
CHAPTER 1

THE 8051 MICROCONTROLLERS

OBJECTIVES

Upon completion of this chapter, you will be able to:

- »» Compare and contrast microprocessors and microcontrollers
- »» Describe the advantages of microcontrollers for some applications
- »» Explain the concept of embedded systems
- »» Discuss criteria to consider in choosing a microcontroller
- »» Explain the variations of speed, packaging, memory, and cost per unit and how these affect choosing a microcontroller
- »» Compare and contrast the various members of the 8051 family
- »» Compare 8051 microcontrollers offered by various manufacturers

This chapter begins with a discussion of the role and importance of microcontrollers in everyday life. In Section 1.1 we also discuss criteria to consider in choosing a microcontroller, as well as the use of microcontrollers in the embedded market. Section 1.2 covers various members of the 8051 family such as the 8052 and 8031, and their features. In addition, we discuss various versions of the 8051 such as the 8751, AT89C51, and DS5000.

SECTION 1.1: MICROCONTROLLERS AND EMBEDDED PROCESSORS

In this section we discuss the need for microcontrollers and contrast them with general-purpose microprocessors such as the Pentium and other x86 microprocessors. We also look at the role of microcontrollers in the embedded market. In addition, we provide some criteria on how to choose a microcontroller.

Microcontroller versus general-purpose microprocessor

What is the difference between a microprocessor and microcontroller? By microprocessor is meant the general-purpose microprocessors such as Intel's x86 family (8086, 80286, 80386, 80486, and the Pentium) or Motorola's 680x0 family (68000, 68010, 68020, 68030, 68040, etc.). These microprocessors contain no RAM, no ROM, and no I/O ports on the chip itself. For this reason, they are commonly referred to as *general-purpose microprocessors*.

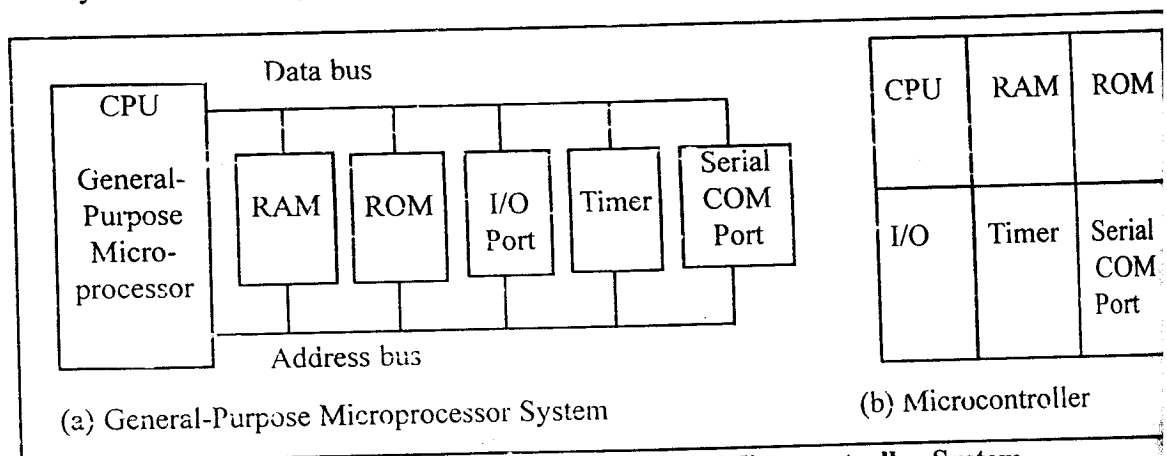


Figure 1-1. Microprocessor System Contrasted With Microcontroller System

A system designer using a general-purpose microprocessor such as the Pentium or the 68040 must add RAM, ROM, I/O ports, and timers externally to make them functional. Although the addition of external RAM, ROM, and I/O ports makes these systems bulkier and much more expensive, they have the advantage of versatility such that the designer can decide on the amount of RAM, ROM, and I/O ports needed to fit the task at hand. This is not the case with microcontrollers. A microcontroller has a CPU (a microprocessor) in addition to a fixed amount of RAM, ROM, I/O ports, and a timer all on a single chip. In other words, the processor, the RAM, ROM, I/O ports, and timer are all embedded together on one chip; therefore, the designer cannot add any external memory, I/O, or timer to it. The fixed amount of on-chip ROM, RAM, and number of I/O ports in microcontrollers makes them ideal for many applications in which cost and space are

