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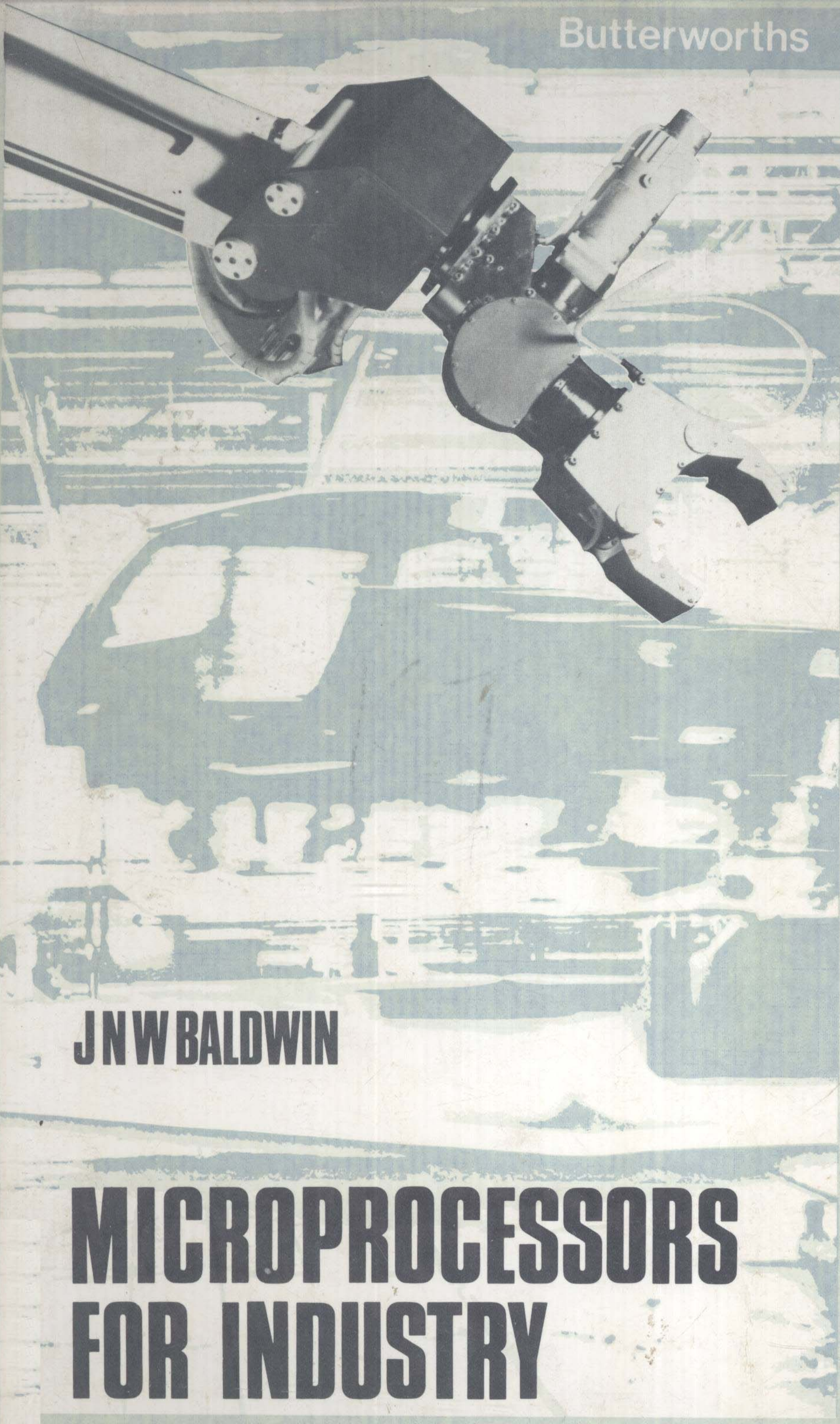

J N W BALDWIN

MICROPROCESSORS FOR INDUSTRY

Microprocessors for industry

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Butterworth Scientific
London Boston
Durban Singapore Sydney Toronto Wellington

First published 1982

British Library Cataloguing in Publication Data

Baldwin, J. N. W.
Microprocessors for industry.
1. Microprocessors 2. Industry – Data processing
I. Title
338′.06 HD2353

ISBN 0-408-00517-3

Photoset by Butterworths Litho Preparation Department
Printed in England by Hartnoll Print Ltd., Bodmin, Cornwall

Preface

Since the early 1950s, nuclear scientists and aeronautical engineers have pressed digital system designers to strive for ever greater speed and computing power. In the same way, large business corporations have been eager to purchase expensive computer systems to replace their manually kept records. Fifteen years later, the minicomputer appeared and was quickly installed in many academic and research centres ready to spend £25 000. But, £2500 in 1981 hardly compares with £25 000 in 1965 and it is this difference which underlines the need for this book. Many dozens of conversations with people holding senior positions in commerce, industry and education have revealed a shocking ignorance of even the most rudimentary knowledge of digital electronics. It is in the hope that readers will be encouraged to investigate the subject in relation to their own responsibilities that this book has been written.

