TROUBLESHOOTING ON MICROPROCESSOR BASED SYSTEMS

G B WILLIAMS

West Glamorgan Institute of Higher Education, UK

THE PERGAMON MATERIALS ENGINEERING PRACTICE SERIES

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This book is dedicated
to the memory of my mother
Mrs Margaret Eileen Williams

Materials Engineering Practice

FOREWORD

The title of this new series of books "Materials Engineering Practice" is well chosen since it brings to our attention that in an era where science, technology and engineering condition our material standards of living, the effectiveness of practical skills in translating concepts and designs from the imagination or drawing board to commercial reality, is the ultimate test by which an industrial economy succeeds.

The economic wealth of this country is based principally upon the transformation and manipulation of *materials* through *engineering practice*. Every material, metals and their alloys and the vast range of ceramics and polymers has characteristics which requires specialist knowledge to get the best out of them in practice, and this series is intended to offer a distillation of the best practices based on increasing understanding of the subtleties of material properties and behaviour and on improving experience internationally. Thus the series covers or will cover such diverse areas of practical interest as surface treatments, joining methods, process practices, inspection techniques and many other features concerned with materials engineering.

It is to be hoped that the reader will use this book as the base on which to develop his own excellence and perhaps his own practices as a result of his experience and that these personal developments will find their way into later editions for future readers. In past years it may well have been true that if a man made a better mousetrap the world would beat a path to his door. Today however to make a better mousetrap requires more direct communication between those who know how to make the better mousetrap and those who wish to know. Hopefully this series will make its contribution towards improving these exchanges.

MONTY FINNISTON

Preface

The microprocessor revolution has now spanned over a decade in time; during that period the devices used have developed from rudimentary computing elements to complex, multifunction sub-systems on a single integrated circuit. The explosive growth of microelectronics has been both dramatic and traumatic. Many devices which emerged during this period were rejected by the market place, while others gained wide acceptance and have become standards for industry. We are now at a stage where fifth generation microcomputing systems are nearing fruition and promise computer architectures very different from the classic scheme envisaged by John Von Neumann.

As with all other rapidly developing technologies, industry has been slow to adopt microelectronics on a wide scale. The reasons for this are many and varied; industry tends to show a natural conservatism to change, particularly when existing equipment does not need replacing and functions perfectly well using older technologies. The rapid development by a large number of manufacturers of sets of devices which perform similar functions leads to the problem of which set to adopt. Engineers and technicians within industry have to learn a system which requires considerable investment of both time and money. All these factors contribute to a time lag of two to three years between a product being developed and it finding some acceptance.

In direct contradiction to this conservative approach by the established industries, new companies have been set up with the specific intention of exploiting the new technology. The growth in the home computing market is a prime example of a market developed as an outlet for microelectronics. The device manufacturers are extending into the construction of complete computing systems as a means of increasing the sales of their products.

The structure of a computing system presents unique problems when it fails to operate correctly and requires testing. Unfortunately the development of suitable test equipment has seriously lagged behind the growth of microelectronic devices. Early versions of test equipment were based on conventional instruments, modified to accept and present information from microprocessor based systems.

The information displayed was difficult to interpret and the instruments were difficult to set up. Improvements in design and in the ergonomics of the test equipment have evolved, to make them easier to use and to understand their results.

The techniques used to fault-find on microcomputer systems have themselves developed to the point where there is now an insistence from the product user to have the systems fitted with test facilities at source and not be left as an afterthought for the user to retrofit. Many of the methods used to test microprocessor systems require only simple additions which are considerably easier to fit when the system is being manufactured, but this may prove difficult after it has been constructed.

To test and repair a faulty system intelligently, the tester has to know the system being tested; knowledge is needed of what equipment to apply in a given situation; and a well-thought-out plan of attack should be followed. The first requirement is beyond the scope of this or any other book on test techniques, but the second and third requirements form the basis of this text. A well-formulated approach to testing any system can be established by developing a "troubleshooting tree" which attempts to reduce the testing burden to a sequence of tests which build on each other. This approach as a suitable vehicle for testing digital systems, along with the types of test equipment that should be applied for specific tests, form the main body of this book.

The book is intended for those who wish to discover the techniques and equipment which can be applied to the testing of microprocessor based systems. The material covered should find acceptance from practising test technicians and engineers who need to expand their knowledge in this rapidly growing field. Where possible, the book has been written as separate chapters on particular topic areas which can be read in isolation. The intimate relationships between certain sections of the material, however, do involve cross-referencing between chapters.

The bulk of the material has been taught for several years to full- and part-time students pursuing Higher Certificate and Higher National Diploma courses and to postgraduate students on short refresher courses.

