MICROPROCESSOR SYSTEMS AND SOME APPLICATIONS

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To my parents and my brothers George and Athanasios
whose overall support was essential
for the completion of my studies

ABSTRACT

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Microprocessors-defined as Large Scale Integrated devices are functionally equivalent to the central processing unit of a digital computer - have had a rapid development in the course of the past few years. They are categorized according to the technology employed for their construction, depending on the respective advantages of each technology. Where cost saving is involved, NMOS technology is considered to be the most sensible. Where reduction of power-consumption is the basic preoccupation of the manufacturer, CMOS technology is recommended. Finally, the shortest time requirements are achieved by the BIPOLAR technology. Another criterion which is essential to microprocessor classification is the word size, that is, the unit of information transferred from memory chip to processor chip. Microprocessors able to handle 4-bit, 8-bit, 12-bit or 16-bit word sizes are presently available. Each type of microprocessor fits a specific part of the application spectrum.

The subject matter of this project report consists of an adequate overview of microprocessors and their applications, as well

as a discussion on microprocessor evaluation and selection.

The evolution of integrated-circuit technologies, the distinction between microcomputer and microprocessor characteristics and organization, and the main application areas are also adequately presented.

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LIST OF SYMBOLS AND ABBREVIATIONS

MOS : Metal Oxide Semiconductors
PMOS : P-channel Metal Oxide Semiconductors
NMOS : N-channel Metal Oxide Semiconductors
CMOS : Complementary Metal Oxide Semiconductors
FET : Field Effect Transistor
MOSFET : Metal Oxide Semiconductor Field Effect Transistor
DMOS : Double Diffused MOS
SBMOS/DIMOS : Schottky Barrier MOS/Dielectric Isolation MOS
TTL : Transistor-Transistor Logic
ECL : Emitter-Coupled Logic
I^2L : Integrated-Injection Logic
CDI : Collector Diffused Isolation
SBD : Schottky-Barrier Diode
STTL : Schottky Diode TTL
Kb : Kilobits
RAM : Random Access Memory
SSI : Small Scale Integration
MSI : Medium Scale Integration
LSI : Large Scale Integration
VLSI : Very Large Scale Integration
SOS : Silicon On Sapphire
CPU : Central Processing Unit
I/O : Input/Output
MAR : Memory Address Register

PC	:	Program Counter
MBR	:	Memory Buffer Register
IR	:	Instruction Register
(A)	:	Accumulator
(L)	:	Link
ROM	:	Read Only Memory
PROM	:	Programmable ROM
EPROM	:	Erasable PROM
PLA	:	Programmed Logical Array
CCD	:	Charge-Coupled Device
OPR	:	Operation Code
IOT	:	Input-Output Transfer
ALU	:	Arithmetic Logic Unit
DMA	:	Direct Memory Access
JMS	:	Jump to Subroutine
MSB	:	Most Significant Bit
LBS	:	Least Significant Bit
LIFO	:	Last-In First-Out
ADC	:	Analog-to-Digital Converter
DAC	:	Digital-to-Analog Converter
CRT	:	Cathode Ray Tube
OA	:	Operational Amplifier
PABX	:	Private Automatic Branch Exchange
ACRE	:	Automatic Call Recording Equipment
IC	:	Integrated Circuit
µP	:	Microprocessor

OPE : Operator's Position Equipment

OCU : Operator's Control Unit

VDU : Video Display Unit

PCM : Pulse Code Modulation

TDM : Time Division Multiplexing

PAM : Pulse Amplitude Modulation

VES : Video Entertainment System

PIA : Peripheral Interface Adapter

ACIA : Synchronous Communication Interface Adapter

ORA : Output Register A

ORB : Output Register B

MPU : Microprocessor Unit

TI : Texas Instruments

EKG : Electrocardiogram

FFT : Fast Fourier Transform

INTRODUCTION

Thirty years ago, computers were used in a very restricted number of applications and the required capital investment was very high. Twenty years ago, IBM's first commercial computer cost $1 million dollars. Ten years ago, a comparable system cost $100 000; many commercial users started to take advantage of the computer. Today, an equivalent amount of computer power is available in a single chip costing $20. That is a measure of the extent of the microprocessor revolution.

During this whole period of development, computers were used by the government, military, and private sectors for a wide range of data processing applications.

The changes in computer costs have been due to changes in hardware technology. The vacuum tube was replaced by the transistor, which in turn gave way to the integrated circuit.

For the past decade, the explosive development of integrated-circuit technology has been witnessed.

In the 1960's the electronic industry used integrated-circuit technology in order to incorporate numbers of electronic components onto a single chip. At the beginning, the chips were expensive, the production was low and the connectability poor. However, the advantages of the integration techniques were realized immediately and the manufacturers were enabled to double the packing density each year.

The common uses of integrated circuits are the small scale integration (SSI) with 1-10 active elements per chip, the medium-scale integration (MSI) with 10-100 active elements per chip, and the large-scale integration (LSI) with more than 100 active elements per chip. With the advent of large-scale integration, many thousands of logic functions are accomodated on a single chip.

As the functional complexity of integrated circuitry chips increased, so did the problems of the integrated circuit manufacturers. A small number of different device types is easily produced in a factory. When the number of possible device types is very large the problem is more difficult, considering it from both a marketing and a production point of view. Large-scale integration, did not solve the problem, because the number of different chip functions arising from its use would be virtually limitless. The solution to this problem was the implementation of a relatively small number of chips into which the particular functions required by the user could be installed. As a result of this, the microprocessor was born.

Thus, in 1970 the microprocessor was introduced as a major innovation in the evolution of integrated circuits and it revolutionized the design of systems.

The first microprocessor became commercially available from Intel, for a specific use (calculators). However, the development of microprocessors was motivated by pressures from the LSI manufacturers. The rate of progress in LSI technology over the last nine years owes a great deal to the microprocessor.

Definitions of what is the microprocessor, are both loose and ephemeral, and often fail to include devices which may be reasonably considered to be microprocessors while including devices which might equally reasonably be considered not to be microprocessors. The reason for this terminological lack of clarity is primarily that microprocessors do not differ in any real way from many other circuit forms, but rather they represent different structural and functional emphases in the design and purpose of the circuit. Two definitions, in accord with microprocessor complexity and functional characteristics, are presented in Appendix A. The main features which characterize the microprocessor are the following:

- It is an electronic logic device.
- It consists of one or very few LSI circuits.
- It is a stored program computer.
- It is capable of being used both as:

i) A replacement for random logic.

ii) As a processing element in a computer system [2].

Microprocessors today appear in all shapes and sizes to match a broad range of applications. The advantages of microprocessors are short development time, high reliability and easy maintenance. The disadvantages of microprocessors are low speeds (about 1/3 of minicomputer speed and about 1/20 of hard-wired logic speed) and the necessity of learning new design techniques.

The subject of this project report is an adequate overview of microprocessors and their applications. It consists of two parts. In the first part a general consideration and classification of microprocessors is presented, while in the second part microprocessor applications and selection are discussed.

Chapter 1 exposes the integrated-circuit technologies and the microprocessor evolution. Chapter 2 deals with the microcomputer and microprocessor characteristics including organization and design. The application areas are discussed and presented in chapter 3, while in chapter 4 the factors which must be taken under consideration in microprocessor evaluation and selection are discussed.

PART 1

MICROPROCESSORS-CLASSIFICATION-ARCHITECTURE

Integrated Circuit Technologies

Microprocessor Evolution

Microcomputer-Microprocessor

CHAPTER 1

INTEGRATED CIRCUIT TECHNOLOGIES
MICROPROCESSOR EVOLUTION

The first chapter serves as an introduction to integrated circuit technologies and microprocessor evolution. MOS and BIPOLAR technologies are compared. The evolution of LSI technology and the evolution of microprocessors architecture and applications are examined. The classification of microprocessors is also presented.

1.1 TECHNOLOGIES IN USE

There are numerous semiconductor technologies in use today. They can be classified according to substrate material, device type, basic device structure and circuit forms [2].

Figure 1.1, [2], shows the semiconductor technologies which are currently in production in the industry.

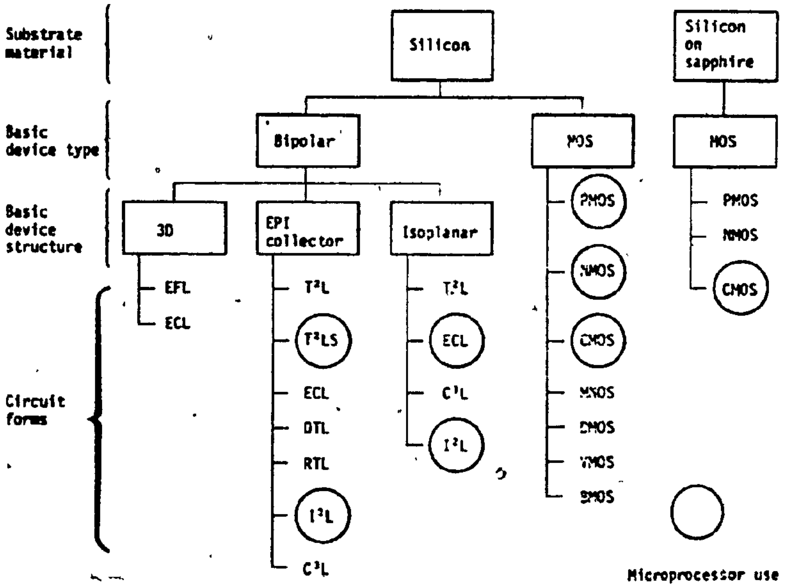

Figure 1.1 Semiconductor Technologies [2]

The main technologies are MOS and BIPOLAR. Each of them has strenghts and weaknesses making it more or less suited to particular applications. MOS technologies have provided very compact but relatively slow circuits whereas bipolar technologies have provided very fast but relatively large circuits.

1.1.1 MOS Technology

The first devices used in monolithic semiconductor microprocessors were the Metal Oxide Semiconductor (MOS) devices. These devices are implemented in various ways. There are three basic MOS structures:

P-channel MOS (PMOS)
N-channel MOS (NMOS)
Complementary MOS (CMOS)

The MOS Field Effect Transistor (MOSFET) is the basic silicon transistor structure. Generally, FETS are placed in series for a NAND function and in paralled for a NOR function.

The first MOS LSI were produced in P-channel form because the processing is less sensitive to process contaminants. However it is more desirable to use an N-channel process because the speed is greater than PMOS by a factor of two or three and the threshold voltages are lower. This is because the mobility of electrons, the majority carriers in NMOS, is greater than the mobility of holes in PMOS. N-channel has become the primary process technology for LSI, in spite of the fact that N-channel devices are more difficult to fabricate. Initially the NMOS process used metal gates, but later processes have used polysilicon gates to improve speed. The "silicon gate" technology is used in MOS Read/Write memory devices and in many microprocessor LSIs. Another circuit using both P and NMOS FETS is Complementary MOS (CMOS). CMOS has the advantage of low power and high noise immunity, but it also has the disadvantage of lower circuit density. It has been used for two commercially available microprocessors (RCA Cosmac and Intersil 6100).

Improvements in speed and density have been achieved by new developments in MOS technology. The VMOS structure uses a technique for obtaining short transistor channel lengths, in V shape, with controlled diffusions. The Double Diffused MOS (DMOS) technology has been applied to LSI devices recently. Also the Schottky Barrier MOS/Dielectric Isolation MOS (SBMOS/DIMOS) technology has just been announced.

1.1.2 Bipolar Technology

Bipolar technology has been widely used in industry. The basic configurations are:

Transistor Transistor Logic (TTL)
Emitter Coupled Logic (ECL)
Integrated Injection Logic (I^2L)

In addition there are some other processes such as Collector Diffused Isolation (CDI) used in the Ferranti F100L [3].

TTL is a well tried technology. It is characterized by very high speed (i.e., small gate delay), low cost, high noise immunity, but it also has high power requirements, lower packing density and generally it has complex manufacturing processes.

ECL technology is not very well tried and tested also it has low packing density and high power dissipation. However, it is the fastest technology (i.e., gate propagation delays below 1 nanosecond), and it generates low noise.

I^2L is a very new technology which is relatively untried. It approaches MOS technology in density, it has fairly high speed and reduced power consumption.

CDI technology has been used only by two manufacturers (Ferranti and Bell Labs). It is a very new technology, with simple manufacturing process (i.e., less masking stages), high speed and it is suited to high temperature operation.

There is a diode called Schottky-barrier diode which can improve switching speed in bipolar technology. For example, when Schottky-barrier diodes are incorporated in the already fast TTL circuits, a very rapid circuit results. These are called Schottky diode TTL (STTL) logic circuits.

1.1.3 Comparison

The various advantages and disadvantages of technologies in use have been indicated. Comparing the technologies, some important points can be extracted.

ECL is about 2 to 3 times faster than TTL. However, the power dissipation is 2 to 4 times as high and the noise immunity is much poorer than in TTL.

CMOS has a very low power dissipation about 100 times less than TTL after transients have died away. However, its switching speed is about 10 times as long as that of TTL. In Table 1.1, [2], comparisons have been made by ranking the technologies in their order of performance on a given attribute. The attempt has been made in order to give a qualititive rating of the processes within a particular category. The circled processes are first in each category. More than one process may have the same number, when they have similar parameters. Each process is first in some category. Hence, no one process dominates for all applications.

Table 1.1

Comparison of MOS and BIPOLAR Technologies [2]

	PMOS	NMOS	CMOS	CMOS/SOS	Bipolar TTL	I^2L
Speed 1 = fastest	6	5	3	2	①	3
Density (circuit layout) 1 = most dense	2	①	3	2	4	2
Power requirement 1 = least	3	2	①	①	4	①
Experience 1 = most	2	3	4	5	1	6
Process complexity 1 = least	①	2	3	4	3	3

1.1.4 The Evolution of LSI Technology

The growth of LSI technology is characterized by an approximate doubling each year of the number of components on a single chip as illustrated in Figure 1.2, [4].

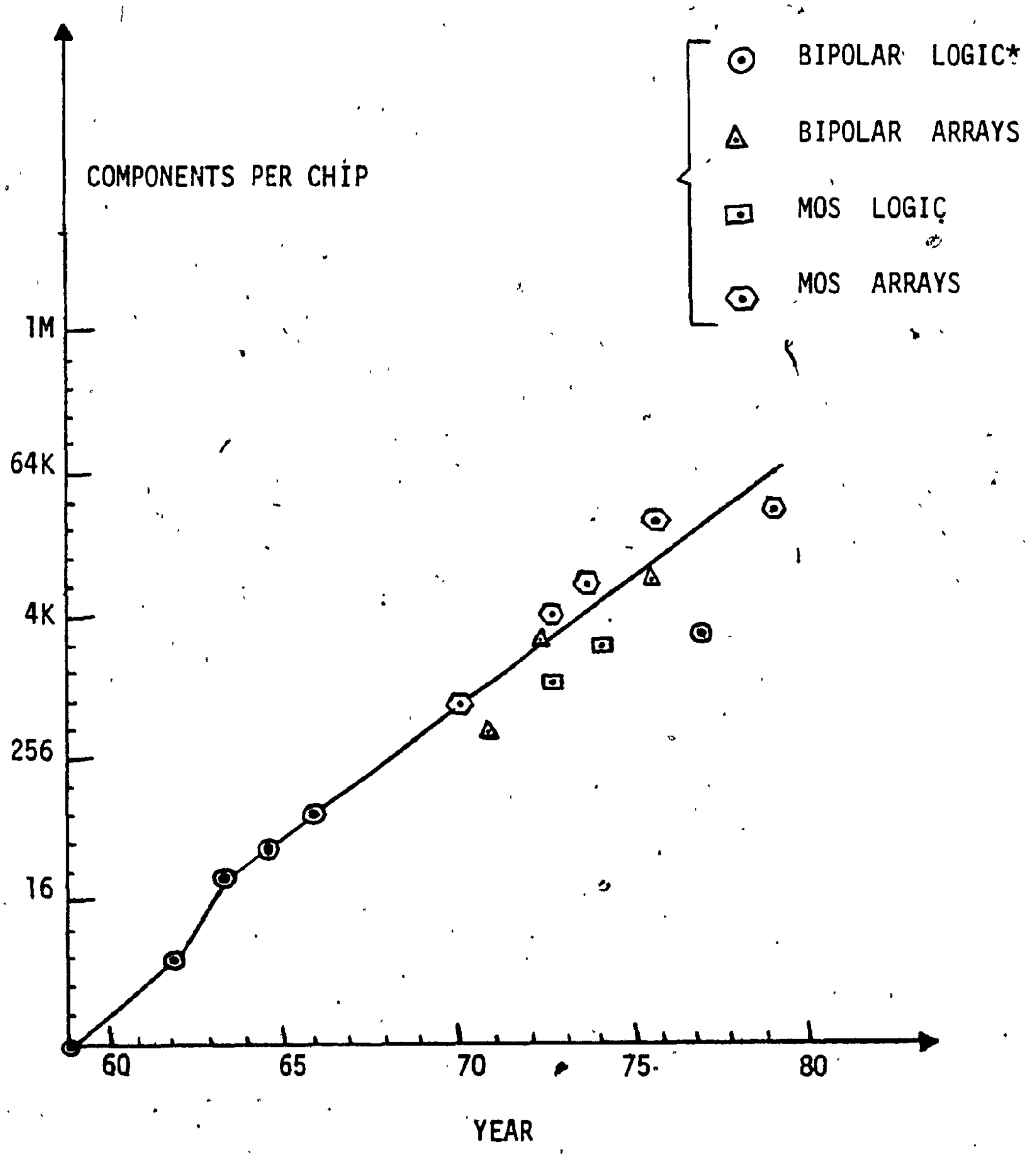

Figure 1.2 Growth of the Scale on Integration of LSI Circuits

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[*] The term logic holds for circuits that produce the electrical equivalent of a logical function, such as a Boolean algebra operation. On the other hand, array is a circuit composed of parallel sets of lines running in perpendicular directions. The lines may be joined by conductive elements at their intersections, and they form a matrix.

It has been predicted that this rate of growth will be maintained until the early 1980s.

Also, another illustration in Figure 1.3 can give the development of integrated-circuit technology by the growth of integrated circuit complexity [4]

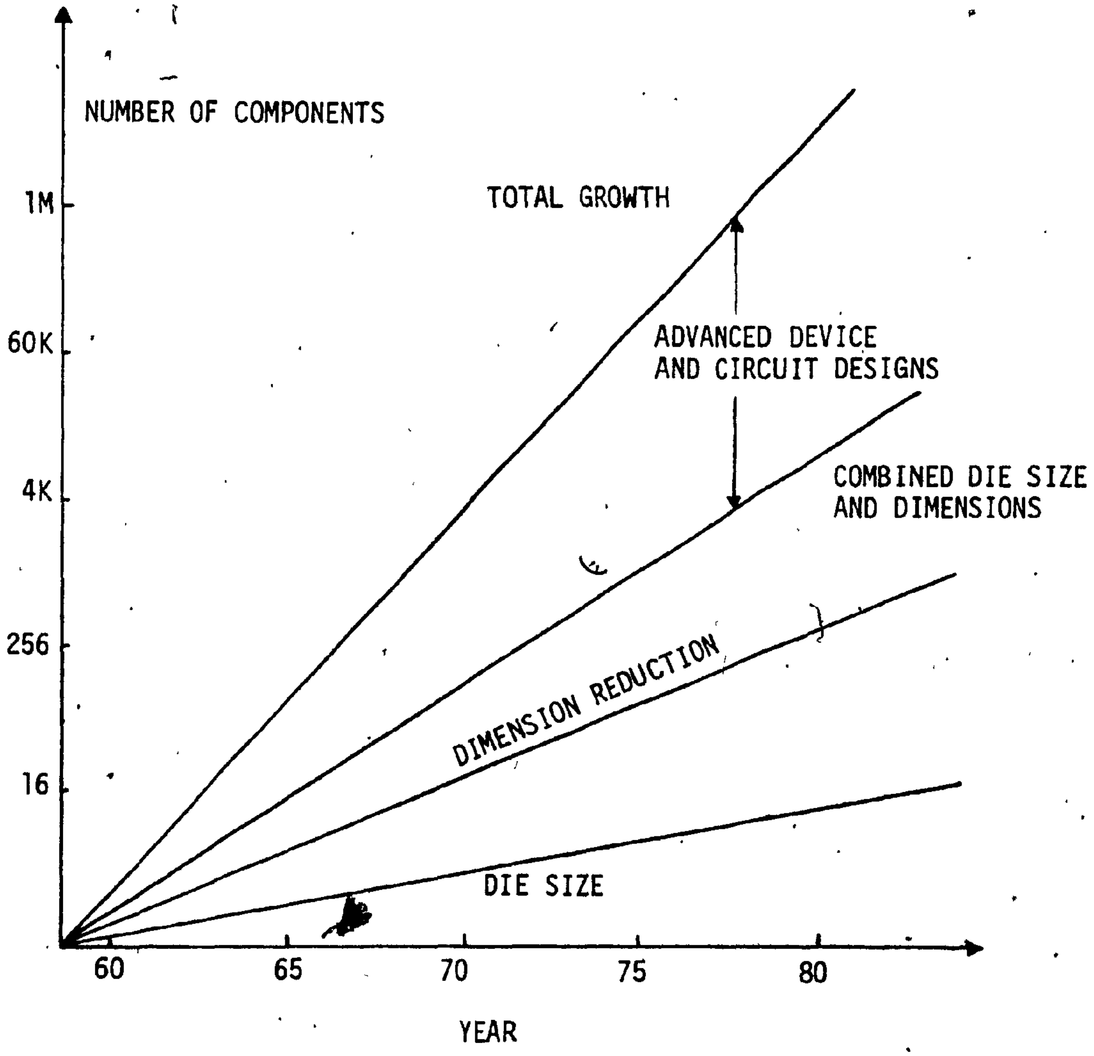

Figure 1.3 Growth of Integrated Circuit Complexity in Terms of Number of Components per Chip.

By combining these two components, the cost per function will have a minimum corresponding to the optimum complexity for the state of the art design technique and process technology, Figure 1.4.

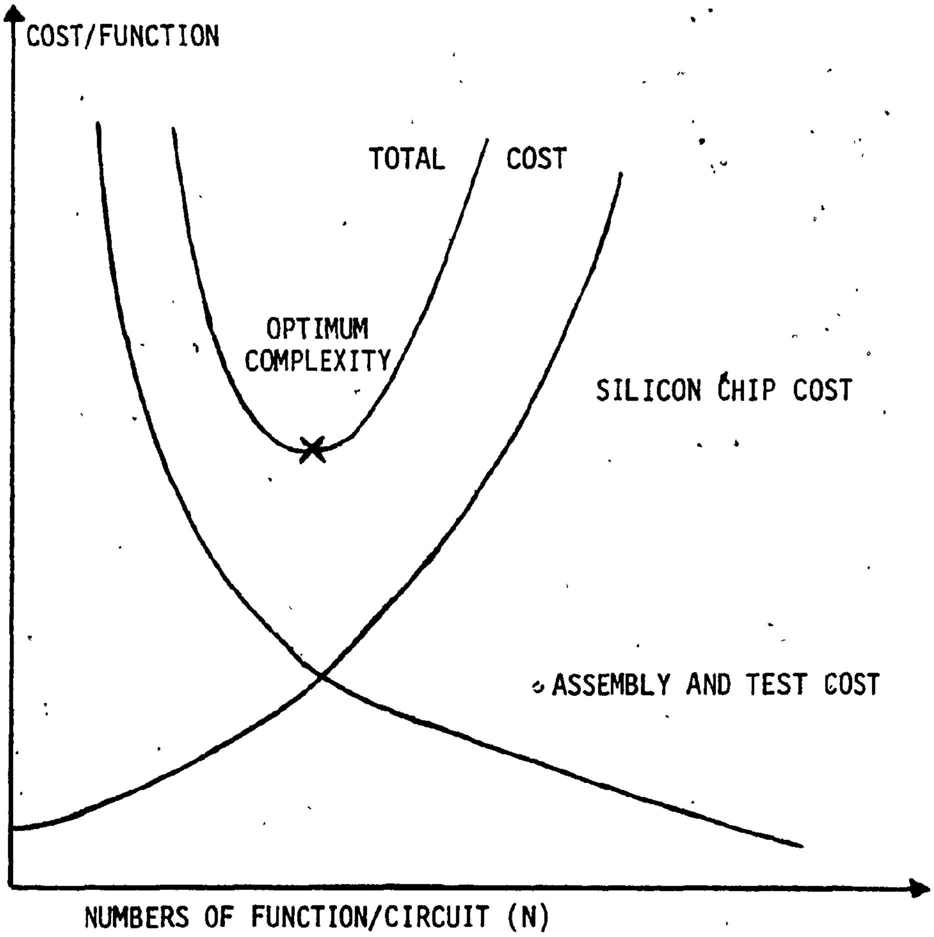

Figure 1.4 Elements of Integrated-Circuit Cost

1.1.5 LSI Technology Future Trends

By 1976 the density of 10 000 gates/chip (NMOS) had already been reached. By 1980, it is expected that the density will increase to 100 000 gates/chip (CMOS, I^2L). By 1985, it will reach

1 000 000 gates/chip (new technologies) [6]. In Figure 1.5, straight-line projections of IC complexities have been accurately forecast.

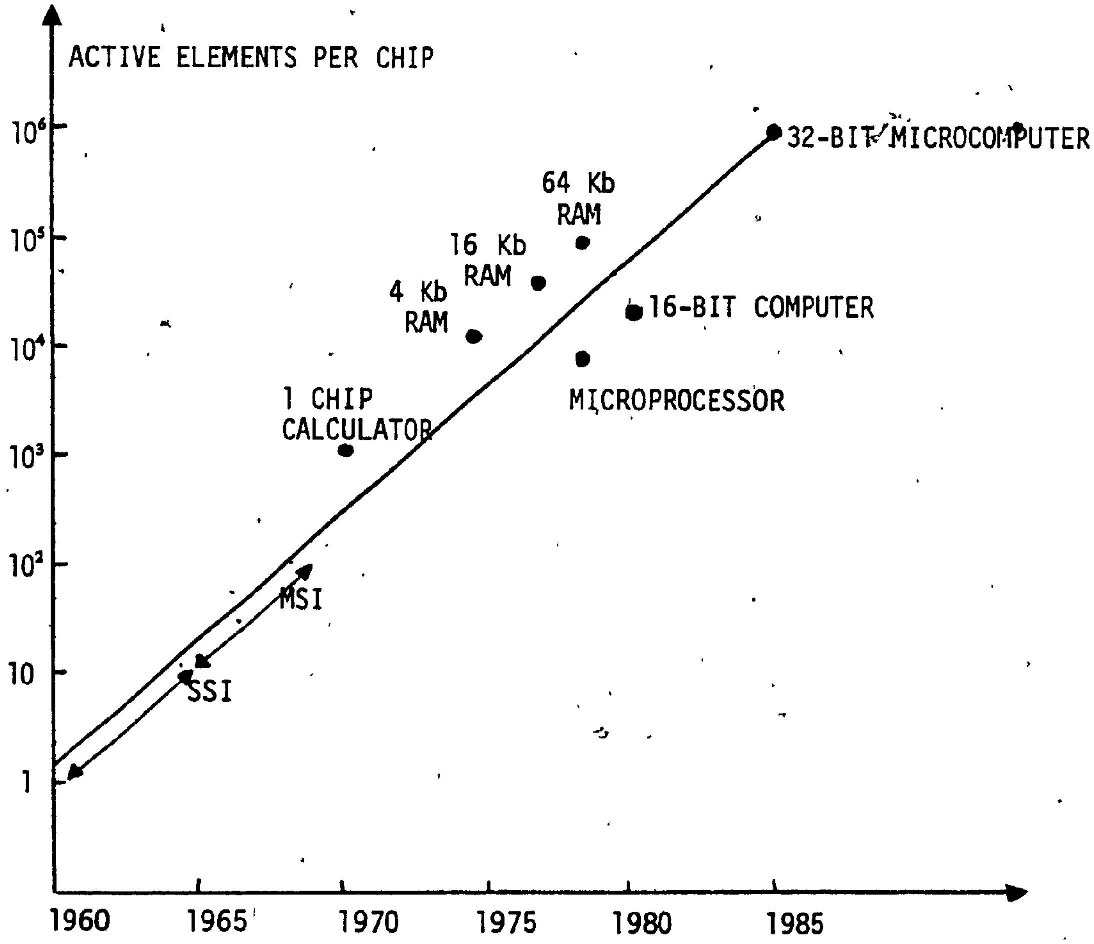

Figure 1.5 The Future Trends of ICs

The age of Very Large Scale Integration (VLSI) with number of devices per chip greater than 20 000 is certainly emerging. Undoubtedly, the future trend will be a rapid reduction in delay/power product using I^2L, CMOS/SOS and new technologies. For example, one technology, Gallium Arsenide, which is still in the research stages, holds promise of subnanosecond gate delays and delay power products less than 0.1 picojoules [7]. This technology will get to the commercial LSI stage after a few years.