This book is addressed to both the industrial and scientific user of automatic equipment in control and measurement. The aim is to provide a foundation of basic information to allow the reader to form a sound judgement on the use of digital electronics in his application. The reader will gain a rudimentary knowledge of the questions to ask and the words to use in order to make real decisions, in order to step over the last 20 years of developments in electronics, computer science and semiconductor physics and employ these powerful new tools.

The author acknowledges with gratitude:

(1) The generous help of Harry Bisby, who originally coined the palindromic acronym, in supplying the information for Chapter 10.
(2) The UK CAMAC Association for providing the illustrations for Chapter 10.
(3) Vacuumatic Ltd of Harwich for permission to publish information about their Vacuumatic Data System VDS microcomputer system.
(4) Wm Collins Ltd of Glasgow for permission to photograph the Vacuumatic Data System VDS installation.
(5) Arne for invaluable secretarial services.
(6) Mr L. Costrell of the US Department of Commerce National Bureau of Standards for permission to use Figure 1.
(7) Data Applications (UK) Ltd for permission to use Figure 12.
(8) Data Type Terminals Ltd for permission to use Figure 15.
(9) Facit Data Products Ltd for permission to use Figure 16.
(10) Integrated Computer Systems (ICS) for permission to use Figure 17.
(11) INCAA (UK) Ltd for all other illustrations.

JNWB

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1 The scene is set

Digital electronics is not a new or revolutionary subject. The techniques we are about to explore have a long history and have been tested and proved in such difficult environments as the surfaces of Mars and Venus, in steelmaking and in many schools and homes. There may be some doubt about the exact time and place where a digital system was first successfully operated, but without doubt related machinery was designed and in use during the 1930s, for such tasks as cryptoanalysis in British Military circles, meteorological research in Germany and ballistic research in the USA. However, the subject goes back well beyond that, as the father of digital computing is widely agreed to be Charles Babbage who worked in Cambridge between 1860 and 1879. He designed a mechanical calculating system and, although little was actually constructed, we owe much of our present terminology to Babbage's efforts. If we assume that digital electronic technology has been in use for over a quarter of a century, we shall have understated the case and should gain confidence from the knowledge that the subject has a respectable pedigree.

There is little difference in the concept between the microprocessor system of today and the digital computer of 1955, nevertheless the microprocessor has a number of important advantages. Instead of a roomful of electronics, several tonnes in weight, we have an *integrated circuit* holding many thousands of transistors, resistors and other circuit components on a small *silicon chip,* about 5 mm square; instead of a cost approaching £200 000 modern equipment is more likely to cost between £5000 and £10 000, and

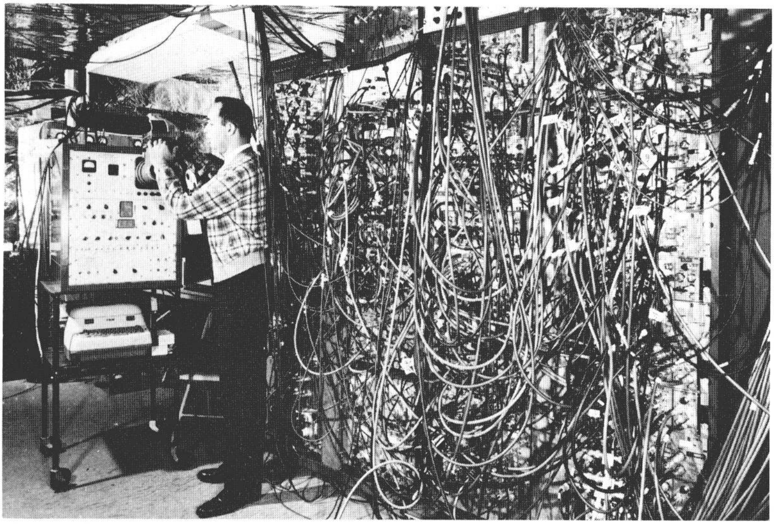

Figure 1. How it used to be: Instrument installation at Lawrence Berkeley Laboratory, c1963.

