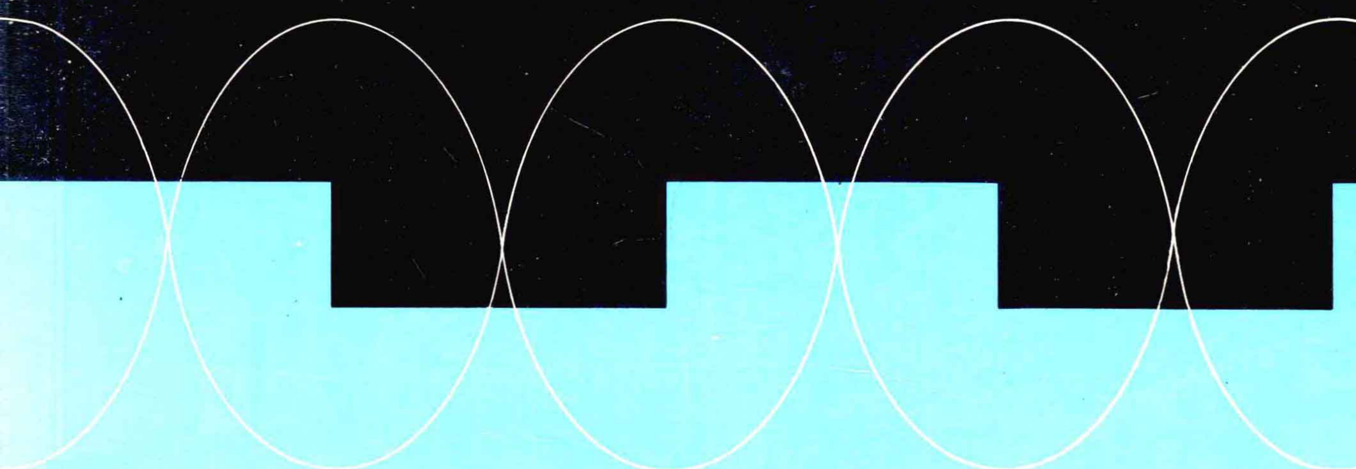
Digital Techniques and Systems

D C Green



PITMAN

Digital Techniques and Systems

D C Green

M Tech, C Eng, MIERE
Senior Lecturer in Telecommunication Engineering
Willesden College of Technology

Pitman

PITMAN EDUCATION LIMITED
39 Parker Street, London WC2B 5PB

Associated Companies
Pitman Publishing New Zealand Ltd, Wellington
Pitman Publishing Pty Ltd, Melbourne

First published in Great Britain 1980

Printed and bound in Great Britain
at The Pitman Press, Bath

ISBN 0 273 01356 4

Digital Techniques and Systems

Preface

This book provides a fairly comprehensive coverage of the basic techniques used in modern digital circuitry and of the elementary principles of data communication. The treatment is such that the book constitutes a suitable first course in the subject for technicians.

The Technician Education Council (TEC) scheme for the education of electronic and telecommunication technicians introduces the student to the concepts of digital circuits and data transmission at the third level in two separate half-units. This book has been written to provide a complete coverage of the Digital Techniques III and Transmission Systems III half-units.

Chapter 1 provides a basic introduction to some of the many and varied uses of digital techniques in modern technology and is intended to give the newcomer to the field some idea of the many possibilities associated with the use of modern digital circuitry. Chapters 2 and 3 cover the subject of electronic gates of all kinds; Chapter 2 discusses the various kinds of gate, e.g. AND and OR, and some of the ways that they can be interconnected to perform various logical functions. Chapter 3 introduces the various logic families with particular emphasis being placed upon t.t.l. and c.m.o.s. logic. The next three chapters deal with, respectively, flip-flops, counters, and ferrite core stores.

The remainder of the book is concerned with the transmission of data over telephone lines. Chapter 7 discusses the elementary principles of d.c. pulse transmission over lines and goes on to consider why modems are generally used for the majority of data links. Chapter 8 deals with the various forms of modulation that are used with data systems and then Chapter 9 introduces the reader to some typical data circuits. Lastly, Chapter 10 considers pulse code modulation which is increasingly used in modern telecommunication networks.

