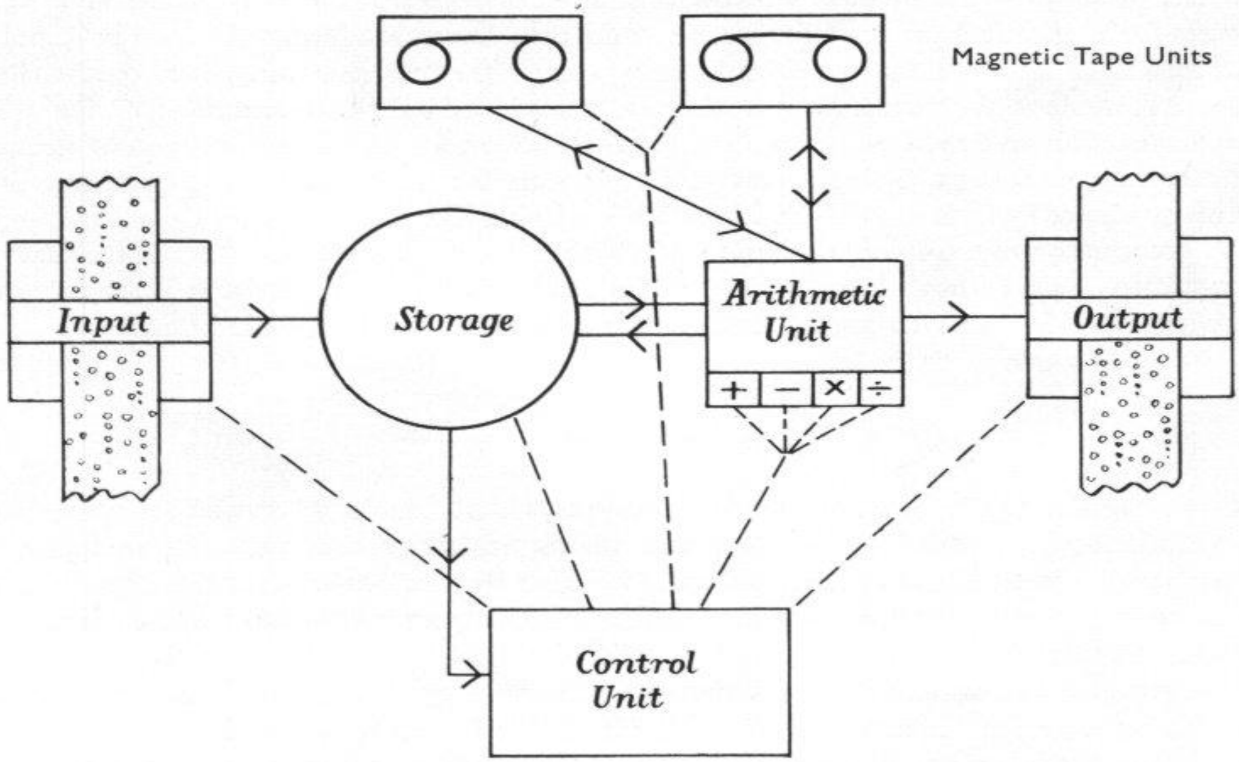
Available in 10½″ and 14″ diam. and all standard widths



This instruction contains two kinds of information; first, an operation such as multiply, or add or subtract or divide as the case might be, and secondly, the addresses of the storage compartments where the two numbers will be found. Suppose, now, we code the possible operations and that in a given position, say 2 stands for adding, 3 for subtracting, 4 and 5 for multiplying and dividing. We can now very quickly write the instruction in numbers by just putting down '4, 412, 700'. If you know the code you would interpret this as multiply hours by rates because you know that 4 means multiply, and hours and rates are stored in compartments 412 and 700.

Now we reach the most important novelty of our electronic computer. It is that these instructions which make it do different things are numbers, and because they are numbers they can be stored by the computer in the Storage Unit. You will remember that the older mechanical calculating machines were also pulse processing devices like electronic computers, although much slower. But, there never has been anything before like this ability to remember and store instructions. Keep in mind that storage capacities run into thousands of words and that because a word can be an instruction the computer can remember a long sequence of operations made up of thousands of detailed instructions.

The Control Unit is the black box to which each instruction is sent in turn. When a particular instruction is in the Control Unit it sets the electronic switches so that the computer carries out only that instruction. (You will remember that we had control switches on the Arithmetic Unit which made it either add, subtract, multiply or divide.) When '4, 412, 700'



Solid lines show channels through which data and instructions flow.
Dotted lines show channels through which the control is exercised.

Fig. 10

appears in the Control Unit it is the presence of the 4 in the first position which turns on the multiplying switch.

A computer can be made to work rhythmically in two-beat time. It takes an instruction automatically from the storage to the Control Unit on the first beat and on the second beat it carries out the instruction; it then reads the next instruction and carries that out. All this is done quite automatically once the complete set of instructions has been placed in the store. This complete set of instructions is called a program,* and may consist of many thousands of instructions. Working out the programs for different jobs is one of the new and interesting tasks which computers have created for human beings. Fig. 10 shows how all the devices and black boxes are linked together. Fig. 11 shows what happens in the Arithmetic Unit Storage Control in each beat.

TEST INSTRUCTIONS

There is one other characteristic which I have not yet mentioned because I wish to emphasize its importance by dealing with it separately. This is the ability to choose different parts of a program. Circuits have been designed to find out if the sign of the word is a 'plus or a minus', and if it is a 'minus' a different sequence of instructions will be sent to the Control Unit.

An example from a program for calculating wages will show why this is such a powerful tool. Let us suppose the pension contribution to be deducted from a pay packet is 5 per cent of wages for men but 3 per cent for women, and that the code number for men is 2, and that for women is 1. This code is stored in the computer; if the program brings it to the Arithmetic Unit and is made to subtract 2 from it, the result would be 0 for men and minus 1 for women. A test instruction will then call up a 5 per cent deduction for men but a 3 per cent deduction for women by choosing a different part of the program for the women. It is quite astonishing how many choices which have to be made can be coded like this.

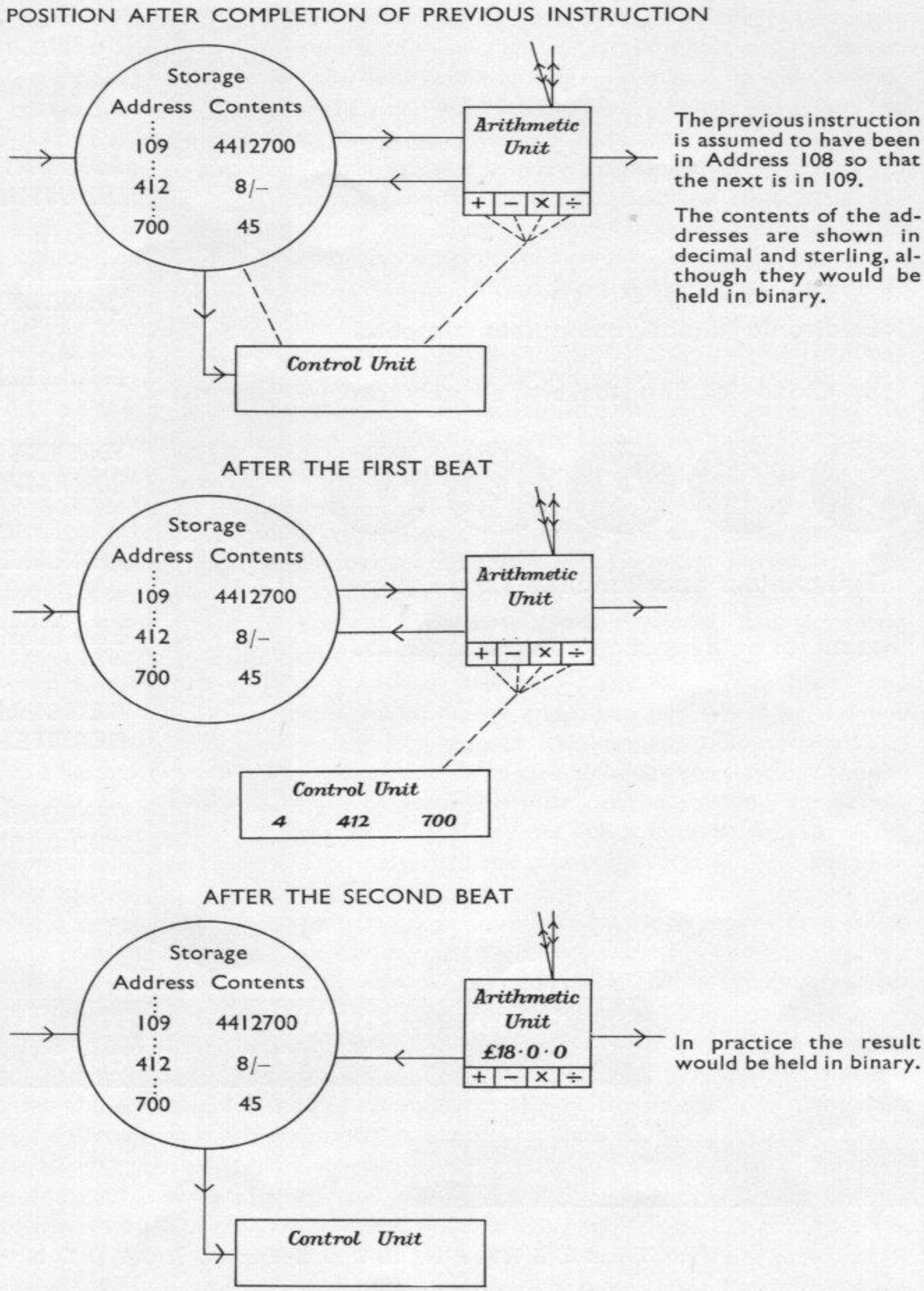
A computer program contains many of these choices; you can see, therefore, that quite automatically, and without human intervention, the computer can make a large number of decisions. This is another reason why it is so often called an 'electronic brain'.