Home
Appliances
Intercom
Telephones
Security systems
Garage door openers
Answering machines
Fax machines
Home computers
TVs
Cable TV tuner
VCR
Camcorder
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Video games
Cellular phones
Musical instruments
Sewing machines
Lighting control
Paging
Camera
Pinball machines
Toys
Exercise equipment
Office
Telephones
Computers
Security systems
Fax machine
Microwave
Copier
Laser printer
Color printer
Paging
Auto
Trip computer
Engine control
Air bag
ABS
Instrumentation
Security system
Transmission control
Entertainment
Climate control
Cellular phone
Keyless entry

Table 1-1: Some Embedded Products Using Microcontrollers

critical. In many applications, for example a TV remote control, there is no need for the computing power of a 486 or even an 8086 microprocessor. In many applications, the space it takes, the power it consumes, and the price per unit are much more critical considerations than the computing power. These applications most often require some I/O operations to read signals and turn on and off certain bits. For this reason some call these processors IBP, "itty-bitty processors" (see "Good Things in Small Packages Are Generating Big Product Opportunities" by Rick Grehan, BYTE magazine, September 1994; www.byte.com, for an excellent discussion of microcontrollers).

It is interesting to note that some microcontroller manufacturers have gone as far as integrating an ADC (analog-to-digital converter) and other peripherals into the microcontroller.

Microcontrollers for embedded systems

In the literature discussing microprocessors, we often see the term *embedded system*. Microprocessors and microcontrollers are widely used in embedded system products. An embedded product uses a microprocessor (or microcontroller) to do one task and one task only. A printer is an example of embedded system since the processor inside it performs one task only; namely, getting the data and printing it. Contrast this with a Pentium-based PC (or any x86 IBM-compatible PC). A PC can be used for any number of applications such as word processor, print-server, bank teller terminal, video game player, network server, or internet terminal. Software for a variety of applications can be loaded and run. Of course the reason a PC can perform myriad tasks is that it has RAM memory and an operating system that loads the application software into RAM and lets the CPU run it. In an embedded system, there is only one application software that is typically burned into ROM. An x86 PC contains or is connected to various embedded products such as the keyboard, printer, modem, disk controller, sound card, CD-ROM driver, mouse, and so on. Each one of these peripherals has a microcontroller inside it that performs only one task. For example, inside every mouse there is a microcontroller to perform the task of finding the mouse position and sending it to the PC. Table 1-1 lists some embedded products.

X86 PC embedded applications

Although microcontrollers are the preferred choice for many embedded systems, there are times that a microcontroller is inadequate for the task. For this reason, in recent years many manufacturers of general-purpose microprocessors such as Intel, Motorola, AMD (Advanced Micro Devices, Inc.), and Cyrix (now a division of National Semiconductor, Inc.) have targeted

their microprocessor for the high end of the embedded market. While Intel, AMD, and Cyrix push their x86 processors for both the embedded and desk-top PC markets, Motorola is determined to keep the 68000 family alive by targeting it mainly for the high end of embedded systems now that Apple no longer uses the 680x0 in their Macintosh. In the early 1990s Apple computer began using Power PC microprocessors (604, 603, 620, etc.) in place of the 680x0 for the Macintosh. The Power PC microprocessor is a joint venture between IBM and Motorola, and is targeted for the high end of the embedded market as well as the PC market. It must be noted that when a company targets a general-purpose microprocessor for the embedded market it optimizes the processor used for embedded systems. For this reason these processors are often called *high-end embedded processors*. Very often the terms *embedded processor* and *microcontroller* are used interchangeably.

One of the most critical needs of an embedded system is to decrease power consumption and space. This can be achieved by integrating more functions into the CPU chip. All the embedded processors based on the x86 and 680x0 have low power consumption in addition to some forms of I/O, COM port, and ROM all on a single chip. In high-performance embedded processors, the trend is to integrate more and more functions on the CPU chip and let the designer decide which features he/she wants to use. This trend is invading PC system design as well. Normally, in designing the PC motherboard we need a CPU plus a chip-set containing I/O, a cache controller, a flash ROM containing BIOS, and finally a secondary cache memory. New designs are emerging in industry. For example, Cyrix has announced that it is working on a chip that contains the entire PC, except for DRAM. In other words, we are about to see an entire computer on a chip.