The book has been written on the assumption that the reader will possess a knowledge of electronics and telecommunication transmission techniques equivalent to that reached by the TEC level II units, Electronics II and Transmission Systems II. The reader is also assumed to have studied, or be concurrently studying, the level III unit, Electronics III, since a knowledge of integrated circuits is throughout taken for granted.

Acknowledgement is due to the Technician Education

Council for their permission to use the content of their units which are printed at the end of this book. The Council reserve the right to amend the content of their units at any time.

Some worked examples are provided in the text to illustrate the principles that have been discussed and each chapter concludes with a number of short exercises and longer exercises. A number of these exercises have been taken from past City and Guilds examination papers and grateful acknowledgement of permission to do so is made to the Institute. Answers to the numerical problems will be found at the end of the book; these answers are the sole responsibility of the author and are not necessarily endorsed by the Institute. Finally, a number of multiple choice questions are provided at the end of the book.

D. C. G.

The following abbreviations for other titles in this series are used in the text:

TSII: Transmission Systems II
RSII: Radio Systems II
RSIII: Radio Systems III
EII: Electronics II
EIII: Electronics III

Contents

1 Digital Systems **1**
The digital computer and the microprocessor 2
Digital equipment and systems 4
Telephone transmission systems 5

2 Electronic Gates **7**
The AND gate 7
The OR gate 8
The NOT gate 11
The NAND gate 11
The NOR gate 12
The exclusive-OR gate 13
The coincidence gate 13
The use of NAND/NOR gates to generate AND/OR functions 13
The Karnaugh map 16
Designing a circuit from a truth table 18
Further applications of logic gates 22
Exercises 24

3 Practical Electronic Gates **27**
Requirements of a logic gate 27
Diode-transistor logic 32
Resistor-transistor logic 33
Transistor-transistor logic 34
C.M.O.S. logic 41
Interfacing T.T.L. and C.M.O.S. 43
Emitter-coupled logic 43
Comparison between integrated logic families 44
Exercises 45

4 Bistable Multivibrators **47**
The S-R bistable 47
The J-K flip-flop 51
The D flip-flop 51
The T flip-flop 52
Master-slave and edge-triggered flip-flops 53
Exercises 56

5 Counters **58**
Non-synchronous counters 58
Clocks 67
Synchronous counters 69

Up-down counters 72
Exercises 73

6 Stores **76**
Types of store 76
The shift register 77
The ferrite core store 80
Exercises 84

7 Data Communication and the Transmission of Pulses over Lines **85**
Types of system 85
Single-current and double-current working 87
The arrival curve 90
The frequencies contained in a data waveform 91
Transmission lines 93
The effect of line attenuation and group delay on transmitted pulses 100
The use of modems and amplifiers 101
The use of regenerators in digital systems 103
Exercises 103

8 Digital Modulation **106**
Modems 106
Frequency shift modulation 108
Phase modulation 111
Amplitude modulation 114
Exercises 120

9 Data Links **122**
The use of privately leased circuits and the p.s.t.n. 122
Two-wire and four-wire operation of leased data links 124
Multiplexers, front-end processors, and concentrators 126
Noise and interference 130
Error control 132
Typical data networks 133
Exercises 138

10 Pulse Code Modulation **140**
Pulse amplitude modulation 140
Pulse code modulation 142
Non-linear quantization 148
The bandwidth of a pulse code modulated system 148
Time division multiplex 150
Use of pulse regenerators 152
The transmission of data signals over p.c.m. links 154
Exercises 155

Appendix 1 The T.T.L. Family 157
Appendix 2 The C.M.O.S. Family 159
Appendix 3 Binary Arithmetic 160
Appendix 4 Multiple Choice Questions 166
Learning Objectives (TEC) 172
Answers to Exercises 179
Index 180

1 Digital Systems

Most present-day electronic and telecommunication equipment is still analogue in nature. This means that the signals to be handled, processed or transmitted are represented by voltages whose amplitude and/or frequency vary continuously with time; thus, in a telephone system, the transmitted signals are replicas of the speech waveforms. Many examples of analogue equipment are well known; for example, the radio and television receivers to be found in the majority of homes.

