An Introduction to Digital Electronics—1

Signals, circuits and logic

One of the things which puzzles and confuses many people when they first come across digital circuits and systems is the many terms and ideas derived from fields apparently quite unrelated to electronics. In this introduction the author explains how it is that things like Boolean algebra, logic, number systems and computers have become an integral part of digital electronics.

by JAMIESON ROWE

In the broadest sense, electronics is concerned with physically manipulating an abstract quantity—information. This rather ingenious feat is done by using current or voltage changes to represent the information, often in encoded form. The current or voltage changes are given the general label of "signals".

There are essentially two quite different ways of representing information as electrical signals, to allow us to manipulate it. One way is to make an electrical current or voltage vary continuously, in a manner which directly copies the information itself. Because the current or voltage variations are effectively the electrical analogy of the original information, this technique is known as the "analog" approach.

Conventional radio and TV broadcasting both use the analog method, and so does sound recording. For example in a recording studio, a microphone is used to produce a very small varying current, which copies the sound pressure variations in the studio. This small signal is then amplified, to produce a larger varying current with substantially the same variations, and used to make a recording—say in the form of variations in the magnetisation of a roll of recording tape. Upon playback, a magnetic head generates a small electrical signal once more, and after amplification the electric signal is fed to a loudspeaker to recreate a very close approximation to the original sound information.

Although this analog approach works quite well, it is not without its problems. One major problem is that in order to handle analog signals faithfully, electrical circuits must behave in a very "linear" fashion—that is, their output should be directly proportional to their input. Perfect linearity is impossible to achieve, however, and as a result signals in analog form tend to become "distorted" as they progress through circuits.

Another problem is noise. All electrical circuits tend to generate small random current variations, known as noise. This inevitably tends to add to analog signals passing through the circuits, and because there is often no easy way of distinguishing noise variations from the "true" signal variations, the signals are effectively degraded.

The alternative approach used to represent information in electrical signal form avoids these problems. Instead of using the electrical signal as a direct analogy of the information, this method encodes the information and uses the electrical signal merely as a vehicle to convey the resulting code. The electrical current or voltage is not made to vary continuously, but is switched between a relatively small number of distinct levels.

Most frequently there are only two levels, one of which may correspond to no current (or no voltage). In other words, the two levels may be "current" and "no current", with the encoded information represented by various sequences of these two levels.

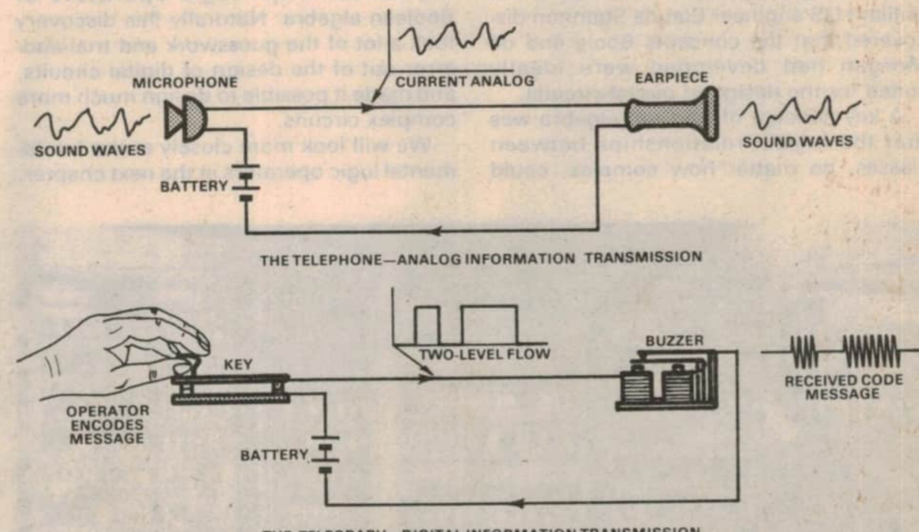
This method of representing and manipulating information in electrical form is known as the digital approach, mainly because the encoded information may often be visualised as a series of numerical digits.

The digital approach may seem less familiar than the analog method at first hand, but it has really been in use for a very long time. Most early signalling systems were digital; from the smoke signals of cave men, through fire towers and mechanical semaphore systems, to the early electrical telegraph systems based on Morse code.