Currently, because of MS-DOS and Windows standardization many embedded systems are using x86 PCs. In many cases using x86 PCs for the high-end embedded applications not only saves money but also shortens development time since there is a vast library of software already written for the DOS and Windows platforms. The fact that Windows is a widely used and well understood platform means that developing a Windows-based embedded product reduces the cost and shortens the development time considerably.

Choosing a microcontroller

There are four major 8-bit microcontrollers. They are: Motorola's 6811, Intel's 8051, Zilog's Z8, and PIC 16X from Microchip Technology. Each of the above microcontrollers has a unique instruction set and register set; therefore, they are not compatible with each other. Programs written for one will not run on the others. There are also 16-bit and 32-bit microcontrollers made by various chip makers. With all these different microcontrollers, what criteria do designers consider in choosing one? Three criteria in choosing microcontrollers are as follows: (1) meeting the computing needs of the task at hand efficiently and cost effectively, (2) availability of software development tools such as compilers, assemblers, and debuggers, and (3) wide availability and reliable sources of the microcontroller. Next we elaborate further on each of the above criteria.

Criteria for choosing a microcontroller

1. The first and foremost criterion in choosing a microcontroller is that it must meet the task at hand efficiently and cost effectively. In analyzing the needs of a microcontroller-based project, we must first see whether an 8-bit, 16-bit, or 32-bit microcontroller can best handle the computing needs of the task most effectively. Among other considerations in this category are:
 - (a) Speed. What is the highest speed that the microcontroller supports?
 - (b) Packaging. Does it come in 40-pin DIP (dual inline package) or a QFP (quad flat package), or some other packaging format? This is important in terms of space, assembling, and prototyping the end product.
 - (c) Power consumption. This is especially critical for battery-powered products.
 - (d) The amount of RAM and ROM on chip.
 - (e) The number of I/O pins and the timer on the chip.
 - (f) How easy it is to upgrade to higher-performance or lower power-consumption versions.
 - (g) Cost per unit. This is important in terms of the final cost of the product in which a microcontroller is used. For example, there are microcontrollers that cost 50 cents per unit when purchased 100,000 units at a time.
2. The second criterion in choosing a microcontroller is how easy it is to develop products around it. Key considerations include the availability of an assembler, debugger, a code-efficient C language compiler, emulator, technical support, and both in-house and outside expertise. In many cases, third-party vendor (that is, a supplier other than the chip manufacturer) support for the chip is as good as, if not better than, support from the chip manufacturer.
3. The third criterion in choosing a microcontroller is its ready availability in needed quantities both now and in the future. For some designers this is even more important than the first two criteria. Currently, of the leading 8-bit microcontrollers, the 8051 family has the largest number of diversified (multiple source) suppliers. By supplier is meant a producer besides the originator of the

Table 1-2: Some Companies Producing a Member of the 8051 Family

Company	Web Site
Intel	www.intel.com/design/mcs51
Atmel	www.atmel.com
Philips/Signetics	www.semiconductors.philips.com
Siemens	www.sci.siemens.com
Dallas Semiconductor	www.dalsemi.com

microcontroller. In the case of the 8051, which was originated by Intel, several companies also currently produce (or have produced in the past) the 8051. These companies include: Intel, Atmel, Philips/Signetics, AMD, Siemens, Matra, and Dallas Semiconductor.

It should be noted that Motorola, Zilog, and Microchip Technology have all dedicated massive resources to ensure wide and timely availability of their product since their product is stable, mature, and single sourced. In recent years they also have begun to sell the ASIC library cell of the microcontroller.

Review Questions

1. True or false. Microcontrollers are normally less expensive than microprocessors.
2. When comparing a system board based on a microcontroller and a general-purpose microprocessor, which one is cheaper?
3. A microcontroller normally has which of the following devices on-chip?
(a) RAM (b) ROM (c) I/O (d) all of the above
4. A general-purpose microprocessor normally needs which of the following devices to be attached to it?
(a) RAM (b) ROM (c) I/O (d) all of the above
5. An embedded system is also called a dedicated system. Why?
6. What does the term *embedded system* mean?
7. Why does having multiple sources of a given product matter?

SECTION 1.2: OVERVIEW OF THE 8051 FAMILY

In this section we first look at the various members of the 8051 family of microcontrollers and their internal features. Plus we see who are the different manufacturers of the 8051 and what kind of products they offer.