In the expanding world of IC chip complexity, another important facet is reliability. As power dissipation must be reduced to accomodate one million devices on a single chip, so must reliability be improved. As a matter of fact , to build a microprocessor of modern complexity using simple, plastic-packaged TTL gates, would have a mean time between failure of only a few months. As an example, [6] , the mean time between failure of a Motorola MC6800 CPU, (3000-gate complexity and packaged in ceramic), was 877 years last year and is projected to reach 1900 this year. From the above example the reliability advantage of LSI is obvious.

Thus, since 1958 the number of components per chip has been doubling each year. By 1985, it is expected to be one million devices on a single silicon chip. That means, in the next decade, microprocessors and related components will be built on ICs with new circuit-design techniques and advanced fabrication processes. Realistically, the microprocessors of today are just the beginning of a new and rapidly developing field.

1.2 MICROPROCESSOR EVOLUTION

The first microprocessor systems were a result of the very rapid advances in LSI technology which made feasible the desk calculator as a small, inexpensive, high volume product. These systems were 4-bit systems. Next, the 8-bit 12-bit and 16-bit processor sets came as extensions of the early 4-bit sets. Lastly, bit-slice architectures enabled tailored systems to be readily configured.

1.2.1 Microprocessors and Discrete Logic

From the definition of the microprocessor it is obvious that in its basic form it is unusable because it is a single component (or possibly a number of chips) which requires a stored program to determine its operation. Basic logic components such as transistors, relays and so on, correspond directly to their electrical inputs without the use of a stored program. Although there does seem to be a fundamental difference between microprocessors and discrete logic, the advantage of microprocessors is the short design turnaround time they make possible.

But to realize this advantage, as well the advantages of easy field alterations and inexpensive customizing, the system designer will need to use new tools - some of which may be unfamiliar to him. Thus, the system designer, instead of gate networks uses masks, comparisons, and jumps; and instead of time delays, he uses circulating loops. The logic system designer combines hardware and software techniques to achieve a system that was formerly all hardware. The resulting design is more flexible since the features of the system can be a function of software (program). In most cases only a new program need be written, when marking conditions require an updated or even totally different system.

1.2.2 The Evolution of Microprocessor Architecture

In looking at the evolution of microprocessor architecture there seems to be a clear distinction between generations of microprocessors.

In the early 70s, the first generation microprocessors were 4-bit systems constructed using mainly PMOS technology. Examples of these systems include the Intel MCS-4 and the Rockwell PPS-4 system. Extensions of the 4-bit microprocessors were the 8-and 16-bit PMOS micro processors. Intel MCS-8 and National Semiconductor IMP-16 are good examples of the respective processors. Around 1973, the beginning of the second generation of microprocessor technology became a fact. The third class of microprocessors were constructed using NMOS technology as 8-bit systems like the Intel 8080 and Motorola MC6800. The third generation of microprocessors is based in the lates technologies (SOS, SBMOS ...). Bit-slice chips are manufactured, like the Fairchild 9400 and Intel 3000 series. In additionto 4-8-and 16 bit architectures there is also the 12-bit architecture from Intersil 6100 and Toshiba TSL-12.

1.2.3 The Evolution of Applications

It has been aforementioned that microprocessors were first developed for use in calculators. Since this application, an increasing number of applications has emerged. In Table 1.2 the percentage use of microprocessors has beeen presented for 1974 and 1975 [10].

Table 1.2

Applications of Microprocessors

Usage	1974	1975	Usage	1974	1975
Test/Instrumentation	16%	18%	Medical	3%	3%
Industrial Control	13%	16%	Consumer	3%	3%
Aerospace	13%	15%	Office equipment	2%	2%
Communications	16%	14%	Education	2%	1%
Computers	14%	13%	Transportation	1%	1%
Military	10%	9%	Other	6%	5%

It is obvious that instrumentation, industrial control and aerospace lead the table. Nevertheless, new application areas will be found and the microprocessor manufacturers will maintain a profitable product line. Microprocessor applications will be discussed in Part II of this project report with more details.

1.3 CLASSIFICATION

Up to here, the technologies in use and the microprocessor evolution have been discussed. Next, the classification of microprocessors will be presented. In Table 1.3 the classification has been made [11] showing the size (in bits) of the element processed, the technologies used the memory address capacity and the manufacturers.

Table 1.3

Classification of Microprocessors

Type Number	Technology	Memory Addressing Capacity (bytes)	Manufacturers* and Comments**
4-bit			
4004	PMOS	4-k	Intel
4040	PMOS	4-k	Intel (National)
PPS-4	PMOS	4-k	Rockwell (National): SV
PPS-4/2	PMOS	8-k	Rockwell: CC,SV
PPS-4/1	PMOS	—	Rockwell: CC, SV, RAM on chip
TMS-1000	PMOS	8-k	Texas Instruments: SV, MP
8-bit			
EA 9002	NMOS	64-k	Electronic Arrays: SV
F-8	NMOS	64-k	Fairchild (Mostek): CC
8008-1	PMOS	16-k	Intel
8080 A	NMOS	64-k	Intel(AMD,/TI, NEC, Siemens)
8048	NMOS	2-k	Intel: 512-bit RAM on chip
6502	NMOS	64-k	MOS Technology - other versions are available with lower address capacity
5065	PMOS	32-k	Mostek
6800	NMOS	64-k	Motorola (AMI): SV
SCAMP	PMOS	64-k	National: CC, SV
1801	CMOS	64-k	RCA: 2-chip CPU
1802	CMOS	64-k	RCA
PPS-8	PMOS	32-k	Rockwell (National): SV
PPS-B/3	PMOS	32-k	Rockwell: CC, SV
2650	NMOS	32-k	Signetics: CC, SV
300	TTL	8-k	Scientific Micro Systems
Z-80	NMOS	64-k	Zilog: SV
12-bit			
6100	CMOS	4-k	Intersil (Harris): SV, CC
TLCS-12	NMOS	4-k	Toshiba: MP

16-bit			
CP1600	NMOS	64-k	General Instruments: MP
MCP-1600	NMOS	64-k	Western Digital: MP, MC
IMP-16	PMOS	64-k	National: MP, MC
PACE	PMOS	64-k	National: MP
PFL-1600A	NMOS	64-k	PanaFacom: MC
TMS-9900	NMOS	64-k	Texas Instruments: SV, general purpose registers in memory
Bit slices			
2901	TTL	64-k	Advanced Micro Devices (Motorola, Raytheon): MP
9400	TTL	64-k	Fairchild: MP, SV
3002	TTL	512	Intel (Signetics): MP, 2-bit slice
6701	TTL	64-k	Monolithic Memories:MP
10800	ECL	64-k	Motorola: MP, CC, ECL
SBP0400	I^2L	64-k	Texas Instruments: CC, MP

NOTES

* Developing manufacturer listed first.

** Key:
MP - microprogrammable
ECL- emitter-coupled logic
TTL- transistor-transistor logic
I^2L- integrated injection logic
SV - single voltage
CC - clock on chip
MC - multi-chip central processing unit

Summary

In this chapter an overview of integrated circuit technologies and the microprocessor implementation have been exposed. It should be apparent that, in general, use of MOS technology requires fewer steps than BIPOLAR technology. Furthermore, MOSFET logic can reduce both the isolation problem as well as power dissipation. However, the switching speed is much faster using BIPOLAR technology.

The evolution of LSI technology has an impact on microprocessor evolution. The impact of the microprocessor is in the design of systems and the nature of the resulting products.

The architecture of microprocessors, the applications and the selection will be examined throughout the following chapters in detail.

CHAPTER 2

MICROCOMPUTER - MICROPROCESSOR

The terms microcomputer and microprocessor will be clarified and their features will be distinguished in this chapter. Basic microcomputer and microprocessor organization, microcomputer instructions, implementation of the instructions semiconductor stores and microprocessor characteristics are also explained.

2.1 DIGITAL MICROCOMPUTER

A microprocessor is a central processing unit (CPU) on a single LSI chip. A microcomputer is a microprocessor combined with memory and input/output (I/O) interface, on a single chip, Figure 2.1.

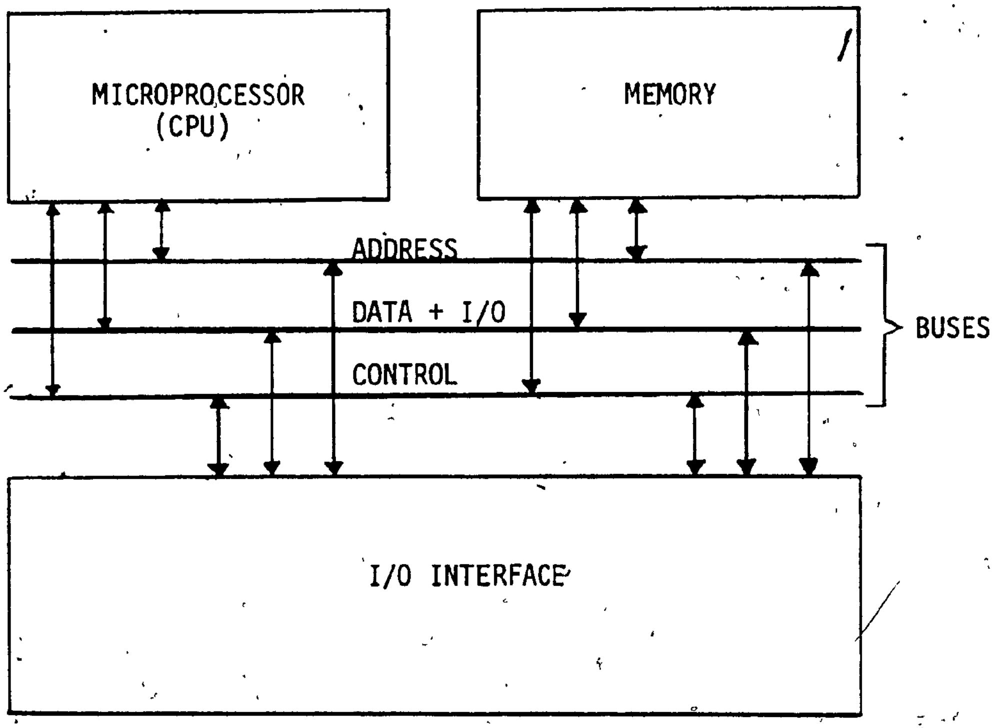

Figure 2.1 The Microcomputer

The CPU subsystem performs all the classical arithmetic, logic, and control functions. The memory contains both the program (instructions to be executed by the CPU) and the currently active data on which the CPU is operating. The I/O interfaces represent the critical communication links between the internal computer operations and the external world (I/O devices including mass memory, human operators, etc.). The buses are conductors which interconnect CPU, memory and I/O interface. Data can travel along the buses in either direction.

2.1.1 Basic Organization

The basic structure of the microcomputer is composed of the memory, data buses, registers and the CPU. The memory provides the storage for the program, the data and intermediate results in binary form. It is known [12] that a binary word can indicate a numerical value (data), a memory address or a computer instruction. This makes the memory an exceptionally versatile component. The microcomputer fetches the instruction from the memory and performs the operation dictated by the instruction. The instruction can also tell the microcomputer the address of the data. Then, the microcomputer takes the data from the specified memory location.

Data buses move binary information between different parts of the microcomputer. They can be one-directional or bidirectional (three-state buses). They are composed of many wires, one wire for each bit.

Registers are used for the temporary storage of data, addresses, and instructions. They are composed of a number of flip-flops, one flip-flop per bit. The microcomputer has several registers. The basic registers are accumulator (A), link (L), memory address register (MAR), memory buffer register (MBR), program counter (PC), instruction register (IR), index register and stack pointer (Appendix B). The CPU will be examined in detail in section 2.2 (Microprocessor Organization).

2.1.2 Storage Devices

The memory of the microcomputer contains a large number of memory locations (memory cells). Information stored in one memory location is called a word. The word size varies from machine to machine. The memory can be composed of a few thousand locations. Each location is labelled with a unique number called its address. There exist memories ranging from 4 bits to 64 Kbits. Types of memory which are in current use, are:

- Magnetic memories such as core memories, drums, disks, magnetic tapes and magnetic bubbles.
- Semiconductor memories such as Random-access memories (RAMs), Read-only memories (ROMs), programmable ROMs (PROMs), and programmed logical arrays (PLAs).

The memory access time* of core memories is of an order of less than 1 μsec. The average access time of drum memories is usually in the order of 2 to 10 msec., [1]. In disk memories the access time is composed of a positional time (100 msec.) and of the rotational delay (10 msec.).

Semiconductor memories have replaced magnetic cores

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*The time to complete the transfer of data, requested by a control unit, to or from the memory.

in modern digital systems. They are available in the form of integrated circuits. Bipolar and MOS technologies are utilized in memory fabrication [13].

In computers, generally, the data are usually stored separately from the program. The program is stored in ROMs or PROMs while data are stored in magnetic core memories or RAMs.

RAMs are "volatile memories" - that is, information is lost when power is switched off. The solution to the volatility problem is a battery-backup power supply. Read and write operations can be performed with RAMs which use flip-flops for bit storage. There exist two types of RAMs, the static RAM and the dynamic RAM. Static RAM has the considerable advantage over dynamic that, as long as the power is maintained, information once written is held indefinitely without special provision by the system designer. Information written into a dynamic RAM will be lost within a few milliseconds unless action is taken to "refresh" it. The main advantage of dynamic RAM is very low power dissipation. Also access time in dynamic RAM is much greater than in static RAM because of refresh requirements.

ROMs are semiconductor memories containing fixed information which has been built into them during manufacture. Information which may be kept in ROMs are, code-conversion tables, standard programs etc. The programming of ROMs is permanent and irreversible. PROMs are ROMs which can be reprogrammed. The reporgramming process requires specially designed apparatus (for example, an ultra-violet radiation source for erasure and a source of relatively high voltage pulses for rewriting).

The advantages of ROMs over RAMs are, low cost, low power, nonvolatile storage and fast access time (35 to 1200 nsec.). In some applications part of ROMs may remain unused. Instead of them, programmed logical arrays (PLAs) which have the advantage of flexible addressing, are used.

Another new semiconductor memory is the charge-coupled device (CCD). This device stores data in the form of electrical charge that can be moved from one memory cell to the other.

It should be noted that the most important microcomputer memories, are semiconductor ROMs, RAMs and Bubble memories.

2.1.3 Microcomputer Instructions

Every microcomputer has its instructions represented in a different format. However, there are three basic types of instruction format:

- Memory reference
- Register reference
- Input-output reference

A memory reference instruction, as its name implies, references memory during the instruction execution. A register reference instruction is called an operate microinstruction and can perform operations without referring to a memory location. An input-output instruction performs the transfer of data between the microcomputer and the peripheral devices. Table 2.1 contains some typical instructions under each type.

Table 2.1

Typical Microcomputer Instructions

Memory Reference	Register Reference	I/O Reference
Add	Shift	Read
Substract	Rotate	Write
Multiply	Increment	
Divide	Complement	
AND	Bit Test	
Inclusive OR		
Exclusive OR		
Store		
Load		
Compare		
Unconditional Jump		
Conditional Jump		

The format of these instructions will not be discussed below, since considerable literature exists on the subject [1] - [14].

The microcomputer instructions can also be grouped according to the function they perform. They are five such groups:

- Move data, arithmetic and logical instrucions (STORE, ADD, AND).
- Control instructions (HALT, JUMP, IF, SKIP).
- Subroutine linking instructions (JMS).
- Operate instructions (CLEAR, INCREMENT, ROTATE).
- Input-output instructions (WRITE, READ).

In the microcomputer all the operations are performed step by step. One step represents a microcomputer cycle which lasts about 1 μsec.

The instructions are performed in one, two or three cycles. For each cycle the machine is in a different state. There are three possible states: fetch, defer, and execute.

In the <u>fetch state</u> the instruction is read from the memory and it is decoded.

In the <u>defer state</u>, which follows the fetch state, the address of the operand is read. This state depends on the addressing mode which will be discussed below.

In the <u>execute state</u>, the operation, specified by the operation code of the instruction, is performed. This state is used in all memory-reference instructions except jump.

It should be noted that the memory-reference instruction has the form [1]

OPR, tag bits, operand address.

The tag bits are used for the addressing mode. The most important methods of addressing memory from the many in use are summarized below:

i) <u>Indirect addressing</u> - the memory location specified by the address in the memory-reference instruction selects the address of the operand rather than the operand itself.

ii) <u>Program relative addressing</u> - the operand address is the sum of the address in the instruction word and the contents of the program counter.

iii) <u>Base relative addressing</u> - this addressing mode operates in the same way as program relative addressing except that a specialized base register is used instead of the PC.

iv) Indexed addressing - the operand address is the sum of the address in the instruction word and the contents of the index register.

v) Autoincrement addressing - the contents of the locations in the memory are incremented by unity immediately before the instruction.

vi) Extended addressing - an extension (or page) register is used to extend the address in the instruction word.

vii) Immediate addressing - the operand is contained in the location immediately following the instruction.

viii) Literal addressing - the address part of the instruction word is used as the operand itself.

2.1.4 Interfaces and Peripheral Devices

The microcomputer is able to communicate with many peripheral devices such as teleprinter, paper tape reader/punch, card reader/punch, line printer, digital plotter, magnetic tape unit, magnetic drum, magnetic disk and visual display. The exchange of information between the peripheral devices and the microcomputer is controlled either by a program or by interface devices. The input-output transfers controlled by a program are called programmed data transfers, and they are performed by the I/O transfer instructions (IOT). With the input-output transfers, commands are sent to the peripheral devices, information describing the status of the peripheral device are received and tested, data from the microcomputer to the peripheral devices and vice versa are sent. The above can be achieved with unconditional transfer, conditional transfer or program interrupt. These programmed input-output transfers can be shown in Figure 2.2.

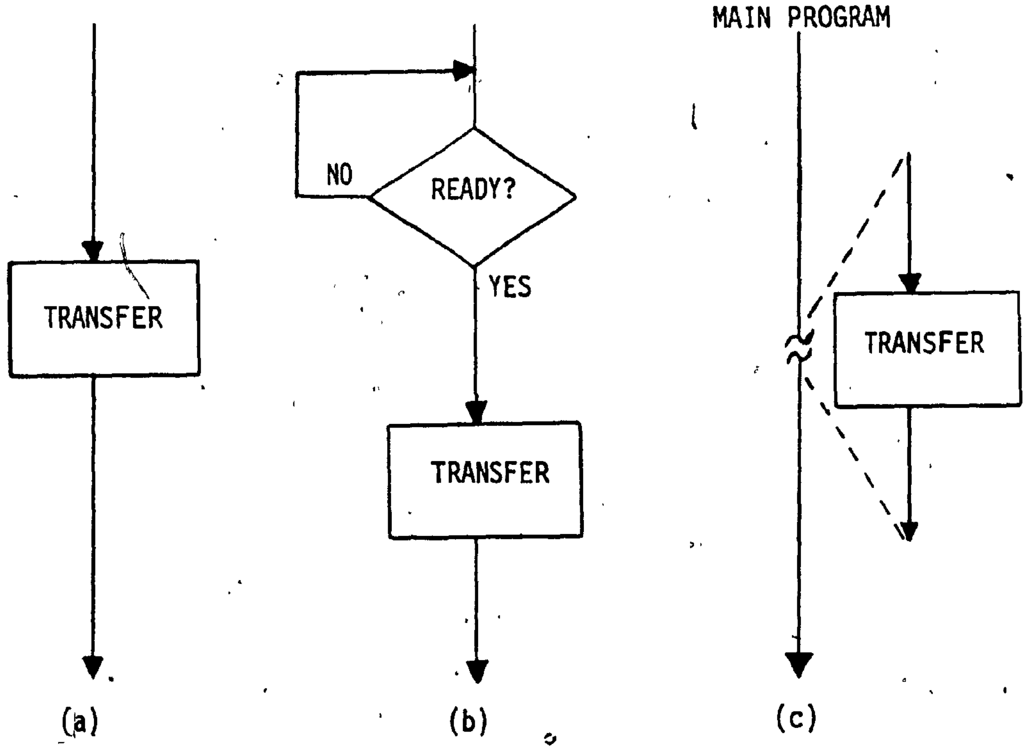

Figure 2.2 Programmed I/O Transfer. (a) Unconditional; (b) Conditional; (c) Program interrupt.

An input-output transfer instruction is read from the memory into the memory buffer register. The operation code goes into the instruction register and the input-output transfer timing generator is activated. The microcomputer has several lines by which it communicates with the peripheral devices. Such lines are, the device selection lines, the command lines, the data line, the skip line and the interrupt line. In Figure 2.3 all the parts of a microcomputer, and all the lines, involved in the programmed O/I transfers, are shown.

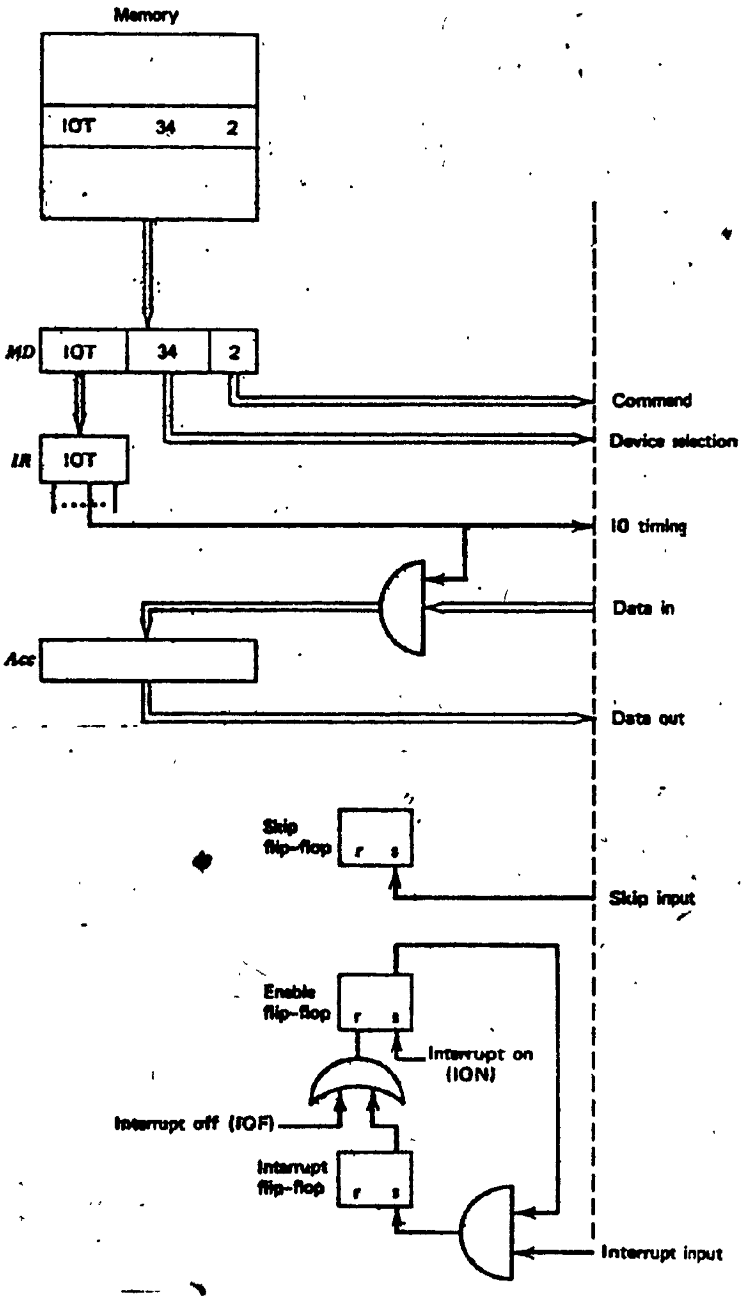

Figure 2.3 Parts of a Microcomputer Involved in the Programmed Input-Output Transfer.[1]

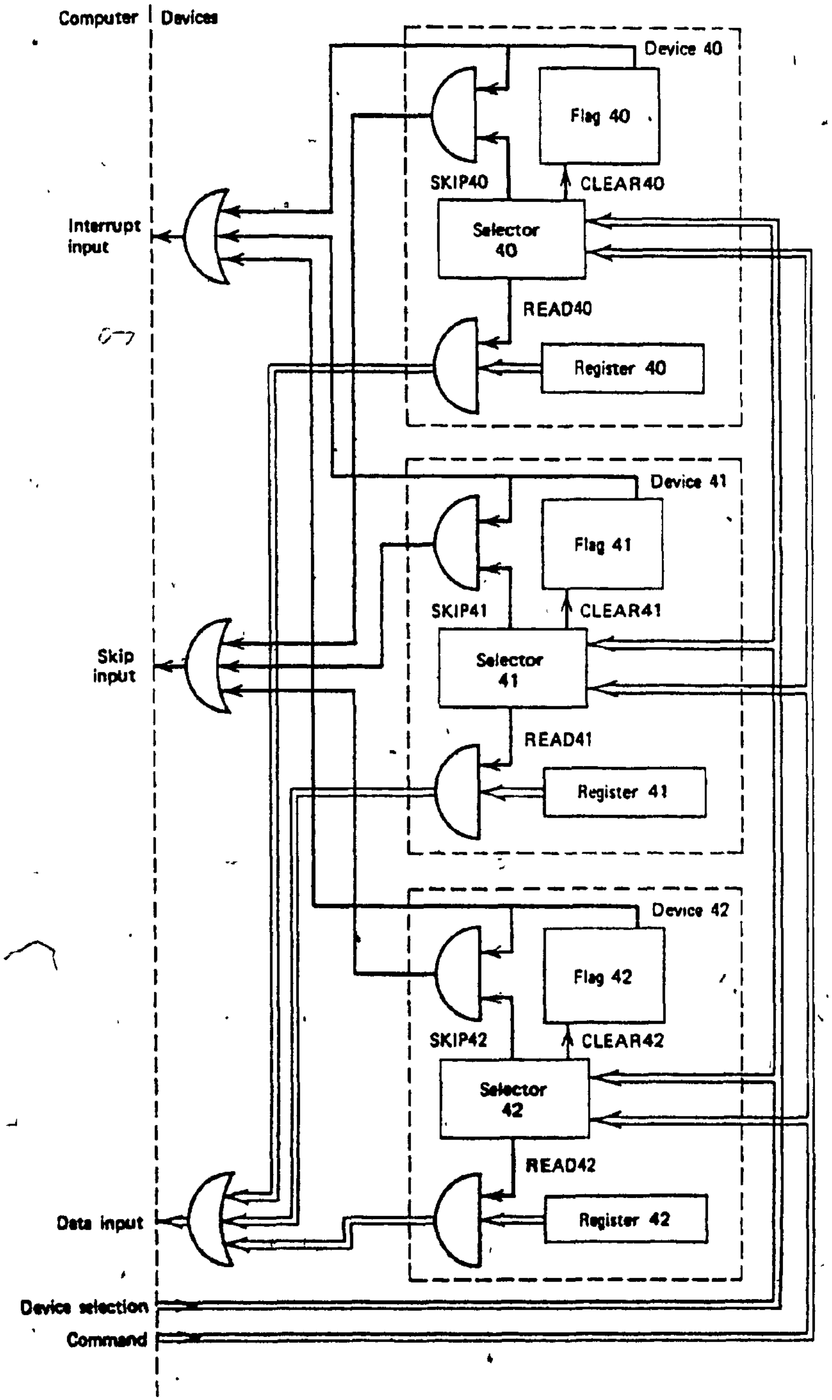

Figure 2.4 Interface Components for Multiple-Interrupt Structure [1]

The microcomputer can communicate with more than one device. An example with three devices coded 40, 41 and 42 is shown in Figure 2.4 to present the interface components for a multiple-interrupt structure. Each device receives three I/O instructions. The command SKIPn is used to read the flag of the device n in the microcomputer. The command CLEARn is used to clear the flag when the device n is serviced. The command READn is used to read the data in the microcomputer [1](6100 μP, Appendix B).