ANALOGUE COMPUTERS

What is an analogue computer? The dictionary says that 'analogy' means an agreement or correspondence in certain respects between things otherwise different. In analogue computers the agreement is a mathematical one. In other words, two entirely different things can be shown to have a likeness by the mathematical equations which define their movements or states.

Let me give you an example of a mathematical analogy. Imagine a small weight hanging on the end of an elastic band. If the weight is pulled down in such a manner as to stretch the elastic past its normal rest position and it is then released, it will oscillate—that is to say, it will move up and down, each successive oscillation becoming smaller until the weight finally comes to rest. Now imagine a large pointed knife

* Usual spelling in computer circles.



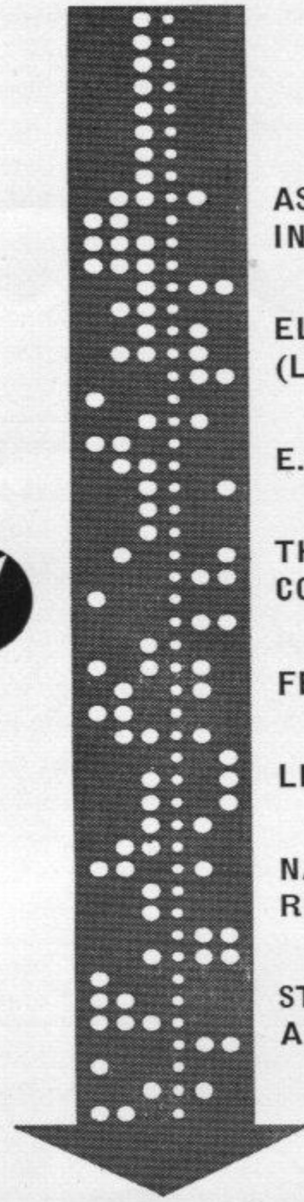
Computing rate of pay multiplied by hours worked.

Fig. 11

Electronic digital computers supplied by these leading makers all rely on

creed

Teleprinters and Punched Tape Equipment for data input and output facilities.



ASSOCIATED ELECTRICAL INDUSTRIES LIMITED

ELLIOTT BROTHERS (LONDON) LTD

E.M.I. ELECTRONICS LTD

THE ENGLISH ELECTRIC COMPANY LIMITED

FERRANTI LTD.

LEO COMPUTERS LTD

NATIONAL CASH REGISTER COMPANY LTD

STANDARD TELEPHONES AND CABLES LIMITED

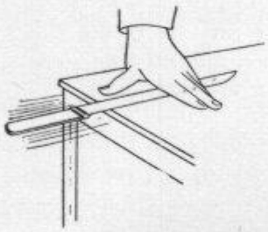
major contributor to Britain's computer industry

Creed & Company Limited

TELEGRAPH HOUSE · CROYDON · ENGLAND

Telex 28836

AN ITT ASSOCIATE



with a flexible blade held on at able in such a way that the pointed part of the blade is clamped to the table and the rest of the blade and the handle overhang the table. If the handle of the knife is plucked, it will move up and down until it comes to rest. The weight on the elastic moves up and down and comes to rest; the knife moves up and down and comes to rest. It is clear that the two systems have much in common.

Both these systems have weights, springs, and air resistance, and although they are different in shape and texture the thing that they have in common is that they both obey the same mathematical laws; the only difference is that the values of the weights, springs, and air resistance are quite different in each case. Under these conditions we say that one system is analogous to the other.

To take a practical case, think of a pipe through which water is flowing, the pressure being applied by a pump at one end of the pipe. The water will flow through the pipe at a speed which depends on the shape of the pipe, the internal roughness of the pipe, and the pressure which is being applied by the pump. Similarly, a wire through which electricity is flowing as a result of a voltage applied to its outer ends will have current flowing through it which depends on the texture and size of the wire and the pressure of the voltage. Voltage, as you know, is electrical pressure. These two systems are similar and the thing they have in common is that they obey the same mathematical equations. The electrical wire with the current flowing through it is said to be analogous to the pipe with the water flowing through it. If we have to design a system with a pipe in which the flow of water through it is to be very large, requiring a pipe, say, two feet in diameter and perhaps twenty miles long, with a very powerful pump to push the water through, it would be extremely costly to build such a system with a real pipe and a real pump on which to make design experiments. What we do is to use an electric analogue. This consists of electrical resistances fixed on a workshop bench and connected by wire to a battery to represent the pressure. The electrical current flowing through the resistances representing the flow of water through the pipe can be read on an electric meter. On the workshop bench, it is a simple matter to carry out any measurements involving changes, say, in the length of the pipe and the capacity of the pump by varying the resistances and the battery. You will see the amount of time and equipment this saves. (Fig. 12)

When we set up a system such as this electrical resistance network to represent a much more complicated and costly arrangement we say that the electrical system is ‘ simulating ’ the actual device, it is, in fact, analogous to the life-size system and one of the main advantages of analogue computers is this model concept.

Analogue computers are made in a variety of ways and in such a manner that they can be set up as models of the system we want to study. When this system is very complicated the analogue computer has the advantage of giving the operator the facility of changing the values of the various terms involved in the problem such as weights, stiffnesses, wind resistances, and so forth, without having to make costly changes on the real equipment and in some cases even preventing the possibility of making changes that might be dangerous. In the past, analogue computers were constructed as specific mechanical and electrical models of the real systems, but nowadays electronic analogue computers can be set up to do a large variety of jobs. They are much more flexible, cheaper and easier to operate than they were. But I would say the greatest advantages are generally to be found where a mixture of mechanical devices, electrical networks, and electronic amplifiers are used.