A brief history of the 8051

In 1981, Intel Corporation introduced an 8-bit microcontroller called the 8051. This microcontroller had 128 bytes of RAM, 4K bytes of on-chip ROM, two timers, one serial port, and four ports (each 8-bits wide) all on a single chip. At the time it was also referred to as a “system on a chip.” The 8051 is an 8-bit processor, meaning that the CPU can work on only 8 bits of data at a time. Data larger than 8 bits has to be broken into 8-bit pieces to be processed by the CPU. The 8051 has a total of four I/O ports, each 8 bits wide. See Figure 1-2. Although the 8051 can have a maximum of 64K bytes of on-chip ROM, many manufacturers have put only 4K bytes on the chip. This will be discussed in more detail later.

The 8051 became widely popular after Intel allowed other manufacturers to make and market any flavor of the 8051 they please with the condition that they remain code-compatible with the 8051. This has led to many versions of the 8051 with different speeds and amounts of on-chip ROM marketed by more than half a dozen manufacturers. Next we review some of them. It is important to note that although there are different flavors of the 8051 in terms of speed and amount of on-chip ROM, they are all compatible with the original 8051 as far as the instructions are concerned. This means that if you write your program for one, it will run on any one of them regardless of the manufacturer.

8051 microcontroller

The 8051 is the original member of the 8051 family. Intel refers to it as MCS-51. Table 1-3 shows the main features of the 8051.

Table 1-3: Features of the 8051

Feature	Quantity
ROM	4K bytes
RAM	128 bytes
Timer	2
I/O pins	32
Serial port	1
Interrupt sources	6

Note: ROM amount indicates on-chip program space.