In fact the electrical telephone and telegraph are very simple examples which illustrate the difference between the analog and digital methods. In the telephone, the information is transmitted from one end to the other via a current which varies continuously as a direct equivalent of the sound waves striking the microphone—the analog approach. In the telegraph, the information is encoded and sent as a sequence of current/no current pulses, illustrating the digital approach.

In comparison with the analog approach, the digital method of representing and manipulating information tends to be less demanding in terms of electrical circuit performance. It does not require circuits to be "linear", merely requiring that they switch between two or more fixed and well-defined states—often simply "on" and "off", or "high" and "low". This means that distortion tends to be less of a problem.

Similarly because the levels used tend to be quite distinct, noise also tends to be less of a problem. For example with a digital system using only two levels—say "on" and "off"—any noise introduced into the system has to become very large indeed before it is capable of degrading the wanted information. In fact it has to



A simple illustration of the two ways of manipulating information electronically—the analog method and the digital method.

become large enough to make the "on" level capable of being mistaken for "off", and vice-versa.

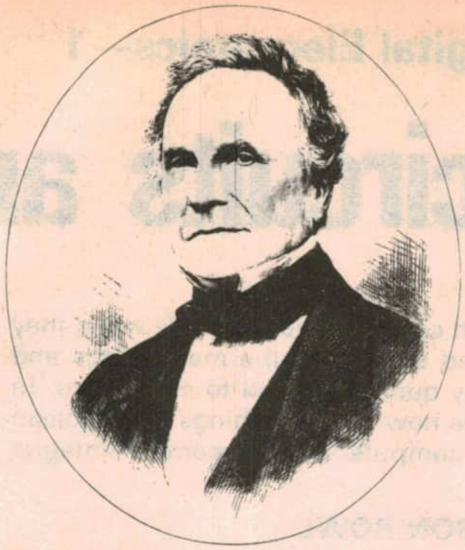
Because of these advantages, digital techniques have become very widely used in electronics, and they are likely to become even more common in the future. It is already true to say that the digital approach has been used to advantage in almost every field of electronics—even in sound and television recording and broadcasting, which have been traditional analog strongholds.

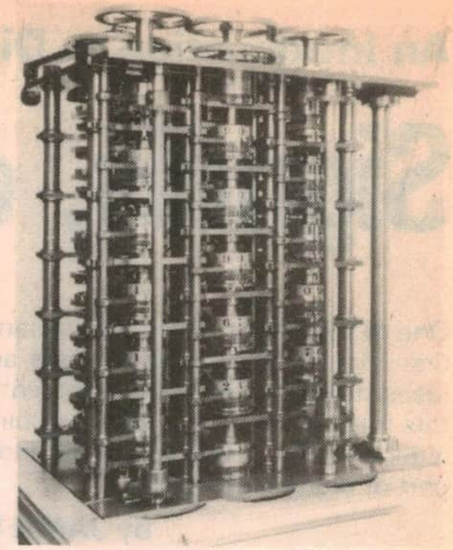
An understanding of the basic principles involved in digital electronics is therefore going to be very necessary for anyone aiming to be involved with electronics in the future. Our aim here will be to provide you with this understanding.

Historically, the techniques of digital electronics grew from electrical telegraphy and from early work on switching and control circuits. Along the way, the people who developed the techniques found it worthwhile to borrow ideas and concepts from many other fields, some of which may seem at first sight to be quite unrelated to traditional electronics.

One of these fields was Boolean algebra, developed around 1850 by the logician George Boole as a way of representing and analysing the relationships between classes or sets of objects. The work of Boole and his contemporary Augustus de Morgan was regarded as rather abstract and theoretical at the time, but when digital electronics was starting to appear in the 1930's, the brilliant US engineer Claude Shannon discovered that the concepts Boole and de Morgan had developed were ideally suited for the design of digital circuits.

A key concept of Boolean algebra was that the logical relationships between classes, no matter how complex, could always be broken down into combinations of a relatively small number of basic or fundamental relationships. These "logical operators" were thus seen as the building blocks of all complex logical relationships.



