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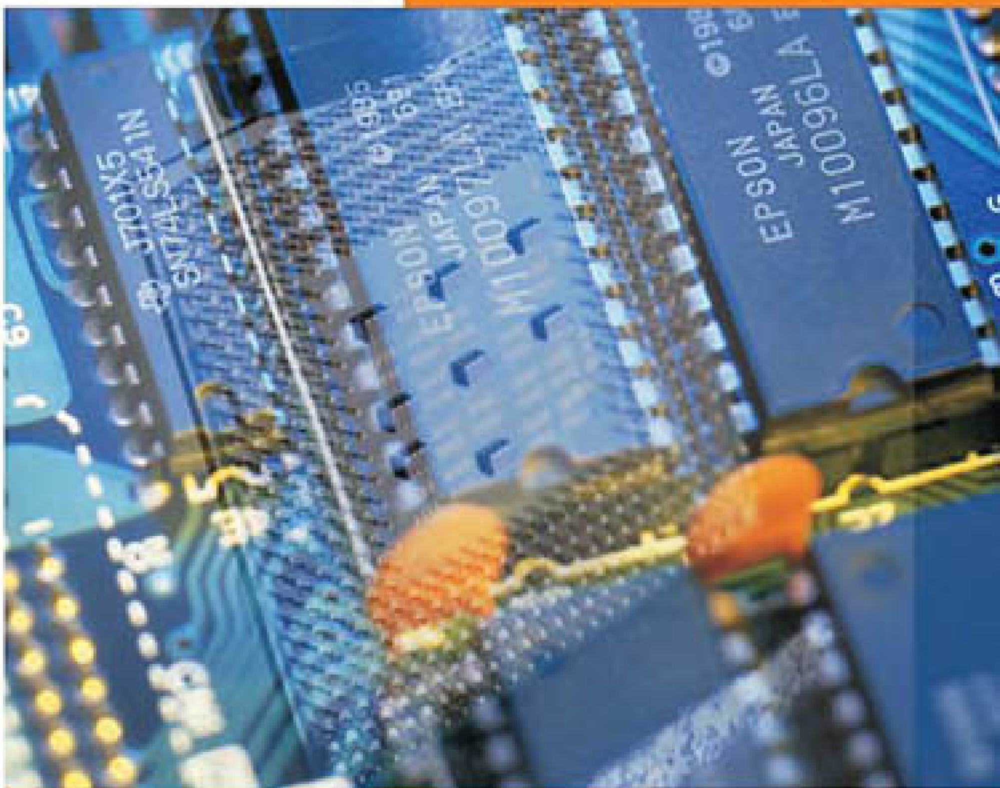
Microcontrollers and Applications



Ramani Kalpathi
Ganesh Raja

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Powersoft Systems
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This book is dedicated to our families

Dr. Ramani Kalpathi
Mr. Ganesh Raja

Preface

The art of manipulating bits of data to achieve intelligent systems can be attributed to the invention of the microcontroller. The flexibility of reconfigurable hardware using software is the reason for the success of microcontrollers in consumer and industrial applications. The availability of powerful microcontrollers in compact packages combined with low cost has enabled their widespread use in appliances.

Microcontrollers are popular among students of all disciplines due to their ease of programming and the availability of complete technical support offered by several companies. Though some of the tools for using the microcontrollers are still quite expensive, evaluation boards and demonstration hardware are freely distributed to colleges and schools regularly to popularize the latest microcontrollers. A decade back the microprocessor was famous due to its flexibility in adding needed peripherals and memory according to its application. However the volume of such systems with similar peripherals have led to the development of the microcontroller that packs most commonly used peripherals and memory. It is quite common therefore to see microcontrollers that contain I/O ports, timers, serial ports and interrupt controller all in a single compact chip. Various manufacturers have come out with 8-bit and 16-bit microcontrollers with a variety of peripherals to choose from. The power of the microcontroller has increased to such an extent that their difference with traditional DSPs or digital processors is fading away. Microcontrollers can process math routines and control real time events and are being sought after in applications that are cost sensitive and produced in large volume.