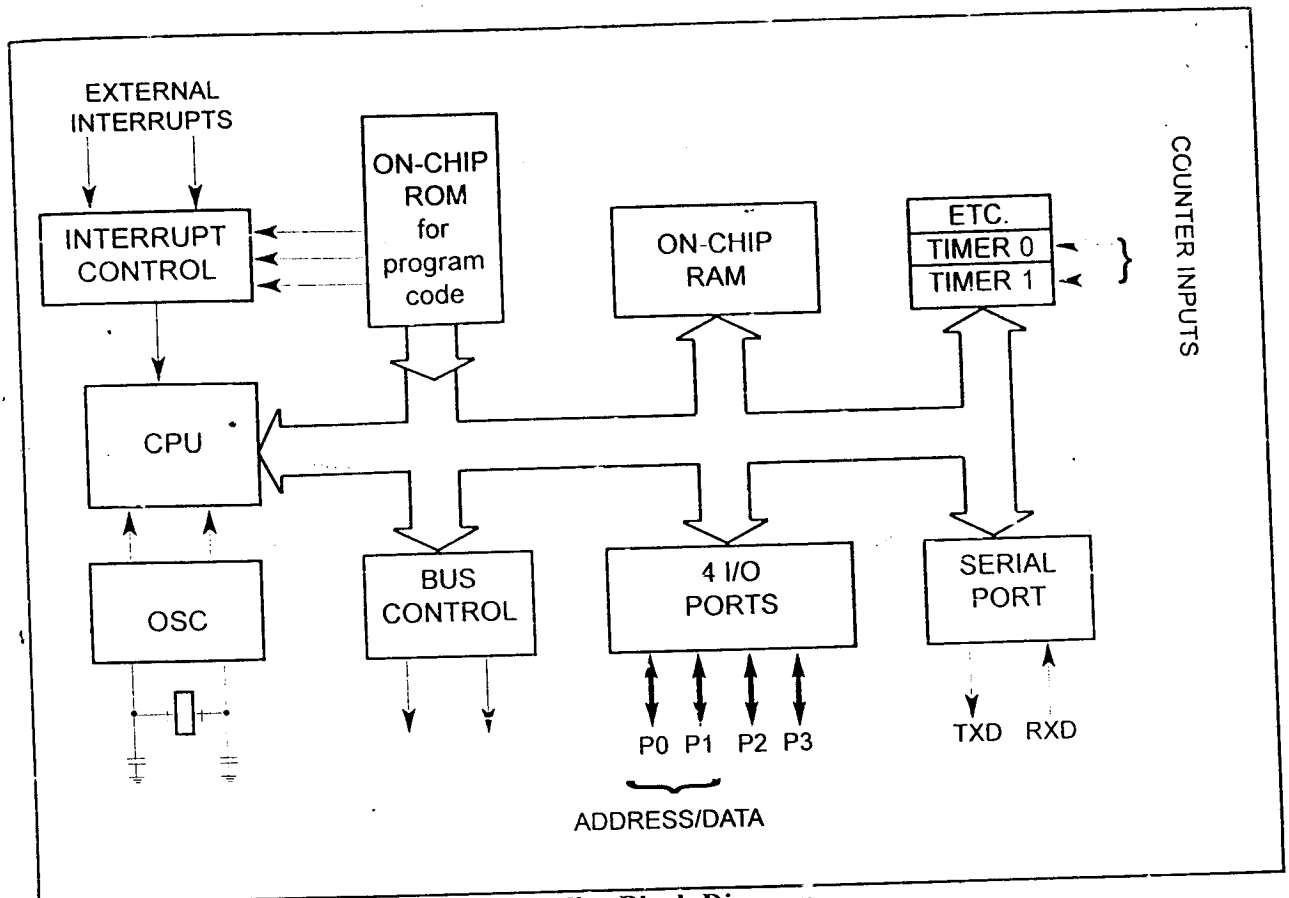


Figure 1-2. Inside the 8051 Microcontroller Block Diagram

Other members of the 8051 family

There are two other members in the 8051 family of microcontrollers. They are the 8052 and the 8031.

8052 microcontroller

The 8052 is another member of the 8051 family. The 8052 has all the standard features of the 8051 in addition to an extra 128 bytes of RAM and an extra timer. In other words, the 8052 has 256 bytes of RAM and 3 timers. It also has 8K bytes of on-chip program ROM instead of 4K bytes. See Table 1-4.

Table 1-4: Comparison of 8051 Family Members

Feature	8051	8052	8031
ROM (on-chip program space in bytes)	4K	8K	0K
RAM (bytes)	128	256	128
Timers	2	3	2
I/O pins	32	32	32
Serial port	1	1	1
Interrupt sources	6	8	6

As can be seen from Table 1-4, the 8051 is a subset of the 8052; therefore, all programs written for the 8051 will run on the 8052, but the reverse is not true.

8031 microcontroller

Another member of the 8051 family is the 8031 chip. This chip is often referred to as a ROM-less 8051 since it has 0K bytes of on-chip ROM. To use this chip you must add external ROM to it. This external ROM must contain the program that the 8031 will fetch and execute. Contrast that to the 8051 in which the on-chip ROM contains the program to be fetched and executed but is limited to only 4K bytes of code. The ROM containing the program attached to the 8031 can be as large as 64K bytes. In the process of adding external ROM to the 8031, you lose two ports. That leaves only 2 ports (of the 4 ports) for I/O operations. To solve this problem, you can add external I/O to the 8031. Interfacing the 8031 with memory and I/O ports such as the 8255 chip is discussed in Chapter 14. There are also various speed versions of the 8031 available from different companies.

Various 8051 microcontrollers

Although the 8051 is the most popular member of the 8051 family, you will not see "8051" in the part number. This is because the 8051 is available in different memory types, such as UV-EPROM, flash, and NV-RAM, all of which have different part numbers. A discussion of the various types of ROM will be given in Chapter 14. The UV-EPROM version of the 8051 is the 8751. The flash ROM version is marketed by many companies including Atmel Corp. The Atmel Flash 8051 is called AT89C51. The NV-RAM version of the 8051 made by Dalias Semiconductor is called DS5000. There is also the OTP (one-time programmable) version of the 8051 made by various manufacturers. Next we discuss briefly each of the above chips and describe applications where they are used.

8751 microcontroller

This 8751 chip has only 4K bytes of on-chip UV-EPROM. To use this chip for development requires access to a PROM burner, as well as a UV-EPROM eraser to erase the contents of UV-EPROM inside the 8751 chip before you can program it again. Due to the fact that the on-chip ROM for the 8751 is UV-EPROM, it takes around 20 minutes to erase the 8751 before it can be programmed again. This has led many manufacturers to introduce flash and NV-RAM versions of the 8051 as we will discuss next. There are also various speed versions of the 8751 available from different companies.

AT89C51 from Atmel Corporation

This popular 8051 chip has on-chip ROM in the form of flash memory. This is ideal for fast development since flash memory can be erased in seconds compared to the twenty minutes or more needed for the 8751. For this reason the AT89C51 is used in place of the 8751 to eliminate the waiting time needed to erase the chip and thereby speed up the development time. To use the AT89C51 to develop a microcontroller-based system requires a ROM burner that supports flash memory; however, a ROM eraser is not needed. Notice that in flash memory you must erase the entire contents of ROM in order to program it again. This erasing of flash is done by the PROM burner itself and this is why a separate eraser is not needed. To eliminate the need for a PROM burner Atmel is working on a version of the AT89C51 that can be programmed via the serial COM port of an IBM PC.