2.2 MICROPORCESSOR ORGANIZATION

A microprocessor consists of three basic units. The arithmetic logic unit (ALU), the control unit and the memory transfer unit. Each of these units contains a number of registers. The arithmetic logic unit is used for arithmetic and logical operations on data. The control unit directs data transfers within the CPU and controls the operations performed within the registers. The memory transfer unit controls all operations between memory and the CPU. A schematic layout of the microprocessor organization is shown in Figure 2.5. Other structures of microprocessors from different manufacturers are shown in Appendix B.

Timing of the operations within the microprocessor is governed by an electronic "clock" which produces a pulse at regular intervals. The time between clock pulses is the microprocessor cycle time. Usually one μP cycle is several clock cycles. At the beginning of a microprocessor cycle the contents of the location specified by the program counter are loaded into the instruction register via the memory

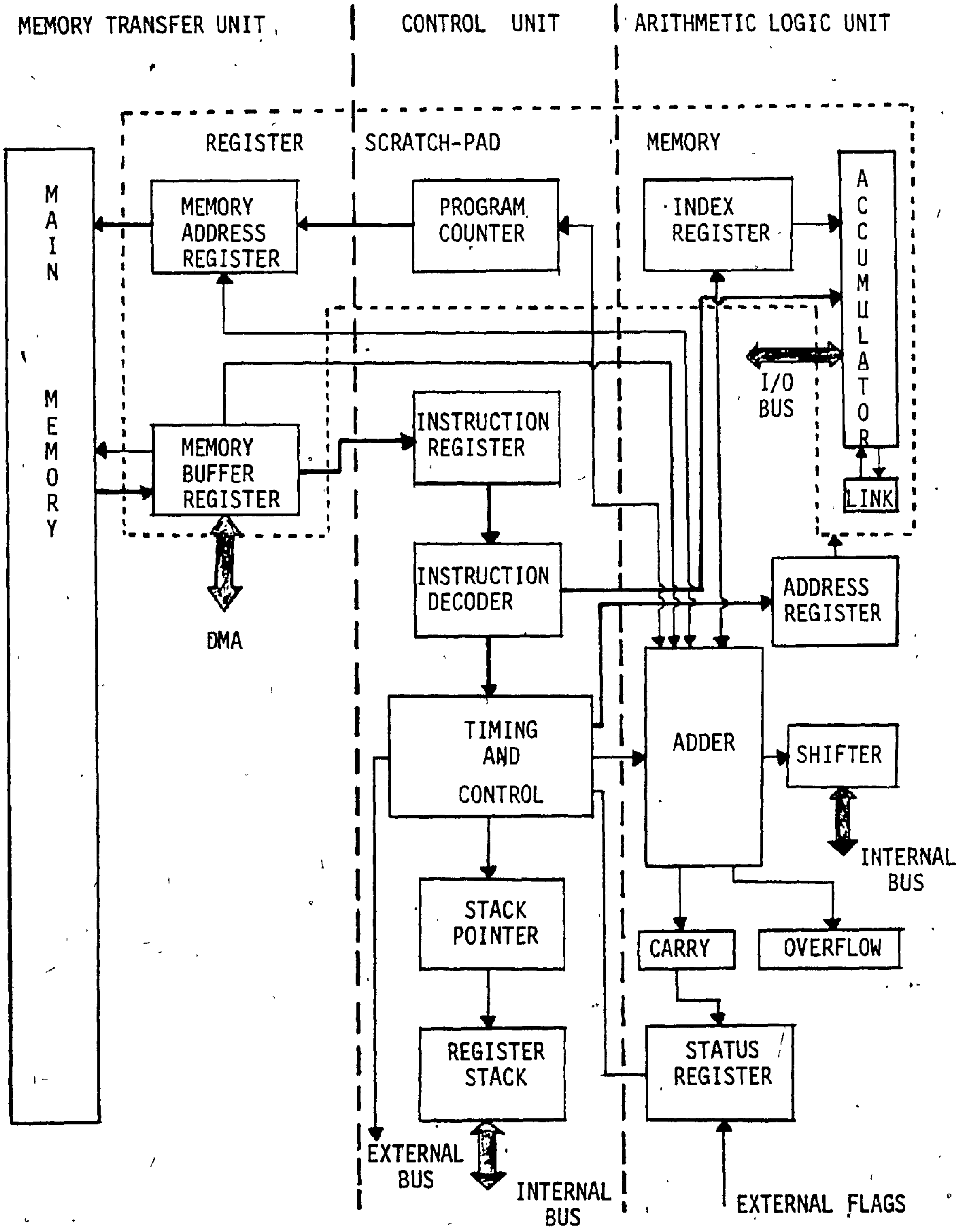

Figure 2.5 Block Diagram of a Typical Microprocessor

buffer register. The instruction is decoded and the operation performed within the arithmetic logic unit.

Another way of presenting the microprocessor as a chip, is shown in Figure 2.6 [16].

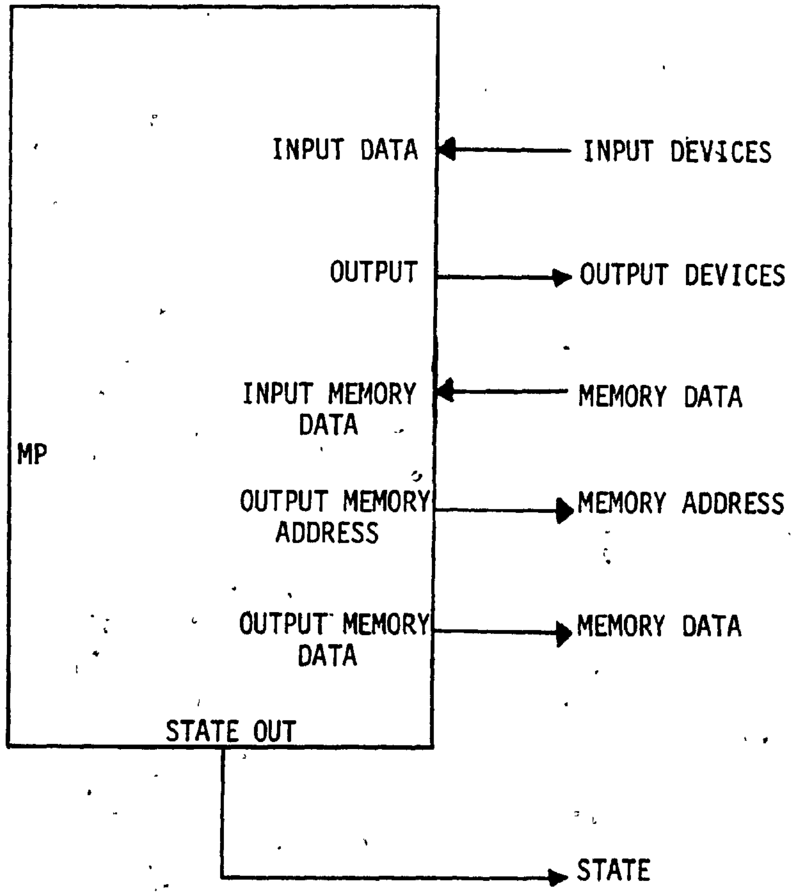

Figure 2.6 Schematic Diagram of a Microprocessor

2.2.1 Arithmetic Logic Unit

The arithmetic logic unit performs various arithmetic, logic and shift micro-operations, on one or two data words. The internal construction of the ALU depends on the micro-operations that it implements. The ALU consists of n identical stages. Figure 2.7 shows the block diagram of an ALU partitioned into n identical stages. A typical logic diagram of a one-stage ALU is shown in Figure 2.8.

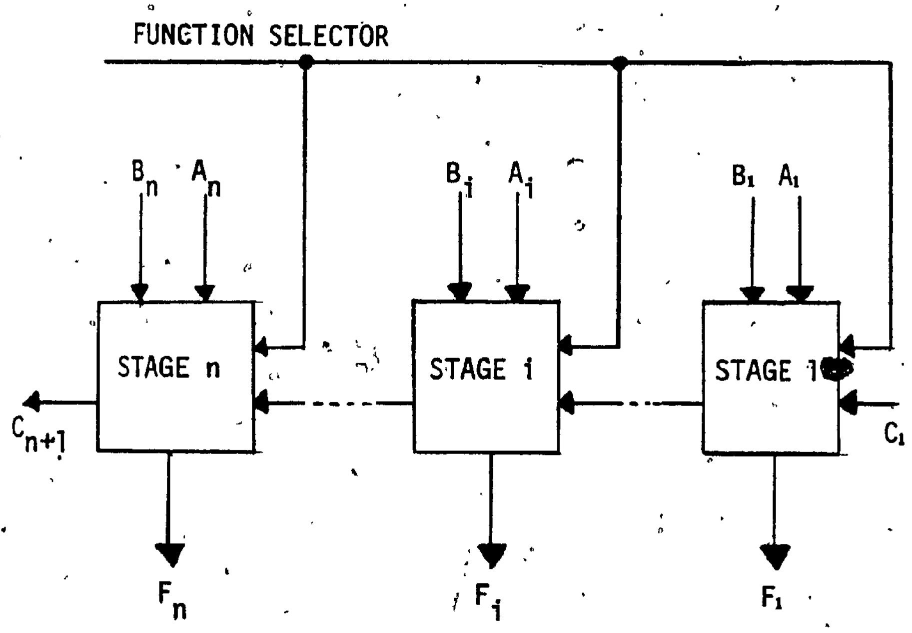

Figure 2.7 ALU Partitioned into n Stages

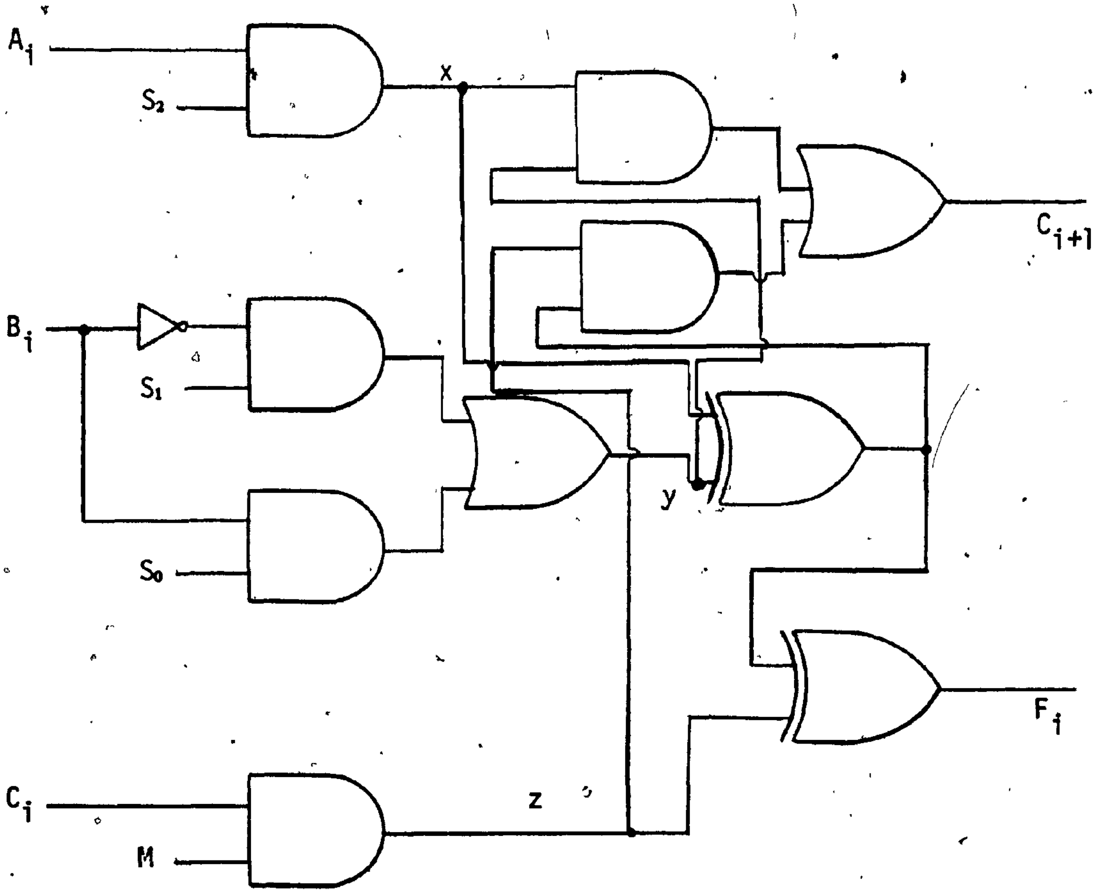

Figure 2.8 One Stage ALU

Selection line S_2 controls input A_i. Selection lines S_1 and S_0 control input B_i. The mode M controls the input carry C_i. When M=1 and $S_2S_1S_0$ = 101 the terminals x, y, and z have values equal to A_i, B_i, and C_i, respectively. The exclusive -OR of the three variables provides the sum output of a full-adder. In the diagram the other circuit provides the carry output for the next higher-order stage.

2.2.2 Control Unit

The control unit is the nerve center of a microprocessor. A typical microprocessor can execute perhaps fifty or more different instructions in any sequence. The role of the control unit is to fetch instructions one at a time from the ROM or RAM program memory connected to the microprocessor buses, decode and then execute them with a sequence of microinstructions; after which, it fetches the next instruction. In order to grasp the concept of control an example is presented in Figure 2.9 [12]; three registers are controlled by an appropriate combination of control inputs. There are nine ways to transfer data between these registers. All the combinations are presented in Table 2.2.

Table 2.2

Bit Pattern of Control Inputs

Operation	Control Inputs					
	A/R	A/W	B/R	B/W	C/R	C/W
A → B	1	0	0	1	0	0
A → C	1	0	0	0	0	1
B → A	0	1	1	0	0	0
B → C	0	0	1	0	0	1
C → A	0	1	0	0	1	0
C → B	0	0	0	1	1	0
A → B & C	1	0	0	1	0	1
B → A & C	0	1	1	0	0	1
C → A & B	0	1	0	1	1	0

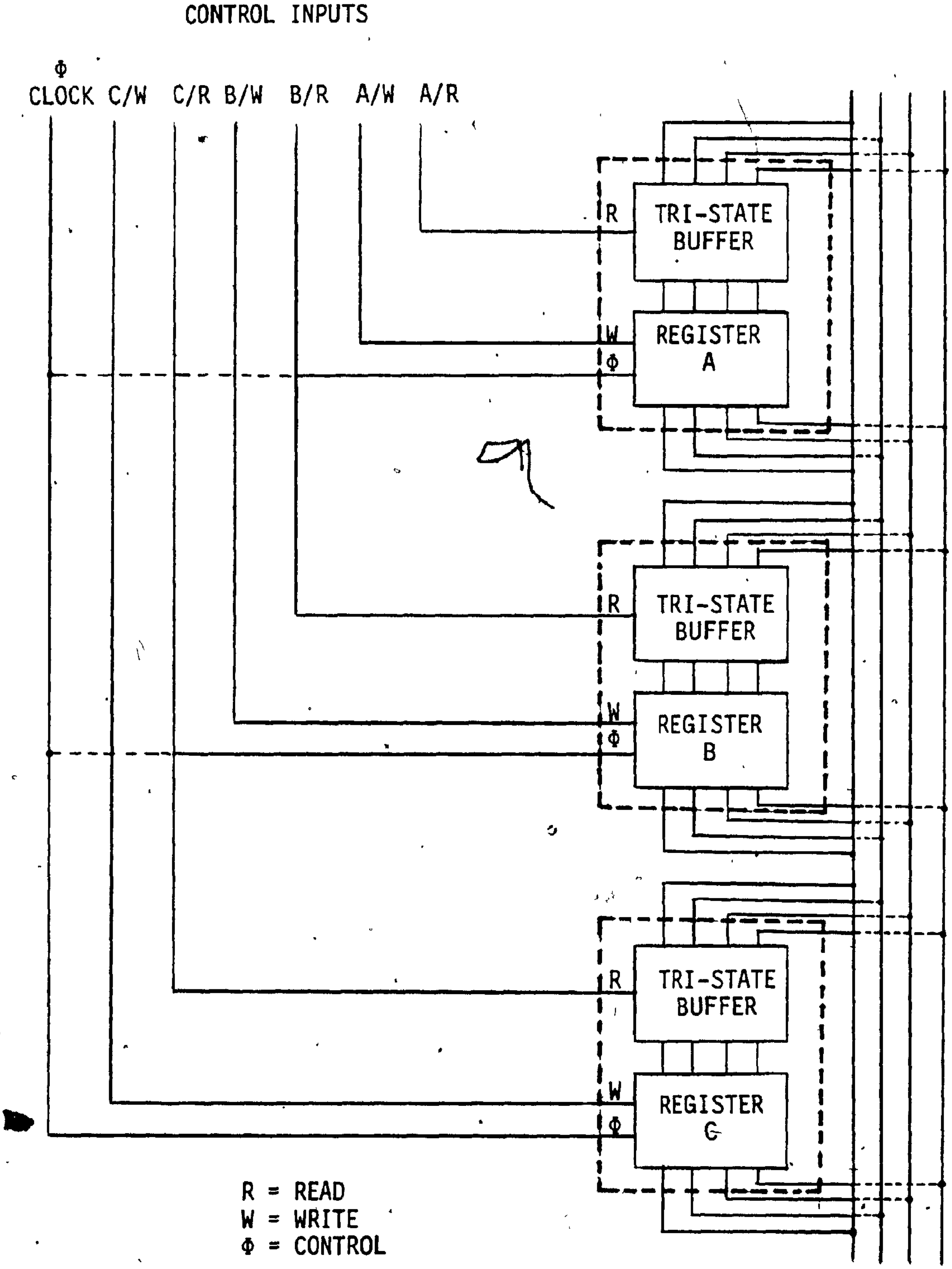

Figure 2.9 Control of Three 4-bit Registers

Each of the transfer possibilities is identified by one control word. These control words are called microinstructions. For example, the sequences A into B; B into C; and C into A require the microinstructions: 100100, 001001, 001001, 010010.

2.2.3 Registers

Several registers which compose the main units of a microprocessor (Appendix B) are shown in Figure 2.5. These registers temporarily store data, addresses and instructions.

The adder performs all the arithmetic (add, substract, etc.) and logical (OR, AND, etc.) operations.

The accumulator is a register that adds an incoming binary number to its own contents and then substitutes the results for the contents. It normally provides one of the inputs to the adder.

The link has only one bit and is used to receive the carry from the accumulator and to connect the most significant bit (MSB) and the least significant bit (LSB) of the accumulator.

The carry indicator is a single bit which is set equal to the MSB of the adder during every operation involving the adder.

The shifter transfers the output of the ALU into the output bus. It may transfer the information directly or may shift it to the right or left [15].

The status register stores status conditions such as output-carry from ALU, contents of accumulator equal zero, and status of external input and output flags.

The address register is used to select the address of the scratch-pad memory.

The index register is used in addressing memory. The address of the next instruction may be found by summing the contents of the program counter and the index register.

The program counter keeps track of the program currently being executed. It is simply a counter. The count usually increases by one as each instruction is carried out, since instructions generally are stored in sequential locations.

The instruction register holds the instruction currently being executed.

The instruction decoder decodes the contents of the IR. The code is interpreted by the control.

The control then generates a sequence of signals to initiate the required micro-operations.

The stack pointer is used when the microprocessor must receive an interrupt from an external device. The stack is a last-in first-out (LIFO) type of memory [15]. Instructions are provided to push (store) the contents of any register into the stack or to pop (load) registers from the stack.

The memory address register holds the address of the memory location used to transfer a word to/from the memory buffer register.

The memory buffer register holds a word during transfers to/from memory. Every transfer to/from memory passes through this register.

Both (MAR) and (MBR) have the same number of bits as the memory word.

2.2.4 Microprocessor Characteristics

The most significant characteristics of today's microprocessors are their speed, addressing modes, interrupt capabilities, and the number of internal registers. The more addressing modes and the more internal registers, in a microprocessor, the less external memory capacity is likely to be required. In most systems, the requirement for external memory is important because memory cost dominates all other considerations.

In Table 2.3 [17] the characteristics of some available microprocessors are presented.

2.3 MICROPROCESSOR DESIGN

The basic architecture of all microprocessors is fundamentally the same, although, there are differences of emphasis between microprocessor architectures, mini and mainframe computers.

Four main aspects will be considered in the following sections regarding microprocessor design:

- Bit slices
- Instruction sets
- Microprogramming
- I/O interfacing

2.3.1 Bit Slices

Microprocessors with word length ranging from 4-bits to 16-bits are dominating control and data processing in small and medium performance systems. Tough process-control and high-speed controller

Table 2.3 Microprocessor Characteristics [17]

Manufacturer	Processor	technology	word size (data/instr.)	direct addressing (words)	# of basic instructions	clock freq. MHz/phases	instruction time shortest/longest (μS)	TTL compatible	BCD arithmetic	on-chip interrupts	# of internal registers	# of stack registers	on-chip clock	DMA capability	Memory & I/O avail.	prototyping avail.	Assembly language	package size (pins)	supplies (volts)
Motorola	MC14500	CMOS	1/4	0	16	1/1	1/1	Yes	No	Yes	1	0	Yes	No	No	No	No	16	3 to 18
Intel	4004	PMOS	4/8	4k	46	0.74/2	10.8/21.6	No	Yes	Yes	16	3x12	No	No	Yes	No	Yes	16	15
Intel	4040	PMOS	4/8	8k	60	0.74/2	10.8/21.6	No	Yes	Yes	24	7x12	No	No	Yes	Yes	Yes	24	15
NEC Microcomputers	μPD541	PMOS	4/8	4k	69	0.5/2	6.4/38.4	Yes	Yes	Yes	4	8x12	No	Yes	Yes	Yes	Yes	42	5.—5
Fairchild	F8	NMOS	8/8	64k	69	2/1	2/13	Yes	Yes	Yes	64	RAM	Yes	Yes	Yes	Yes	Yes	40	5.12
General Instrument	8000	PMOS	8/8	~~1k~~	48	0.8/2	1.25/3.75	No	Yes	Yes	48	0	No	No	Yes	Yes	No	40	5.—12
Intel	~~8008~~	~~PMOS~~	~~8/8~~	~~16k~~	48	0.8/2	12.5/37.5	No	Yes	Yes	6	7x14	No	No	Yes	Yes	Yes	18	5.—9
Intel	8080A	PMOS	8/8	64k	78	2.6/2	1.5/3.75	Yes	Yes	Yes	8	RAM	No	Yes	Yes	Yes	Yes	40	5.12.—5
Intel	8085	NMOS	8/8	64k	80	3/1	1.3/5.85	Yes	Yes	Yes	8	RAM	Yes	Yes	Yes	Yes	Yes	40	5
Motorola	M6800	NMOS	8/8	64k	89	2/1	1/2.5	Yes	Yes	Yes	0	RAM	No	Yes	Yes	Yes	Yes	40	5
Motorola	M6809	NMOS	8/8	64k	100+	2/1	2/5	Yes	Yes	Yes	0	RAM	Yes	Yes	Yes	Yes	Yes	40	5
Motorola	M6802	NMOS	8/8	64k	89	2/1	2/5	Yes	Yes	Yes	0	RAM	Yes	Yes	Yes	Yes	Yes	40	5
National Semiconductor	SC/MP	PMOS NMOS	8/8	64k	46	4/1	5/10	NMOS only	Yes	Yes	0	RAM	Yes	Yes	No	Yes	Yes	40	5. -7
NEC Microcomputers	μPD8080A	NMOS	8/8	64k	78	2/2	1.92/8.16	Yes	Yes	Yes	8	RAM	No	Yes	Yes	Yes	Yes	40	5.12.- 5
RCA	1802	CMOS	8/8	64k	91	6.4/1	2.5/3.75	Yes	Yes	Yes	16	RAM	Yes	Yes	Yes	Yes	Yes	40	3 to 12
RCA	1803	CMOS	8/8	64k	91	6.4/1	2.5/3.75	Yes	Yes	Yes	16	RAM	Yes	Yes	Yes	Yes	Yes	28	3 to 12
Signetics	2650	NMOS	8/8	32k	75	1.2/1	4.8/9.6	Yes	Yes	Yes	7	8x15	No	Yes	Yes	Yes	Yes	40	5
Zilog	Z80	NMOS	8/8	64k	150+	4/1	1/5.75	Yes	Yes	Yes	14	RAM	No	Yes	Yes	Yes	Yes	40	5
Intersil	6100	CMOS	12/12	4k	81	4/1	2.5/5.5	Yes	No	Yes	0	RAM	Yes	Yes	Yes	Yes	Yes	40	4 to 11
Data General	mN601	NMOS	16/16	32k	42	8.33/2	1.2/29.5	Yes	No	Yes	4	RAM	Yes	Yes	Yes	No	Yes	40	5.10.14.—4.25
Digital	LSI-11/2	NMOS	16/16	64k	66	10/2	2.1/232	Yes	Yes	Yes	8	RAM	No	Yes	Yes	Yes	Yes	40	5.12.—5
Fairchild	9440	I²L	16/16	64k	42	10/1		Yes	No	Yes	4	RAM	Yes	Yes	No	No	No	40	
General Instrument	CP1600	NMOS	16/16	64k	87	4/2	1.6/4.8	Yes	No	Yes	8	RAM	No	Yes	Yes	Yes	Yes	40	5.12.—3
National Semiconductor	INS8900/PACE	NMOS/ PMOS	16/16	64k	45	2/2	2.5/5	No	Yes	Yes	4	10x16	No	Yes	Yes	Yes	Yes	40	5.8.—12
Texas Instruments	TMS9980	NMOS	16/16	16k	69	4/4	3.2/49.6	Yes	No	Yes	16	RAM	Yes	Yes	Yes	No	Yes	40	5.12.—5
Texas Instruments	TMS/SBP9900	NMOS I²L	16/16	64k	69	4/4	2/31	Yes	No	Yes	16	RAM	No	Yes	Yes	No	Yes	64	5.12.—5

jobs created the need for microprocessors with longer word length, and consequently led to the manufacturing of bit-slice microprocessor. The bit slice is a single logic unit which forms only a section of a central processing unit. Each slice has a small (2 - or 4-bit) word length [18]. A number of cascaded slices constitute a processor with longer word length.

The advantages of the bit slices are the ability to operate at very high speeds and the considerably superior performance which they can achieve. A tailored system can be built for a particular application. For high-speed processors there are the 2-bit and 4-bit Schottky TTL slices produced by a growing number of bipolar-circuit manufacturers (Table 1.3). For the control of big mainfraim memories there are the highest-performing ECL logic processor slices. Motorola has already announced a 4-bit ECL processor slice. Another application for the bit-slice architecture is in the area of message switching where the control of high-speed code conversion, and format control can be conveniently accomodated. Bit-slice microprocessor designs are considerably more expensive than those built with MOS microprocessors.

By designing a system using bit-slice microprocessor, a greater control must be available over the instruction set of the proposed machine. This point of versatility makes the bit-slice microprocessors very suitable for emulating (simulating) the instruction set of another computer.

The bit-slice microprocessor devices depend on microprogramming to implement a specific instruction set (sec. 2.3.3). The microprogramming is implemented by using a ROM and/or Programmable Logic Array (PLA) in conjunction with other devices. An instruction which is being emulated is accepted as a starting address to a series of microinstructions stored in the ROM or PLA. This series of microinstructions direct the microprocessor chips to emulate the desired instructions in a specific way.