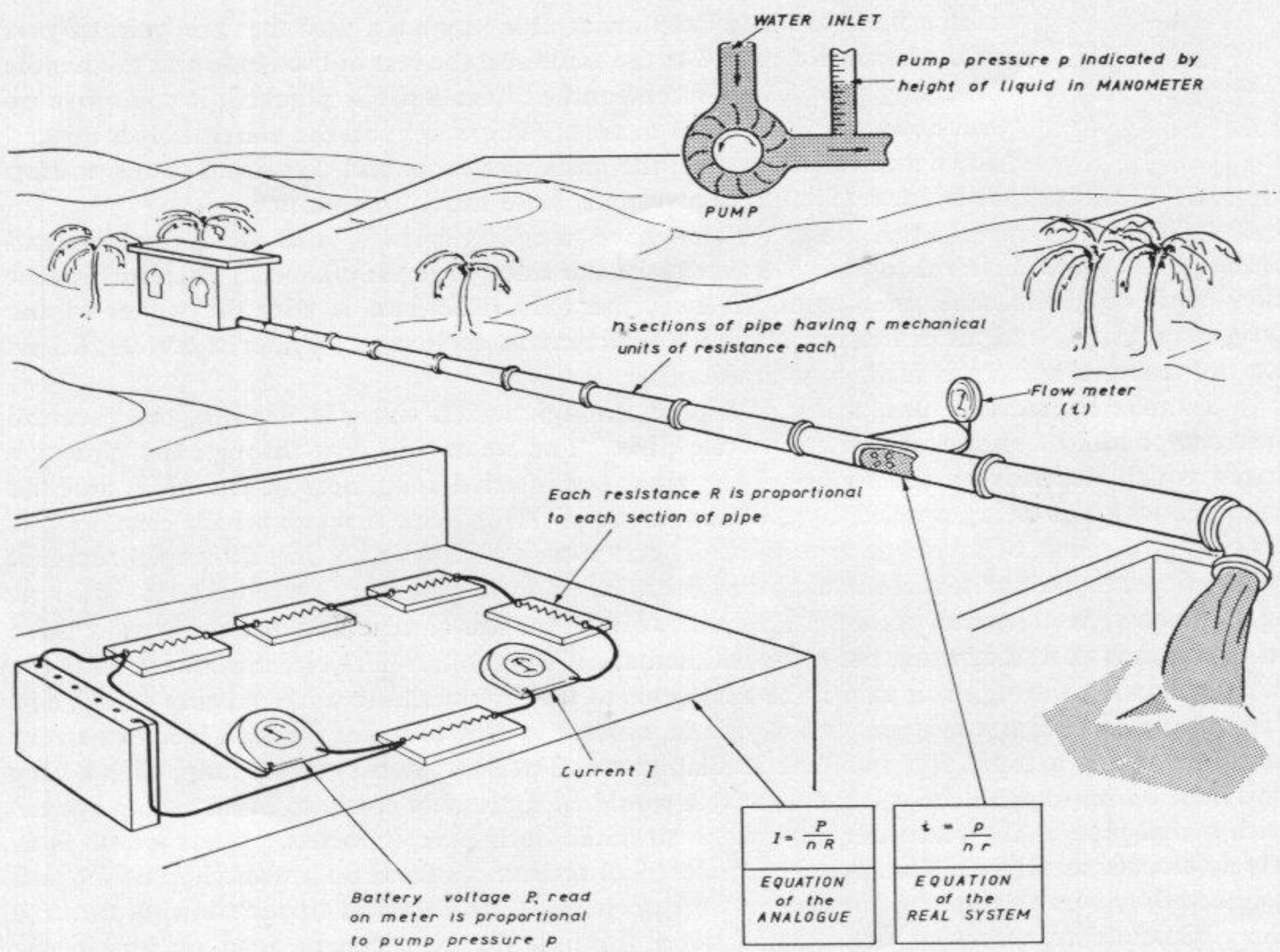


Fig. 12

So you see that analogue computers are used where it is necessary to study the effect of varying certain factors, in a complicated system in which it is difficult to make the required calculations, by other methods, either by reason of the complexity or because it is impractical to construct a life-size version of the system on which to experiment.

If you are designing a complicated system which you want to simulate, you could, for example, break it down into a number of mathematical equations and each term in the equation can be represented by a single box of electronic equipment carrying out just that one arithmetic function. This might be the addition of several quantities or an integration of changes with respect to time. There are many of these boxes: as many boxes or functional units as there are terms in the equations. As in the digital computer, the wire is a most important element because it is by joining two wires that the analogue computer simulates, or copies, the sign of equality in an equation.

In a typical computation there would be a number of elements; 60 would represent quite a complicated problem. These would be inter-connected by wires, and every element will be computing simultaneously.

Typical of a problem solved by analogue computers is the study of the stresses in an aeroplane. Here a number of parts may vibrate at the same time, and so when the analogue computer is set to simulate the aeroplane the electronic analogues of the real life situation all vibrate at the same time. If the period of oscillation is the same as that in real life the computer is said to be working in real time. Many of the applications of analogue computers stem from this fact. Imagine the alternative of building a life-size aeroplane to try out different sizes and shapes of wings operating under different conditions of speed, wind, and air density, to mention only a few of the facts which have to be studied.

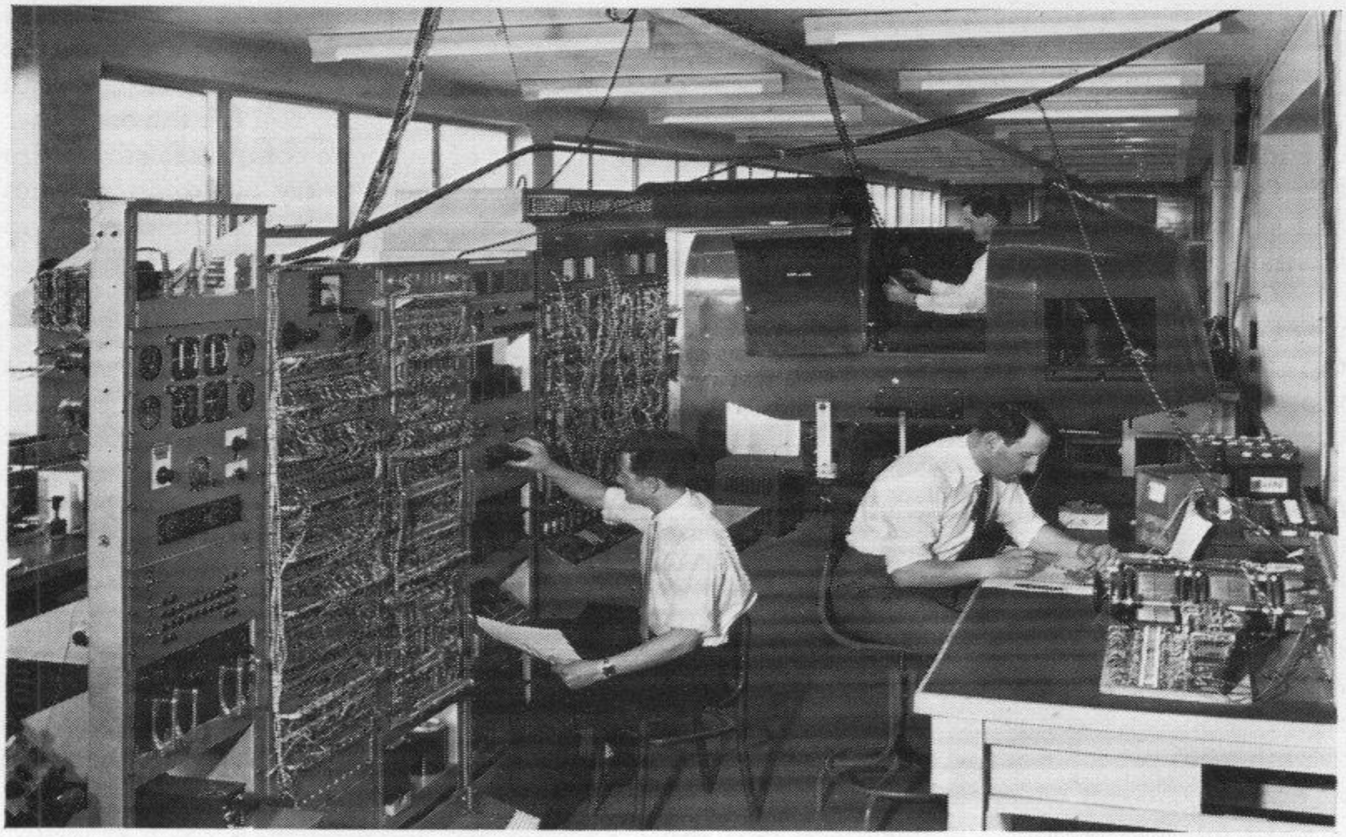
One interesting application where analogue computers are now widely used is the setting up of a model of a Nuclear Power Station. The analogue computer can be set up to represent the atomic pile, or reactor as it is called, which produces the heat; also the computer simulates the effect of the coolant, and the properties of the heat exchange and steam raising plant, eventually finishing up with a model of the turbine which turns the generators. In this case the effect of one of the variables of a complicated system can be studied by simply making a change in the value of that variable on which interest is centred. It also has the advantage that the designer and the plant engineer get to know what is described as the ' feel of the plant '—that is changing a certain variable might make the other parts of the plant change at a much more rapid rate. In some circumstances this could become highly dangerous, and it is therefore desirable that the plant engineer when starting up must know in what steps he can begin to operate the plant to get maximum output with safety. The reactor simulator with the complicated connections just described would enable a plant operator to study the warming-up procedure, thereby understanding the effects of the various controls on the plant as a whole without endangering either himself or the valuable plant.

In another application the flight of guided missiles can be predicted. Certain properties of their shapes have to be related to their flight, and when these have been evaluated by wind tunnel tests the answers can be applied to the computer in mathematical terms. These are then set up on the computer, the machine is switched on and an artificial stimulus representing, say, forward speed, or roll angle is set into it. The resulting flight of the missile appears in the form of a curve drawn on a piece of paper which can be studied, enabling the engineers to decide how to change the design in order to obtain an improved flight performance.

Analogue computers can be used for training engineers to control complicated machinery in almost any form. They can also be used to train pilots for their skilled job. For training aircraft pilots, we set up an analogue computer to simulate the behaviour of an aircraft; the pilot is seated in a replica cabin, seeing in front of him only the flying instruments. The cabin is then moved in accordance with the way he operates the controls, and by this method his flying capabilities and reactions to emergencies can be judged without anything or anybody leaving the ground—in fact, without using an aeroplane at all.