The introductory chapter on microprocessor systems has been *included for completeness and is not intended as a complete work on* the subject. The chapter concentrates on certain topics, such as tri-state gates and address decoding which are fundamental to the operation of computer systems but which are often scantily covered in many of the available texts. The design of a microcontroller, suitable as the control element for many industrial processes, is outlined and the chapter concludes with a short discourse on programming levels.

The second chapter deals in a general way with some of the problems specific to bus structured systems and discusses many of the basic concepts used to test and isolate faults on computers. The view of a system as a kernel, surrounded by peripheral devices, is expounded, where the kernel has to be operative before any major tests can be applied. Chapter 3 introduces many of the basic principles that are applied when testing systems, particularly at first line maintenance level. The topics covered include stress testing and the "troubleshooting tree" as a formulated approach to fault finding.

The fourth chapter deals with the use of conventional test equipment such as oscilloscopes and digital voltmeters, as applied to testing microcomputers. The intention is to highlight their limitations and to introduce the need for test equipment specifically designed to analyse faults in microcomputers.

Chapters 5 to 8 deal with the instrumentation used specifically on digital equipment. Chapter 5 introduces the simplest test instruments and explains their uses. The chapter covers logic probes, logic pulsers, current tracers and logic comparators. Each of these hand-held tools is explained in terms of their operations and usage in typical test situations. The limitations of hand-held tools serves as an introduction to the following chapters on the more complex digital testing instruments.

Chapter 6 discusses logic analysers from their development as oscilloscope based instruments to the sophisticated equipment currently available. The types of display available are discussed along with their uses in test situations. Several of the ideas expounded in this chapter stem from projects undertaken with final year Higher National Diploma students and I am particularly indebted to Mr P. Davies and Mr S. Hunter for their contributions.

Chapter 7 covers signature analysis and its development from the transition counting technique. The mathematical basis for the method and its high probability of detecting errors are explained. The technique requires the system under test to be configured to accept it; this involves extra hardware in the system, along with built-in test programs. The majority of systems in use can however be retrofitted with these facilities, which are described in the chapter.

Chapter 8 deals with emulation as a test technique. It opens with a discussion of simulation as a means of mimicking system behaviour and expands into methods of controlling one system from another so that various levels of emulation can be applied. The term "emulation" is now applied to a wide variety of instruments from large development systems to self-contained test instruments; the rudiments of development systems are covered along with an outline of the types of free-standing emulators in use. This area of test equipment covers many of the previously outlined methods and is subject to wide disparity between instrument capabilities.

The penultimate chapter deals with the type of test programs used to check out parts of a system. These range from self-test programs which are executed whenever a system is switched on to programs which are only executed after a fault has appeared. Examples of test programs are given which may be used to check out the major components of a computer system.

The final chapter covers the testing of devices and systems peripheral to the computer system. Functional testing of a system is covered with an example of a data acquisition scheme configured with functional testing in mind. The use of go/no go indicators as a means of simplifying first line maintenance is discussed and applied to the data acquisition scheme. The chapter also covers the serial communication standard RS232C and the IEEE-488 parallel interface bus.

The main intent of the book is to bring together in one volume the major test methods in current use and as far as possible to explain them and describe their development from basic principles. Test equipment, in common with the systems they are applied to, evolve as better techniques are developed and as the systems they test become more complex. The book can under these circumstances only represent one viewpoint in time and the material contained within it will, in the course of time, be replaced by improved systems and techniques. The book does, however, provide a good starting point from which to enter this ever-increasing complex world and should provide the reader with a basis on which to judge future developments.

I wish to extend my thanks to Mr P. A. I. Davies and to Mr K. R. Webber of Gwent College of Higher Education, Newport, Gwent, for proof reading the manuscript and making helpful suggestions about the form and content of the material contained within this book.

CHART OF SYMBOLS

T	transistor
D	diode
R	resistor
C	capacitor
V_{cc}	the most positive potential in a bipolar circuit (typically +5 volts)
V_{dd}	the most positive potential in a CMOS circuit (typically +5 volts)
V_{ss}	the most negative potential in a CMOS circuit (typically at ground potential)
V_{IL}	input potential of a logic gate when in the logic "0" state
V_{IH}	input potential of a logic gate when in the logic "1" state
V_{OL}	output potential from a logic gate when in the logic "0" state
V_{OH}	output potential from a logic gate when in the logic "1" state
V_N	noise potential
N	the number of sequences
P_x	the probability of x

Contents

Chapter 1

Introduction to Microprocessor Based Systems

There are few, if any, electronic components that can match the prolific growth and diversity of use of the microprocessor. The first readily available device was released by the Intel Corporation of California in 1971 and was quickly followed by a multiplicity of similar devices from other manufacturing sources. The microprocessor attempted to implement, in a single integrated circuit, all the functions found in the *Central Processing Unit* (CPU) of a digital computer. The architecture of these first generation microprocessors was relatively rudimentary, when compared with a typical minicomputer, which was the smallest and cheapest digital computer then available. The original devices were followed by second and third generation components, which were significantly more powerful and complex than their forerunners. The increase in packing density and speed of operation can be directly attributed to continual improvements in the fabrication technology used to manufacture integrated circuits.