This book provides an insight into the 8051 family of microcontrollers starting with the system architecture and providing a fundamental knowledge on how to use these systems in real time control and monitoring. This book guides the user through the basic steps of assembly language starting with examples on register manipulation and math processing. Various assembly language instructions have been used with examples that can be directly run on development boards. The use of I/O ports, timers and interrupts have been illustrated with examples in C language and assembly language. A section has been included on applications of the 8051 microcontroller to real-time engineering projects. While some readers may view this section as advanced, this section illustrates by way of methods and algorithms the power of the microcontroller in designing such systems. It has been left to the user to imaginatively use the peripherals and power of the software in putting together such projects after going through the examples and algorithms provided. The user is provided a lot of common interface examples that are required in the implementation of such projects. The user is expected to carefully use this material in combination with the datasheets and application notes provided by the manufacturer of the microcontroller in project design.

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Ganesh Raja

About the Author

Dr. Ramani Kalpathi completed his Bachelor's Degree in Electrical Engineering from Bangalore University in 1987, Master's degree from Indian Institute of Technology, Madras in 1989 and Ph.D in Electrical Engineering from Texas A & M University in 1994. He was employed with Dana Corporation, USA from 1995 to 2000 as a Senior Project Engineer working in the area of Power Electronics and Motor Controls. Presently he heads Powersoft Systems which specializes in providing embedded solutions for power electronic applications. He has been the recipient of seven US patents and has several IEEE publications to his credit.

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Microprocessors and Microcontrollers

1

1.1 Introduction

In this age of information technology it is hard to find a product around us that has been manufactured without the use of a computer in some form. While manufacturing tools and processes are heavily dependent on computers for their control, smaller appliances are more dependent on a smaller version of the computer. Termed as microprocessors, these semiconductor devices are the heart of any computer. The advances in microelectronics have led to the growth of single-chip computers for a variety of applications.

The purpose of this chapter is to provide fundamental knowledge about microprocessor and microcontroller architecture and their evolution from a design point of view. A comparison of microcontrollers with micropocessors and a survey of the most popular families are discussed. The tools and systems used for developing microcontroller applications are introduced with examples. The different types of computer architecture and their evolution up to the present configurations are presented next. Finally a discussion of number systems that form the foundation to understand computer arithmetic and logic is presented.

1.1.1 Microprocessors and Microcontrollers

A microprocessor is a central processing unit fabricated on a silicon substrate. It is the heart of every computer, laptop or server. The first microprocessor was manufactured in 1971 by Intel Corporation. It had an arithmetic unit that could add, subtract and do logical operations on 4-bit numbers. The first portable embedded system built using the Intel 4004 microprocessor was a calculator. Intel Corporation came out with the first home computer in 1974 based on the 8-bit Intel 8080. The most popular IBM PC that was introduced in 1979 had Intel 8088 inside. Since then Intel has introduced 80286, 80386, 80486 and lately the Pentium class of processors.

Table 1.1 Comparison of Intel microprocessors

Microprocessor	Date	Transistors	Microns	Clock speed	Data width	MIPS
8080	1974	6,000	6	2 MHz	8 bits	0.64
8088	1979	29,000	3	5 MHz	16 bits 8-bit bus	0.33
80286	1982	134,000	1.5	6 MHz	16 bits	1
80386	1985	275,000	1.5	16 MHz	32 bits	5
80486	1989	1,200,000	1	25 MHz	32 bits	20
Pentium	1993	3,100,000	0.8	60 MHz	32 bits 64-bit bus	100
Pentium II	1997	7,500,000	0.35	233 MHz	32 bits 64-bit bus	300
Pentium III	1999	9,500,000	0.25	450 MHz	32 bits 64-bit bus	510
Pentium 4	2000	42,000,000	0.18	1.5 GHz	32 bits 64-bit bus	1,700
Pentium 4 "Prescott"	2004	125,000,000	0.09	3.6 GHz	32 bits 64-bit bus	7,000

Table 1.1 lists the various performance features of the microprocessors that were first introduced by Intel Corporation. When we refer to a microprocessor the following features assume significance.

- Microprocessors contain millions of transistors per device.
- Microns (Millionth of an inch) refers to the smallest wire width that interconnects transistors in the silicon
- Clock speed refers to the speed with which the processor works.
- Data width refers to the width of the arithmetic and logic unit. An 8-bit ALU unit can perform 8-bit math in each instruction. To perform 32-bit addition, an 8-bit ALU may take four or more instructions.
- MIPS stands for millions of instructions per second. The comparison of different processors using MIPS terminology helps in describing the complex architecture of any microprocessor.