Digital signals are not continuous in nature but consist of discrete pulses of voltage or current which represent the information to be processed. Digital voltages can vary only in discrete steps; normally only two voltage levels are used—one of which is zero—so that two-state devices can be employed. A two-state device is one which has only two stable states; so that it is either ON or it is OFF. Examples of two-state devices are: a lamp which is either glowing visibly or it is not; a buzzer which is either producing an audible sound or not; or an electrical switch which either completes an electrical circuit or breaks it. Further examples of two-state devices that are used extensively in electronic circuitry are the semiconductor diode and the transistor—bipolar and field effect [EII and EIII].

The advantages to be gained from the use of digital techniques instead of analogue methods arise largely from the use of just the two voltage levels. Digital circuitry, mainly integrated in modern systems, operates by switching transistors ON and OFF and does not need to produce or to detect precise values of voltage and/or current at particular points in an equipment or system. Because of this it is easier and cheaper to mass-produce digital circuitry. Also, the binary nature of the signals makes it much easier to consistently obtain a required operating performance from a large number of circuits. Digital circuits are generally more reliable than analogue circuits because faults will not often occur through variations in performance caused by changing values of components, misaligned coils, and so on. Again, the effects of noise and interference are very much reduced in a digital system since the digital pulses can always be regenerated and made like new whenever their waveshape is becoming distorted to the point where errors are likely. This is not possible in an analogue system where the effect of unwanted noise and interference signals is to permanently degrade the signal.

There are two main reasons why the application of digital techniques to both electronics and telecommunications has been fairly limited in scope until recent years. First, digital circuitry was, in the main, not economic until integrated circuits became freely available, and, secondly, the transmission of digital signals requires the provision of circuits with a very wide bandwidth. Some digital circuits and equipments have, of course, been available since pre-integrated circuit days but their scope and application were very limited.

The Digital Computer and the Microprocessor

Nowadays the digital computer is an integral part of the day-to-day operation of many firms and organizations, ranging from Government departments, commercial concerns such as banks and insurance companies, to industrial firms in all branches of engineering and science. Computers are employed for the calculation of wages and salaries, taxes, pensions, bills and accounts; for the storage of medical, scientific and engineering data; and for the rapid booking of aircraft seats, theatre tickets and foreign holidays. Computers are also used to carry out complex scientific and engineering calculations, to control engineering processes in factories, to control the operation of telephone exchanges and military equipment and weapons, to control the distribution networks for gas, water and electricity, and for many other purposes.

A digital computer is able to store large quantities of data in its memory which can be made available as and when required. The task to be performed by the computer is detailed to the computer by means of a set of instructions known as the *programme*. The programme is fed into the computer and stored in another part of its memory.

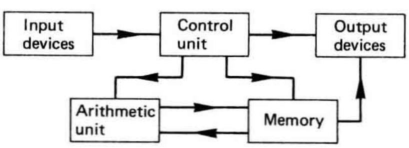


Fig. 1.1 Digital computer

The basic block diagram of a digital computer is shown in Fig. 1.1. The instructions contained in the programme are taken sequentially (one after the other) from the memory under the direction of the control unit. Each instruction causes the arithmetic unit to perform arithmetic and logic operations on the data, also taken from the memory. The results of the calculations can be stored in the memory or they can be held temporarily in a part of the arithmetic unit known as an accumulator. When a calculation has been completed, the control unit will transfer the results to an output device, which will (probably) produce the results in printed form; alternatively the results may be transmitted over a *data link* to a distant point where they are needed.