The availability of complex functional units as single integrated circuits has shifted the emphasis of design from circuits to systems. The components of the system have all the attributes of a digital computer with the functional detail of the system mapped onto them by a set of programs. The designer configures what is essentially a general purpose set of components to carry out the specific functions of a system by arranging for the computer to execute a list of instructions that implement the required system actions. The behaviour of the system is now controlled by the system's software, i.e. its set of programs.

A computer system is symbiotic in the sense that its electrical components (the hardware) and its programs (the software) are totally dependent upon one another and either is of little use without the other. Particularly during the development phase of a microprocessor based product, this interaction often makes the problem of deciding whether a fault lies in the hardware or the software a difficult decision. To assist in clarifying the problem area, special purpose test equipment has been developed which ranges from simple instruments up to complex, multifunction test systems.

The skills demanded of engineers and technicians who have to design, maintain and repair these systems are necessarily wider than their traditional roles previously catered for. The education system has had to broaden its perspectives to cope with these needs, at a time when many of the fundamental principles underlying the design and testing of computer systems are themselves undergoing change. The widespread use of computing systems has brought into question the design of system software at all levels of programming. The manner in which many processors are connected together to form a distributed system and the overall control of such schemes remains largely unsolved. The testing of complex systems through built-in testing programs and the use of special test equipment has seriously lagged behind their application.

1.1 THE DIGITAL COMPUTER

Any digital computer contains the three essential elements shown in Figure 1.

The central processing unit (CPU) exercises control over the computer and internally carries out all arithmetic and logic operations. In a microcomputer, a microprocessor carries out the functions of a CPU.

The memory stores the lists of instructions (the programs) that are operated upon by the CPU. Each instruction is brought into the CPU and decoded by it to carry out the operations encoded into the

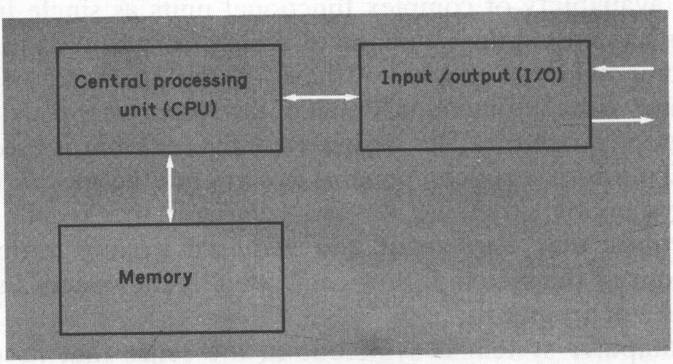

FIGURE 1 THE DIGITAL COMPUTER

instruction. Usually, a program will consist of a set of instructions, whose sequential execution by the CPU defines the system's operations. The memory is also used to store data values, such as the intermediate results of calculations, that cannot be conveniently stored within the CPU itself.

The *Input/Output* (I/O) stage allows the computer to communicate with the outside world. Under control of the CPU, data may be read in through an input port or sent out to some external device through an output port.

The type of external device connected to a computer will be determined by the application of the system. A general purpose computer will use peripheral devices, such as keyboards, *Visual Display Units* (VDUs) and printers, which allow human interaction with the machine. Digital computers used for control and instrumentation applications will have transducers connected to them to provide electrical analogues of process variables such as pressure, temperature and flow rate. Their output ports will connect to actuators such as stepper motors and control values to regulate process parameters. Human interaction with these systems is often only allowed through adjustment of a set point for a process.

The digital computer provides a general purpose structure, which, through the connection of suitable external devices and programming, can be used to fulfill a wide variety of tasks.

1.2 BUS STRUCTURED SYSTEMS

Information is conveyed from one point in a computer system to another over lines which carry only binary valued signals. Binary valued signals can only have two possible states or voltage levels, referred to as logic "0" and logic "1" states. A positive logic convention ascribes zero volts to the logic "0" state and typically +5 volts to the logic "1" state.

If information is transferred from one place to another over a single line by the sending end placing logic levels on the line as a sequential time series, then the form of communication is called serial transmission.

Figure 2 illustrates the transmission of the 8-bit binary word 01001100 over a serial transmission line. The word is shown being sent with the *Most Significant Bit* (MSB) transmitted first; in practice, it is usual to send a word of data in a reverse order, with the *Least Significant Bit* (LSB) leading. Serial transmission uses the least number of communication lines possible, but takes *N* clock periods to send a word of *N* binary digits or bits.