Table 1-5: Versions of 8051 From Atmel (All ROM Flash)

Part Number	ROM	RAM	I/O pins	Timer	Interrupt	V _{CC}	Packaging
AT89C51	4K	128	32	2	6	5V	40
AT89LV51	4K	128	32	2	6	3V	40
AT89C1051	1K	64	15	1	3	3V	20
AT89C2051	2K	128	15	2	6	3V	20
AT89C52	8K	128	32	3	8	5V	40
AT89LV52	8K	128	32	3	8	3V	40

Note: "C" in the part number indicates CMOS.

There are various speed and packaging versions of the above products. See Table 1-6. For example, notice AT89C51-12PC where "C" before the 51 is for CMOS, which has a low power consumption, "12" indicates 12 MHz, "P" is for plastic DIP package, and "C" is for commercial (vs. "M" for military). Often, the AT89C51-12PC is ideal for many student projects.

Table 1-6: Various Speeds of 8051 From Atmel

Part Number	Speed	Pins	Packaging	Use
AT89C51-12PC	12 MHz	40	DIP plastic	commercial
AT89C51-16PC	16 MHz	40	DIP plastic	commercial
AT89C51-20PC	20 MHz	40	DIP plastic	commercial

DS5000 from Dallas Semiconductor

Another popular version of the 8051 is the DS5000 chip from Dallas Semiconductor. The on-chip ROM for the DS5000 is in the form of NV-RAM. The read/write capability of NV-RAM allows the program to be loaded into the on-chip ROM while it is in the system. This can be done even via the serial port of an IBM PC. This in-system program loading of DS5000 via a PC serial port makes it an ideal home development system. Another advantage of NV-RAM is the ability to change the ROM contents one byte at a time. Contrast this with UV-EPROM and flash memory in which the entire ROM must be erased before it is programmed again.

Table 1-7: Versions of 8051 From Dallas Semiconductor's Soft Microcontroller

Part Number	ROM	RAM	I/O pins	Timers	Interrupts	V _{CC}	Packaging
DS5000-8	8K	128	32	2	6	5V	40
DS5000-32	32K	128	32	2	6	5V	40
DS5000T-8	8K	128	32	2	6	5V	40
DS5000T-8	32K	128	32	2	6	5V	40

Notes: All ROM are NV-RAM.

"T" means it has a real-time clock.

Notice that the real-time clock (RTC) is different from the timer. The real-time clock generates and keeps the time of day (hr-min-sec) and date (yr-mon-day) even when the power is off.

There are various speed and packaging versions of the DS5000 as shown in Table 1-8. For example, DS5000-8-8 has 8K NV-RAM and a speed of 8MHz. Often the DS5000-8-12 (or DS5000T-8-12) is ideal for many student projects.

Table 1-8: Versions of 8051 From Dallas Semiconductor

Part Number	NV-RAM	Speed
DS5000-8-8	8K	8 MHz
DS5000-8-12	8K	12 MHz
DS5000-32-8	32K	8 MHz
DS5000T-32-8	32K	8 MHz (with RTC)
DS5000-32-12	32K	12 MHz
DS5000T-8-12	8K	12 MHz (with RTC)

OTP version of the 8051

There are also OTP (one-time-programmable) versions of the 8051 available from different sources. Flash and NV-RAM versions are typically used for product development. When a product is designed and absolutely finalized, the OTP version of the 8051 is used for mass production since it is much cheaper in terms of price per unit.

8051 family from Philips

Another major producer of the 8051 family is Philips Corporation. Indeed, they have one of the largest selections of 8051 microcontrollers. Many of their products include features such as A-to-D converters, D-to-A converters, extended I/O, and both OTP and flash.

Review Questions

1. Name three features of the 8051.
2. What is the major difference between the 8051 and 8052 microcontrollers?
3. Give the size of RAM in each of the following.
(a) 8051 (b) 8052 (c) 8031
4. Give the size of the on-chip ROM in each of the following.
(a) 8051 (b) 8052 (c) 8031
5. The 8051 is a(n) _____-bit microprocessor.
6. State a major difference between the 8751, the AT89C51 and the DS5000.
7. List additional features introduced in the DS5000T that are not present in the DS5000.
8. True or false. The AT89C51-12PC chip has a DIP package.
9. The AT89C51-12PC chip can handle a maximum frequency of _____ MHz.
10. The DS5000-32 has _____ K bytes of on-chip NV-RAM for programs.