It may interest you to know that analogue computers can vary in size from the small general purpose machine that you could put on a table, costing about £1,500, to the very complicated special purpose machine costing three-quarters of a million pounds and needing a three-storey building to house it.

I am sure you will agree that analogue computers are very versatile tools which can be used to assist engineers in the design of the complicated equipment necessary to build and to



Elliott Brothers (London) Ltd.

An analogue computer (left) producing 'flight conditions' which are presented to the pilot in the cockpit

operate nuclear power plants and fast flying aeroplanes, and other modern plants, as well as making it easier to train people to handle these complicated things. They are great time-savers and are tools which under modern conditions will eventually replace a large number of operations which at present can only be done rather inadequately by large numbers of people.

The analogue computer is, in many ways, complementary to the digital computer. It is probably in the fields of control that I have mentioned that the greatest advances are possible, by integrating the two forms of computer in a combined and co-ordinated system.

JOBS FOR COMPUTERS

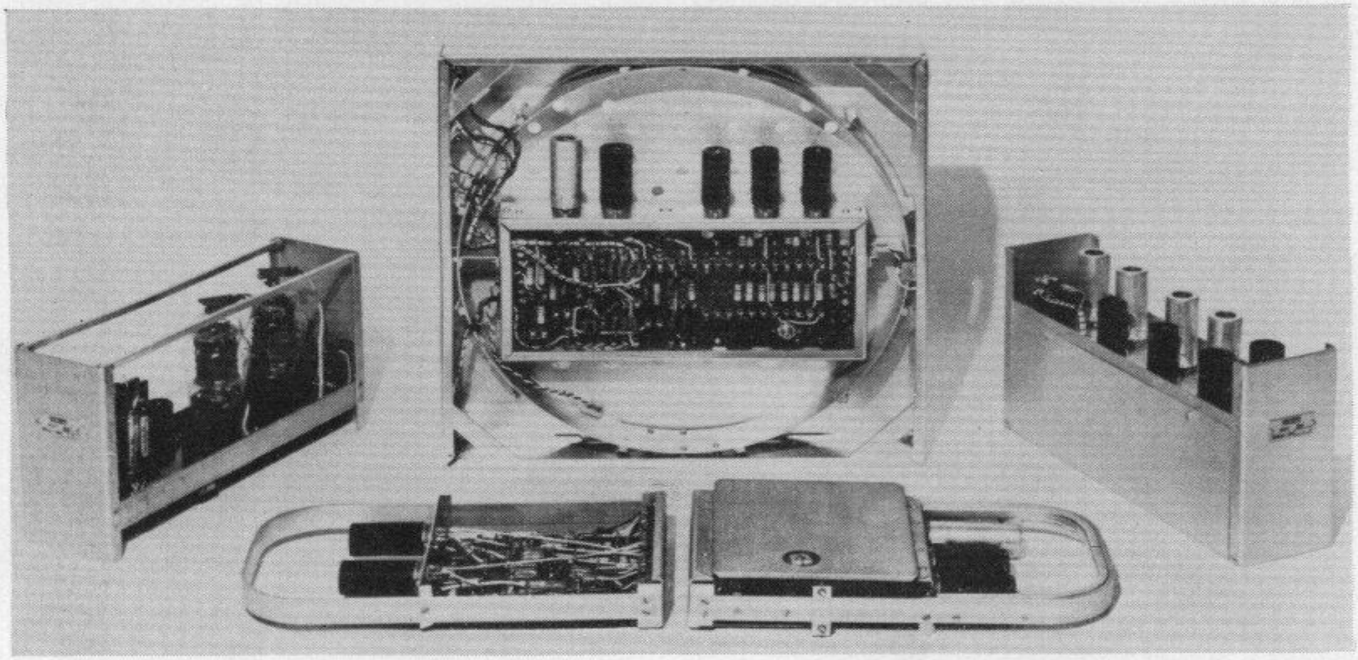
I am now going to say something about the different kinds of digital computers in use today and the sort of jobs which they are doing to increase safety, efficiency, and productivity.

There are two main types of digital computer, one a ' general purpose ' machine and the other a ' special purpose ' one. A general purpose digital computer is one that can carry out any calculation or logical operation which can be broken down into systematic steps.

A special purpose computer is sometimes designed with a fixed program built into it, so that the job can be done with the greatest possible efficiency. The whole operation is con-

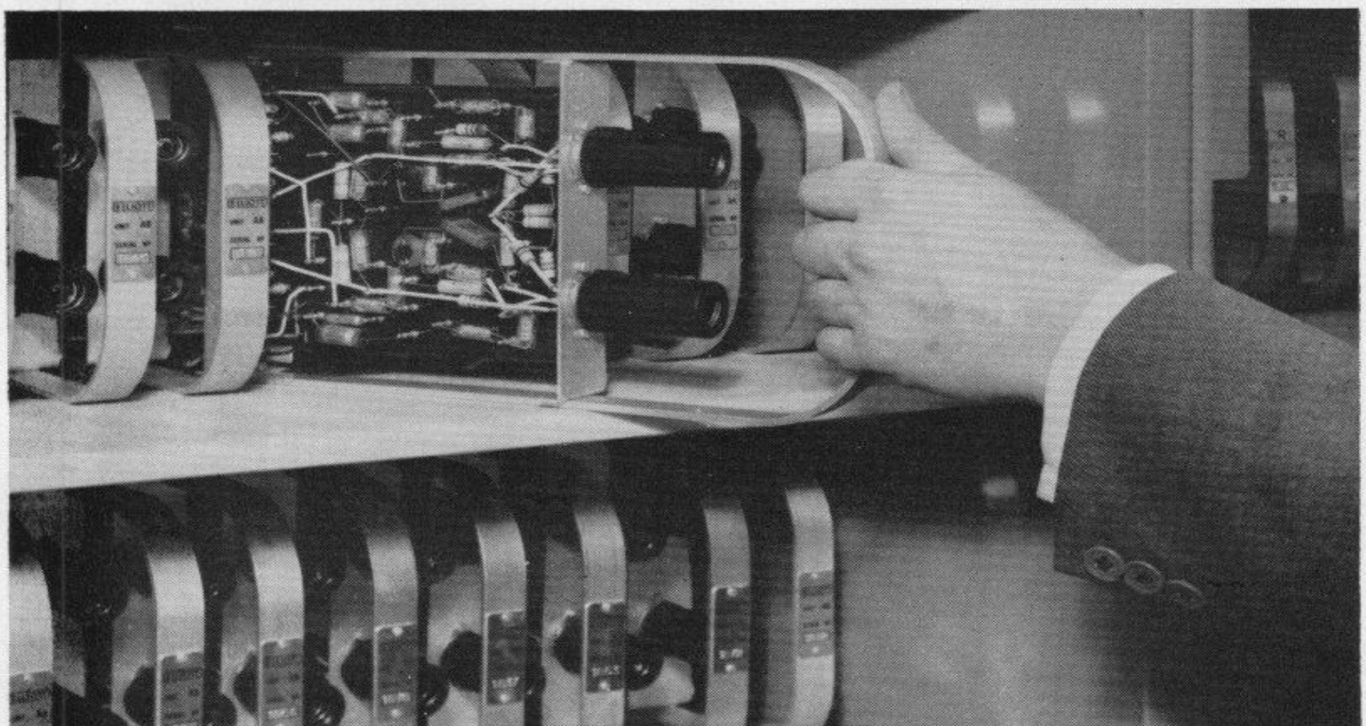
Associated Automation Ltd.

One of the many applications for computers is in the field of Production and Stock Control.



Elliott Brothers (London) Ltd.

Different types of plug-in units. (Rear) *Power stabilizing unit, 16-word nickel delay line, amplifying unit;* (foreground) *logical unit, 1-word nickel delay line*



Elliott Brothers (London) Ltd.

Close up of a computer cabinet showing removable plug-in unit trolled by fixed wired connections, no provision having to be made for a memory to store different programs since the machine will be fully employed doing the one job.

Different computers are more suitable for either scientific calculation or commercial purposes or industrial applications. Early uses of digital computers were on military problems and from this has developed the present-day large volume of scientific calculations which have even greater civilian uses such as the new techniques we call operational research. For instance, if you want to build an airfield or a trunk road much work can be done by digital computers to work out which route a runway or road should take in order to involve the smallest quantity of earth being moved. Another case is in the aircraft industry.

We can avoid making costly prototypes of aircraft by carrying out calculations on a computer on the flutter of wing structures and other stress problems, thereby saving testing in actual flight with the possible loss of both the pilot and the aircraft. As modern air travel increases, one application which is affecting all of us more and more is the use of computers to keep track of all the aircraft which are flying towards a certain airport and keeping them on steady courses, separated from one another, in order to avoid collision and to ensure that the arrivals and departures from a busy airfield follow one another in smooth succession. Another aspect of the same problem is the direct control of aircraft through their automatic pilots and associated equipment enabling landings to take place when weather conditions and visibility are very bad.