2.3.2 Instructions

The instruction set of a microprocessor defines the architecture of the microprocessor to the user. The instruction set need not correspond in a direct way to the hardware of the system. The size of the instruction set for the various microprocessors is a function of the word size. Most 4-bit processors have between 40 and 50 instructions in their order code; most 8-bit processors have between 55 and 80 instructions and the 16-bit processors have between 33 and 70 instructions [19]. The analytical classification of microcomputer instructions have already been examined (2.1.3). From the microprocessor design point of view there are two major classes of instruction statements:

- The operation statements (move, add, load, etc.,) which are classified according to the number of operands, and the addressing mode, and
- The program control statements (jump and call) which are classified as conditional or unconditional.

2.3.3 Microprogramming

The essence of microprogramming is that there is a level of software permanently stored in a control memory which is executed whenever an object program is obeyed. The user writes a program in assembly language [14], defined by the manufacturer of the microprocessor, generates an object program and loads it. Since there are hardwired processors and microprogrammed ones the difference between them takes effect when the machine code is executed. When hardwired logic is used, a lot of gates and flip flops are interconnected with the logic for each instruction supplied in the user's interface to the system. In the microprogrammed approach, each instruction of the assembly language consists of a number of small steps made up of micro-instructions. The software which determines the mapping between user-interface and micro-instruction is written usually by the microprocessor supplier and held in a ROM. Sometimes the microprogramming can be done by the user, via PLAs.

Microprogramming, positively, provides greater hardware simplicity enabling extensions and modifications to be made to a basic microprocessor design without extensive re-design of the hardware. Negatively, the extra layer of software between the application and the hardware may lead to slow execution of of machine code. Some of the single chip microprocessors relying on microprogramming are shown in Table 2.4

Table 2.4

Microprogrammed Microprocessors.

Number of Bits	Manufacturer and Type
4-bit	Texas Instruments TMS 1000, Rockwell PPS4, American Microsystems AM1, Essex SX 200
8-bit	Mostek F8, Rockwell PPS8, Fairchild F8, Western Digital 1600
12-bit	Toshiba TLCS 12
16-bit	General Instrument CP 1600

2.3.4 I/O Interfacing

I/O interfacing is a crucial aspect of microprocessor system design. Typically I/O is provided by bus structures and the flow of data is controlled by program, Direct Memory Access (DMA) or interrupt mechanism.

The kind of bus structures that can be implemented is the control signal configuration of the microprocessor chip which is determined by the available pins.

A control problem exists where a bus is shared between memory and one or more peripherals. It is essential that there be a technique for allocation of the bus to enable a particular device to obtain control of the bus and transmit data over it. There exist two bus control techniques:

i) The software-controlled I/O techniques which include programmed mode I/O, memory mapped I/O and serial I/O ports.

ii) The asynchronous I/O methods which include DMA and interrupt driven systems.

The programmed mode I/O instructions transfer information from a peripheral device into memory or from memory to a peripheral device. The memory-mapped I/O concept is straight forward. Any 8-bit I/O port can be viewed as a memory location.

Serial I/O ports are physical CPU pins whose level can be set via software. Additional information on software-controlled I/O techniques is available in [20].

The DMA technique permits a peripheral device to enter or extract blocks of data from the microcomputer memory without involving the CPU. In some cases a CPU can perform other functions while the transfer occurs. The transfer is performed through special channels which steal time slices from the CPU whenever necessary [1]. During each stolen time slice one transfer is performed.

The interrupt technique can be viewed as a subroutine call mechanism. When the interrupt line of a CPU is activated, the CPU will branch to a specified location in memory which is the entry point of the interrupt service routine. In the interrupt service routine, other forms of I/O are used to identify both the interrupting device and the specific cause for the interrupt. Then, additional I/O will be used to service the interrupt.

There are also some special-purpose interface devices such as UART and USART which are described in [21].

2.4 FUTURE TRENDS IN ARCHITECTURE

Advances in LSI technology affect the developments in architecture of microprocessors. Most microprocessors have internal architectures that are patterned after classical CPU structures. This trend is changing rapidly. High-performance LSI microprocessors are emerging at a slow but steady pace, with architectural features borrowed from larger and more powerful computers.

For the improvement of the overall performance of the next generation of microprocessors, it is essential that new ground be broken in the design and architecture phases. Despite the limitations of the technologies, machines with features that resemble their counterparts in large computer systems (supercomputers, in some cases) will no doubt emerge shortly [22].

It is also widely agreed upon that microprogrammed processors will become the predominant form of microprocessor architecture. The reason for that is flexibility. A new technique, called nanoprogramming, has recently been introduced to further increase computer capability.

Developments in microprocessor architecture seem to follow developments in minicomputer architecture.

Summary

The microcomputer and microprocessor organization have been exposed in this chapter.

A microprocessor with a memory and I/O interfaces constitute a microcomputer.

The characteristics of microprocessors are very important in applications.

Available software is also an important aspect of the use of microprocessors.

Some microprocessors are microprogrammed. The use of microprogrammed processors is restricted to less than half the current range of microprocessors now available. Among the microprogrammed processors, a large percentage belongs to the bit-slice architecture.

The first part of this project report has been completed having presented a fairly adequate overview of the microprocessor. In the second part of the project report the microprocessor applications and selection will be examined.

PART II

MICROPROCESSOR APPLICATIONS - SELECTION

Application Areas

Evaluation and Selection

CHAPTER 3

APPLICATION AREAS

This chapter deals with the use of microprocessors in the following application areas:

- Process Control
- Testing and Instrumentation
- Telecommunications
- Data Capture
- Commercial Data Processing
- Personal and Single-Board Computers
- Consumer Products
- Computer Peripheral Devices
- Automotive Industry
- Biomedical Systems

In the above areas different types of microprocessors are used. Some interesting examples are described using microprocessors in different applications.

3.1 PROCESS CONTROL

Microprocessors are playing a remarkable role in process control. The direct replacement of a component with a microprocessor has resulted in substantial cost savings and significantly improved performance. There is, of course, an exemption in isolated cases. Microprocessor-based control systems are divided in two distinct categories; a) general purpose systems designed for use on large numbers of process systems and b) dedicated systems that control a unit process of some sort. The use of microprocessors has created two basic control problems to control equipment manufacturers. These are, 1) increasing the reliability and flexibility of large systems through distributed control and 2) shrinking the size of standard computer control systems so that smaller processes can use computer control. Five important technological steps have taken place in process control systems in the factory environment [61].

i) Mechanical
ii) Pneumatic
iii) Electromechanical
iv) Electronic Control
v) Minicomputers

The mechanical and pneumatic control systems predominate to a very large extent. Electromechanical systems are widely used as well. Moving on from that, the electronic control of production line processes is possible and beyond that the use of minicomputers is also feasible.

In this section of the project an overview of the status of microproprocessor applications in process control is presented. First the hardware configurations that are being used and proposed are examined and then some applications that have been reported are considered.

3.1.1 Hardware Configuration

Before process computers appeared, distributed control was in use. The introduction of microprocessors in distributed control, resulted to the use of digital communication with "data highway". The data highway is a single "line" (multiconductor) which carries data to and from a large number of devices [24]. In Figure 3.1 the data highway versus conventional data transmission in a process plant is shown. In this system the various devices are separated by thousands of meters. These data highway allow a system to retain the advantages of both distributed controllers and centralized information, while at the same time wiring problems are simplified in the plant. A big hardware design problem is avoidance of noise for signals that must travel for thousands of meters. Data highway systems currently in circulation are supplied with coaxial cable in order to eliminate this problem. Noise rejection being such a serious problem, current speculation is that fiber optics may become the data highway medium of the future provided that cost and technical problems can be overcome [24], [25], [26].

3.1.2 Applications

A number of remarkable points arise from microprocessor

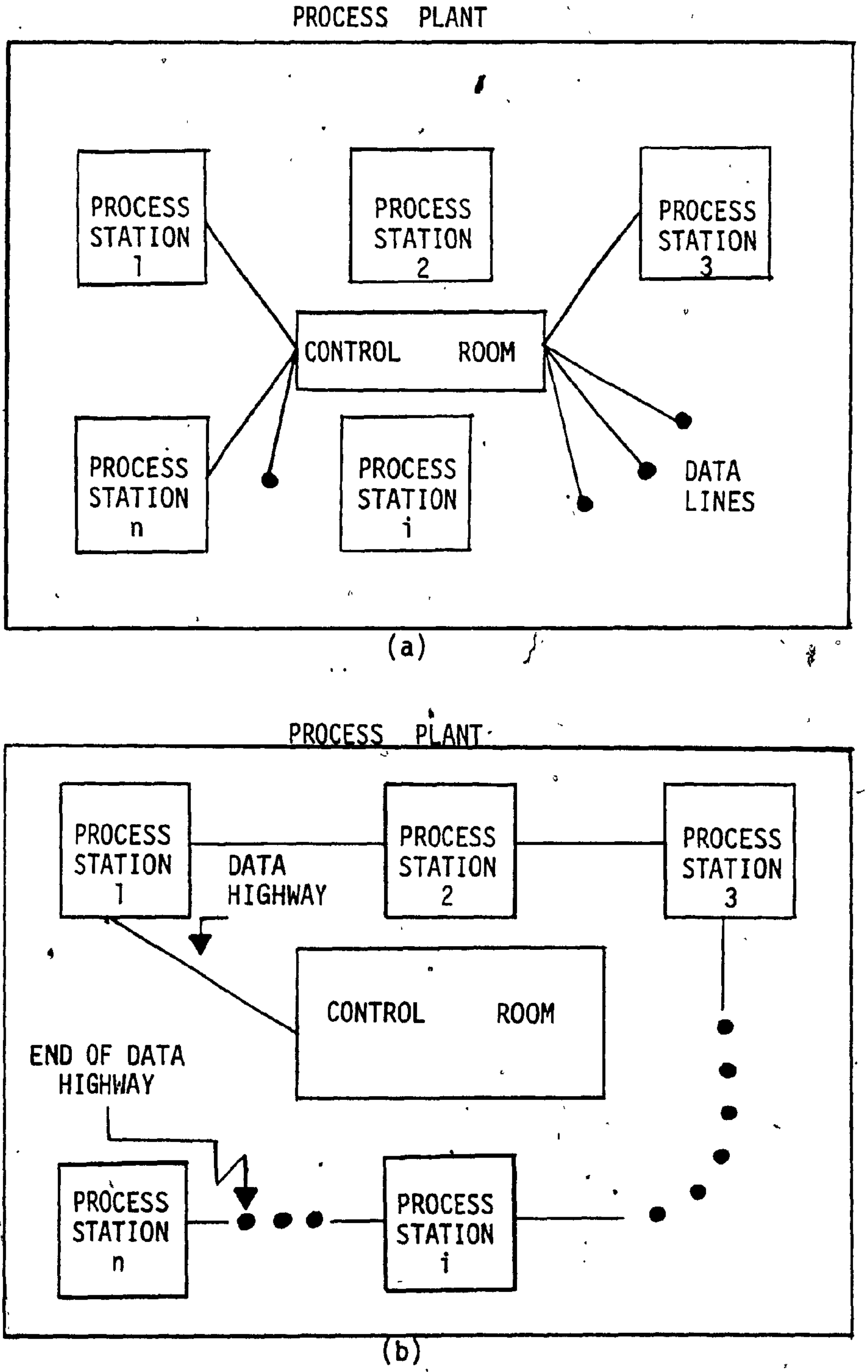

Figure 3.1 Data Highway versus Conventional Data Transmission in a Process Plant.

applications in the area of process control:

i) The number of control loops associated with a system is limited (<50).

ii) Provision of programming solutions is preferable compared to the addition of non-standard hardware.

Examples of two different microprocessors in process control are presented below.

The first is the TDC 2000 controller file [11] that is built around General Instruments CP 1600 microprocessor. The file controls eight process loops. It has 28 control algorithms stored in a 120-kilobit ROM. The controller file is shown in Figure 3.2. It is organized around a 16-bit bidirectional data bus which is controlled

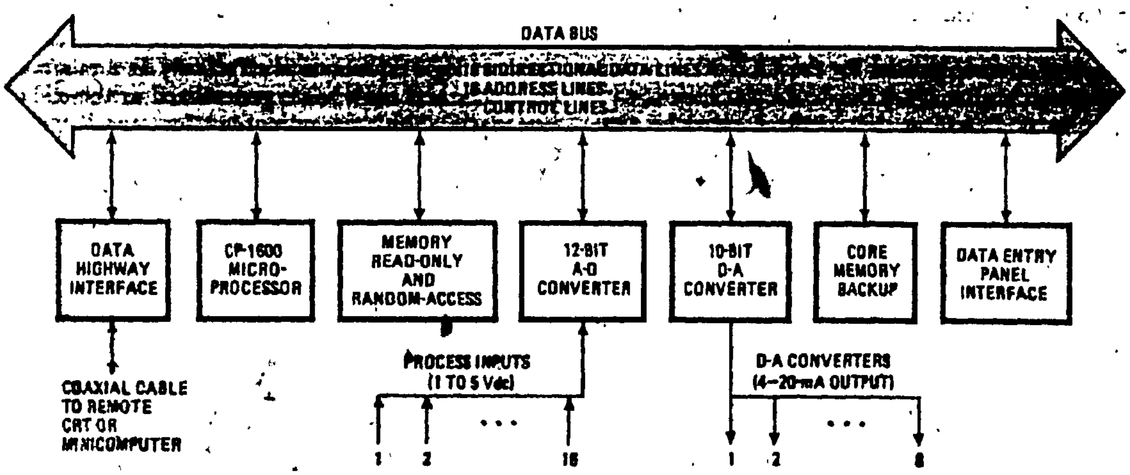

Figure 3.2 The TDC 2000 Controller File [11]

by the microprocessor. The process inputs are encoded via the ADC (analog-to-digital converter). The microprocessor controls the valves and converts their responses to analog form by eight independent DACs (digital-to-analog converters). It also controls the transmission of the responses to the process-control valves. The core memory is used for information to be transferred form the volatile RAM when they are too critical.

The file can communicate with a remote CRT or a minicomputer with the highway interface card and the coaxial data highway.

Another example is shown in Figure 3.3 where a process controller microprocessor-based UCS-3000 serves chemical, petrochemical, oil, gas, water treatment, food, steel, and paper industries [11]. This process controller is built around Intel 8080 microprocessor. It produces 486 interrupts and performs DMA in 30 I/O boards. The memory consists of 64 Kbytes in core and in semiconductor, both in RAM and PROM. All devices communicate over an 8-bit I/O bus. The 8080 sends 12 address lines to the boards. Ten of them carry the 5-bit board addresses. When a board is selected, its five address lines are high. The other two address lines go to all the boards, for further device selection.

When a board pulls down the bus INTERRUPT line, the 8080 sends out an INTERRUPT QUERY, which elicits its five-bit address from the nearest board with an interrupt pending. This address triggers a second-level interrupt that branches to one of 30 program starting points. Then a third-level of interrupts may be triggered

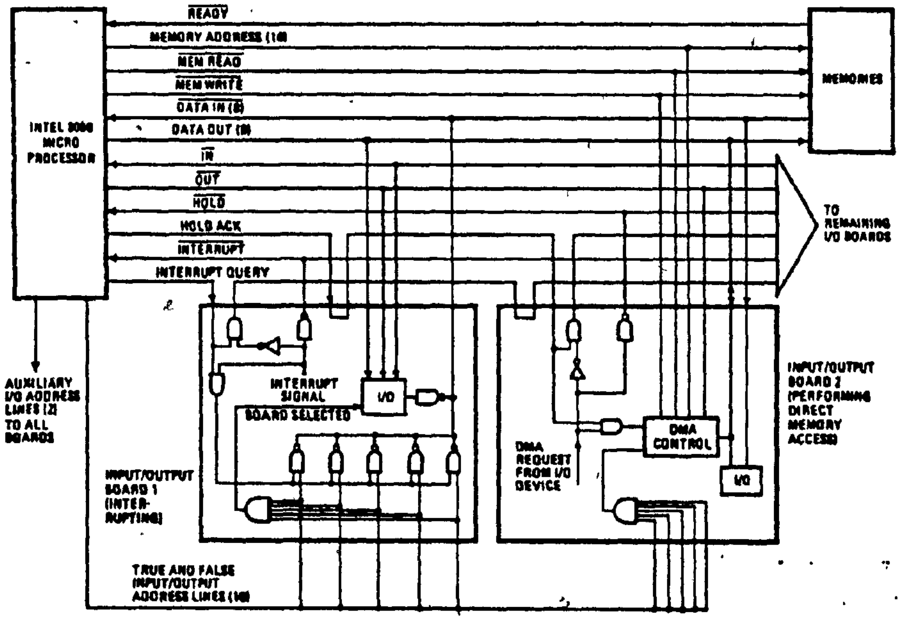

Figure 3.3 The Process Controller UCS-3000 [11]

by the 16 digital inputs on each I/O board.

A DMA transfer may be initiated by any I/O boards by pulling down the common HOLD line and waiting for a HOLD ACK from the microprocessor. Then the board places its memory address on the

16-bit MAR and either puts data on the DATA OUT bus and issues a MEM WRITE, or takes data from the DATA IN bus and issues a MEM READ. Afterwards the HOLD is released by the I/O board and the CPU resumes operation.

Other applications are much more specific. A specially tailored microprocessor is described in [27] for use in missile guidance control. A bit-slice design [28] was used to build in the high speed for guidance and control. A standard microprocessor could be used in the prosthetic arm application described in [29]. A system to control a hydraulic industrial arm using a 4-bit microprocessor is described in [23]. Other recently reported applications are in control of high precision machine tools [30] and in control of a solar heating system [31].

3.2 TESTING AND INSTRUMENTATION

Microprocessors are being used in test systems to identify failures of components. The block diagram of an automatic tester is presented in Figure 3.4 [2] where a signal package, a measurement package, a processor acting as system controller, and a disk for mass storage are presented.

The types of testing which are possible include digital functional test (i.e., truth table), analog functional test (i.e., linearity of O. A.). Also DC tests (i.e., printed circuit board continuity, amplifier gain, saturation voltages etc.) and dynamic tests (i.e., time domain parameters such as overshoot, system delay) can be achieved.

Another use of microprocessors is in instruments. There are many advantages to adding a microprocessor to an instrument. Instrumemnts with microprocessors contain more automatic features and are designed to achieve results output (electrical and visual) for direct use. Also accuracy in calibration is a distinct advantage. Most automatic calibration is done by first measuring a "standard", then measuring the unknown and mathematically removing the error. Hewlett-Packard uses this technique in model 3455A voltmeter [32].

There exist several microprocessor-based instruments in use, such as multimeters and CRT controllers. Future microprocessor-based products will become more complex as the abilities and cost effectiveness of digital processing are fully utilized. Programmable instruments are effectively used in scientific and industrial laboratories. Programmable instrumentation has resulted in a need for standardization in the area of instrument interfacing. Recently, a few

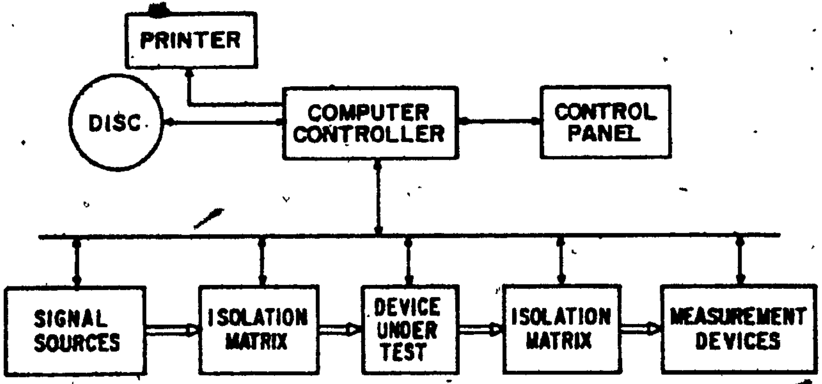

Figure 3.4 Typical Computer Based Test System [2]

standards have been accepted. The IEEE Standard 488 (or general purpose interface bus - GPIB) [33] is an important standard interface for programmable instrumentation.

One example of a measuring instrument with an internal commercial microprocessor (Intel MCS-4) is presented below. In Figure 3.5 the Boonton's Model 76A Capacitance Bridge is shown in block diagrams [34].

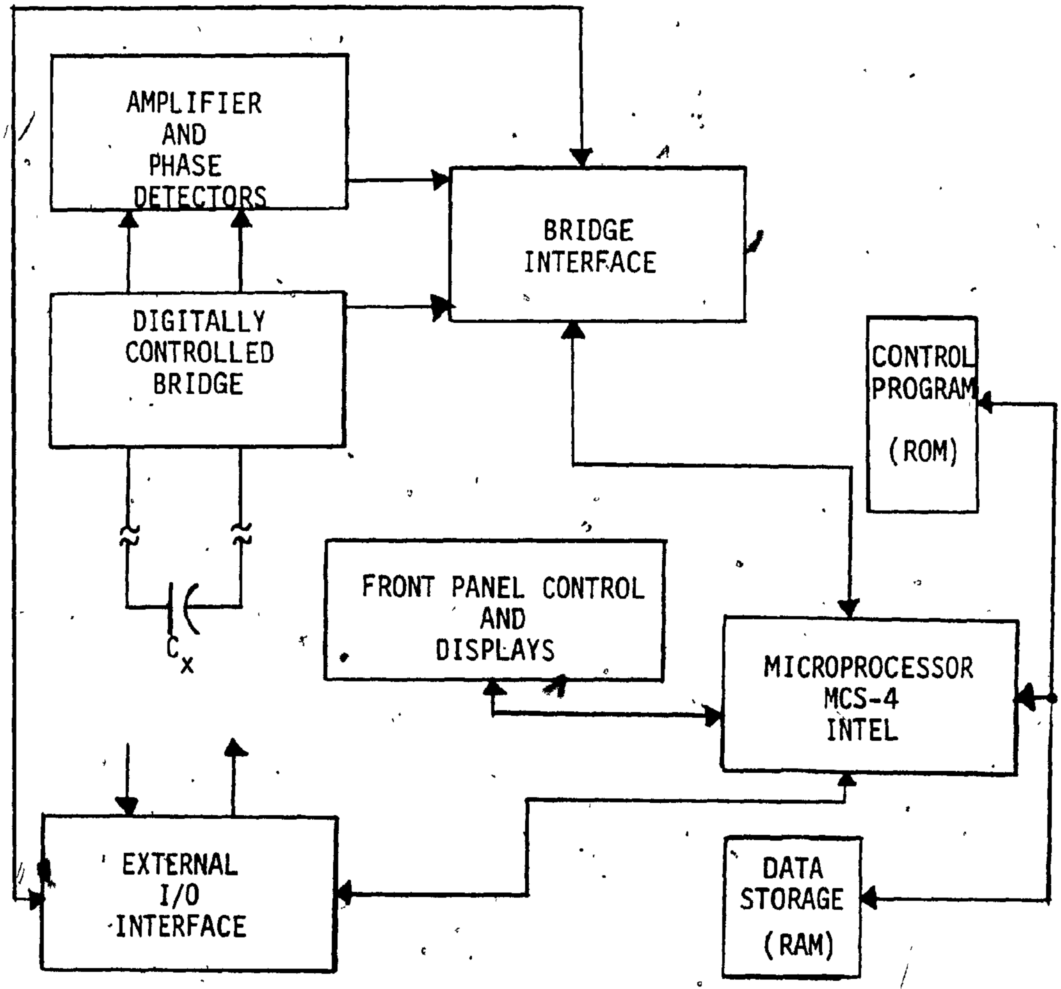

Figure 3.5 The Model 76A Capacitance Bridge

The organization of the bridge consists of a 4-bit data bus and a 4-bit address bus. The microprocessor controls the various front panel, display and I/O functions, as well as the bridge balance. It also computes the unknown capacitance, conductance, Q factor and dissipation (D). On top of this, the 76 A automatically corrects all predictable bridge errors, autoranges over 0 to 2000 pF and digitally displays the results.

Other examples of microprocessor-based instruments are the HP's 3330 frequency synthesizer, which has an internal digital processor, the Tektronix' 7704A Digital Processing Oscilloscope, which can perform calculations on its input signals, and the digital microprocessor based oscilloscope (DMO) with the Inter 8080 or the Motorola 6800 microprocessors [35].

3.3 TELECOMMUNICATIONS

Today microprocessors greatly affect the design of telecommunication systems in various ways. By using microprocessors, the designers are employing structures that provide new capability not found in earlier systems at a lower cost. Microprocessors are being used in a wide range of communication products. The structure of the microprocessor system in these products can be classified into one of the three categories shown below [36]:

1) Stand-Alone Processors
2) Distributed Processors
3) Multiprocessors

Stand-alone processors, operate independent of other controllers within a system.

Distributed processors communicate with each other through an interconnected I/O system in a distributed system.

Multiprocessors are systems where many processors are interconnected in a tightly coupled way such that the processors share resources and operate under a single operating system.

The applications of these processor structures to telecommunication systems are numerous. For example stand-alone processors are applied by Bell to Transaction telephones [37] which are used to verify credit transaction, between banks or stores and a customer service center. In a typical transaction for credit authorization, a clerk initiates a call by sliding a magnetically encoded dialing card through the reader followed by the customer's credit card. The call connection is made under microprocessor control. A computer at the customer service center receives the information from the Transaction telephone and verifies the customer's credit. The clerk is informed of credit status by either an audio response unit or through tones which instruct the microprocessor to activate indicators on the Transaction set. Another example of a stand-alone system is the 921A data test set [38], which is controlled by a microprocessor and is used in the testing of digital and voiceband analog data services within the Bell System.

The Bell System's E-telemetry network is an example of a system which employs distributed processing within a network [38]. This system collects data at remote stations and transmits them to a central location. It also controls operations at a remote station from a central location. Also the PLATON system [39], which has been introduced in Europe, employs distributed processing. This system is shown in Figure 3.6. In this arrangement, the switching function is distributed both functionally and geographically.

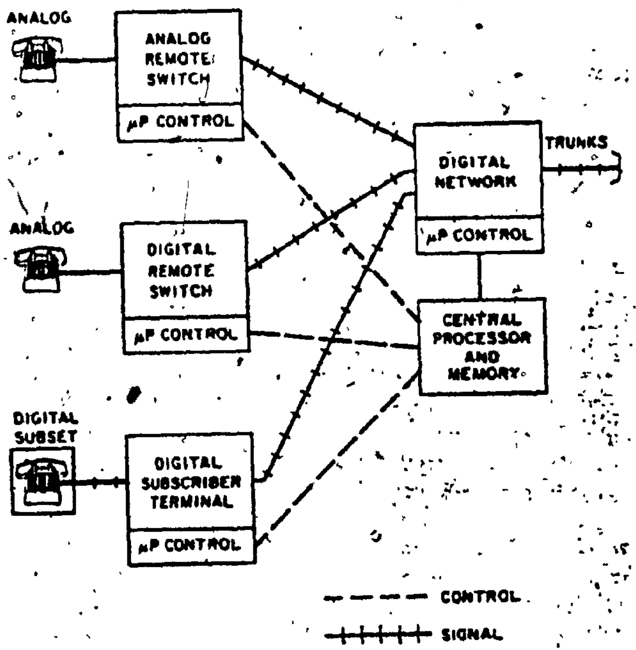

Figure 3.6 Distributed Switching in a Decentralized Network [39]

Customer lines are connected through a local switch which is controlled by one or more microprocessors. The local switches are located as close as possible to the customer equipment. These switches are capable of local functions, such as completing a call among its subscribers. The remote switches are either analog or digital switches connected to analog lines. Another alternative would be a switch connected to a subscriber terminal which transmits digital information.

The functional distribution of processing leads to less complex overall switching systems which are becoming cost effective with compact, reliable, stored program systems such as the microprocessors. The geographical distribution of the switch permits the concentration of subscriber lines onto digital trunks.

Another interesting data communications product is the CODEX 6030 Intelligent Network Processor which employs three microprocessors [41]. Generally, the 6000 series network processors designed by Codex consist of a multiple number of microprocessors which do information processing while sharing a central memory [40]. Also in communication systems the Pluribus system developed by Bolt, Beranek and Newman, Inc. [42] is being used. The Pluribus system consists of processor units communicating with several memory and I/O modules within the system. This system is being used in the Advanced Research Projects Agency (ARPA) network as the interface processor between computers and either terrestrial or satellite circuits.

Microprocessors and LSI memories provide low cost components for multiprocessor system design. Currently, designers are investigating structures for multiprocessor systems, such as Carnegie Mellon's CM [43], which will provide for networks containing hundreds of processor nodes.