The input devices used to feed information into a computer are usually some kind of teleprinter, or a paper tape or card reader, or a magnetic tape reader. Binary information can be stored on a paper tape by punching holes in the tape; a hole in the paper tape represents binary 1 and the absence of a hole

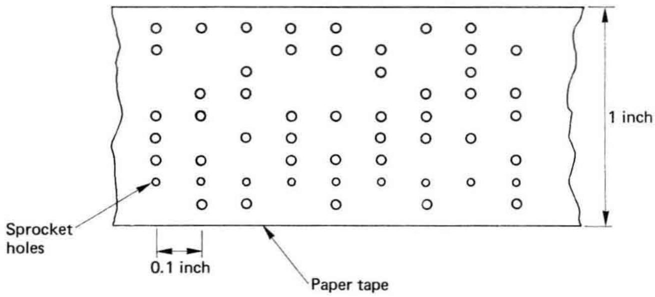


Fig. 1.2 Punched tape

indicates binary 0. The number of holes, and absences of holes, needed to represent a character depends upon the code that is used but Fig. 1.2 shows how a punched tape will look. The top binary digit or *bit* is a parity bit which is used to detect any errors that may exist. The remaining seven bits represent the character to be signalled to the computer. The smaller hole, labelled sprocket hole, that exists in every row is provided to engage the tape with the mechanism of the tape reader.

Teleprinters and other similar printing apparatus, and paper tape/card punchers, can be used as output devices but very much faster in operation are equipments known as line printers. Visual display units (VDUs) are also employed and these basically consist of a cathode ray tube upon the screen of which data can be displayed.

Minicomputers

A minicomputer has a smaller storage capability than a mainframe computer but the capacity provided is adequate for very many applications. A minicomputer is small enough physically to be brought into an office, often on a trolley, when it is needed, plugged into the electric mains supply, and then used. Minicomputers are also used as relatively inexpensive means of controlling industrial systems and processes.

Microprocessors

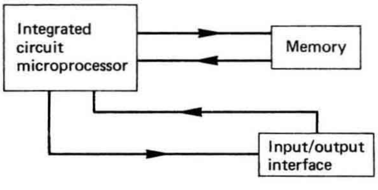


Fig. 1.3 Microprocessor

The term microprocessor is generally applied to a form of minicomputer that is able to control the operation of a wide variety of equipments. A microprocessor occupies very little space since much of its circuitry is contained within an integrated circuit. As a result, a microprocessor can be built into the equipment whose operation it is to control. Fig. 1.3 shows the basic block diagram of a microprocessor; the chip contains various registers, an arithmetic unit and control circuitry very similar to a main computer. Often the memory is also integrated.

As an example, microprocessor control of modern radio receivers and systems is increasingly used in the latest equipments. A microprocessor can be programmed to control the tuning, the gain and the selectivity of a receiver as the receiving conditions alter. Remote h.f. radio stations can be distantly controlled by means of a microprocessor; the functions controlled being the selection of the frequency to be transmitted and the frequency to be received as determined by a pre-set schedule. Also, the performance of the station can be monitored and any faults or degradation of service detected and recorded.

Digital Equipment and Systems

Hand-calculators are nowadays in common use and provide another example of the use of digital circuitry. All calculators are able to carry out the basic mathematical procedures while many are provided with several more advanced mathematical facilities. Some models are programmable. The circuitry contained within a calculator is complex and these devices have only become practical since the advent of integrated circuits.

Many cash registers and weighing scales used in the shops are electronic and these provide a readout in digital form of the total money to be paid and, once the money offered has been entered by the operator, of the change to be given, as well as a printout of the purchases. The cash register also keeps a record of the cash input and in some cases this is signalled to a central point where a complete record for the shop or department can be maintained. Often a microprocessor is also involved so that records are automatically kept of the items sold, and the stock left on the shelves and in the store. This enables the management to know at all times the stocks held of all items so that re-stocking can be carried out in ample time. It is possible to programme the microprocessor to order from the warehouse those items whose stocks are falling below an appointed figure.

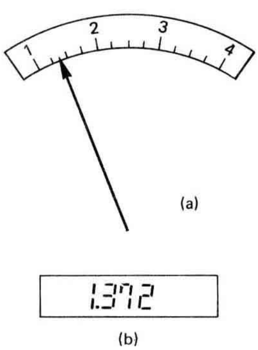


Fig. 1.4 Indication of measured quantity by (*a*) analogue, (*b*) digital method

In engineering, digital readouts of data are often more convenient and accurate than analogue readings. Digital voltmeters and frequency meters or counters are particularly suited to measurement applications where a large number of repetitive readings are to be made. The advantage of digital meters is most noticeable when relatively unskilled personnel are employed to carry out the tests. With a digital instrument the operator can read at a glance the value of the displayed parameter, but very often an analogue reading requires care if reasonable accuracy is to be obtained. This point is illustrated by Fig. 1.4. When the pointer (Fig. 1.4*a*) is in between two scale markings, some doubt exists as to the value indicated. No such doubt is present with the digital instrument; its indicated value (Fig. 1.4*b*) is easy to read.