Other computers are playing an important part in advancing scientific knowledge in nucleonics and in research leading to new synthetic materials such as nylon, terylene, and polythene.

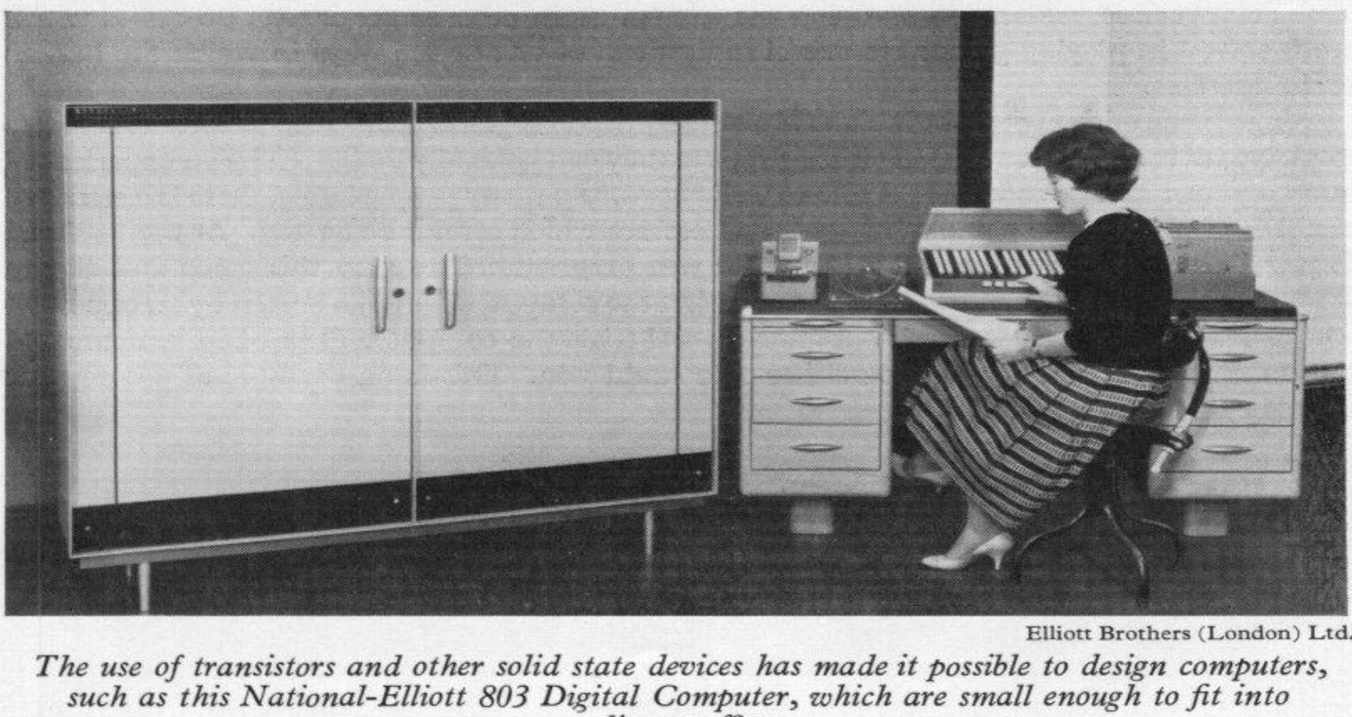
Computers are also employed to delve into the unexplored realms of mathematical theory and into the way in which human and animal brains actually operate. For instance, much time has been spent in investigating the theory of games played against a human opponent by computers.

This work is valuable in studying the human brain because the logical processes which are involved in playing games are useful indications of one of the ways in which the human brain operates.

The game of draughts or checkers has already been programmed. This enables computers to play with some degree of skill although so far they can generally be beaten by an experienced human player able to consider the moves well ahead. As many people know, there is a standard method of playing the game of noughts and crosses which cannot be beaten. At the National Physical Laboratory in England a computer was programmed to play this game and also to store, or remember, the games it played. At first the computer could be beaten by an opponent who used the standard method, but after several trials the computer found and remembered the unbeatable rules after which neither side could win. This is an example of a computer learning from experience.

Panellit Ltd.

Computers are being increasingly used to perform actual control functions in industrial processes. Computers, as part of complete information systems, are being installed in such places as Chemical Plants, Oil Refineries and Power Stations in many parts of the world.



Elliott Brothers (London) Ltd.

The use of transistors and other solid state devices has made it possible to design computers, such as this National-Elliott 803 Digital Computer, which are small enough to fit into ordinary offices.

PREDICTION BY COMPUTERS

Closely allied to purely mathematical calculations are those which deal with the gathering and analysis of statistics. During the last General Election in Great Britain the BBC used a computer called ELLA to analyse the results continuously as they came in from the constituencies.

Ella held in its memory all the results of the previous election. The incoming results were given to Ella who automatically compared them with the old ones and printed the changes. The results were also stored under various categories such as Urban, Rural, London, and the commentators could call for the up-to-date figures in any of these categories. An illuminated scoreboard showing the state of the parties was kept continuously up to date by the computer. The final result of the General Election was forecast with a high degree of accuracy after only a few results were in.

Similarly, the surveys carried out by market research companies or polls can be rapidly analysed on a computer. Such surveys are used very widely to assess public opinion and to determine the value of different forms of advertisement whether they be posters displayed by the roadside or television flashes.

Companies which are going to market a new toothpaste, for example, may decide on which flavour to use by testing public opinion. The results would be analysed on a computer and would show the flavours most popular for different age groups, parts of the country, and for men or women.

COMPUTERS IN INDUSTRY

In industry, apart from the calculation and preparation of payrolls and the close control of inventory, there is a large amount of data to be processed in the ordering of raw materials and components, and the planning in detail of the storage, manufacturing, and distribution processes. It is in this planning field where perhaps most is to be gained through what is called Linear Programming, which is the task of finding the best way of either distributing or obtaining goods to meet the need which one knows is present or which one can predict.

Let me quote an application of Linear Programming in the petroleum industry. Here, the raw material is the crude oil shipped to the refineries. From this crude oil can be made, by a chemical process called ' cracking ', not only petrols of different qualities appropriate for aeroplanes, or motor-cars, or motor-scooters, but the materials used in the manufacture of nylon or terylene. Crude oil from different wells has different properties, and the refineries vary in their abilities to turn the crude oil into the different products; of course the demand for different petrols and other products also varies from time to time. The computer determines the best division of the crude oil between the various refineries and within each refinery the best way of using the various plants to satisfy the demand.

I have mentioned special purpose computers which can be typified by a Sales Analyser which has recently been made in Britain. The printed rolls which are produced by cash registers in stores scattered all over the country can be removed and fed into a computer at headquarters: these transfer the printed characters directly into the special purpose computer.

British Broadcasting Corporation

Ella, in the background, prints the first results on Election night

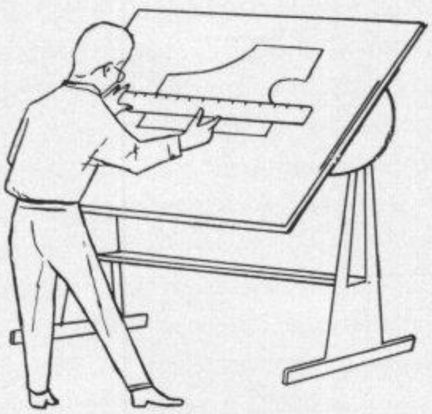
Two of the characters printed on the roll denote which assistant made the sale and what type of goods were sold. The cost of the item is then added up within the Analyser under different classifications such as the assistant's number, the cash register's number, the number of the section of the store, the number of the branch, and the type of goods. This system produces the facts in an orderly manner with a speed to enable management to decide what action is necessary to achieve greater efficiency.

The application of process control divides broadly into two classes. One, that of continuous processes where there is a flow of liquid or a gas, or electricity, and the other, where individual and separate items are manufactured. In a chemical plant or oil refinery, continuous control must be kept on the many variables. This normally involves continuously scanning many instruments which record the flow, the temperature, and the pressure. These can be checked by the computer against previously determined limits, outside which it is dangerous or uneconomical for the plant to stray. The computer will raise an alarm when this happens and control can be exerted to put the plant right. Furthermore, at frequent intervals the machine will log or make a printed record of all the values recorded by these instruments, in order that we may learn more about what is actually happening within the plant from minute to minute.