Many other communication products have incorporated microprocessors such as mobile telephones [44], data sets [45], test sets [46], business telephones [37], the CM 8010 Toll Access Controller [47], and PABX's [48] - [50].

After classifying the general microprocessor applications in telecommunication systems, it is necessary to describe four significant areas where microprocessors are being used. These areas are [2]:

i) Existing networks

ii) Processor Controlled exchange

iii) Automatic Call Recording Equipments (ACRE's)

iv) Digitally switched private automatic branch exchange

3.3.1 Existing Network Applications

In the existing switched telephone networks, the relay sets interface the exchange switching equipment with the exchange lines. These relay sets have been designed to perform logic functions, timing, counting and also to signal to line and to detect line conditions. By introducing microprocessors in these existing networks a great improvement has been achieved. The timing, counting and storage functions are carried out by a microprocessor. By applying a microprocessor to a plug-in replacement, transmission of dial pulses, and fee charging pulses are performed. The completed plug-in replacement employs 39 IC's. The Intel's 8008 microprocessor is being used and is equipped with 4K of ROM program store and RAM. In Figure 3.7 the block schematic of the microprocessor controlled relay set is presented. This relay set has been installed in a local exchange and operated for 25 000 hours without failure of the IC's.

Also another mciroprocessor control equipment which replaces six relay sets in pay-on-answer coin [illegible] telephones is being used executing control of coin slots, application of pay tone, selection and counting of coin pulses and signalling of coin pulses to the operator. In this equipment the Intel's 8080 microprocessor is employed. The program is stored in 1789 8-bit words of memory. There are six channels which are supported. The sampling period is 10 ms and the time-slot* period is 1.2 msec.

A comparison of the hardware between old and new coin-box relay sets is shown in Figure 3.8.

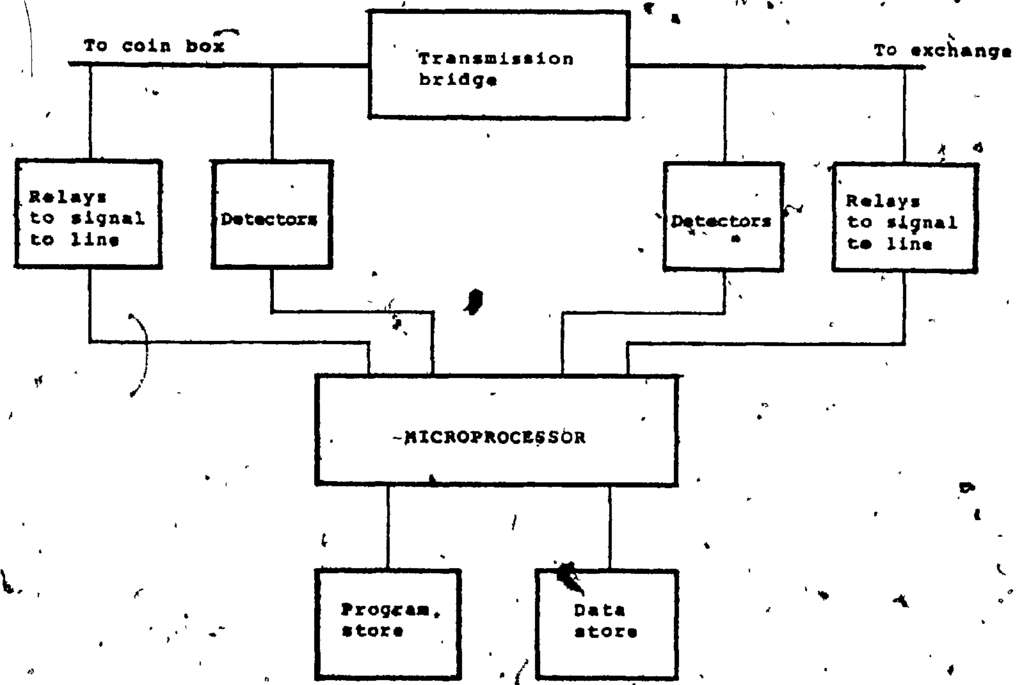

Figure 3.7 Block Schematic of Relay Set [2]

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*Time-slot = $\frac{\text{Sampling period}}{\text{Number of time-shared equipments}}$

	Existing Relay Sets	µP Controlled Relay Set
Relays	34	9
Contacts	170+	11
Relay Set/Rack	180	150
Time Between Failures	10-14 Months	3-4 Years

Figure 3.8 Coinbox Relay Set - Old and New.

3.3.2 Processor Controlled Exchange

In a small local telephone exchange microprocessors are being used to examine the signal characteristics and to interpret the signalling information by using the appropriate analysis program. Thus, a variety of telephone types can be connected to the exchange. In Figure 3.9 the processors are arranged in three levels. In the highest level the multiprocessor shares the facilities between many exchanges. In the second level the miniprocessors control the basic telephone service, and in the third level the microprocessors perform the simpler peripheral tasks.

3.3.3 Automatic Call Recording Equipment (ACRE)

The ACRE system is a multiple microprocessor system which improves the operator service by automating the billing procedures. In Figure 3.10 a schematic diagram of this system is presented.

In the manual centre, each operator has a special data entry terminal called an Operator's Position Equipment (OPE). This terminal is being used as an interface with the existing telephone

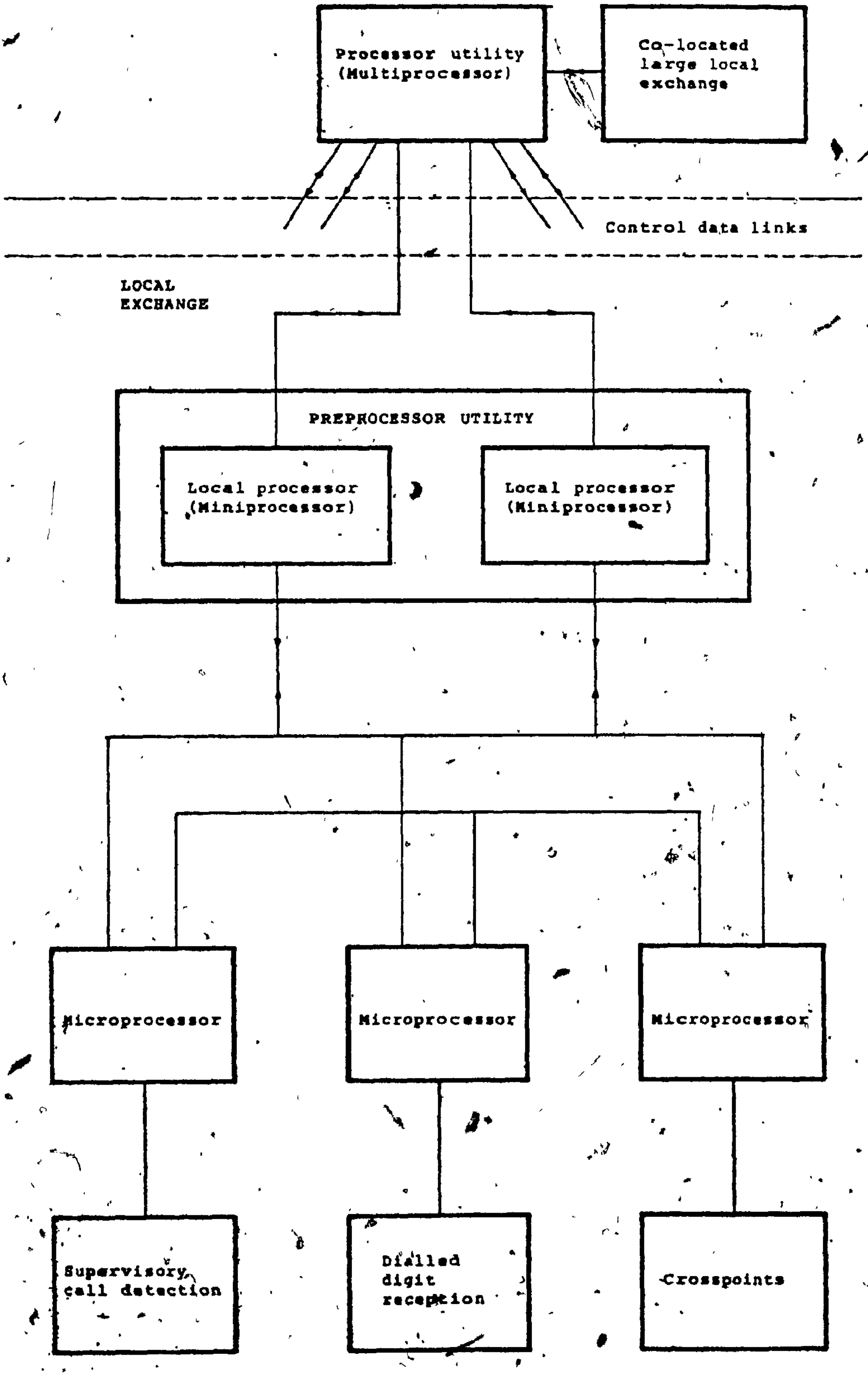

Figure 3.9 A Small Local Telephone Exchange [2]

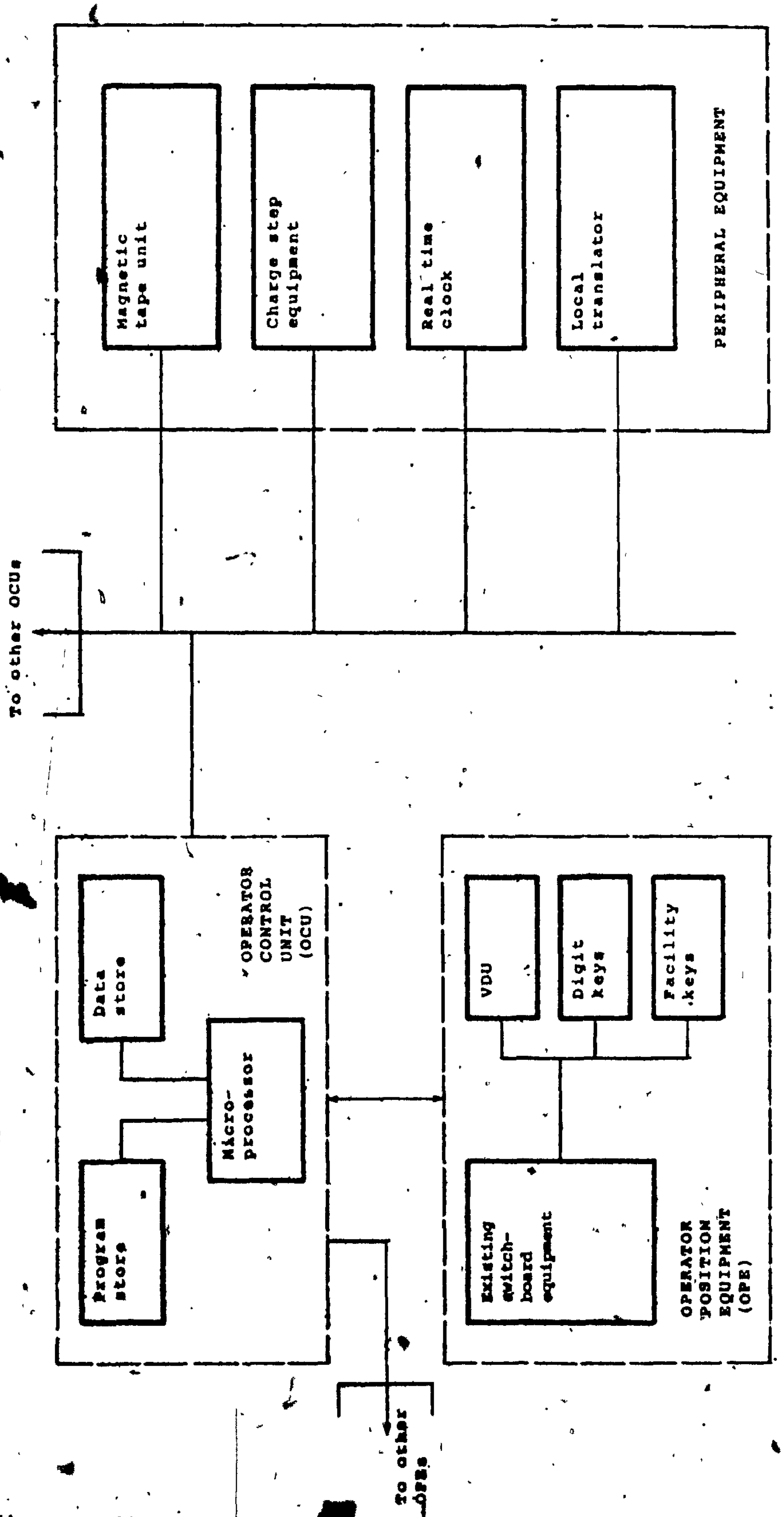

Figure 3.10 Block Schematic of ACRE System [2]

switching system. Information from the OPE is processed by an 8080 microprocessor which is in the Operator's Control Unit (OCU). The microprocessor handles charging information and performs code translation for call connections. It also records timing details and releases the connections. One OCU can support up to eight OPE's. When one OCU is failed, there exist adjacent OCU's which accomodate and extra four OPE's each. Thus, full system availability is maintained. Each OCU has a 64K 8-bit words memory.

3.3.4 Digitally Switched Private Automatic Branch Exchange

A Private Branch Exchange (PBX) is a circuit-switching system which provides service to one user organization. It has three classes of ports: 1) Extensions, which are telephones connected directly to the switch; 2) operators; and 3) trunks, which connect the switched telephone network. The PBX allows station-to-station calls without the use of the telephone network. It also allows station users to access the telephone network for outgoing calls. The PABX is a system which employs a microprocessor, pulse-code modulation (PCM) technique and time-division multiplexing (TDM). This system is an increasingly popular tool for increasing the flexibility and reducing the cost of business telephone operations.

A basic block diagram of a PABX is shown in Figure 3.11. The structure [53] employs a switching matrix for call interconnection between lines and trunks. A scanner circuit monitors the status of lines and trunks. The CPU performs all processing necessary to handle telephone calls. A small RAM is provided to store some dynamic data,

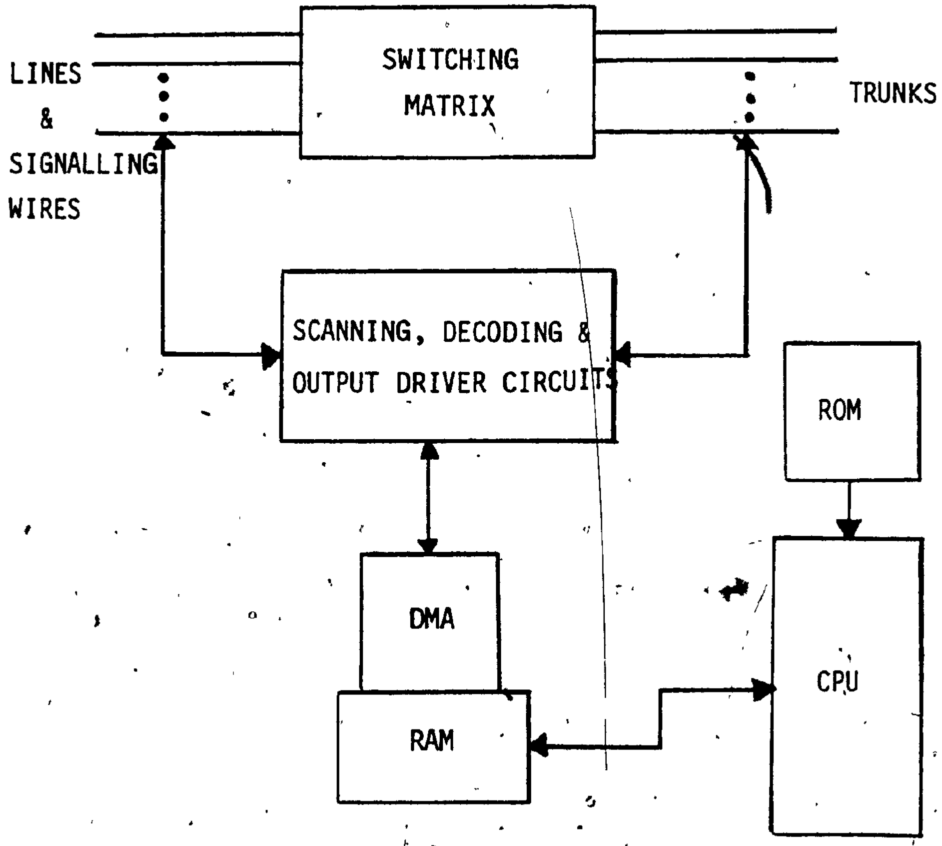

Figure 3.11 PABX - Simple Microprocessor Oriented Structure

and a ROM to store the main program. The output drivers provide the interface used for signalling purposes and also for opening and closing of crosspoints.

A specific example of such a system is the GTE Automatic

Electric's GTD-120 PABX [51] which handles 120 extensions, 28 exchange lines and can carry 36 simultaneous conversations. A block diagram of interrelationship of functional parts of GTD-120 is shown in Figure 3.12. The CPU, designed around and 8-bit microprocessor chip, includes a clock circuit (500 ns), 512 word ROM, TTL interface logic, and a 32K RAM for storing all data base information. The time switch consists of digital networks and control circuitry. It also includes three groups of A/D (encoders) and D/A (decoders) converting circuitry. Each encoder/decoder circuit has 24 channels for converting pulse amplitude modulation (PAM) voice samples from the lines and trunks to PCM signals and vice versa. The time switch cyclically scans the channel memory ever 125 μs and receives and stores in the information memory, a new voice sample. Thus, speech samples are exchanged

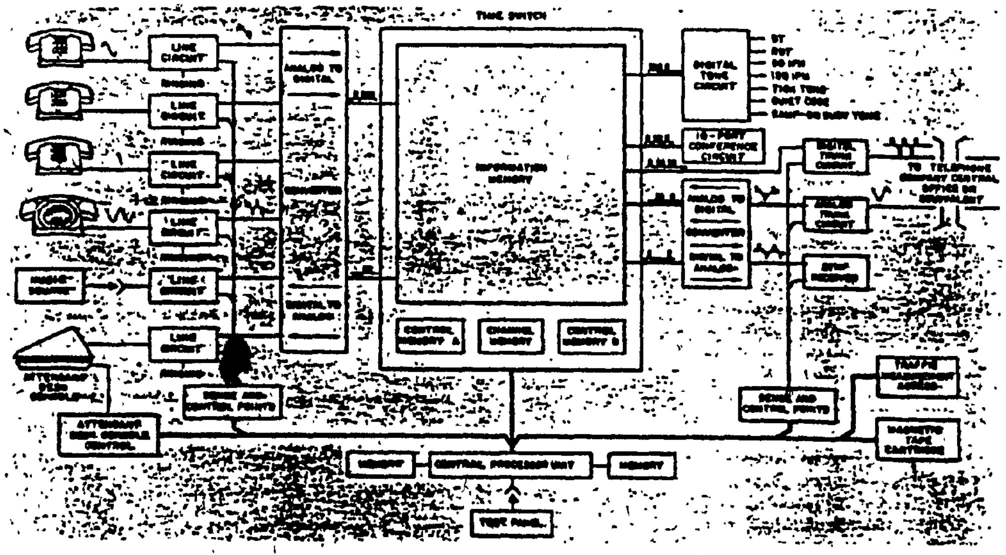

Figure 3.12 Block Diagram of GTD-120 PABX [51]

between the connected parties every 125 μsec. The GTD-120 PABX has been designed to meet both the present and future needs of the small PABX market environment. It forms a family with the GTD-1000 PABX and the GTD-4600 Digital Business Service Module.

Another advanced digital PBX is the Rolm computerized Branch Exchange [52] which employs a 16-bit microprocessor.

3.4 DATA CAPTURE

Data capture is an area where microprocessors are being used as controllers in data capture terminals and in complex industrial and laboratory applications. A typical data acquisition system designed for use in university laboratories [53] is described below as an example of data collection from a variety of test equipment. This system performs any code or speed conversion and also sends data for processing by a remote computer. The Intel's 8080 microprocessor is being employed by this system. All devices are addressed as memory locations, so I/O instructions in the microprocessor are not necessary. The organization of the system is presented in Figure 3.13.

The microprocessor is continuously polling all the devices. The status of each device is been checked by the polling program. If one device has a character ready for transmission to the remote computer, this character is transferred to a special buffer area in the memory. The processor then proceeds to poll other devices. This process continues until a complete message has been assembled. The flowchart for the main polling program is shown in Figure 3.14. A large portion of the processing involves the testing and setting of status flags.

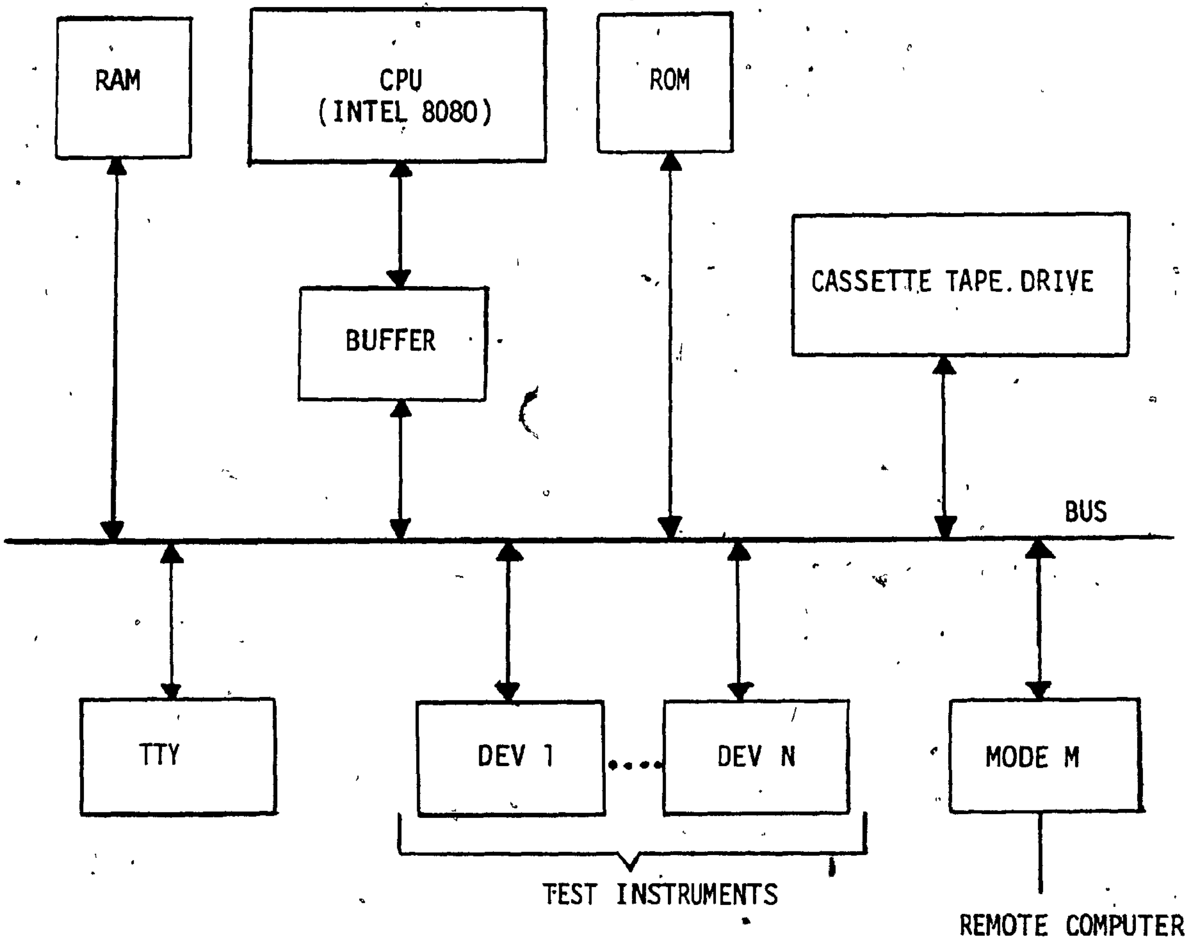

Figure 3.13 Organization of a Data Collection System

The main function of the microprocessor is that of routing and buffering messages while in transit. Most I/O operations are performed under program control. In order for the polling program to move from servicing one terminal to the next with minimum overhead, addressing modes are required. An indexed addressing could be suggested. However, this addressing mode is absent in the 8080 microprocessor. Thus, the following memory fetch is implemented to do this job: i) load the offset X into the H and L register pair [54]; ii) add the B and C register pair to H and L; and iii) load the accumulator from the memory location pointed at by the contents of registers H and L. Register pair B and C is used as an index register and the offset X is specified as an immediate operand in the first instruction. This sequence occupies 5 bytes of memory and requires 8 memory cycles for execution. A similar memory fetch with Motorola MC 6800 [55] microprocessor can be accomplished in one instruction which occupies 2 bytes and takes 5 memory cycles to execute.

Another interesting example of a microprocessor controlled data logging system is described in [56]. Also the Alphabec-75 Data Capture System which uses a 16-bit microprocessor is described in [57].

3.5 COMMERCIAL DATA PROCESSING

Commercial data processing is an under-exploited area as far as microprocessors are concerned. There exist some systems in data processing industry which make an extensive use of microprocessors. Such systems are [2]:

i) Customer-bank communications terminals.

ii) Automatic Teller Machines (Trans-Action Teller by the FDS Corporation uses three Intel 4004 microprocessors).

iii) Time and attendance terminals.

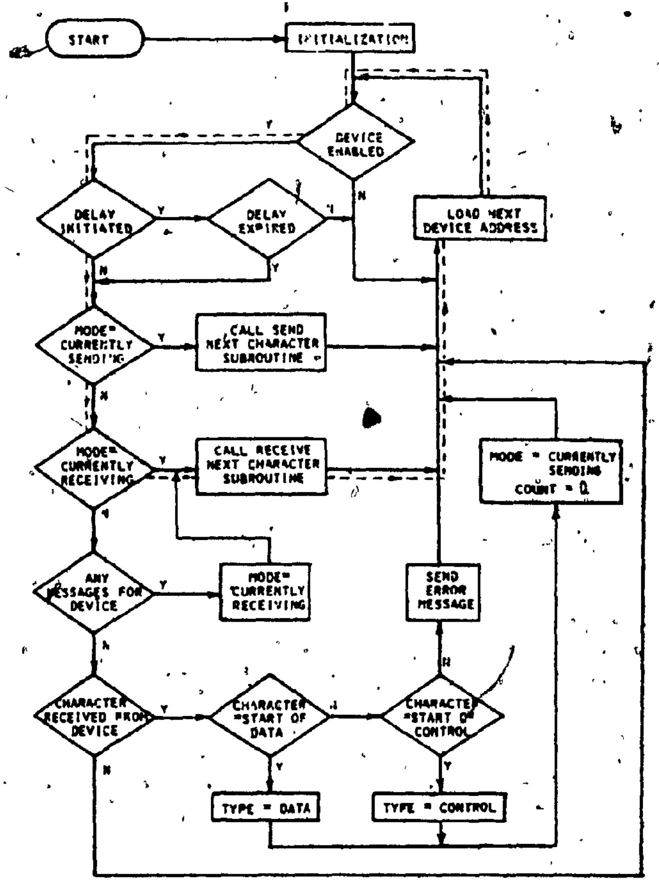

Figure 3.14 Polling Program for the Data Acquisition System [34]

iv) Cash registers (TDS series 300 uses the Rockwell PPS 4 microprocessor) [11].

v) Bar code readers (use of MC 6800 Motorola microprocessor).

This area will undoubtedly have a significant growth in the future.

3.6 PERSONAL AND SINGLE-BOARD COMPUTERS

Personal computers are computing systems bought by consumers, through computer stores for individual use. They are equipped with terminals or keyboards and video displays, and programmed in BASIC language [58].

Single-board computers are purchased from manufacturers or from electronics distributors, for industrial use. They are often used to control, measure or communicate - in real-time - any physical process. They are programmed in assembly or system-oriented languages.

However, both personal and single-board computers exploit microprocessor technology.