Data-loggers are digital circuits that convert the analogue output from a transducer (a resistance strain gauge, a thermocouple, a potentiometer for example) into a digital form so that the measured parameter can be recorded on a paper tape or some other means.

Another application of computers and digital techniques that is gaining in importance in the modern world is in the field of transport. The movement of vehicles in a large transport system can be controlled and monitored by a computer. British Rail, for example, have introduced a computerized system for the optimised control of its freight traffic. Each truck has its movements continuously monitored and the computer works out and augments the best way of moving the trucks around the network in order to carry the maximum amount of freight in the most economic manner. In many large cities, computers control the traffic lights that direct the flow of traffic across road junctions. The computer continuously monitors the number of cars passing and waiting to pass the various junctions and varies the frequency of the traffic light operations to optimise the flow of traffic.

Telephone Transmission Systems

Telecommunication systems have traditionally been analogue in their nature, with the exception of Morse code telegraphy. Speech signals are transmitted over purely analogue circuits routed over a combination of physical pairs in telephone cables and frequency division multiplex channels over line and/or radio links. Digital transmission using *pulse code modulation* is increasingly used and much of the junction network in the United Kingdom now uses this technique. The future development of the trunk network of the U.K. is destined to use digital techniques and the Post Office have announced the introduction of SYSTEM X. System X is to be an integrated telephone network in which junction and trunk transmission, signalling and exchange switching are all to be achieved using digital methods under the control of digital computers. One advantage of digital working is that it can be used for all kinds of signal, be it speech, music, television, telegraphy or data. Other advantages are discussed in Chapter 10.

The distribution of the frequency-modulated v.h.f. sound broadcast signals and the audio signals of television broadcasts from studios to transmitters is carried out digitally using pulse code modulation. Teletext services are now transmitted by both the B.B.C. and the I.B.A.—using the names CEEFAX and ORACLE respectively—to provide information to the home. The data is transmitted digitally using some of the lines in each field of the television signal which are not modulated by the video signal. In the television receiver a digital decoder is provided to recover and display the incoming information on the television screen. A similar kind of information service, known as PRESTEL, is being introduced by the Post Office. The data is transmitted, again in digital form, over a telephone line to the home and, after decoding, is displayed by the television receiver.

Private mobile radio systems operating in the v.h.f. and the u.h.f. bands can also be controlled by a computer to ensure the optimum performance as the mobiles move around the service area. Such systems are used by organizations that employ a large number of mobiles, such as the Gas Board in the U.K.

2 Electronic Gates

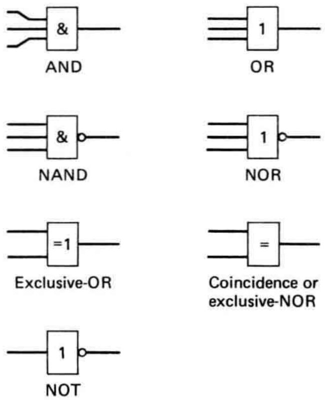


Fig. 2.1 Gate symbols

An electronic gate is a circuit that is able to operate on a number of input binary signals in order to perform a particular logical function. The logic gate is one of the basic building blocks from which many different kinds of logical system can be constructed. Electronic gates are readily available in integrated circuit form and the various logic families in common use will be discussed and their characteristics compared in the next chapter. In this chapter the emphasis will be on the various types of gates and the ways in which they can be interconnected to perform different logical functions. The types of gate to be considered are the AND, NOT, OR, NAND, NOR, exclusive-OR, and the exclusive-NOR or coincidence gate. The British Standard symbols for each of these gates are given in Fig. 2.1. Positive logic is assumed throughout this chapter; that is, logic 1 is represented by the more-positive voltage, and logic 0 by the less-positive voltage, of two possible values.