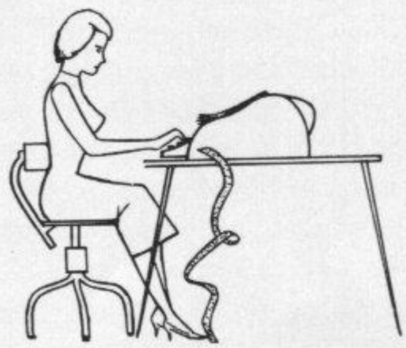
MACHINE TOOL CONTROL

Machine tools or machines for working in metal are very good for turning out parts of a comparatively simple nature but when you want to make complicated shapes, such as turbine blades in jet engines, manual control is difficult, if not impossible. However, the movements of a machine can now be controlled by a special purpose computer in accordance with instructions worked out by a general purpose computer and recorded on tape.

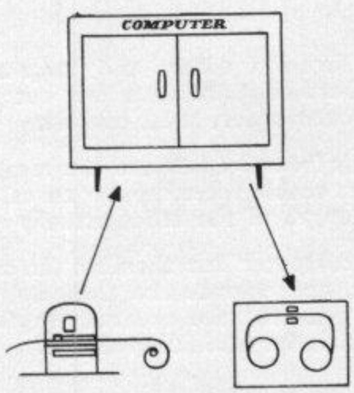
The computer controlled machine tool produces extremely accurate work; the wear on the tool which takes place during the milling or grinding process would ordinarily lead to inaccuracies but the versatility of the computer automatically modifies its programme to adjust the machine tool movements to the inaccuracies. (Fig. 13).



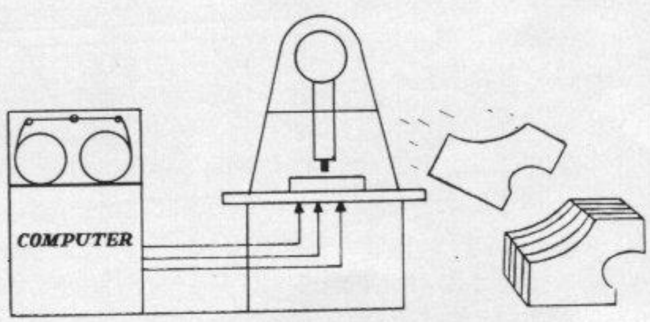
a The draughtsman takes dimensions from the part drawing



b The punch girl transfers the dimensions to paper tape



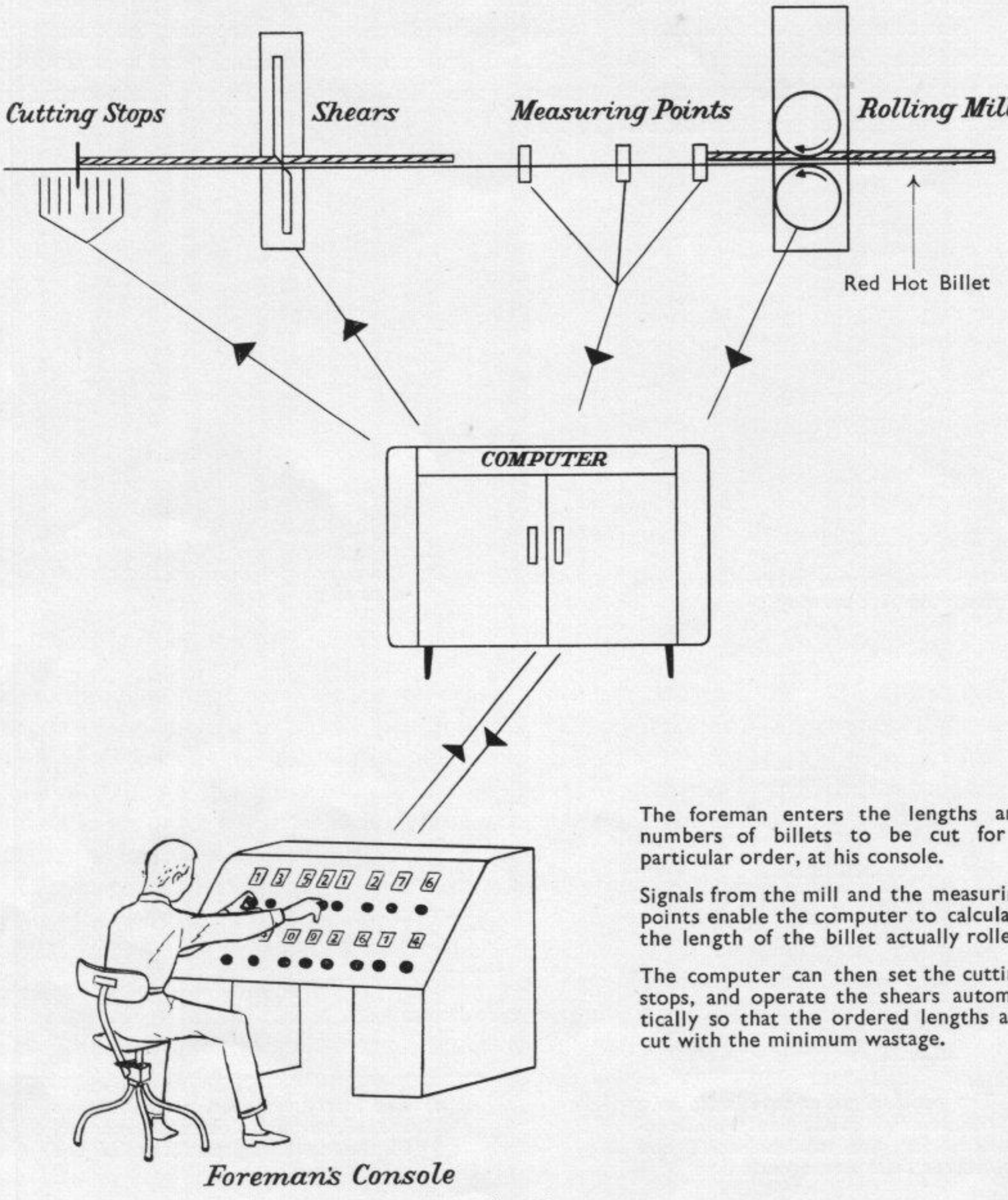
c The punched paper tape is fed to a computer which calculates the instructions for the machine tool, and records them on magnetic tape



d The instructions on magnetic tape are fed, through a control computer, to the operating platforms of the machine tool

Fig. 13

One of the most revolutionary applications of this kind is control of a machine or a process in a steel mill. The problem here is to take the red hot billets of steel as they emerge from the mill all in varying lengths and to cut them into the lengths ordered by the mill's customers, so as to avoid costly wastage. Only a computer in direct control of the cutting operation can select instantaneously the most suitable length to cut a particular billet, so as to ensure the absolute minimum of wastage. (Fig. 14).



The foreman enters the lengths and numbers of billets to be cut for a particular order, at his console.

Signals from the mill and the measuring points enable the computer to calculate the length of the billet actually rolled.

The computer can then set the cutting stops, and operate the shears automatically so that the ordered lengths are cut with the minimum wastage.

Fig. 14

THE FUTURE

Let me point out that, broadly speaking, computers in their present stage of development are only about ten years old. Already there are many different kinds of machines working on many different kinds of jobs.

If all this has taken place in so short a time, what are the prospects for these machines in the future? My belief is that they will change and improve our way of life much more than will any other technical developments, even the application of atomic energy.