Personal computers are being used for entertainment, problem solving, education, home and personal management and for database and communications services [59]. In Table 3.1 the existing hobby/personal computer mainframes and terminals are presented including CPU, chassis, IK byte RAM, power, ROM, video, cassette, and I/O interfaces keyboard[58].

Single-board computers offer low-cost, flexibility and a wide range of applications such as machine or process control, instrumentation, test equipment, communications and peripheral controllers. The existing single-board computers are presented in Table 3.2 including CPU, RAM, parallel I/O, serial I/O, and timers.

Personal and single-board computers are based on many engineering innovations and low cost.

Table 3.1

Hobby/Personal Computer Mainframes and Terminals [58]

SYSTEM	DESCRIPTION	CPU	BUS	KIT PRICE	ASSEMBLED PRICE	MANUFACTURER
ALTAIR 8800B	Enhanced Altair panel lights, switches	8080	S100	$750	$ 995	MITS Albuquerque, NM
BYT 8	6 slots, no RAM	8080	S100	$349	$ 525*	Byte Inc. Santa Clara, CA
CROMEMCO Z2	21 slots, no RAM	Z80	S100	$595	$ 995	CROMEMCO Mountain View, CA
DIGITAL GROUP	2K byte RAM, 64 I/O lines, video interface	Z80	DG	$475	$ 695	Digital Group Denver, CO
HEATHKIT H8	Hex keyboard, displays	8080	Heath	quasi:	$ 514	Heath Benton Harbor, MI
HEATHKIT H11	8K bytes RAM	LSI-11	Q BUS	quasi:	$1295	Heath Benton Harbor, MI
HORIZON H-1	16K bytes RAM, mini floppy disk, serial interface	Z80	S100	$1599	$1899	North Star Computers Berkeley, CA
IMSAI 8080	panel lights, switches	8080	S100	$699	$ 931	IMSAI San Leandro, CA
OSI 500-1 CHALLENGER	4K bytes RAM 8K byte BASIC ROM serial interface	6502	OSI	$ NA	$ 429	Ohio Scientific Hiram, OH
POLY 88	video interface cassette interface no RAM, 1K byte ROM	8080	S100	$735	$1175	Polymorphic Systems Goleta, CA
SWTPC 6800	4K bytes RAM serial interface	6800	SWTPC	$395	$ 595*	Southwest Technical Products, San Antonio, TX
VECTOR 1	Real time clock 2K bytes RAM,	8080	S100	$619	$ 849	Vector Graphic Westlake Village, CA
XITAN ALPHA 1	2K bytes RAM, 2K bytes ROM, 2 serial interfaces	Z80	S100	$ 769	$1039	Technical Design Labs Princeton, NJ

NA – Not Available as kit
* – Retail computer store will assemble

Prices Subject to Revision

SYSTEM	DESCRIPTION	CPU	BUS	KIT PRICE	ASSEMBLED PRICE	MANUFACTURER
SOL TERMINAL	Black & white video	8080	S100	$ 995	$1495	Processor Technology Emeryville, CA
APPLE II	Color video, 4K byte RAM, 8K byte BASIC ROM	6502	Apple	NA	$1298	Apple Computer Cupertino, CA
PET 2001	9" video display, Cassette recorder, 8K byte BASIC ROM, 4K byte RAM, IEEE-488 interface	6502	PET	NA	$ 595	Commodore Palo Alto, CA
TRS 80	12" video display, Cassette recorder, 4K byte BASIC ROM, 4K byte RAM	Z80	TRS	NA	$ 599	Radio Shack Fort Worth, TX

NA – Not available as kit

Prices Subject to Revision

Table 3.2

Single-Board Computers [58]

SYSTEM	CPU	BUS	PRICE QTY 100	RAM ON BOARD (BYTES)	PROM CAPACITY (BYTES)	PARALLEL I/O LINES	SERIAL I/O INTERFACE	TIMERS	INTERRUPT LEVELS	MANUFACTURER
Fairchild OCM 1	F8	none	$249	1K	2K	32	1	2	1	Fairchild Mountain View, CA
Intel iSBC 80/10A	8080	MULTIBUS Single master	$295	1K	8K	48	1	0	1	Intel Santa Clara, CA
iSBC 80/04	8085	none	$ 99	256	4K	22	1 (CPU)	1	3	Intel Santa Clara, CA
iSBC 80/05	8085	MULTIBUS Multimaster	$195	512	4K	22	1 (CPU)	1	3	Intel Santa Clara, CA
iSBC 80/20	8080	MULTIBUS Multimaster	$440	2K	4K	48	1	2	8	Intel Santa Clara, CA
iSBC 80/20-4	8080	MULTIBUS Multimaster	$495	4K	8K	48	1	2	8	Intel Santa Clara, CA
Motorola M68MM01	6800	Motorola BUS Single master	$275	1K	4K	48	0	0	2	Motorola Phoenix, AR
M68MM01A	6800	Motorola BUS Single master	$295	1K	8K	32	1	0	2	Motorola Phoenix, AR
Mostek SDB-80	Z80	Mostek BUS Single master	$520	16K	5K	32	1	3	2	Mostek Carrollton, TX
National BLC 80/10	8080	MULTIBUS Single master	$266	1K	4K	48	1	0	1	Nat'l Semiconductor Santa Clara, CA
TI TM 990/100M	9900	TI 100M BUS Single master	$300	512	8K	16	1	2	6	Texas Instruments Dallas, TX
Zilog	Z80	Zilog BUS Single master	$319	4K	8K	16	1	3	2	Zilog Cupertino, CA

Prices Subject to Revision

3.7 CONSUMER PRODUCTS

Microprocessors have an impact in a vast array of consumer products like calculators, microwave ovens, and home entertainment products [61].

Calculators of increasingly higher complexity levels appear daily in the market at lower prices.

Microwave ovens which require very precise timing employ microprocessors like the Litton's Model 460 Memorymatic (microcomputer TI TMS 1000) and the Amana RR-9 Radarange (microprocessor from General Instrument Corporation) [60].

Home entertainment microprocessor-based products exist in a very large number. Nonvideo intelligent games and programmable video games cover a large part in home entertainment products. The Parket Brothers "Code Name: Sector", the Milton Bradley's "Battleship" and the Mattel Inc.'s "Football" are all microcomputer-based games. References [62] - [63] present additional details on these games. Also the Fairchild Video Entertainment System (VES) and the Atari Video Computer System are microprocessor-based programmable video game products.

The Fairchild VES system employs the F8 microprocessor and consists of over 40 IC's. The Atari system consists only of 5 IC's [60].

Another remarkable programmable video game is the RCA Studio II which is organized around the COSMAC microprocessor [60], [64].

The Accutrac 4000, an intelligent turntable, is also a microcomputer-based high-quality system. This turntable can be programmed to sequence through the tracks in any order, repeat favorite selections, reject to the next record, or turn the device on/off. With regards to the future, microprocessors will maintain and consolidate their position in the consumer products.

3.8 COMPUTER PERIPHERAL DEVICES

A lot of computer peripheral devices are using microprocessors. Three categories are exposed below [65].

i) Input devices such as keyboards and label scanning wands;
ii) Output devices such as visual displays and hand-copy printers;
iii) Data interchange devices such as teletype terminals, tape cassettes, and floppy disks.

In all these categories, high performance microprocessors like the MC 6800 provide an efficient means for controlling the devices.

More detailed trends are described in literature [65], regarding keyboards, for manual entry of data, scanning wands for capturing data from printed symbols, the SEIKO AN-101F printer, floppy disk controllers, and the SA 900/901 diskette storage drive. All of the above employ the MC 6800 microprocessor with the MC 6820 PIA (peripheral interface adapter) and the MC 6850 ACIA (Asynchronous Communication Interface Adapter).

To illustrate the significant role of the microprocessors in this area, an example of the SEIKO AN-101F printer, controlled by the MC 6800 microprocessor, is being presented below.

3.8.1 Printer Controller

The SEIKO AN-1-1F Printer uses a continuously rotating drum as it is shown in Figure 3.15a [65]. The trigger magnet causes

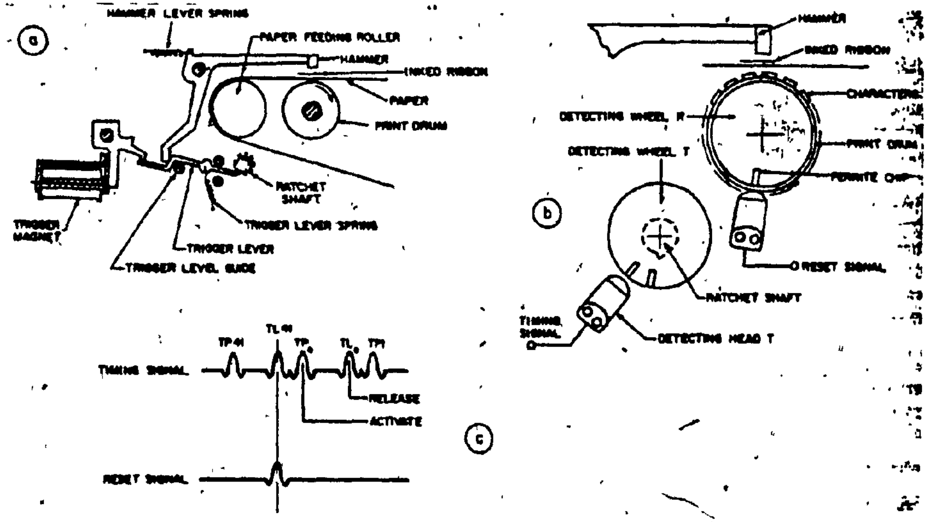

Figure 3.15 SEIKO AN-101 Printing Mechanism and Timing Signals [65]

the hammer to strike the paper through the inked ribbon and to print a character. Any of 42 characters (alphanumeric plus special characters*, $, ", -, and/) can be printed in 21-column format. Each column position has a complete character set spaced evenly around the drum. A given character appears once during every revolution of the drum and is the same for all column positions. The hammers operate in parallel. All column positions, that have the same letter, have the corresponding lines (trigger magnets) armed simultaneously.

The hammers are actuated by the control circuitry at the right instant if printing is to occur. Timing signals are generated by detection heads and ferrite magnets associated with the ratchet shaft and drum. The ratchet shaft rotates 42 times to each rotation of the drum and generates signals TP and TL for each character (Figure 3.15b). TP defines the time for energization of the trigger magnets and TL the de-energization. The reset signal R occurs once in each drum revolution and indicates the completion of a print line as well as the need to advance paper and ribbon (Figure 3.15c).

The control circuit is organized around the MC 6800 microprocessor with Motorola's MC 6820 PIA. The PIA internally is divided into two symmetrical but independent register configurations. Each half contains an output register, control register and data-direction register. In Figure 3.16 and 3.17 the control circuit of the printer and the internal structure of the interface are presented respectively. In Figure 3.16 it is shown that the PIA appears as an adapter of six memory locations that can be addressed in the same manner as main memory.

Each hammer driver is controlled by one of the PIA's 16 data lines. These lines are the outputs of registers ORA (output register A) and ORB (output register B) in the PIA, which are regarded as memory locations by the MPU. Hence the MPU enables the activation of a particular column hammer by setting the appropriate bit position

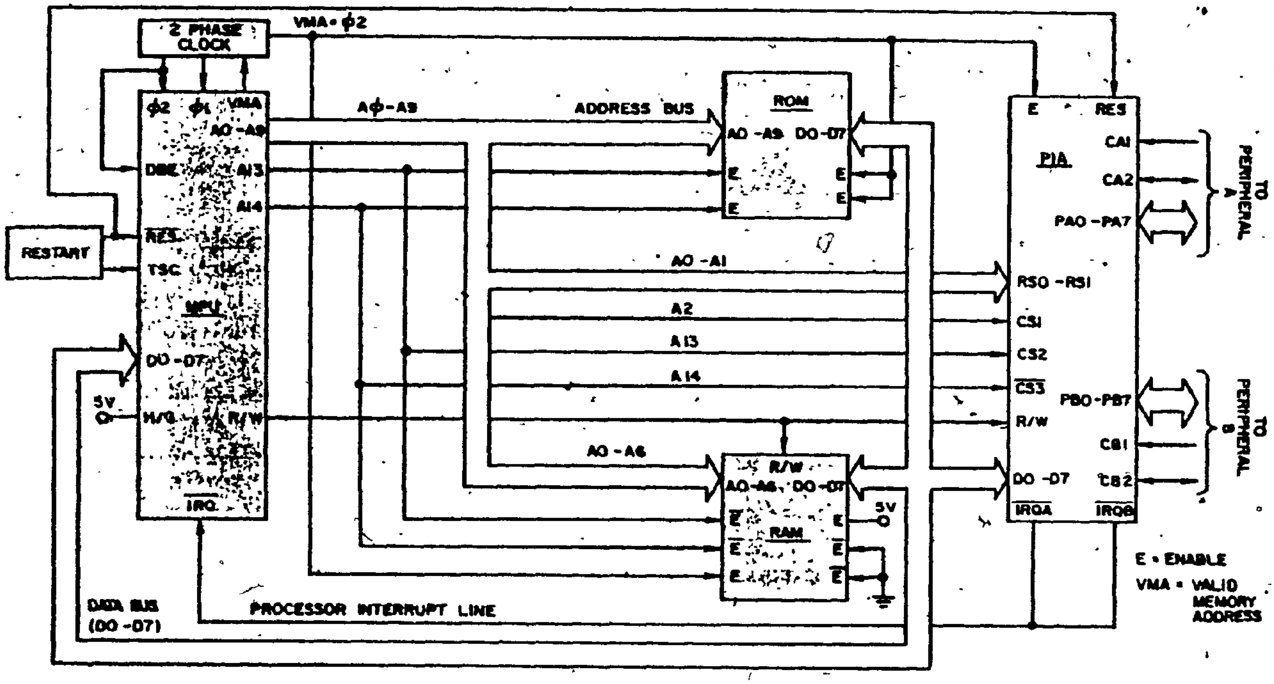

Figure 3.16 The Control Circuit of the Printer [65]

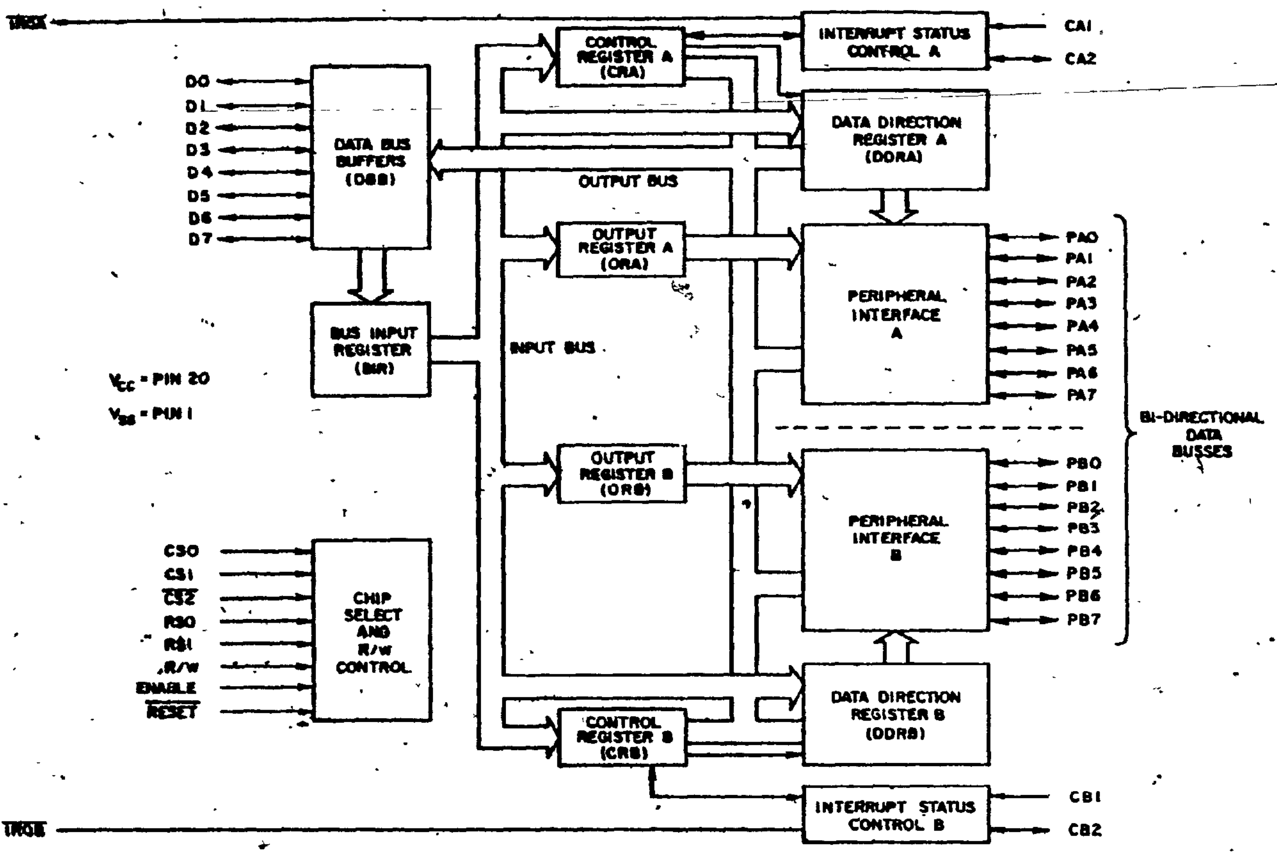

Figure 3.17 The Internal Structure of the Interface [65]

in the memory locations assigned to ORA and ORB (Figure 3.18).

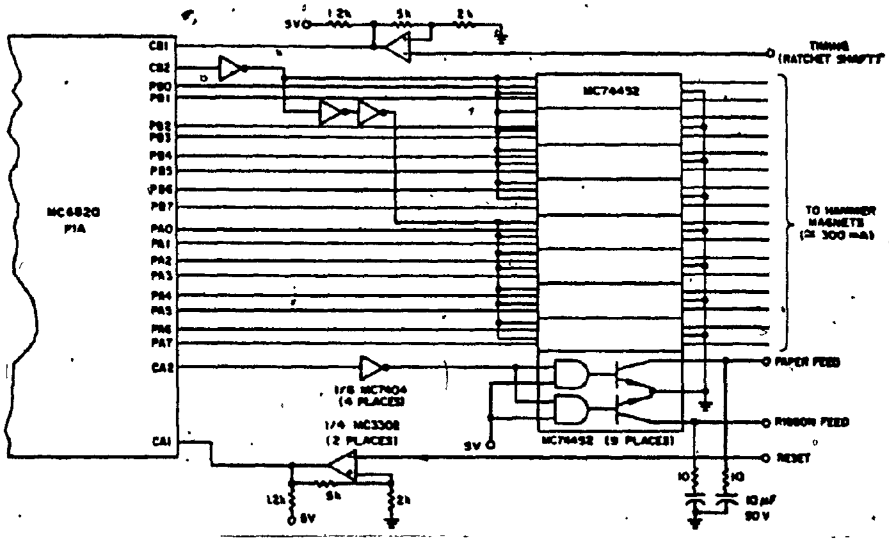

Figure 3.18 SEIKO Printer Circuit Requirements [65]

The time for one print-drum rotation is divided into 42 intervals, t_0 through t_{41}. All similar characters in the text are printed simultaneously.

After each TL interrupt, the microprocessor examines the entire message to see if there are any characters to be printed during the next time interval.

Messages are stored in memory in 16-byte blocks, with each memory position corresponding to a printer column position. The address of the message to be printed is loaded into a buffer, prior to calling the printer. The printer routine then uses this address in conjunction with the MPU's indexed addressing mode to locate the desired message.

A 42-byte Character File, corresponding to the printer's character set, is stored in a ROM in the same sequence as it appears on the printer drum. The Character File pointer is incremented and points to the address of the next character on the drum, as each TL interrupt is serviced. The microprocessor then compares every character of the text with the current Character File character and keeps a running column count.

There exist some subroutines which serve as control programs to perform four tasks: 1) Initialization (PKIRT) [65]; 2) Printer Enable (PKNTRL); 3) Reset Service Routine (PRNTIR); 4) Print Service Routine (PRNTIT). During initialization all the driver circuits are disabled and the PIA's interrupts are masked. With the Printer Enable routine the interrupt is enabled and the printer "tells" the MPU that it requires servicing. With the Print Service routine the hammers are engaged and disengaged at the required times. Most of the processor time (approximately 0.6 ms following each TL pulse) is spent determining which hammers should be engaged during the next interval. Finally, with the Reset Service Routine the printer's paper and ribbon are advanced. This requires a 36-ms pulse.

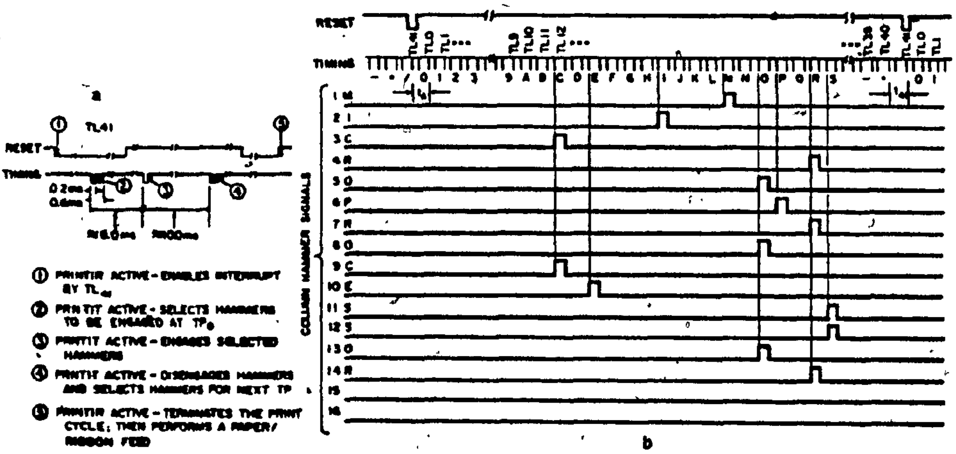

Figure 3.19 Print Cycle Timing: "Microprocessor" [65]

The printer timing signals are asynchronous with respect to the microprocessor clock. So, when the printer is enabled immediately following an interrupt, it takes approximately 1.5 sec., to print a line of text. But the printer does not require continuous control during this period. The printer signals may be used to interrupt the MPU briefly while it is performing other tasks. The relationship between the printer signals and MPU activity is shown in Figure 3.19

3.9 AUTOMOTIVE INDUSTRY

Microprocessors have started to influence automotive industry. Although, they almost exist in the developmental level, the forecast of what can be achieved by them in the near future is rather favourable. There are some factors which cause changes in the organization of the custom microprocessors. Such factors are the following: long-term reliability, high-speed continuous real time performance, electrical and physical environments and adaptability [66]. Different microprocessor designs will evolve to satisfy these factors. At the present time, there exist tentative and hypothetical systems [66] which involve microprocessors in the development phases and are not yet ready for mass production.

Thus, the possible next generation electronic controllers, input sensors, output actuators and display panels for automotive engine management will employ new microprocessors which will be filled with unique sequences of instructions and will fit a wide variety of changing circumstances and a variety of car models.

Intel, Texas Instruments, RCA, Motorola and Toshiba are companies which develop such microprocessors. Ford intends to use a 12-bit system from Toshiba, for a 6000 cc V-8 engine.

General Motor plans to use an 8-bit system from Motorola. Chrysler has made a contract with TI to use the 9900 series NMOS micro in a future engine control system. The same company has cooperated with RCA for engine control work.

In Japan an experimental car with a central microprocessor system has already been produced.

3.10 BIOMEDICAL SYSTEMS

There exists a large number of biomedical instruments and systems which employ microprocessors. They are either commercially available or in varying states of testing.

One of the most commonly monitored physiological variable is blood pressure. A microprocessor monitor for the electrocardiogram (EKG) and blood pressure has been developed which provides a day long analysis of EKG signals and periodic recordings of blood pressure. This system is presented in Figure 3.20. It monitors the pressure, digitizes the input signals, computes the systolic and diastolic pressures, and records the results. There are three input signals to the system. The output of the pressure transducer which converts the cuff pressure to an analog voltage; the output of a crystal microphone inserted under the cuff which picks up the Korotkoff sounds [68]; and a single channel EKG signal. These signals pass through differential amplifiers with high impedance and high gain.

The Korotkoff sounds and the EKG signal are passed through low pass filters (110-Hz cutoff) to eliminate aliasing problems associated with sampling.

The resultant three signals are sampled (256 samples/s) by a four channel (one-input grounded) multiplexer and are then coupled to a 10-bit single polarity ADC. Between the multiplexer and the ADC exists a summing amplifier which primarily acts as a voltage level

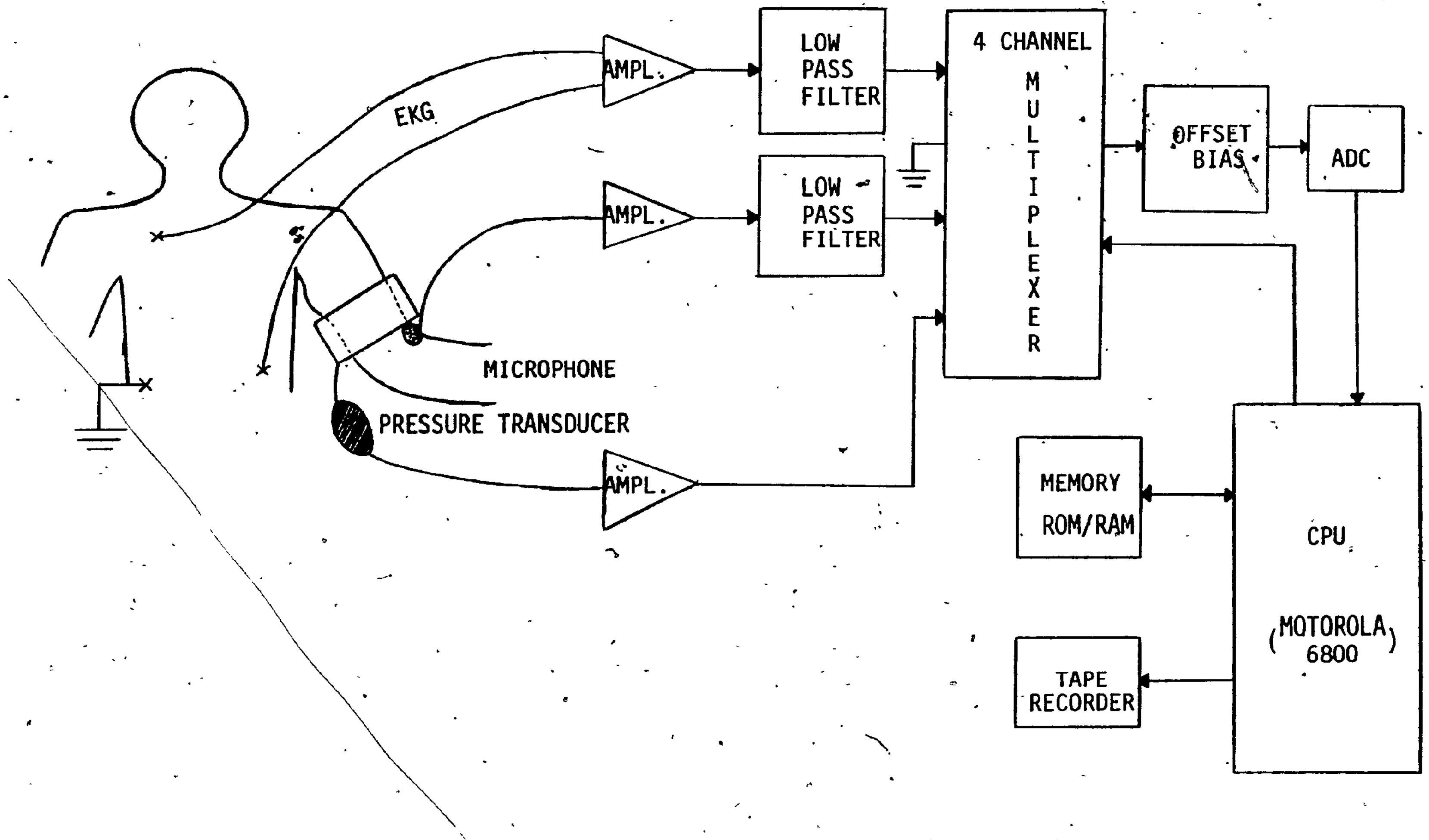

Figure 3.20 System Block Diagram of a EKG and Blood Pressure Monitor

shifter. It converts the dual polarity analog input signals to a negative polarity signal for the ADC. It also acts as an analog signal amplifier, an one pole low pass filter and as a buffer.