Microprocessors are conventionally programmed using assembly language. Assembly language refers to the list of instructions provided to the microprocessor to perform arithmetic/logical operations on a given set of data. Assembly language is usually converted to machine language, which consists of binary numbers (0 and 1) using a software called the assembler. Based on the list of machine language instructions, a microprocessor would perform the following operations:

- Arithmetic operations such as addition, subtraction, multiplication and division.
- Logical Operations like AND, OR, NOT, EXOR.
- Transfer data between memory locations.
- Decision control based on the results of the mathematical/logical operations.

Fig. 1.1 shows the block diagram of a microprocessor. The significant architectural features are listed as follows:

- An address bus that selects a memory location.
- A data bus that can transfer data between the ALU and memory.
- Read and Write control lines to assist in data transfer between ALU and memory.
- Clock control line that is responsible for sequentially timed operation.
- A reset control line that is responsible for starting the program from an initial location.
- Registers R0,R1 and R2 are memory locations available inside the microprocessor.
- The arithmetic and logical unit (ALU) has the capability to perform arithmetic and logical operations.
- The program counter is a counter that holds the memory location of the next instruction to be processed.
- Temp is a temporary register that could be used to hold intermediate values of arithmetic operations that could be used for decision making.
- The buffers are controllable registers that have the states of 0, 1 or not connected.
- The instruction register and instruction decoder control the other components.

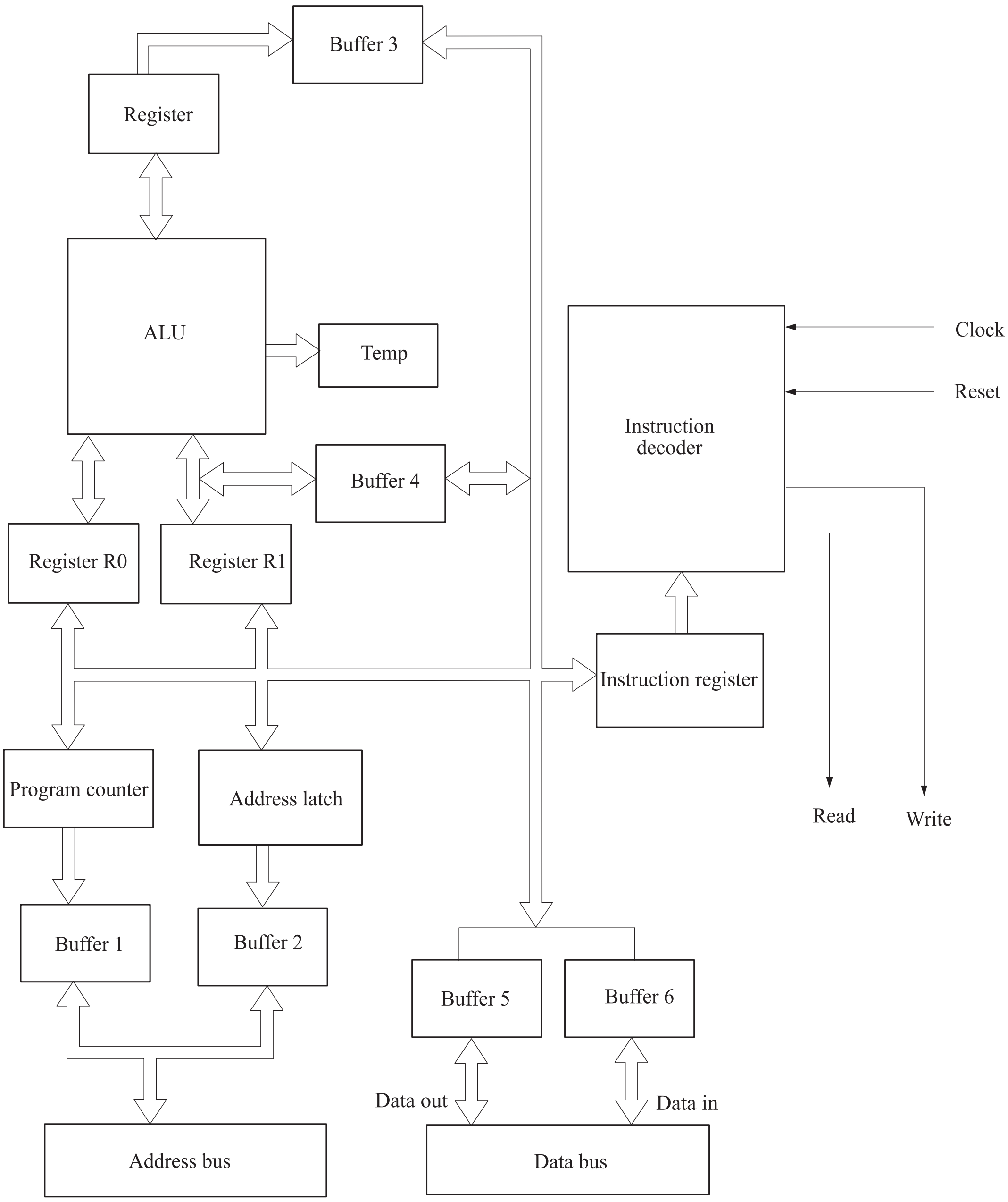

Fig. 1.1 Block diagram of a microprocessor.