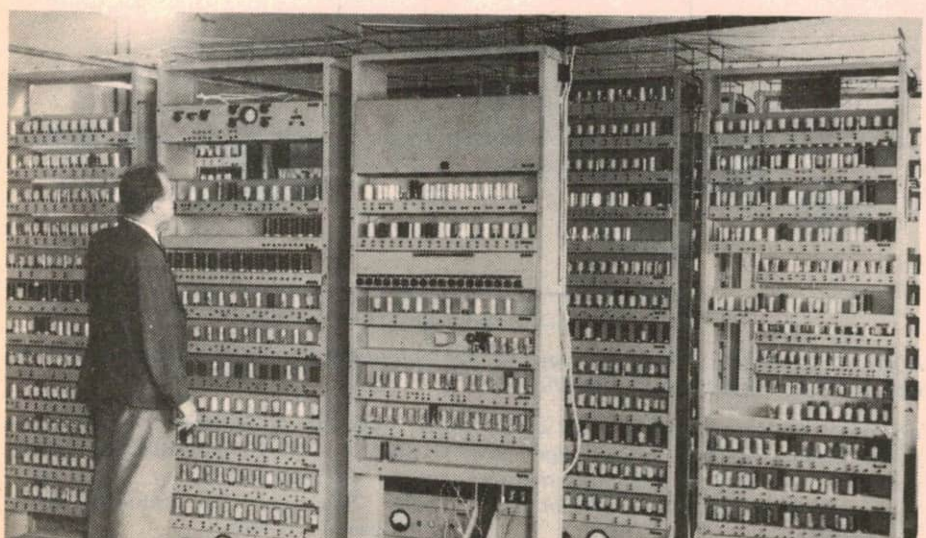


Charles Babbage, gifted mathematician of the early 19th century, and his "analytical engine"—an early mechanical digital computer.

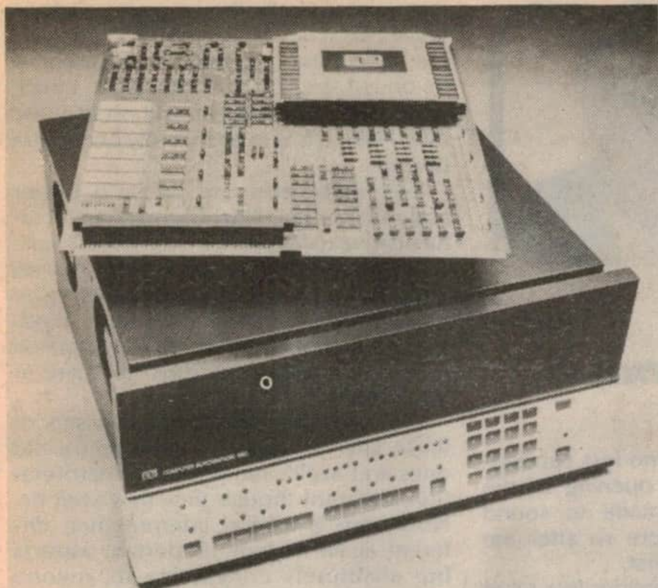
Shannon discovered that the same concepts also applied to digital circuit design. If a circuit was required to perform a relatively complex function, it could be built up efficiently and elegantly using circuit "building blocks", based directly upon the fundamental logic operators of Boolean algebra. Naturally this discovery took a lot of the guesswork and trial-and-error out of the design of digital circuits, and made it possible to design much more complex circuits.

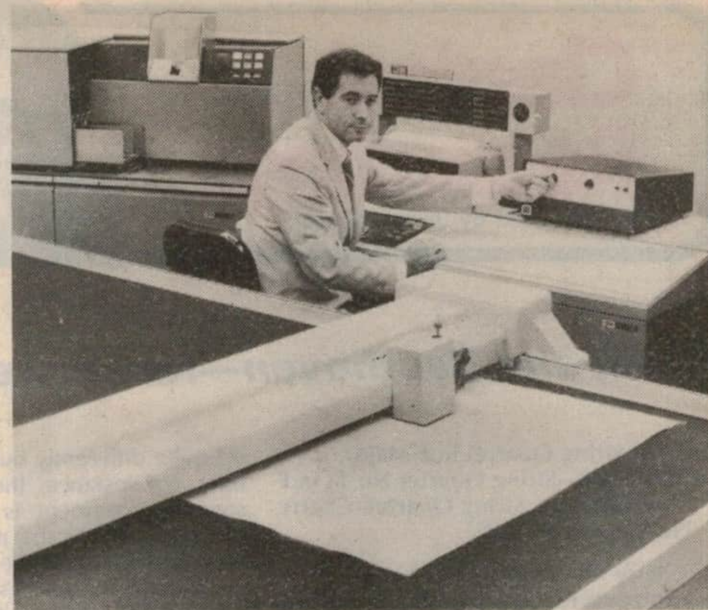
We will look more closely at the fundamental logic operators in the next chapter, as they are important enough to deserve a full discussion on their own. But perhaps you can see already why the concepts of logic start cropping up as soon as you look into books and articles on digital electronics. And also the reason why digital circuits are often alternatively called "logic" circuits.