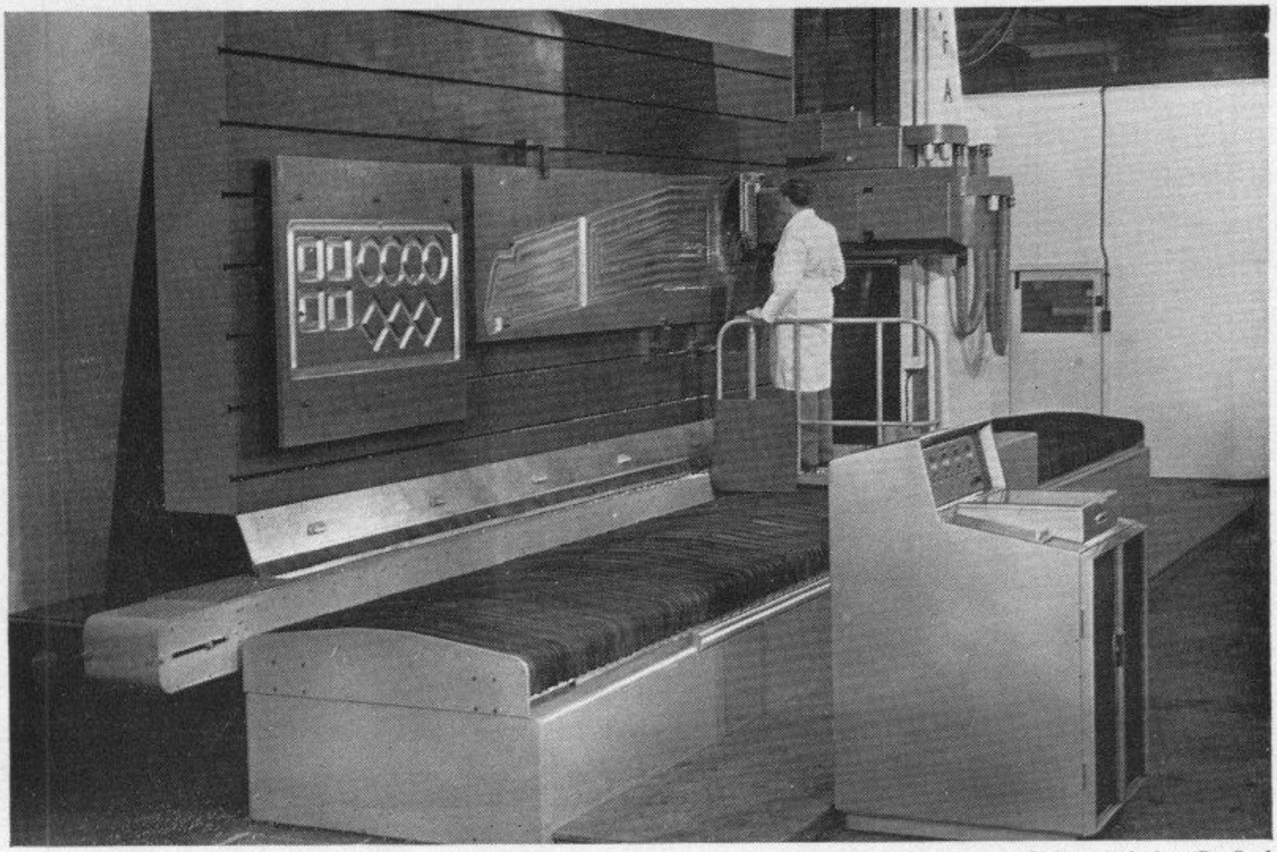
There are two aspects to the future of computers; one is in the improvements and advances in the machines themselves, which will become better, faster, smaller; and secondly—and I think many times more important—the ever widening application in the use of these machines. First, what about the machines themselves. As you have learnt, speed is one of their most important attributes. Using existing transistors, machines will be made soon to add up two ten-figure numbers in less than half a millionth of a second. Fast though present-day computers are, this is something like two hundred times faster. To express this fantastic speed, a new word has had to be coined—a milli-microsecond. This is one-thousandth of a millionth of a second. To try to give a better idea of what is implied by this very small interval of time, let me say that, in a milli-microsecond, light would only travel about one foot.

Almost any physical phenomenon you care to think of has been invoked to improve speed, reliability, cheapness, size, and so on. For example, superconductivity is an effect which takes place at extremely low temperatures, in fact, within a few degrees of absolute zero, or the lowest temperature point possible. At these temperatures certain metals offer literally no resistance to the passage of an electric current, and the transition from this state to one of having a resistance may be effected either by raising the temperature or applying a suitable magnetic field. Devices using this effect are known as cryogenic elements. Much work is going on in laboratories to make both memory cells and logical elements of such units, but because these units will operate only at extremely low temperatures in a bath of liquid helium, the experiments are not easily made. However, the chances are that when the experiments are successfully completed it will be possible to make the computer itself of minute size with speeds measured in milli-microseconds. Is this the ultimate in speed? To answer this, let us look at the parametron and the paramagnetic amplifier.

The parametron, invented by von Neumann, is a logical element, and the paramagnetic amplifier is a device using an effect in the crystal structure of a semi-conductor such as germanium or silicon. A parametron using radar techniques with paramagnetic amplifiers will result in at least a ten-fold increase in speed over the milli-microsecond I have already mentioned.

You may wonder whether it is necessary to make computers faster than the already very useful and revolutionary machines: in fact you cannot stop scientists seeking to enlarge our knowledge and to improve our technical achievements. Moreover, mankind is so ingenious that a useful application is found for most of the achievements of the research worker.

Thin metal films, deposited on glass rods, which can be magnetized are one of the lines being followed to produce large storage in a small space. Considerable work is being put into the development of this thin film technique. One can quite soberly think of reduction in size to a point where a computer is made the size of a packet of twenty cigarettes. This may be attained by using printed circuits, printed by electron microscopes. Space travel will demand a reduction in size of computers to be mounted in spaceships.



Fairey Aviation Co. Ltd

General view of machine with control console in foreground

Let us now turn from the construction of computers to their uses. Computers were first invented about ten years ago to deal with scientific calculations of a complex nature. Then about five years ago they were introduced into office accounting procedures. Because they can do any job that a man's brain can do, if the data is specific and the job to be done is systematic, it is in the control of automated systems that computers will find ever-increasing application in the coming years.

At present, scarcely more than accounting operations are being carried out on any scale; there has been little done in putting the real operations and processes of management on computers. A revolution in the accounting methods may occur which will hinge an entire company's activities around its electronic data processing system instead of the equipment simply reproducing existing methods.

The increased speed and economy in doing what is now done without a computer are important advantages in using a computing system, but I am now visualizing the introduction of new systems possible only because of the advent of computers. Saving of personnel is not the sole aim of such systems, but increases in overall efficiency such as the optimum use of the capital resources of a company and in particular, having information which enables the right decision to be made at the right time.

Completely automatic and more accurate weather forecasting is now theoretically possible, as of course is a flight to the moon, but the next few years should see much progress towards the satisfactory solution of weather prediction, although it may be that the use of earth satellites in a world-wide integrated network for cloud observation will be necessary before the ultimate in weather forecasting is reached. Plans of this magnitude will demand automatic control systems that will react with appropriate speed.

The advent of high-speed jet aircraft will soon force a situation in air traffic control that will make the introduction of automation in some form imperative. Already inside an aircraft the conventional autopilot is growing so that it looks after not only the normal flight control but also the navigational and environmental safety of the aircraft. Data links between ground control and aircraft will tie the control system in the aircraft into the overall air traffic control network, integrating without human intervention the passage of every aircraft on major airlines from departure to arrival.

Also, the increase in road traffic congestion might require some form of automatic control on the roads. The wider integration of traffic control in towns is already being considered, and it should be possible to develop systems which minimize blockages due to accidents and unforeseen peaks of traffic concentration.

But it is in industry where the major advances will come in the next few years. This will be less obvious but it is already evident that these new techniques will have an outstanding effect on the economy of the whole world. For Britain this is particularly important. Britain is an exporting country with a large investment in existing plant. The replacement by new plant is not enough to deal with competition; automation techniques must be used and must now be introduced and added to existing plant to increase their efficiency. I have already mentioned an example of this: the automation equipment being fitted to existing steel mills to save many hundreds of thousands of pounds per year in scrap alone.

The blending of different materials to form a range of products is a common process, and installations are being made increasingly automatic. The combination of weighing techniques and data handling, for instance, linked with material handling, may make it possible to foresee in a very few years factories where the customers' orders are fed into the system with the raw material while the entire manufacturing process, controlled by the computers, would send orders for material to the suppliers, produce delivery notes and other documentation and control the whole manufacturing processes of the plant. Automation will control and organize the plant as an integrated whole rather than be concerned only with the mechanization of separate operations. This is particularly true in production plants like car factories where automation will still require personnel for machining, paint spraying, trimming, and fitting, but where the automatic equipment will direct the timing and the organization of the different possible jobs that the operator and machines may do.

In five years we should see many fully automated processes in operation, where, by the integration of customer orders and raw material supply, all major industries will achieve far greater efficiency, far greater utilization of floor space, reduction of stock holdings, and superior products than is conceivable today. This will give vast increases in the production of the material things which the inhabitants of the modern world need, at much lower costs and with much smaller human effort. As I said at the beginning, the computer is the key to an age of leisure coupled with plenty; the reduction of the burden of drudgery with a higher standard of living for all. I hope that the world will be wise enough to understand the nature of the times in which we live, and to order its future so that with our material gain we will achieve an increase in the total of human happiness on this small globe of ours.

REPRINTED from **"THE TIMES"**

ADVANCES IN MECHANIZATION IN THE OFFICE

SPEEDING UP WORK ON ACCOUNTS

The recording and analysis of business statistics, or data processing, as it is more generally known nowadays, has come to be regarded as an exercise, presumably of value, carried out by firms large enough to afford electronic equipment or well staffed enough to be able to spare a sufficiently large force to perform the lengthy operations needed.

The halo of mystery surrounding the installation of high priced electronic computing machinery has tended to obscure the advances made in mechanical calculating equipment, as well as in electro-mechanical devices which are priced in thousands or even hundreds of pounds instead of the hundreds of thousands which may have to be paid for the latest types of computer.