The heart of the system is the Motorola MC 6800 microprocessor. The microprocessor controls the multiplexer; the ADC is self-timed (140 μs) and accesses the CPU interrupt line and data bus via a peripheral interface adapter. The microprocessor loads all the data for a blood pressure measurement through the ADC.

3.10.1 Blood Pressure Measurement Algorithm

The blood pressure is determined from the comparison of the frequency spectrum of the Korotkoff sounds associated with previous heartbeats relative to the spectrum of the current beat. When changes in specific frequency components exceed a fixed threshold, then the systolic and diastolic points are identified [69].

At the start of the measurement, the offset bias is established. The microprocessor selects the cuff pressure signal and waits until the pressure exceeds a fixed threshold for one second. Then a LED indicator is turned on to notify the operator that the threshold has been exceeded and that the measurement process is about to begin. Once the light comes on, the operator stops inflation of the cuff. At this time the microprocessor enters a five second wait period to allow the operator to respond to the light and the pressure to settle in the cuff. During the first second, the EKG signal is sampled for dynamic range and a threshold for QRS* slope identification

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* QRS slope is taken from the response of an EKG; it determines whether the patient suffers from a cardiovascular disorder or not.

is established. In the last 4 seconds the cuff pressure is gradually eased . The LED is turned off to indicate the starting of processing. The EKG is then continuously sampled until a new QRS complex is ~~identified.~~ The microprocessor monitors the EKG signal to detect each heartbeat in order to sample the Korotkoff sounds. The QRS identification necessitates sampling the EKG for several heartbeats (during the five seconds wait period), using an one-second sampling window, testing for negative slope and retaining twenty percent of the slope as a threshold. Thus, QRS complexes are identified. Following that stage, the microprocessor waits approximately 140 milliseconds before sampling the Korotkoff sounds. This delay gives time to the blood pressure to rise in the artery. Then the microprocessor selects the cuff pressure and stores it in the memory. The next step for the microprocessor is to determine the spectral response of each sound by using the Fast Fourier Transform (FFT). This is the major operation of the microprocessor. To minimize processing time a 32 point sample window is used. Also the number of multiplications is minimized by using the shift and add/no add technique. The microprocessor stores sixteen consecutive samples of Korotkoff sounds; it loads the next sixteen samples and performs the FFT.

After the FFT has been completed, a comparison between the transform results to the previous results is performed. That is, adjacent responses are compared for differences in certain spectral characteristics. If there is an increase above a preset value in the 18-26 Hz range, then the systolic point is obtained;

if a decrease exists in the 60-75 Hz range, then the diastolic point is received . If both systolic and diastolic points are not obtained within a fixed number of beats, an escape condition terminates the algorithm.

3.10.2 Other Biomedical Applications

A large number of microprocessor applications exist in different disciplines, such as:

Anesthesiology [70]; cardiology [71] - [75]; neurology [76] - [78]; obstetrics [79] - [80]; ophthalmology [81]; psychology [82] - [84]; physiology [83] - [87]; radiology [88] - [91] and rehabilitation medicine [92] - [94].

Examination of the literature gives the picture that the possibilities for microprocessor applications in medicine appear almost limitless.

3.11 FUTURE APPLICATIONS

In addition to those application areas which have been exposed in the foregoing paragraphs, there are other areas in which microprocessors will maintain and consolidate their position in the future. Such areas are:

i) Commercial data processing
ii) Automobiles
iii) Domestic products

Applications in the commercial data processing area includes communication systems, data capture, cash registers, stock control systems and electronic funds transfer. The data processing world is just in the beginning of the microprocessors era [61].

It has been mentioned (section 3.9) that automotive industry will have a remarkable growth in the future due to the use of microprocessors. Companies such as Intel, RCA, Texas Instruments, Toshiba and Motorola will develop microprocessors for U.S. A. and Japanese motor manufacturers [95].

There is a prediction [61], that by 1980 there will be about ten microprocessors in every home. Some of the possible areas in which microprocessors will have an impact are: washing machines, central heating, lighting systems, home entertainment, and alarm systems.

Summary

An overview of microprocessor applications has been presented in this chapter.

Microprocessors have an impact on the test equipment from both the automation and instrumentation points of view.

In process control telecommunications and biomedicine microprocessors have a major impact on equipment design. The new equipment is more economical, more flexible, more reliable, more powerful, and realizes a greatly improved human interface.

Finally, the consumer area will absorb the largest volume of microprocessors, particularly in the automotive, games and appliance areas.

CHAPTER 4

EVALUATION AND SELECTION

The last chapter of this project report gives the answer to two questions associated with microprocessors:

a) Does the microprocessor solve a design problem, or is an alternative technology more suitable?

b) Which microprocessor is the best for a specific application?

Factors which play significant role in evaluation and selection of microprocessors are examined.

4.1 HARDWARE FAMILIES

When a particular application is under investigation, and microprocessors are among the candidate technologies to be used, the following alternatives must be taken into consideration:

a) Minicomputers

b) Microprocessors

c) Random logic

In order to make the decision between these hardware families some significant factors will be examined in the following sections.

The above three hardware families will be examined for processing and control purposes.

4.1.1 Minicomputers or Microprocessors

The major difference between the minicomputer and the microprocessor lies in their completeness. The minicomputer consists of the memory, clock circuits, bus interfaces, CPU etc. All of them are mounted on a board and they are ready for use. In some cases the CPU of the minicomputer is itself a single chip microprocessor.

Both minicomputers and microprocessors when considered as processing devices, may be used in different applications.

Since minicomputers are general purpose systems they may be used in scientific and business applications. Microprocessors, being designed for specific functions, can be used in systems with limited performance i.e., desk top computers/calculators etc. The examples which have been considered in chapter 3, concerning different application areas, show the use of minicomputers and microprocessors. As a matter of fact, in process control, telecommunications, data capture and commercial data processing, both minicomputers and microprocessors may be used depending upon the application requirements, while in testing and instrumentation, consumer products, personal computers and biomedical systems microprocessors are preferable.

In Table 4.1 the factors which determine the suitability of minicomputers or microprocessors are presented.

Table 4.1

Minicomputers versus Microprocessors

Factors	Minicomputers	Microprocessors
Type of devices	General purpose	Specific function
Control	Many inputs and outputs	Few inputs and outputs
Speed	High speed	Low speed
Use	Complex (need operators)	Simple
Cost	High	Low
Flexibility	High	Low

The fundamental factors involved in the decision between a microprocessor and a minicomputer are cost and facility level. However, it is clear that the minicomputer is a more powerful, costlier, larger and a more flexible machine than the microprocessor. Nevertheless, in many applications they are both capable of providing an excellent implementation.

4.1.2 Microprocessor or Random Logic

Microprocessors and random logic, when considered for control purpose, have different attributes. The microprocessor replaces hardware by software. The logical functions are implemented by code stored in memory rather than by permanent interconnection patterns between components. This reduces the production cost, size, weight and component count; it also increases reliability.

It has been shown [96] that the direct cost of putting an integrated circuit of random logic into a system is about $158 including manufacture, power supply and testing. The cost of using a microprocessor to implement the gating function are considerably less provided of course that a sufficient number of gates are required. Thus, a 500 gate equivalent network can be implemented using a microprocessor design for less than $15.

Another factor which is presented considering the alternative - microprocessor or random logic - is the development time. Savings may be made throughout the development cycle with microprocessors.

The production of a system is speeded up because a microprogrammed implementation enables modifications to be made later in the development cycle. System and logic design is implemented as a program and development aids such as compilers facilitate this process.

However, all these advantages of the microprocessor approach have to be considered in relation to the software cost. When a large number of systems are developed, the software costs can be distributed over the systems, so that the cost per system will be acceptable. When only a small number of systems are produced, then perhaps there is no alternative but to use a microprocessor; therefore the high software costs must be justified and become accepted. When systems are produced in reasonable quantities, the software is growing in complexity, so that the product continues to have a marketing advantage. In these situations the software cost per system is extremely relevant to the overall profitability of the venture [97].

Reliability and security are factors which have to be considered, especially in telecommunication systems. Hence, each application needs different consideration. However, two general principles apply.

- If flexibility is the most critical feature of an application, microprocessors are the choice.
- Since microprocessors are essentially sequential machines, they are best suited to tackling sequential problems.

In addition, while microprocessors need standard hardware and new programs can be developed using them, random logic needs rewiring and it is faster.

However, there exist applications where both microprocessors and random logic can be used. In such hybrid systems the approach is to use microprocessors to perform the sequential operations and to employ random logic for combinational or sequential functions where high speed is required, as for example in real-time working. Thus, exploiting the advantages of microprocessors and random logic.

The main trade offs which determine the suitability of microprocessors or random logic for an application implementation are presented in Table 4.2.

Also, in Figure 4.1 a flowchart can help in the process of choosing between microprocessors or random logic.

Table 4.2

Microprocessors versus Random Logic

Trade Offs	Microprocessors	Random Logic
Applicability	Suited to sequential problems	Suited to time independent problems
Speed	Moderate	High
Flexibility	Very flexible	Difficult to modify and expand
Relative cost	Cheap in large numbers	Cheap in small numbers
Power consumption	Low	High
Utilization	Complex problems	Simple problems
Number of packages	Few	Many
Expertise requirements	Software	Hardware
Limitation on I/O	Limited	No limit

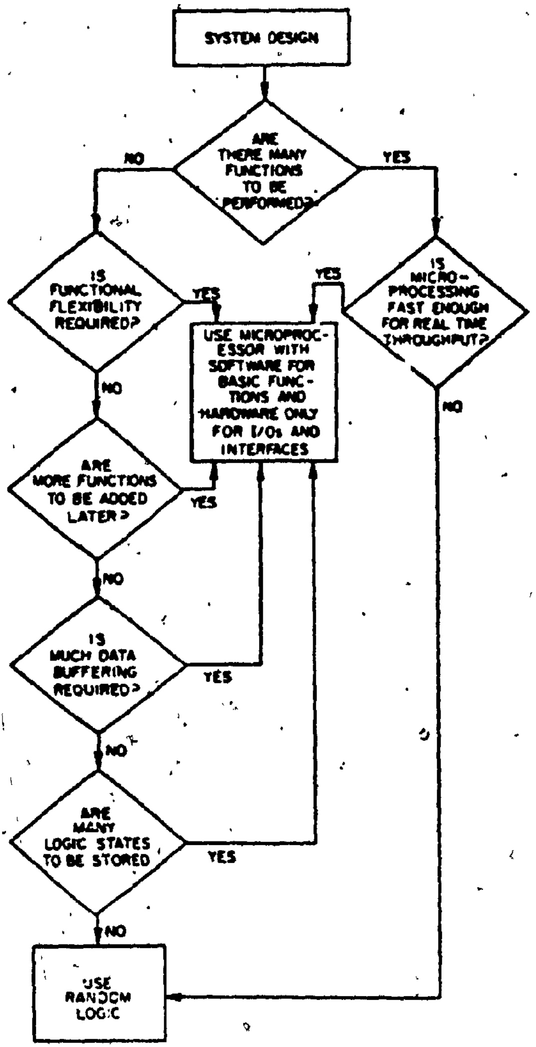

Figure 4.1 Flowchart which Helps in the Process of Choosing between Microprocessors or Random Logic [34]

4.2 MICROPROCESSOR CHOICE

If, for a particular application, the decision has been made, and there is no other alternative but to use a microprocessor, then the selection of the appropriate microprocessor is a question of considering in detail the requirements of the application and investigating the market in terms of these requirements.

The main requirements in an application are [98]:

1) Performance: The performance includes some factors such as instruction format, data word length, I/O rate and format. The appropriate microprocessor can be chosen by comparing required performance with the microprocessor functional and electrical specifications.

2) Availability: This factor has to be considered when anticipating the use of advanced devices.

3) Cost: The cost comparison must be based on total system costs, because different microprocessors may require additional peripheral circuits due to speed requirements, I/O device availability or architectural configuration. The cost estimates must take into account software and its requirements.

4) Physical structure: The package type and the pin count determine the number of boards required and the trade-off between data word length, memory addressing capabilities, and speed.

5) Programming: The amount of memory required for a given application is equivalent to the number of instructions and data words required in the application program. The programming efficiency for

a given application is a function of the instruction set available.

6) <u>Reliability</u>: Although the reliability of an SSI device is slightly higher than that of an LSI device, a much higher system reliability can be achieved using LSI devices. The reason for that is the fewer LSI devices required for a given system, and the fewer external bonds permitted in an LSI device.

7) <u>Second sourcing</u>: This factor is a significant consideration in microprocessor selection. In the past, second sourcing of microprocessors was inadequate; nowadays many manufacturers duplicate the detailed characteristics of a device (i.e., timing, voltages, etc).

8) <u>Testing</u>: It is a time consuming and expensive factor for microprocessors. Testing consideration is required at each of the various processing and assembly levels.

Also, there exist some other factors which are involved in microprocessor selection. Such factors are chip technology and support hardware. Although chip technology is a secondary selection criterion, speed, size, power supply, second sourcing and cost are the primary requirements rather than the technology itself. The support hardware supplied by the manufacturers of the microprocessor is one of the choices to be made concerning a particular application. The second choice is a special-purpose logic built by the designer. Circuits such as clock generators, memory and I/O decoders are required to complete the interface from the microprocessor to its memory and I/O components. Many microprocessor manufacturers provide special-purpose chips of this nature. A typical example is the ZILOG range of devices available for interfacing to the Z80 microprocessor. These include [99]:

- Serial I/O controller (Z80-SIO) for a direct interface to a range of serial interface peripherals.
- Parallel I/O controller (Z80-PIO) for a direct interface to a range of parallel interface peripherals.
- Direct Memory Access controller (Z80-DMA) for DMA between the I/O controllers on a CPU cycle-steal basis.
- Counter timer circuit (Z80-CTC) for control of real-time events.

All these devices are programmable and can provide considerable savings in development time and final package count.

If the mass production of a system using microprocessor is necessary, then part of the selection process must concentrate on ensuring that adequate supplies of the component can be had over the anticipated delivery and maintenance life cycle.

Finally, the word length of the microprocessor is a singificant factor in selection.

4.2.1 Word Length of Microprocessors versus Applications

The applications for which the different word sizes are used vary [100].

The 4-bit microprocessors can be used in low-cost control applications such as domestic products, vending machines etc.

The 8-bit microprocessors can be used in applications where unit costs are high and the logical sequencing requirements are significantly complex.

The 16-bit microprocessors can be treated either as more powerful versions of the 8-bit microprocessors or as minicomputers. Although they are faster than the 8-bit microprocessors, they are more cost-effective because of their increased program and data storage overheads. It can be very wasteful to use a 16-bit microprocessor in an application where 16-bit data values are not required. The application range versus the word length of microprocessors is presented in detail in Figure 4.2

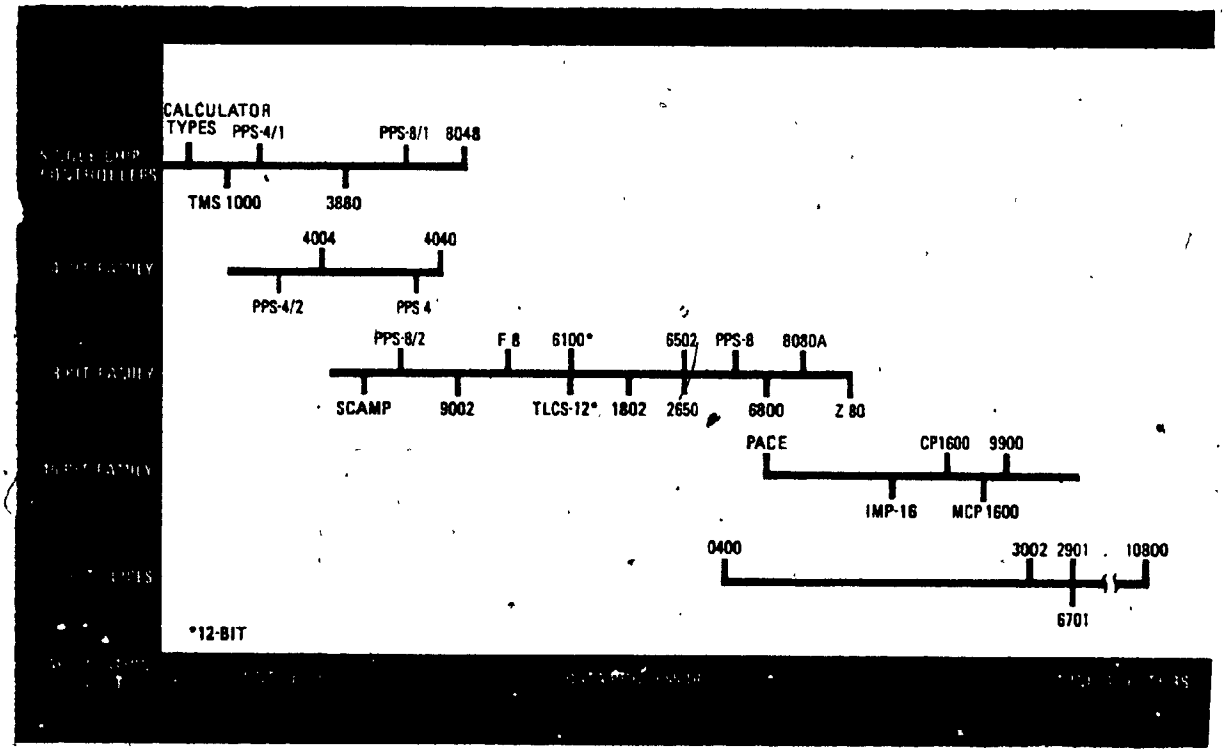

Figure 4.2 Word Length of Microprocessors versus Applications [11]

In most applications, microprocessors such as the F8, 6800, 8080 and Z-80 are highly recommended because they are all sufficiently well second-sourced to ensure supply.

However, for a particular application it is not the question of choosing a new microprocessor, but being in a position of saying [61], "For this particular application this microprocessor is the most suitable. Let us choose this one for this job."

Summary

In the last chapter the factors involved in the evaluation and selection of microprocessors have been examined.

If the decision has been made by a designer to select a microprocessor for a particular application, then he must first decide on the word size and the type of instructions needed. After this, it is possible to determine the execution speed and I/O capability required. With these four basic factors decided upon it is time to look at costs, power requirements, technology and support hardware.

The speed factor has to be taken under consideration in microprocessor selection; it is advisable to remember that the clock speed is not the same as the microprocessor speed. The key to microprocessor speed is often its internal architecture.

CONCLUSIONS

In this project report an adequate overview of microprocessors and their applications has been presented and factors which are involved in microprocessor evaluation and selection have been examined.

It is apparent that the evolution of LSI technology has an impact on microprocessor evolution. The main technologies MOS and BIPOLAR are being used by the microprocessor manufacturers. Although MOS technology requires fewer steps than BIPOLAR technology, the switching speed is much faster using BIPOLAR technology.

The microprocessor, which is a central processing unit on a single LSI chip, combined with memory and input/output devices creates a microcomputer.

Exposing the microcomputer and microprocessor organization, the microcomputer instructions and microprocessor characteristics, it has been found that each microprocessor has different internal architecture. Software is a very important aspect of the use of microprocessors. Microprogrammed processors cover almost half the current range of microprocessors presently available. Bit-slice microprocessors provide the advantages of tailorability and high performance in a particular application; also they are microprogrammed.

The microprocessors are being used in many application areas such as process control, testing and instrumentation, telecommunications, data capture, commercial data processing, portable/personal computers, consumer products, computer peripheral devices and biomedical systems. In the future, it is expected that microprocessors will be used in many domestic products such as washing machines, central heating, lighting systems, alarm systems home entertainment etc. Also, they will be employed by the automotive industry.

The evaluation and selection of microprocessors depends upon many factors which must be considered for different applications. Each application needs to be considered in depth before the decision is made.

However, some general principles apply:

- If flexibility is a critical feature of an application, then microprocessors are the choice.
- For sequential problems, microprocessors are best suited.

In order to select a microprocessor the following factors must be taken under consideration:

Word size, type of instructions needed, execution speed, I/O capability required, costs, power requirements, technology and support hardware. Also, the software costs must be examined.

In summary, the overview presented in this project report has shown the significance of the new microprocessor technology. It must be emphasized that microprocessors influence the design of systems and the nature of the resulting products.

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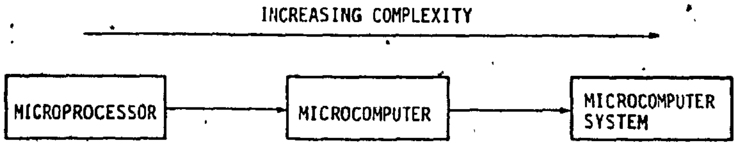
APPENDICES

A. MICROPROCESSOR DEFINITIONS

B. MICROPROCESSOR ARCHITECTURES

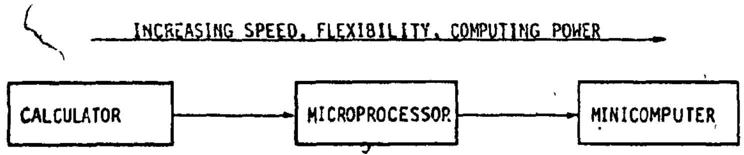
APPENDIX A

MICROPROCESSOR DEFINITIONS



Consists of LSI circuit or set of circuits	Consists of microprocessors assembled on board plus memory and I/O receivers/drivers	Consists of microcomputer (board mounted on chassis) plus application power supplies, control panel and peripherals
Capable of processing logical and arithmetic data under program control or in parallel mode		
Qty/Yr < 10000 standard circuits	Qty/Yr ~ 10-1000	Qty/Yr ~ 1-10
Qty/Yr > 10000 custom circuits		

Microprocessor definition by complexity [100]

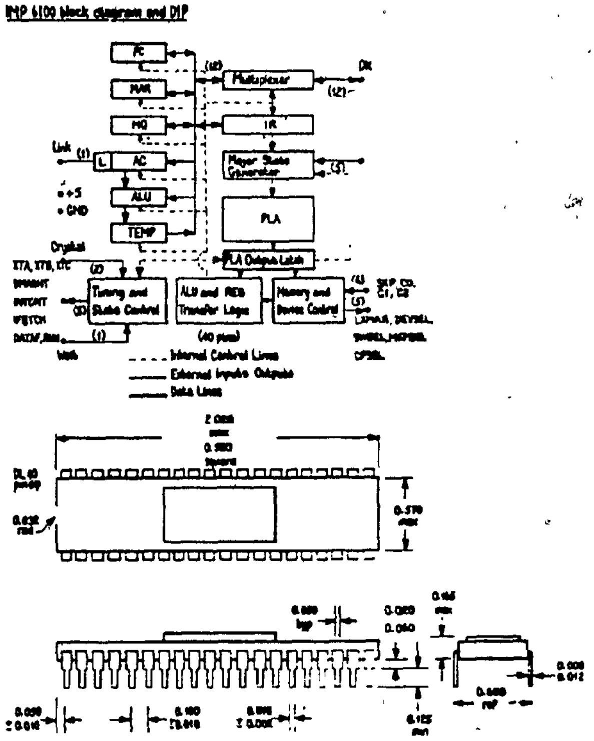


Word length (bits)	1, 4	4, 8, 12, ...16	8, 12, 16, 32
Serial/parallel	Serial	Parallel	Parallel
Micro instruction cycle time	4-40 microsec	500 nanosec - 1 microsec	200 nanosec - 1 microsec
Instructions	20 - 40	30 - 100	70 - 200
Input/Output	Keyboard, display, printer	Flexible (Smart interface devices)	Flexible
Bit manipulation	No	Yes	Yes
Interrupt	No	Some	Yes
Direct memory access	No	Some	Usually
Multi-chip	Some	Yes	TTL or TTL/MOS
Microprogrammable	No	Some	Some
Arithmetic	BCD (Binary Coded Decimal)	Binary and BCD	Binary and BCD

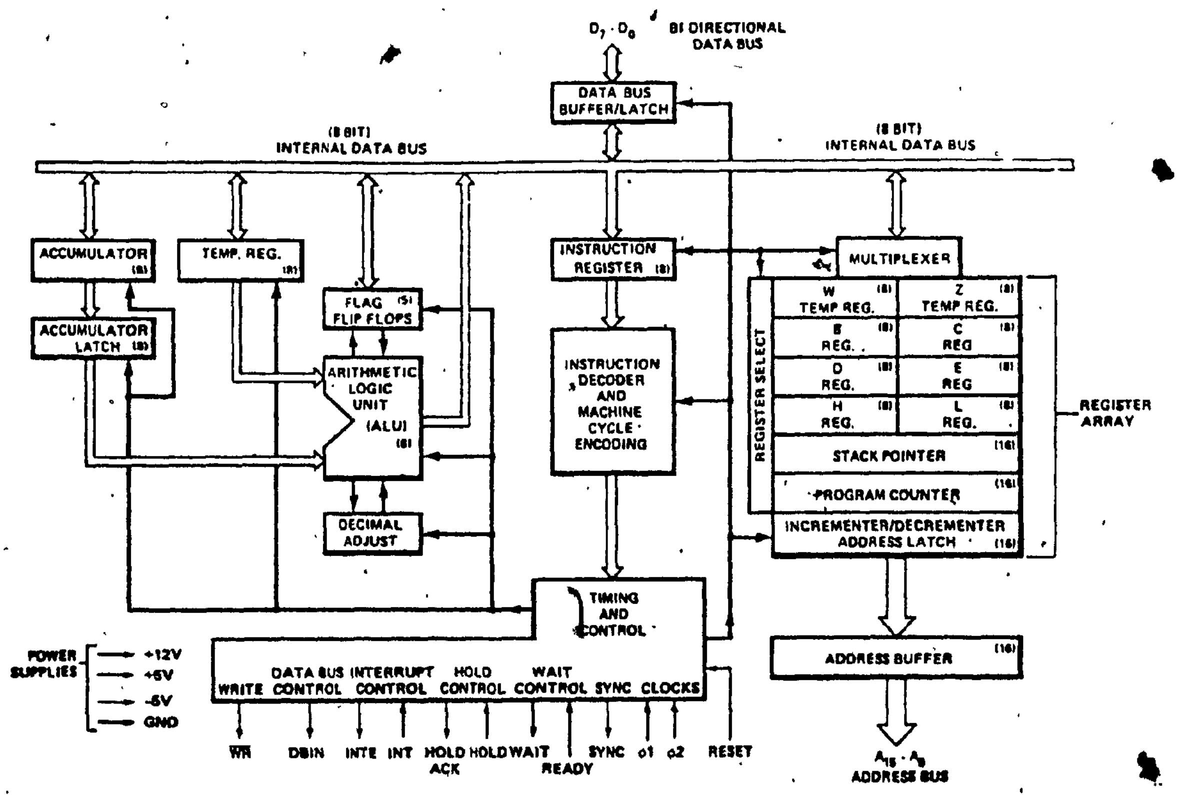
Microprocessor definition by functional characteristics [100]

