Chapter 1

Microcomputer Systems

1.1 Introduction

The term microcomputer is used to describe a system that includes a minimum of a microprocessor, program memory, data memory, and input/output (I/O). Some microcomputer systems include additional components such as timers, counters, analogue-to-digital converters and so on. Thus, a microcomputer system can be anything from a large computer having hard disks, floppy disks and printers, to a single chip computer system.

In this book we are going to consider only the type of microcomputers that consist of a single silicon chip. Such microcomputer systems are also called microcontrollers.

1.2 Microcontroller Systems

Microcontrollers are general purpose microprocessors which have additional parts that allow them to control external devices. Basically, a microcontroller executes a user program which is loaded in its program memory. Under the control of this program data is received from external devices (inputs), manipulated and then sent to external output devices. A microcontroller is a very powerful tool that allows a designer to create sophisticated input/output data manipulation. Microcontrollers are classified by the number of bits in a data word. 8-bit microcontrollers are the most popular ones and are used in many applications. 16- and 32-bit microcontrollers are much more powerful, but usually more expensive and not required in many small to medium general purpose applications where microcontrollers are used.

The simplest microcontroller architecture consists of a microprocessor, memory, and input/output. The microprocessor consists of a central processing unit (CPU) and the control unit (CU).

The CPU is the brain of a microprocessor and is where all of the arithmetic and logical operations are performed. The control unit controls the internal operations of the microprocessor and sends out control signals to other parts of the microprocessor to carry out the required instructions.

Memory is an important part of a microcomputer system. Depending upon the application we can classify memories into two groups: program memory, and data
memory. Program memory stores all the program code and this memory is usually non-volatile, i.e. data is not lost after the removal of power. Data memory is where the temporary user data is stored during the various arithmetic and logical operations. There are basically five types of memories as summarized below.

1.2.1 RAM

RAM means Random Access Memory. It is a general purpose memory which usually stores user data. RAM is volatile, i.e. data is lost after the removal of power. Most microcontrollers have some amount of internal RAM. 256 bytes is a common amount, although some microcontrollers have more, some less.

1.2.2 ROM

ROM is Read Only Memory. This type of memory usually holds program or fixed user data. ROM memories are programmed at the factory and their contents cannot be changed by the user. ROM memories are only useful if you have developed a program and wish to order several thousand copies of it.

1.2.3 EPROM

EPROM is Erasable Programmable Read Only Memory. This is similar to ROM but the EPROM can be programmed using a suitable programming device. EPROM memories have a small clear window on the chip where the data can be erased under a UV light. Many development versions of microcontrollers are manufactured with EPROM memories where the user program is usually stored. These memories are erased and reprogrammed until the user is satisfied with the program. Some versions of EPROMs, known as OTP (One Time Programmable), can be programmed using a suitable programmer device but these memories cannot be erased. OTP memories cost much less than the EPROMs. OTP is useful after a project has been developed completely and it is required to make hundreds of copies of the program memory.

1.2.4 EEPROM

EEPROM is Electrically Erasable Programmable Read Only Memory. These memories can be erased and also be programmed under program control. EEPROMs are used to save configuration information, maximum and minimum values, identification data etc. Some microcontrollers have built-in EEPROM memories (e.g. PIC16F84 contains a 64-byte EEPROM memory where each byte can be programmed and erased directly by software). EEPROM memories are usually very slow.

1.2.5 Flash EEPROM

This is another version of EEPROM type memory. This type of memory has become popular recently and is used in many microcontrollers (e.g. PIC16F84 contains 1K bytes of flash memory) to store the program data. The data on a flash EEPROM is
erased and then reprogrammed using a programming device. The entire contents of the memory should be erased and then reprogrammed. Flash EEPROMs are usually very fast.

One important distinction between a microcontroller and a microprocessor is that a microcontroller has special hardware in the form of input/output ports for dealing with the outside world. Input/output (I/O) ports allow external signals and devices to be connected to the microcontroller. These ports are usually organized into groups of 8 bits and each group is given a name. For example, the PIC16F84 microcontroller contains two I/O ports named port A and port B. It is very common to have at least eight I/O lines. Some microcontrollers have 32 or even 96 I/O lines, where others may have only six. On most microcontrollers the direction of the I/O port lines is programmable so that different bits can be programmed as inputs or outputs. Some microcontrollers provide bi-directional I/O ports where each port line can be used as either input or output. Some microcontrollers have ‘open-drain’ outputs where the output transistors are left floating. External pull-up resistors are normally used with such output port lines.

1.3 Microcontroller Features

Microcontrollers from different manufacturers have different architectures and different capabilities. Some may suit a particular application while others may be totally unsuitable. The hardware features of microcontrollers in general are described in this section.

1.3.1 Supply Voltage

Most microcontrollers operate with the standard +5 V supply. Some microcontrollers can operate at as low as 2.7 V and some will tolerate 6 V without any problems. You should check the manufacturers’ data sheets about the allowed limits of the supply voltage.

1.3.2 The Clock

All microcontrollers require an oscillator (known as a clock) to operate. Most microcomputers will operate with a crystal and two capacitors. Some will operate with resonators or with external resistor–capacitor pair. Some microcontrollers have built-in resistor–capacitor type oscillators and they do not require any external timing components (e.g. PIC12C672). If your application is not time sensitive you should use external or internal (if available) resistor–capacitor timing components for simplicity and low cost.