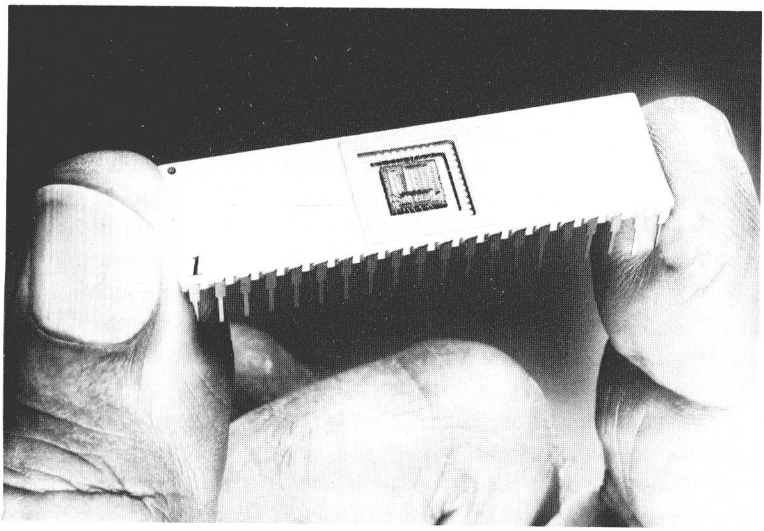

Figure 2. The Ferranti F100L is Europe's first – and so far only – microprocessor. It is ¼ inch square and 0.015 inch thick. It contains about 7000 components and about 6 ft of metallic interconnections. It operates on a mere 5 milliwatts and functions happily at any temperature between −55 and +125°C. (Courtesy Ferranti)

bear in mind that inflation means the difference in real cost is even greater than the apparent difference in cost. Instead of a team of engineers working a full eight hour day to provide five or six hours of operation, it now requires only a few minutes to diagnose and repair faults by simply changing a low cost printed circuit card. In many cases, today's digital electronic system will represent an insignificant percentage of the cost of the machinery under its control. Another great step forward during the past 25 years has been the reduction in power consumption. Until the mid 1960s a digital system would probably have required a special electric supply, not only because of the considerable amount of power required but because it was necessary to isolate the system from possible sources of interference. For example, the author can recall the regular failure of a system in 1956 at about 11 am each day. This problem was eventually traced to the canteen staff switching on the cooking equipment in order to prepare lunch. Corrective measures were costly and involved the provision of a special motor-generator set. Modern microelectronic power regulation components have done away with this sort of problem and most systems today require only an ordinary domestic style mains supply.

This book is for the reader who is considering the use of modern digital techniques for the control of, or the collection of data from, a machine, an industrial plant, or a scientific experiment. Variations on these themes are many but essentially similar in nature. If you consider for a moment, the control of traffic lights by means of vehicle detectors in the road you will be thinking of a suitable application of digital methods. In order to determine how best to use these methods it is worth looking first at some general ideas.

Flow charts

The key to the design of any digital computer process is the *flow chart* which graphically represents the process. Each step in the process is depicted as a block, and the blocks are connected together by *flow lines* which show how the steps are related. If a decision is to be made, the relevant block is conventionally diamond shape with alternative routes labelled and leading to the next operation (Figure 3). The uses of this technique are not confined to computers, it is equally applicable to the analysis of office organisation, manufacture and computer programming. By introducing time and quantities to the diagram, more complex

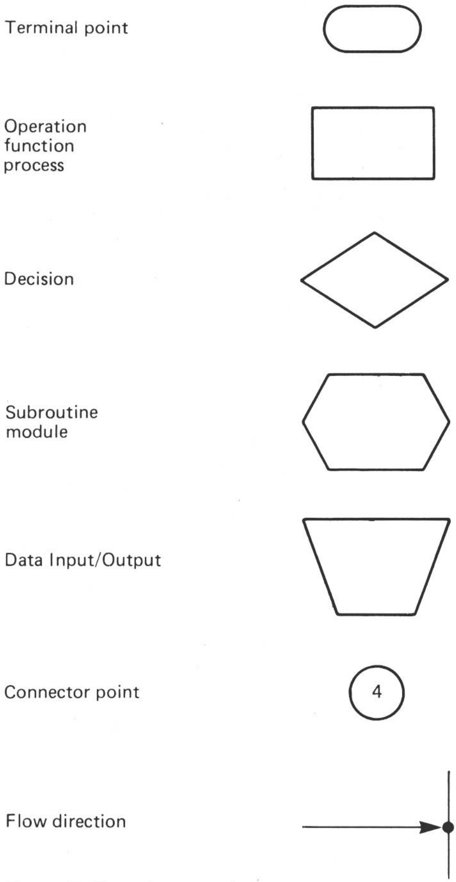

Figure 3. Flowchart symbols.

situations may become understandable as they are broken down into separate units or modules whose position on the chart represents, perhaps, their relationship in time as well as sequence. Possibly the modules on a flow chart may themselves merit individual treatment if the situation is very complex. As a first step, then, a flow chart should be produced for every problem as soon as its features or specifications have been defined.