Using this architecture the microprocessor can perform the following functions.

- Value of R0,R1 or R2 registers can be latched to the data bus.
- Program counter, address latch or instruction register can latch the value to the bus.
- Program counter can be incremented or reset to 0.
- The buffers can be activated.
- ALU can be instructed to perform arithmetic.
- Operations from the ALU can be sent to Temporary register.
- Read and Write lines can be activated.

The data bus and the address bus are connected to memory blocks that contain the program and corresponding data for computation.

The present trend in microprocessor architecture design is to implement 32-bit ALU with in-built floating-point math co-processors. Pipelined execution based on RISC architecture and special instructions based on CISC designs are inter-mixed to deliver one billion instructions per second. The availability of cache memory on the chip combined with multi-million transistors packed in silicon power the latest hand-held computing applications.

1.1.2 Features of microcontrollers

A microcontroller consists of a microprocessor, memory and all input/output peripherals on a single silicon chip. The microcontroller with software loaded in the internal memory is commonly referred to as an embedded chip. An application such as the cell-phone implemented with the embedded chip as the heart of the system is termed as an embedded system application.

Fig. 1.2 shows the block diagram of a microcontroller.

The following features are usually included in the design for a microcontroller.

- Arithmetic and logic unit.
- Memory for storing program.
- EEPROM memory for non-volatile data storage.
- RAM memory for storing variables and special function registers.
- Input-Output ports.

- Timers and Counters.
- Analog to digital converter.
- Circuits for reset, power-up, serial programming, debugging.
- Instruction decoder and timing control unit.
- Serial communication port.