The AND Gate

The AND gate is a logic element having two or more input terminals and only one output terminal. The output logic state is 1 only when *all* of the inputs are at logic 1. If any one or more of the inputs is at logic 0, the output state will also be logical 0. Using Boolean algebra the output F of an AND gate with three inputs A, B, and C can be written down as

$$F = A\,B\,C \tag{2.1}$$

since in Boolean algebra the symbol for the AND logical function is the (omitted) dot (.).

The operation of any logical element can be described by means of a **truth table**; this is a table which shows the output state of the circuit for all the possible combinations of input states. The truth table of a 3-input AND gate is given by Table 2.1. It is clear from the table that the output is 1 only when A AND B AND C is 1.

Table 2.1 AND gate

A	0	1	0	0	1	1	0	1
B	0	0	1	0	1	0	1	1
C	0	0	0	1	0	1	1	1
F	0	0	0	0	0	0	0	1

The AND gate can be used to *enable* and *inhibit* a digital signal. Since the output of a 2-input AND gate will be 1 only if both its inputs A and B are 1, a control signal applied to, say, input A can control the passage of a signal applied to input B. When input A is at the logic 0 level, it will stop, or **inhibit**, the signal at B from passing through the gate. When input A is at logical 1, it will allow, or **enable**, the signal applied to B to pass to the output. Very often the control signal is a regularly

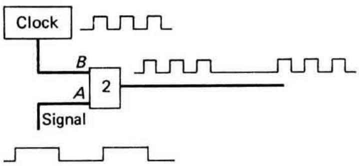


Fig. 2.2 Use of an AND gate to control the passage of a clock waveform

occurring pulse waveform derived from a circuit known as the *clock*. An example of this technique is shown in Fig. 2.2.

The output of an AND gate is always either logical 1 or 0 and cannot be at any in-between voltage. An **analogue gate** is one which acts as an electronic switch to allow an input analogue signal to pass when a control voltage is at logical 1 and to close the transmission path when the control voltage is at logical 0. Such a gate, used for example in the production of a pulse amplitude modulated signal, can be made with discrete components as shown by the circuit given in Fig. 2.3, or is available in integrated circuit form, e.g. the c.m.o.s. 4016. In the circuit of Fig. 2.3 the input analogue signal is only present at the inverting terminal of the operational amplifier [EIII] when transistor T_1 has been turned OFF by a clock pulse.

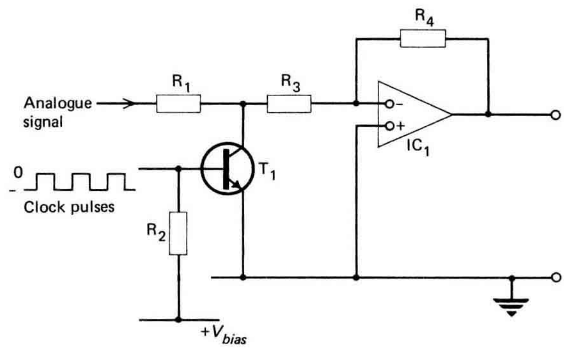


Fig. 2.3 An analogue gate

The OR Gate

An OR gate has two or more input terminals and a single output terminal which will be at logic 1 whenever any one or more of its input terminals is at logical 1. The Boolean expression for the output of a 3-input OR gate is given by equation (2.2), the OR function being represented by the symbol +.

$$F = A + B + C \tag{2.2}$$

The truth table of a 3-input OR gate is given by Table 2.2.

Table 2.2 OR gate

A	0	1	0	0	1	1	0	1
B	0	0	1	0	1	0	1	1
C	0	0	0	1	0	1	1	1
F	0	1	1	1	1	1	1	1

EXAMPLE 2.1

Write down the Boolean expression representing the circuit shown in Fig. 2.4. With the aid of a truth table determine the necessary input state for the output to be at logical 1. Deduce a simpler arrangement that will perform the same logical function.

Solution

$$F = (A\,B\,C)(A + B + C)$$