Figure 4 shows, using a flow chart, the operation of a temperature control system. At certain points in the control process the

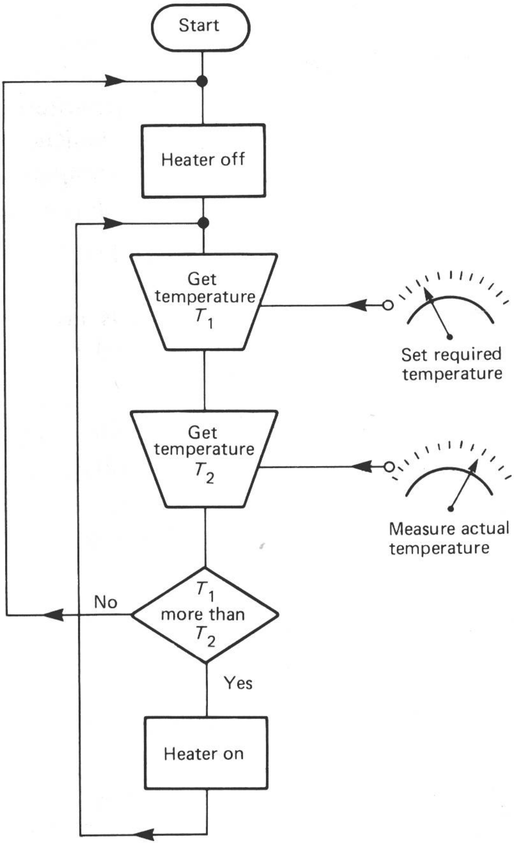

Figure 4. Flowchart of a temperature control system.

system must obtain information about existing temperatures, make decisions and choose between alternative actions and then take appropriate action. The flowchart clearly shows the order in which the various steps must be taken and the relationships between them.

Hardware and software

Once the problem and the flowchart have been specified the next stage is to determine the *hardware* requirements. This term is not difficult to understand; it refers to the objects which can be handled and seen i.e. the metal, plastic and wood components which together make up the system. In office terms, the hardware might include filing cabinets, paper trays, copiers and typewriters. On the production floor, the hardware will comprise benches, machines, tools, storage racks and waste bins. In a computer system, the equivalent items will be central computer, terminal printer and displays, memory units and interface to the plant and machinery to be controlled.

The other aspect of a computer system, *software*, is not so obvious. Software can be defined as all that is essential to the system that is not hardware. The term usually refers to computer programs, procedures and associated documentation. These lay down the exact procedure the computer is to follow in solving the problem and the computer *program* is a detailed, step-by-step list of instructions for the computer. Without this list of instructions, the computer can do nothing. It is a *rule-following idiot.*

An analogy worthy of consideration is musical. The orchestra, including it's instruments and musicians represents hardware and the written music and arrangements the software. The staves, notation and remarks represent the computer instructions and computing 'language'.

The idea of computers as lightning quick, rule-following idiots cannot be emphasised too much. A digital computer proceeds unhesitatingly from one task to the next, if it has not been particularly provided with instructions to beware of certain phenomena and the means of detecting them, it will ignore them unhesitatingly! Consider this unhesitating behaviour carefully: it is seldom met in human experience. Even the trained sportsman or soldier is capable of meeting the unexpected and changing their behaviour to suit the new conditions, and this calls for the ability to hesitate. While a computer system can be instructed to wait for a particular set of circumstances to arise or to change its response as stimuli alter, every step of these functions must be planned in advance. The totally unexpected will produce unpredictable response.

A serious trap for the unwary is the old saying among computer people: 'garbage in means garbage out', meaning that a bad program will produce bad results. Would that it were invariably true, but regretably it is not. All too often bad data or programming can produce results that are convincingly near those which are expected. Nothing is easier to accept than that which we were hoping to hear. A better axiom might be 'Garbage in, apparent truth out'. It is difficult to protect one's designs from this end and it must be constantly borne it mind. Also remember that while it is fact that electronic systems may respond in this way, they are not alone, as people can do the same.