For two or three thousand pounds the smaller firm can now equip its accounting department with machinery with which it will be able not only to keep its books efficiently but also to extract selected information for automatic analysis. This type of equipment, essentially standard accounting machinery linked to a paper tape or card punch, has been in use in the United States for two or three years.

STILL NEW

In Britain, however, it is still new, having been applied by a handful of commercial and industrial companies only during the past year. Accounting machines fitted with punches, wired machines as they are called, have generally been thought of in association with the preparation of input tapes for computers, but it now appears that for every installation feeding directly into a computer there will be dozens of machines producing tape for processing at computer centres, for "translation" into punched cards or simply for storing information in a compact form which is much cheaper than microfilm. There must be a limit to the number of companies in Britain which need, if they can afford, electronic computers (although the size and cost of newer models are being progressively reduced). The wired machine, therefore, is a decisive advance in clerical mechanization.

Key-board-operated machines are used in the normal way to produce working documents such as stock record cards, ledger cards, payslips and invoices. The operator ignores the fact that there is a punch attached to her machine. Meanwhile, selected information is automatically captured from the keyboard operation and punched either into paper tape or cards (the latter being less flexible, and requiring more bulky machinery). Such information can be picked up from the original keyboard entries or from the mechanical registers in the machine which provide totals. The extracted data transferred to the tape or cards can then be processed automatically to give statistical or financial reports.

INTEGRATED SYSTEM

Two kinds of information are thus produced on an integrated system which calls for no manual transcription or document sorting after the original entries have been made—the visible records and working documents for immediate use and the statistical analysis for audit or higher management reports. This method is superior to the conventional punched card system, where all the information is punched into individual cards at the beginning, because it simultaneously creates a readable and proved document.

It therefore eliminates the time consuming tasks of keypunching and putting the cards through a verifier to check that the punching has been accurate. The new unit machines will be strong competitors of punched card systems. There is the added advantage that where a central office needs regular data for analysis from its branches the paper tape information can be immediately and automatically transmitted by teleprinter or Telex systems. One large bank is considering such an installation which will allow the head office to analyse centrally the accounts of all the branch banks regularly and rapidly.

A manufacturing company has been using wired machines for some months as a stock control system. Receipts and issues of all raw materials and parts are posted on stock record cards on two Class 31 machines of The National Cash Register Company, who have devised their integrated data processing method. Simultaneously, the machines calculate the new balances, using a tear-off warning slip incorporated to show when stocks are nearing re-ordering levels.

COLLECTED ON TAPE

When a receipt has been posted the stock card passes to an operator who calculates the new average price so that future issues can be valued correctly during posting. When issues from stock are recorded, information is automatically collected on tape which identifies the material by serial number and gives its quantity, value and a cost code, showing the process for which the material is going to be used.

All these tapes can then automatically be converted to punched cards which can be filed until the end of the month, when they are sorted by identity number and cost code to provide the costing department with prompt and accurate figures. By this means the firm can control stocks in three widely separated factories in London, Liverpool and Glasgow. The stock department is able to supply valuations for the monthly accounts punctually on the fourth working day of the following month. In the past, such regular provision of figures has never been possible by manual operation, nor even with conventional mechanical means. They also obtain more accurate cost data with far less trouble than previously.

An engineering company also uses the unit machine system for stock control but has extended it to keep track of each batch of components as it moves through the stages of manufacture. The progress chaser's job is made easier, but at the same time work-in-progress evaluations can be periodically passed to the senior management by simply transferring the day-to-day information to punched cards for analysis on an electronic calculator. The magnitude of this particular application may be grasped when it is learnt that the company's range of products demands the handling of about 30,000 different items.

DESIGN COMPLEXITIES

The separate mechanical elements in the wired machine system have been in use for some years. The simple step towards linking desk accounting machines, calculators, cash registers and even bus conductors' ticket issuing machines with tape punches presented many practical complexities, notably of design. With the larger machines, and with cash registers, these difficulties have been resolved. The National Cash Register Company have many such applications in hand.

Some trading companies developing more complicated data processing systems are looking beyond the use of punched paper tape, and experiments have been conducted with magnetic tape, and even with printed paper tape to be read by scanning devices like Solartron's E.R.A. (electronic reading automaton), but so far the wired machines lead the field in actual working installations.

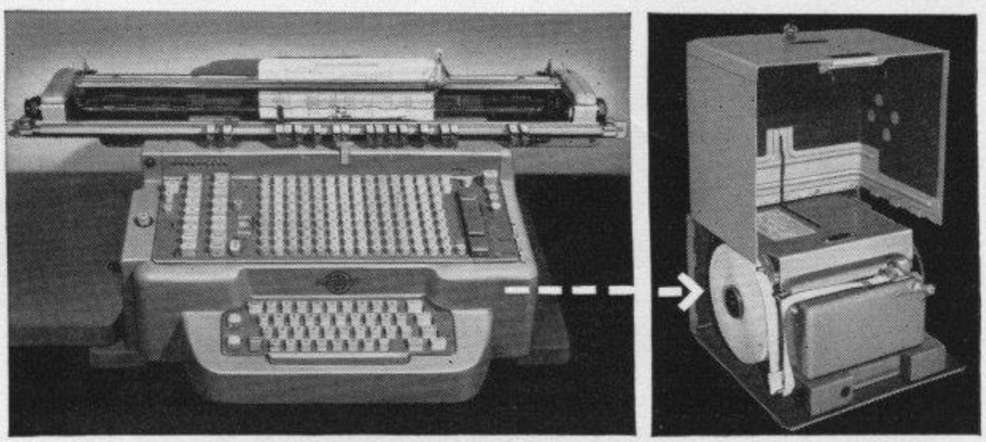
In the United States, where the wired machine made its *dèbut* about three years ago, several thousand installations now exist. The figures of machines actually sold, when set against the number of systems in operation, show that the single machine installation is the most popular. It may be deduced that the users include a fairly high proportion of small firms.

PATIENTS' ACCOUNTS

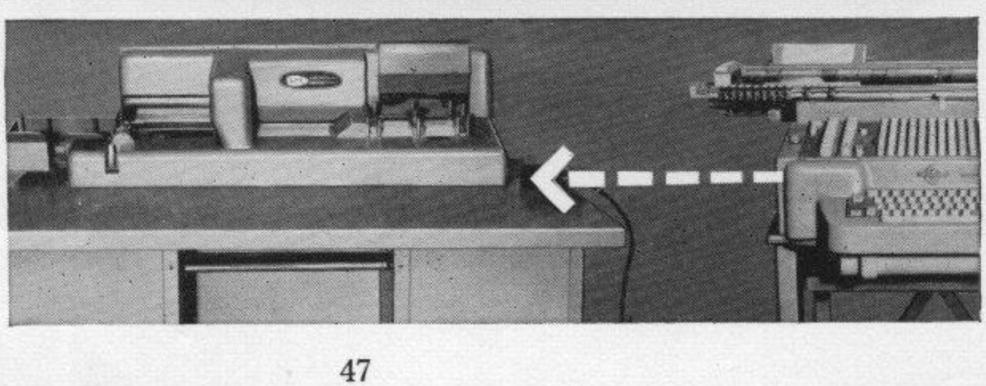
One such "firm" is in fact a physician who is using a book-keeping machine and tape punch to work out his patients' accounts. His receptionist posts the ledger cards on the machine, and the tapes she automatically punches are sent to a punched card service bureau which returns to the doctor a daily cash sheet analysis, itemized statements and any other data he requires for his accounts and for income tax returns.

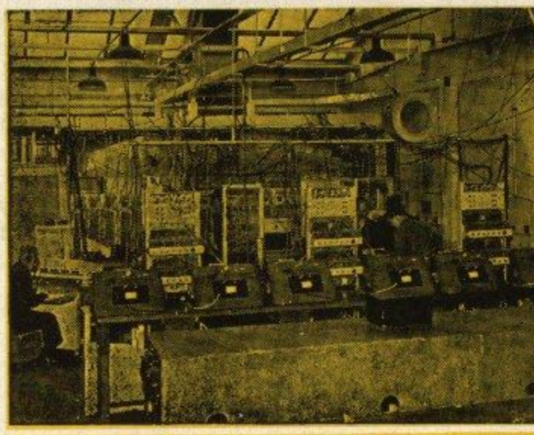
Other American users include publishers, loan companies, stores, manufacturers of all kinds, hospitals, film distributors, electrical power companies and construction engineers. With British manufacturing companies, insurance houses, transport operators, banks and even a newspaper putting in these machines or preparing to do so, such equipment may eventually be almost as common a sight in offices as dictating machines are today.

National Class 31 accounting machine with National Type 461/2 punched tape recorder



National Class 31 accounting machine with I.C.T. Type 029 card punch





Published by Elliott Automation Limited 34 Portland Place London W1
and printed in England by The Hollen Street Press Limited London W1