1.3.3 Timers

Timers are an important part of any microcontroller. A timer is basically a counter which is driven from an accurate clock (or a division of this clock). Timers can be
8 bits or 16 bits long. Data can be loaded into the timers and they can be started and stopped under software control. Most timers can be configured to generate an interrupt when they reach a certain count (usually when they overflow). Some microcontrollers offer capture and compare facilities where a timer value can be read when an external event occurs, or the timer value can be compared to a preset value and interrupts can be generated when this value is reached. It is typical to have at least one timer on every microcontroller. Some microcontrollers may have three or more while others may have two timers.

1.3.4 Watchdog

Many microcontrollers have at least one watchdog facility. The watchdog is usually refreshed by the user program and a reset occurs if the program fails to refresh the watchdog. Watchdog facilities are commonly used in real-time systems where it is required to check the proper termination of one or more activities.

1.3.5 Reset Input

This input resets the microcomputer. Most microcontrollers have a resistor connected to the supply voltage and this ensures that the microcontroller starts properly after the application of power. Some microcontrollers have internal reset circuitry which does not require any external components.

1.3.6 Interrupts

Interrupts are a very important concept in microcontrollers. An interrupt causes a microcontroller to respond to external and internal (e.g. timer) events very quickly. When an interrupt occurs the microcontroller leaves its normal flow of execution and jumps directly to the interrupt service routine. Interrupts can in general be nested such that a new interrupt can suspend the execution of another interrupt. Most microcontrollers have at least one, some have several interrupt sources.

1.3.7 Brown-out Detector

Brown-out detectors are also common in many microcontrollers and they reset a microcontroller if the supply voltage falls below a nominal value. Brown-out detectors are usually employed to prevent unpredictable operation at low voltages, especially to protect the contents of EEPROM type memories.

1.3.8 Analogue-to-Digital Converter

Some microcontrollers are equipped with analogue-to-digital converter circuits. Usually these converters are 8 bits, but some microcontrollers have 10- or even 12-bit converters. A/D converters usually generate interrupts when a conversion is complete so that the user program can read the converted data very quickly. A/D converters are very useful in control and monitoring applications since most sensors produce analogue output voltages.
1.3.9 Serial Input/Output
Some microcontrollers contain hardware to implement a serial asynchronous communications interface. The baud rate and the data format can usually be selected in software. If serial input/output hardware is not provided, it is easy to develop software to implement serial data transfer using any I/O pin of a microcontroller. Some microcontrollers incorporate SPI (Serial Peripheral Interface) or I2C (Integrated InterConnect) bus interfaces. These enable a microcontroller to interface to other compatible devices easily.

1.3.10 EEPROM Data Memory
EEPROM type memory is also very common in many microcontrollers. The programmer can store non-volatile data in such memory and can also change this data whenever required. Some microcontroller types provide between 64 and 256 bytes of EEPROM data memories, while some others do not have any such memories.

1.3.11 LCD Drivers
LCD drivers enable a microcontroller to be connected to an external LCD display directly. These drivers are not very common since most of the functions provided by them can be implemented by software.

1.3.12 Analogue Comparator
Analogue comparators enable analogue signals to be compared easily. These circuits are not very common and are only implemented in some microcontrollers.

1.3.13 Real-time Clock
The real-time clock is another feature which is implemented in some microcontrollers. These microcontrollers usually keep the date and time of day and they are intended for the consumer market.

1.3.14 Sleep Mode
Some microcontrollers (e.g. PIC) offer sleep modes where executing this instruction puts the microcontroller into a mode where the internal oscillator is stopped and the power consumption is extremely low. The devices usually wake up from the sleep mode by external reset or by a watchdog time-out.

1.3.15 Power on Reset
Some microcontrollers (e.g. PIC) provide an on-chip power-on reset circuitry which keeps the microcontroller in reset state until all the internal clock and the circuitry are initialized properly.
1.3.16 Low Power Operation

Low power operation is important in portable applications. Some microcontrollers (e.g. PIC) can operate with less than 2 mA with 5 V supply, and around 15 μA at 3 V supply. Some other microcontrollers may consume as much as 80 mA or more at 5 V supply.

1.3.17 Current Sink/Source Capability

This is important if the microcontroller is to be connected to an external device which draws large current for its operation. Some microcontrollers can sink and source only a few mA of current and driver circuits are required if they have to be connected to devices with large current requirements. PIC microcontrollers can sink and source up to 25 mA of current from each I/O pin which is suitable for most small applications, e.g. they can be connected to LEDs without any driver circuits.

1.4 Microcontroller Architectures

Basically, two types of architectures are used in microcontrollers: Von Neumann architecture and Harvard architecture. Von Neumann architecture is used by a very large percentage of microcontrollers and here all memory space is on the same bus, and instruction and data are treated identically. In the Harvard architecture (used by the PIC microcontrollers), code and data storage are on separate buses and this allows code and data to be fetched simultaneously, resulting in a more efficient implementation.

1.4.1 RISC and CISC

RISC (Reduced Instruction Set Computer) and CISC (Complex Instruction Set Computer) refer to the instruction set of a microcontroller. In a RISC microcontroller, instruction words are more than 8 bits wide (usually 12, 14, or 16 bits) and the instructions occupy one word in the program memory. RISC processors (e.g. PIC) have no more than about 35 instructions, and offer higher speeds. CISC microcontrollers have 8-bit wide instructions and they usually have over 200 instructions. Some instructions (e.g. branch) occupy more than one program memory location.