SUMMARY

This chapter discussed the role and importance of microcontrollers in everyday life. Microprocessors and microcontrollers were contrasted and compared. We discussed the use of microcontrollers in the embedded market. We also discussed criteria to consider in choosing a microcontroller such as speed, memory, I/O, packaging, and cost per unit. The second section of this chapter described various family members of the 8051, such as the 8052 and 8031, and their features. In addition, we discussed various versions of the 8051 such as the AT89C51 and DS5000, which are marketed by suppliers other than Intel.

PROBLEMS

SECTION 1.1: MICROCONTROLLERS AND EMBEDDED PROCESSORS

1. True or False. A general-purpose microprocessor has on-chip ROM.
2. True or False. A microcontroller has on-chip ROM.
3. True or False. A microcontroller has on-chip I/O ports.
4. True or False. A microcontroller has a fixed amount of RAM on the chip.
5. What components are normally put together with the microcontroller into a single chip?
6. Intel's Pentium chips used in Windows PCs need external _____ and _____ chips to store data and code.
7. List three embedded products attached to a PC.
8. Why would someone want to use an x86 as an embedded processor?
9. Give the name and the manufacturer of some of the most widely used 8-bit microcontrollers
10. In Question 9, which one has the most manufacture sources?
11. In a battery-based embedded product, what is the most important factor in choosing a microcontroller?
12. In an embedded controller with on-chip ROM, why does the size of the ROM matter?
13. In choosing a microcontroller, how important is it to have a multiple source for that chip?
14. What does the term "third-party support" mean?
15. If a microcontroller architecture has both 8-bit and 16-bit versions, which of the following statements is true.
 - (a) The 8-bit software will run on the 16-bit system.
 - (b) The 16-bit software will run on the 8-bit system.

SECTION 1.2: OVERVIEW OF THE 8051 FAMILY

16. The 8751 has _____ bytes of on-chip ROM.
17. The AT89C51 has _____ bytes of on-chip RAM.
18. The 8051 has _____ on-chip timer(s).

19. The 8052 has _____ bytes of on-chip RAM.
20. The ROMless version of the 8051 uses _____ as the part number.
21. The 8051 family has _____ pins for I/O.
22. The 8051 family has circuitry to support _____ serial ports.
23. The 8751 on-chip ROM is of type _____.
24. The AT8951 on-chip ROM is of type _____.
25. The DS5000 on-chip ROM is of type _____.
26. Give the speed and package type for the following chips.
(a) AT89C51-16PC (b) DS5000-8-12
27. In Question 26, give the amount and type of on-chip ROM.
28. Of the 8051 family, which version is the most cost effective if you are in the million of them in an embedded product?
29. What is the difference between the 8031 and 8051?
30. Of the 8051 microcontrollers, which one is the best for a home development environment? (You do not have access to a ROM burner).

ANSWERS TO REVIEW QUESTIONS

SECTION 1.1: MICROCONTROLLERS AND EMBEDDED PROCESSORS

1. True
2. A microcontroller based system
3. (d)
4. (d)
5. It is dedicated since it is dedicated to doing one type of job.
6. Embedded system means the processor is embedded into that application.
7. Having multiple sources for a given part means you are not hostage to one supplier. Importantly competition among suppliers brings about lower cost for that product.

SECTION 1.2: OVERVIEW OF THE 8051 FAMILY

1. 128 bytes of RAM, 4K bytes of on-chip ROM, four 8-bit I/O ports.
2. The 8052 has everything that the 8051 has, plus an extra timer, and the on-chip ROM is 8K bytes instead of 4K bytes. The RAM in the 8052 is 256 bytes instead of 128 bytes.
3. Both the 8051 and the 8031 have 128 bytes of RAM and the 8052 has 256 bytes.
4. (a) 4K bytes (b) 8K bytes (c) 0K bytes
5. 8
6. The difference is the type of on-chip ROM. In the 8751 it is UV-EPROM; in the 8755 it is flash; and in the DS5000 it is NV-RAM.
7. DS5000T has a real-time clock (RTC).
8. True
9. 12
10. 32