Summary

(1) Digital electronics is not an untried method. There is over a quarter of a century of experience.
(2) Computer systems are unlikely to be cleverer than their designer. Get the intention and the specification right first.
(3) Write the specification in terms understood by all users.
(4) Break the process down into separate modules.
(5) Design a flowchart to describe the whole proces.
(6) The computer is a fool. You must point out each move and consider all possible errors.

2 The digital philosophy

In the middle ages the passage of time was very often measured using candle clocks. A candle was marked regularly down its length and, having been lit, it was inspected at intervals when the observer would note how the candle had burnt down and therefore how much time had passed. The technique could hardly have been very accurate as the user was constrained by two conflicting requirements: precision and the discrimination of small time intervals on the one hand and the continuous measurement of a reasonable length of time on the other. Mechanically this must have posed problems: for the measurement of small intervals of time a fast burning candle would have been of small diameter and therefore difficult to support if of any length. A large fat slow burning candle would not have indicated small intervals. Other devices in use at the time included water and sand clocks. Of these only the sand timer has continued in use to the present day, usually for the purpose of noting a fixed interval such as about four minutes for boiling an egg.

In these cases it is essential to understand that a visual measurement of a continuously variable quantity is made: a quantity of sand moves, a length of candle burns, some liquid is poured and the amount remaining can be seen. The user can make an estimate and form a judgement on the heights or levels observed. Exactly the same observations are made of the moving hands of a clock or needles of an instrument such as a voltmeter, speedometer or pressure gauge.

Look at your watch or the nearest clock. You will see immediately if it is digital. If it is *digital*, the hours, minutes and seconds etc will be displayed as discrete numbers, or digits. If it is not digital, it is an *analog* clock or watch. Distance and angles are displayed by means of continuously moving hands to represent the passage of time. It is possible that the increments of time are only partially marked and on many analog watchfaces few, if any, of the increments are labelled with the hour values as this has been found unnecessary. As soon as children have acquired the skill of reading the time from a moving hand display, the labels become superfluous as the relative angles are sufficient and tell all we need to know at a swift glance. Like the candle clock, many other familiar instruments are analog and tell their tale swiftly and efficiently: vehicle speedometer and fuel gauges, radio or television tuning dials, weighing machines of various types and recording level indicators. Many more will probably come to mind.

Tried and trusted analog

For a brief period about fifty years ago, the motor industry tried digital speed indicators in cars, but their popularity did not last as they simply do not perform that sort of task efficiently. Similarly, the present fashion for digital watches will probably be short lived, their benefits are mainly for the manufacture rather than the user. On the other hand, analog measuring systems run into difficulty when it is required to display a large quantity in small, defined increments. A watch with more than three hands would become a nuisance and so the date is normally displayed in digital incremental form: the days of the week on a seven segment revolving disc viewed through a window, the month and the date similarly. Another well-known tool, the slide rule, illustrates some of the limitations of analog devices.

For perhaps 400 years the slide rule has been the most important tool for performing complex calculations and like the moving hand watch, is an analog system. Indeed the slide rule is an analog computer using distance as an analogy of number. A slide rule with scales marked linearly as on a ruler or an engineers rule would be capable only of addition and subtraction, a logarithmically marked scale permits multiplication and division, scales marked proportionally to other functions such as trigonometric, engineering, astronomic or any you can think of, will provide calculation facilities to match any need. Precision of calculation is only limited by precision in marking the scales and ability to read them. If the technique were to be extended by the use of a larger instrument or by optical aids in reading it then problems such as variation in length due to temperature would have to be considered. Any analog technique always has such limitations and analog methods are not confined to slide rules as discussed at the beginning of this chapter.

For a period of perhaps forty or more years, electrical analog computers have provided sterling service to research and industry. In this technique, variations in electrical signals are used to perform calculation; voltages and currents measured are analogies of other physical quantities such as weight, pressure, length or temperature. Electrical networks are set up representing mathematical relationships and the electrical signals are treated by them and then measured. A great advantage of the technique was speed of response giving the user the opportunity to study dynamic phenomena and observe instantaneous values by means of normal electrical instrumentation. Provided the user was realistic in his appraisal of the results and had sufficient knowledge of the electrical equipment and components he was using to keep his feet firmly on the ground in making allowances for errors, analog computing was a powerful tool. The precision of the results obtained could never be better than the stability of the electrical supplies and components used. With the exception of very special equipment, slide rule precision of about 0.5% or 1 part in 200 could be reliably provided without difficulty.

Other techniques can be used to give analog computing facilities. I experimented with a water computer for financial simulation in the late 1950s, different coloured liquids were pumped to and from suitably engraved vessels at various speeds. In the event of poor forecasting, one could observe one's assets going down the drain to the accompaniment of dramatic gurgling sounds.