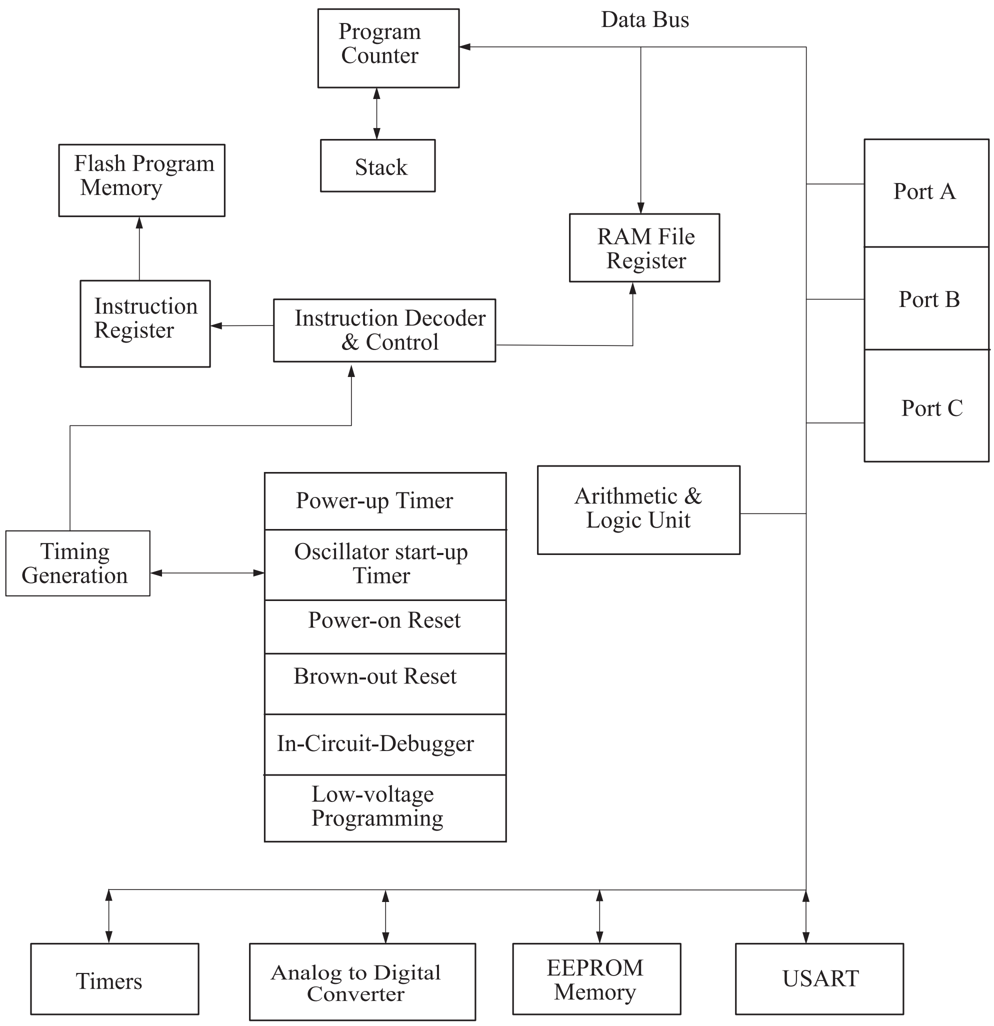

Fig. 1.2 Block diagram of microcontroller.

The design for a microcontroller has evolved from the design of an embedded system application using a microprocessor. In order to implement a small control system with the microprocessor, peripherals such as timers, input ports, output ports and serial communication driver hardware need to be interfaced. Over a period of time it has been found that several control applications can be implemented with the same framework of interfaces. With the advances in large scale integration of transistors, the microcontroller evolved into its present form integrating these interfaces onto a single chip solution.

The demand from several industries for a variety of such interfaces with different precision has resulted in several families of microcontrollers.

Accordingly there are 8-bit, 16-bit and 32 bit microcontrollers in the market today. In addition to this there are several choices of packages starting from 6-pin microcontrollers to 64 pin implementations. The differentiation in the microcontrollers would be in the presence of the number of I/O ports, availability of multiple timers, precision of A/D converters and special functions like high speed serial communications.

1.1.3 Survey of microprocessors

The evolution of the personal computer has depended on the following factors.

- Availability of microprocessors.
- Price of memory devices.
- Video display technology.
- Programmable peripherals.

The advances in the development of the personal computer has driven the growth for manufacturing microprocessors. Intel Corporation has been at the forefront of this revolution. Starting from the release of the first 8-bit microprocessor in 1974, Intel has powered its way to advanced 64-bit designs. Zilog released the Z-80 microprocessor in 1976. This microprocessor could operate with a 5V supply and was the heart of the TRS-80 computer released by Radio Shack. This popular architecture showed how people could add, multiply, divide and subtract and perform complex math using assembly language. The Z-80 was so popular that most of the assembly language subroutines in use have evolved after testing on this platform.

The advances in large scale integration of transistors into compact packages have been the driving factor for a revolution in microprocessor and microcontroller technologies. Digital hardwired systems have been replaced by dedicated microprocessors or microcontrollers.

1.1.4 Intel family

The microprocessors introduced by Intel Corporation follow the timeline shown in Table 1.2. The table shows the gradual growth in the types of applications and the extensive possibilities of the designs.

Table 1.2 History of Intel microprocessors

Year	Intel family	Applications
1971	4004	Powered the first calculator.
1972	8008	Mark-8 computer based on this device.
1974	8080	Powered the first home PC called the Altair.
1978	8086-88	Brains for the first IBM PC.
1982	80286	Hardware upgradeable, runs software of 8088 too.
1985	80386	32-bit multi-tasking processor.
1989	80486	Point and click computing, math co-processor inside.
1993	Pentium	32-bit workstation,server,CAD applications possible.
1999	Celeron	Graphics, gaming applications, Low price.
2001	Itanium	64-bit Explicitly Parallel Instruction Computing.
2003	Pentium M	Wireless LAN applications.

The architectural enhancements have resulted in smaller, robust and faster processors. The goal has been to deliver an efficient processor at a lower price. The external hardware interface in newer designs are not drastically changed between processor upgrades in order to keep the interfaces and peripherals compatible across various versions. The design of the processor these days takes into account the needs of the software developer also. The microprocessor designers therefore work hard to maintain compatibility with older processor versions and also incorporate the latest technologies.

1.1.5 Motorola microprocessors

The explosive growth in the area of embedded systems can be attributed to the microprocessor designs that Motorola has produced for the high volume automotive and consumer appliance market. Motorola devices