APPENDIX B

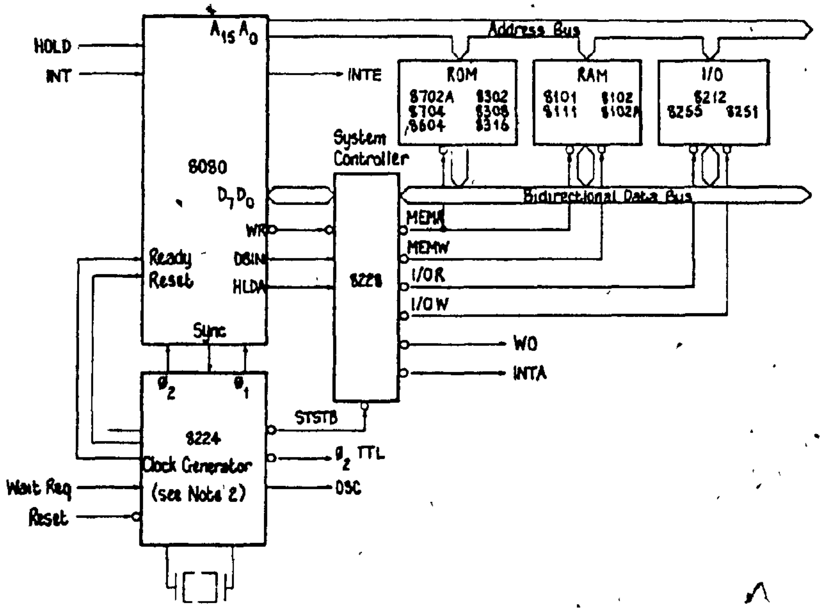
MICROPROCESSOR ARCHITECTURES



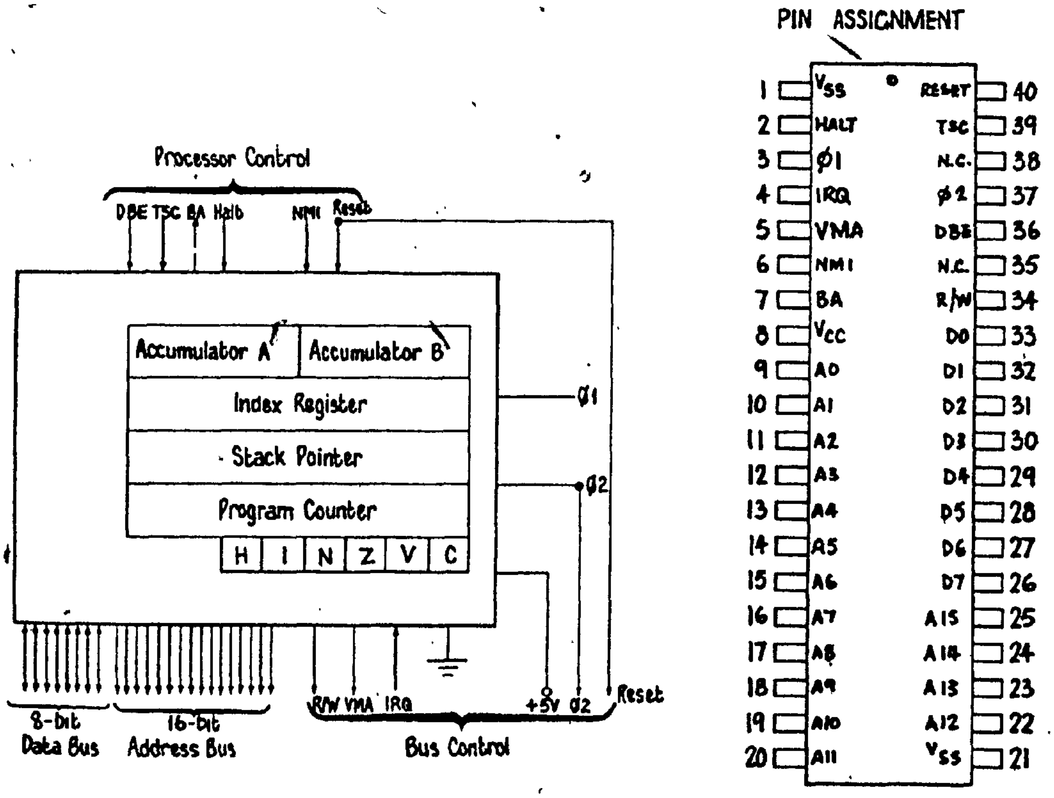
Intersil IM 6100 block diagram [2]



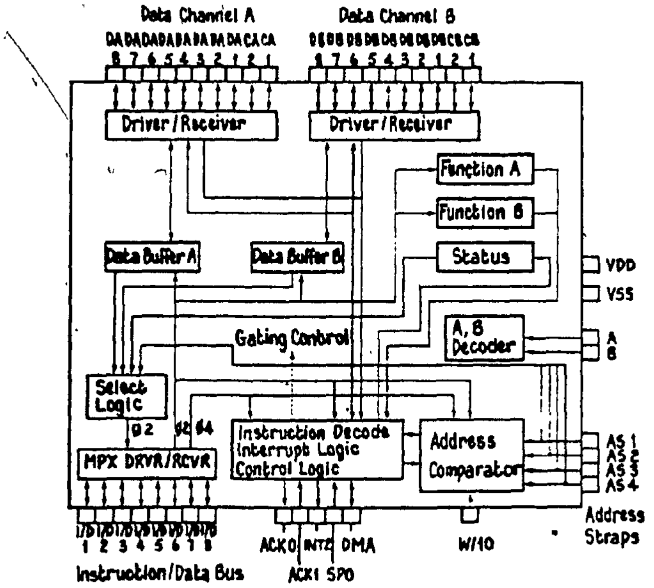
. 8080 functional block diagram. (Courtesy of Intel Corporation). [1]



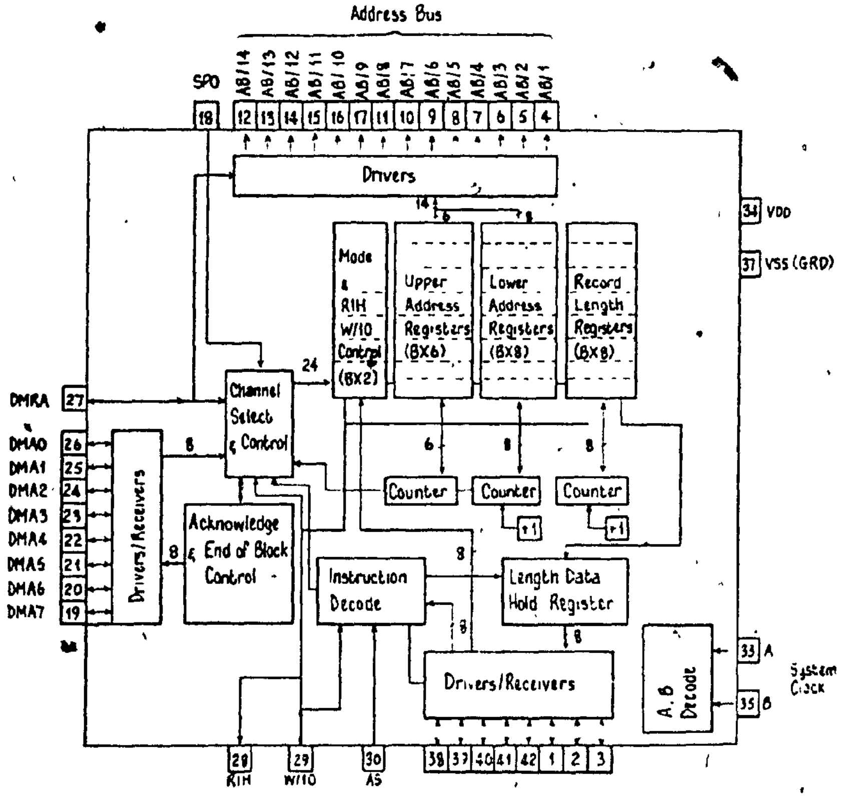
Intel 8080 standard system architecture [2]



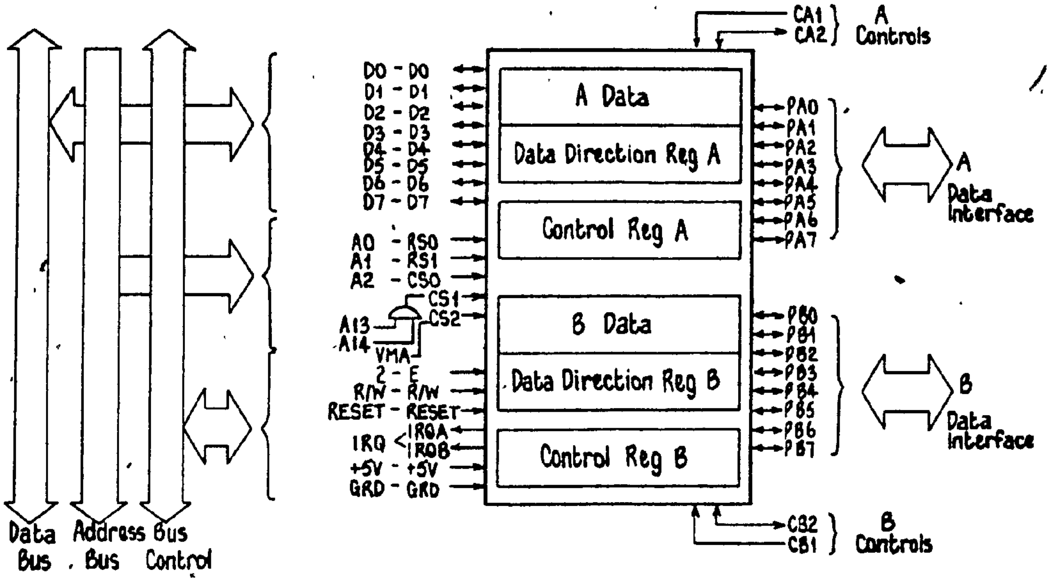
Processor bus interface (Motorola 6800) [2]



Parallel data controller block diagram (Rockwell PPS-8) [2]

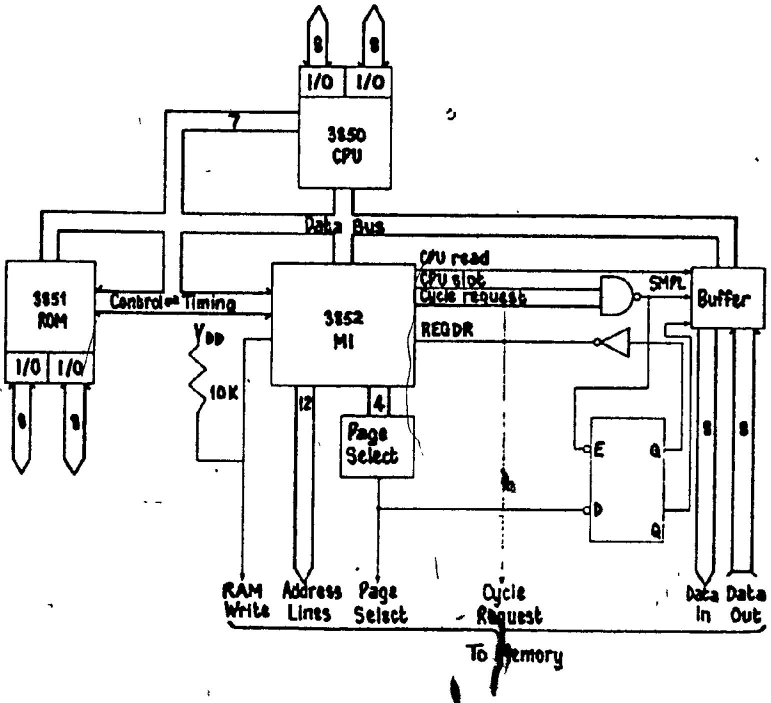


Direct memory access controller (Rockwell PPS-8) [2]

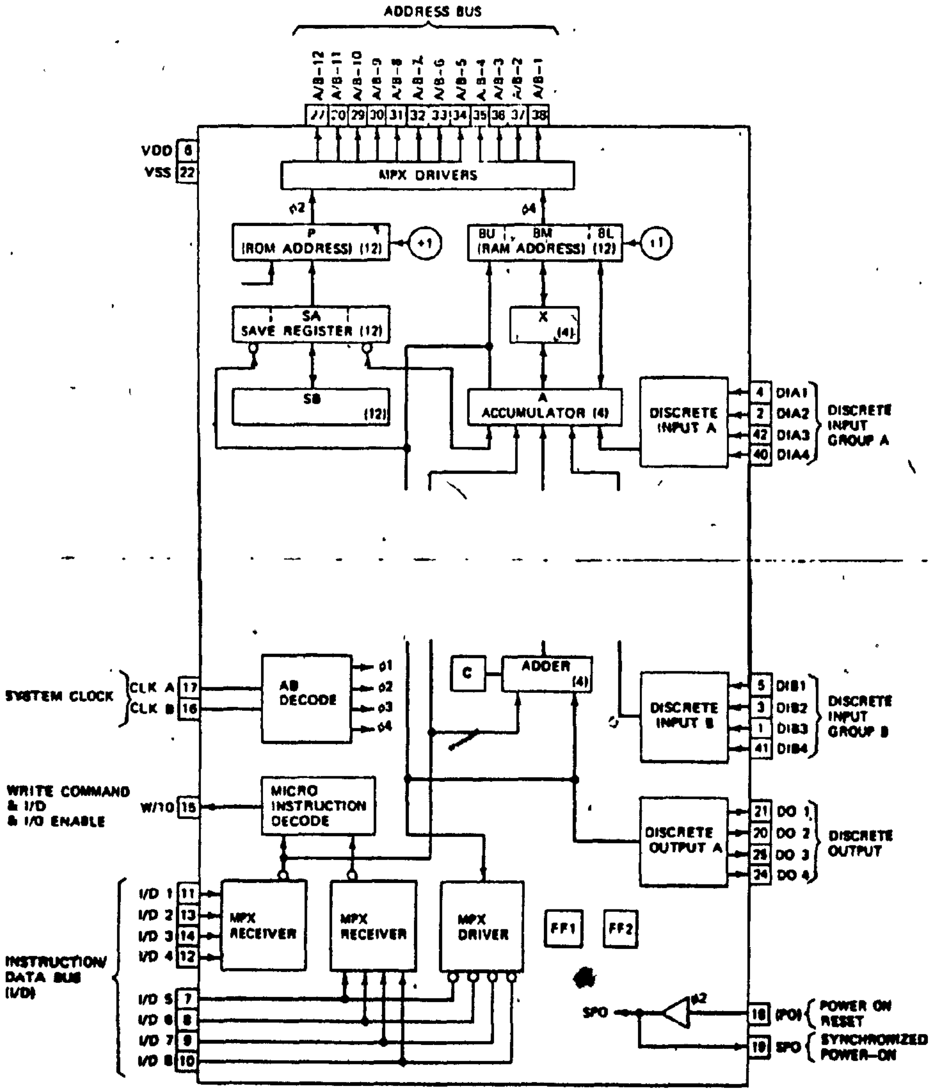


Peripheral interface adapter bus (Motorola 6800) [2]

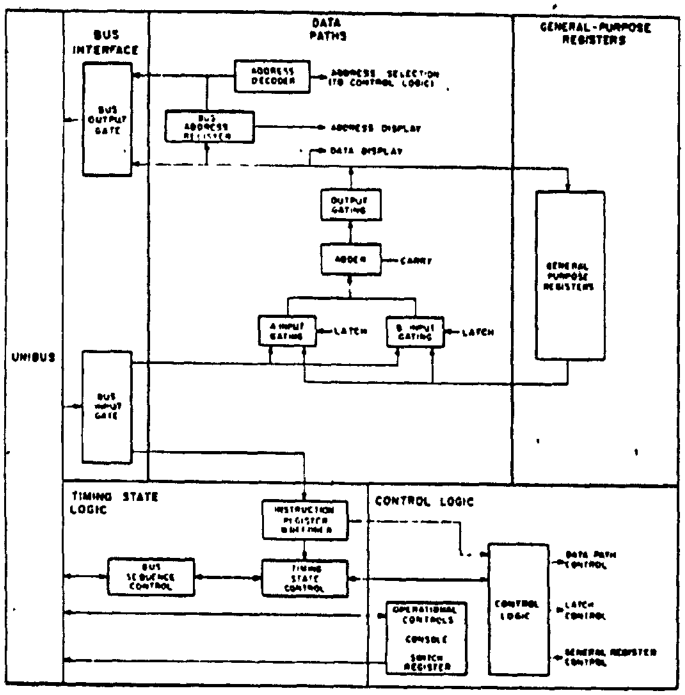
3850, 3851, and 3852 interface in an F8 system



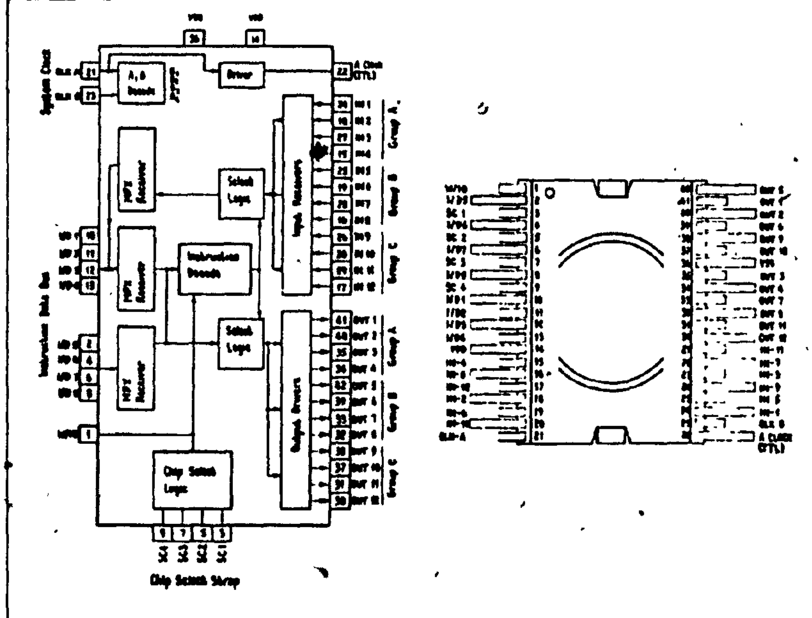
Typical Fairchild F-8 system architecture [2]



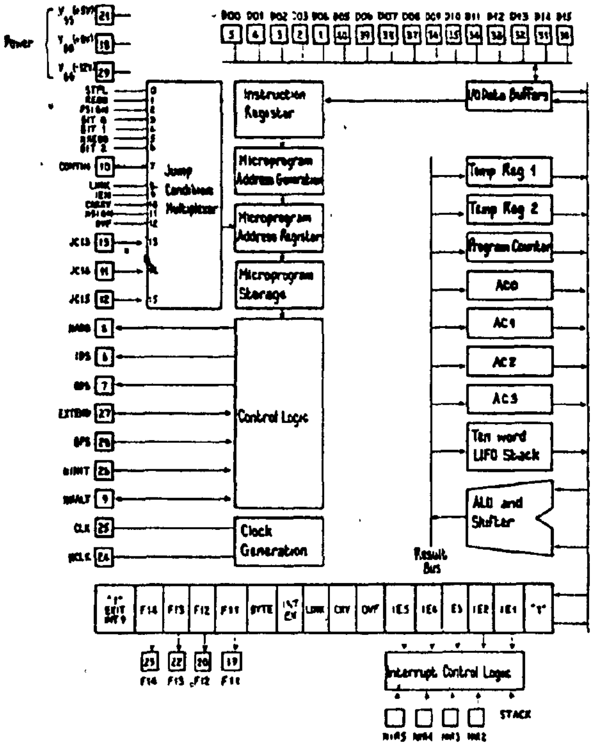
Central processing unit block diagram (Courtesy of Rockwell International Corporation). [1]



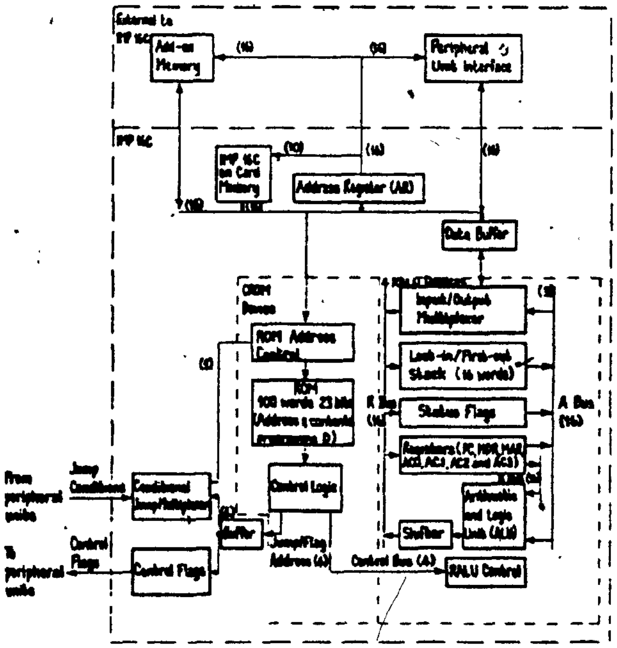
PDP-11 processor block diagram. (a) Simplified internal organization; (b) data flow (courtesy of Digital Equipment Corporation). [1]



General-purpose input/output chip (Rockwell PPS-4) [1]

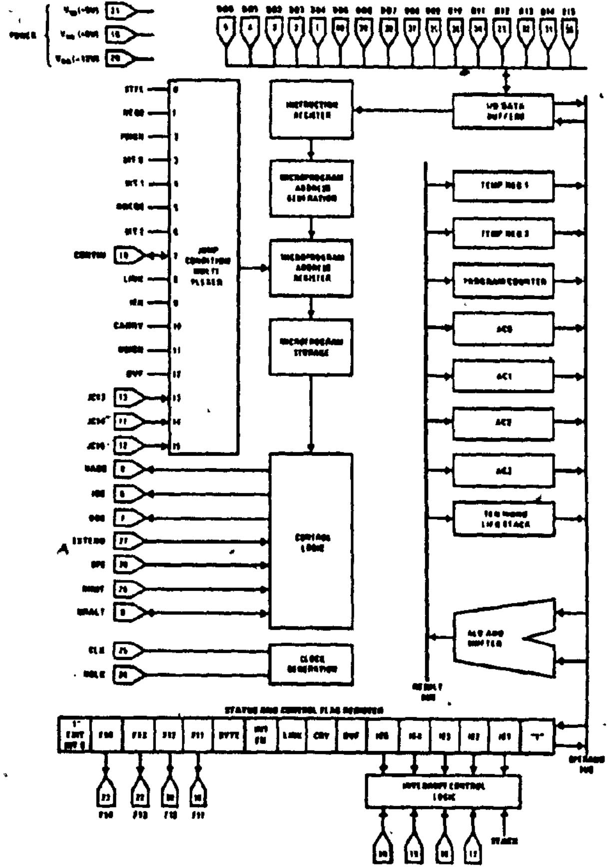


National Semiconductor PACE microprocessor [2]

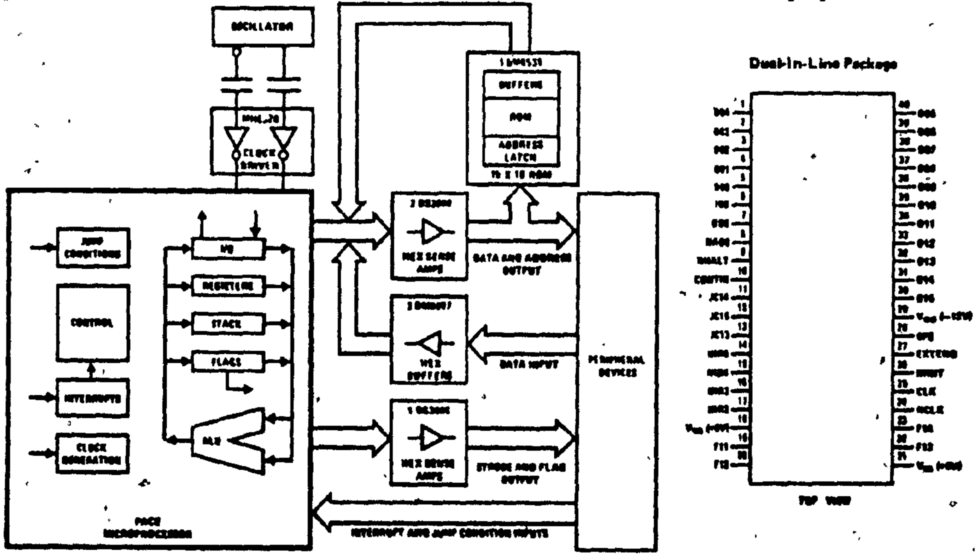


Note: numbers in parentheses designate number of lines

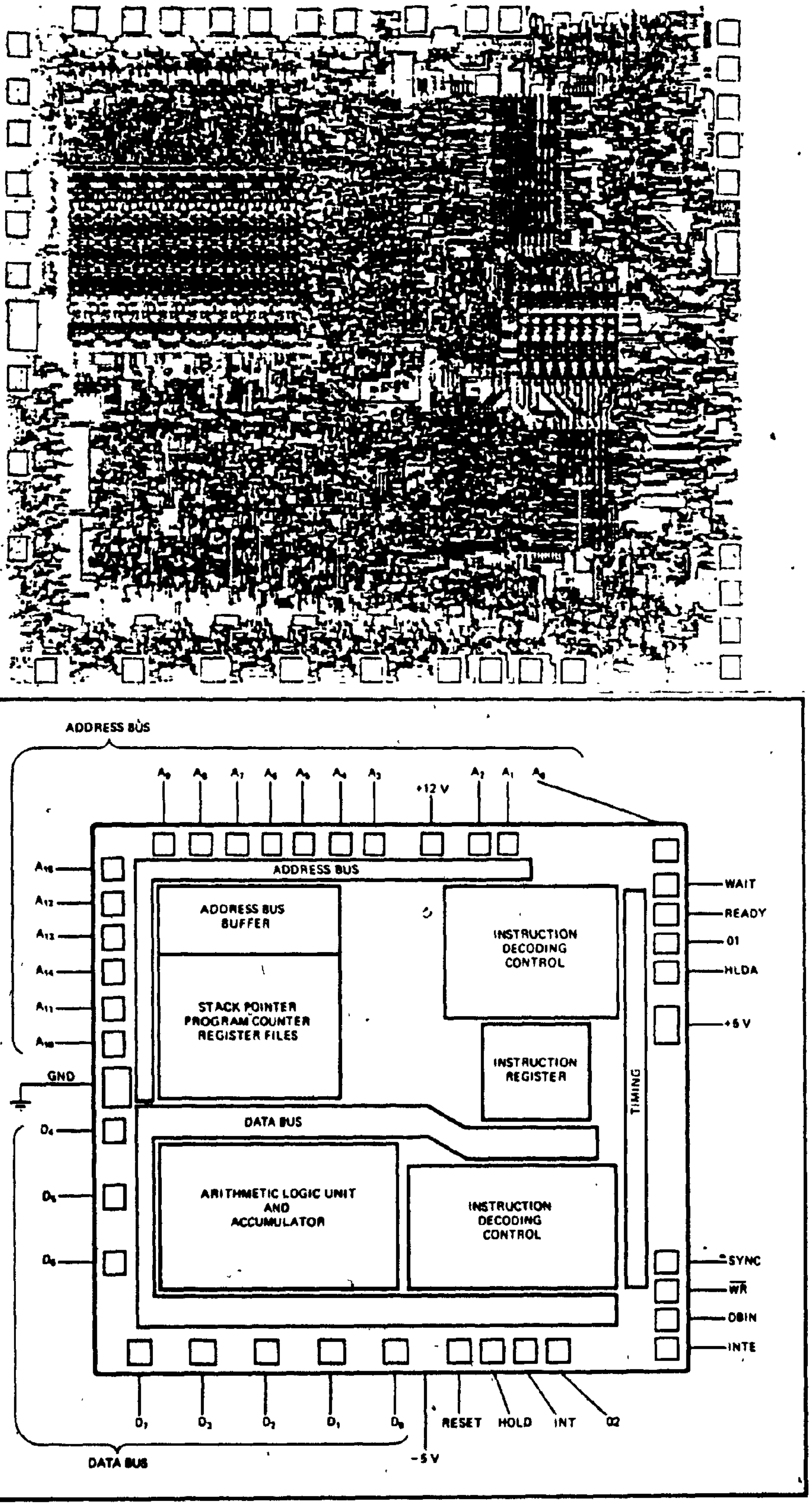
Control ROM and RALU interrelation (National Semiconductor IMP-16) [2]



PACE microprocessor. (Courtesy of National Semiconductor Corporation). [1]



PACE block and connection diagrams. (Courtesy of National Semiconductor Corporation). [1]



The physical layout of elements on a microprocessor chip closely tracks the block diagram. (Courtesy of Intel Corporation) [11]

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