Another field whose ideas became incorporated into digital electronics was the branch of mathematics concerned with numerical notation and number systems. In particular it was found that a number system ideally suited for use in digital circuits was "binary" notation, based on powers of two. This had been discovered early in the 17th century, by either Sir Francis Bacon or the Scottish mathematician John Napier (inventor of logarithms).



EDSAC, one of the first electronic digital computers, built at Cambridge University in 1949. The shot at right shows Dr. M. V. Wilkes, leader of the team which produced the machine. It used more than 3000 thermionic valves. The name "EDSAC" stood for electronic delay storage automatic calculator.





Just a few of the many applications of digital electronics. At upper left is a minicomputer on a single PC board, both "naked" and in a case (Computer Automation); at upper right, a computerised drafting table (IBM, Gerber); at left, a programmable pocket calculator (Hewlett-Packard); above centre, an electronic clock (Digeec); above right, a digital multimeter (Non-Linear Systems).

Unlike the familiar decimal system based on powers of ten, the binary system requires only two different digit symbols—0 and 1. Numbers are represented by combinations of the two, using positional order to indicate the various powers of two. It is therefore very easy for numbers in binary form to be represented by the two current or voltage levels of most digital circuitry. Thus "no current" may be used to represent 0 and "current" to represent 1, or vice-versa.

Binary notation and binary arithmetic are in fact used very widely in digital circuits, and will be discussed in some detail in later chapters.

Another activity which not only influenced, but virtually became intertwined with digital electronics was the development of calculating and computing machines. Men had long dreamed of having machines to free them from the drudgery of repetitive and lengthy calculations, and as early as 1650 crude machines were developed.

Among the more notable were Blaise Pascal's adding machine, Gottfried von Leibnitz's four-function calculator, and Charles Babbage's "difference" and "analytical" engines.

But it was only in the 1930's and forties that really practical computing and calculating machines were developed, using some of the ideas of digital electronics, and in turn helping to expand the concepts of digital electronics in new directions. In 1944 a team led by Dr Howard Aitken at Harvard University produced a relay calculator, while two years later John Mauchly and J. Presper Eckert of the University of Pennsylvania produced "ENIAC", the first wired-program digital computer. In 1949 the first true stored-program general purpose digital computers appeared, developed almost simultaneously at Cambridge University, Manchester University and Princeton Institute of Advanced Study.

Since that time, of course, digital computers have developed in leaps and bounds, and digital electronics has developed largely in parallel with them. Further discussion of computers will also be given in later chapters.

Yet another seemingly unrelated activity from which digital electronics borrowed ideas was weaving. In 1801 the weaving loom maker Joseph Jacquard developed a method of "programming" a loom to automatically weave complex patterns, using cards in which holes were punched. The cards were strung together and fed through the loom in sequence, with sensing needles setting the loom threads according to the "instruction code" formed by the holes.

The idea became used very widely in the weaving industry, but it was not until 1889 that the US statistician Dr Herman Hollerith hit upon the idea of using punched cards to store information for calculating and manipulation. Subsequently, punched cards and punched paper tape played a very important role in the practical development of computers, telegraphy and digital control of machinery.

These and many other concepts from all sorts of other fields have gone together to produce the widely-embracing activity now known as digital electronics. And as you are probably already aware, the resulting techniques have application not only in the more dramatic fields of computers and automation, but also in areas like communication, broadcasting, sound and vision recording, electronic musical instruments and synthesisers, banking, cash terminals, medical instrumentation, games of skill and chance, printing, measurement and timekeeping. Many of these applications will be discussed in more detail as we progress through the subject.