
CHAPTER 4

I/O PORT PROGRAMMING

OBJECTIVES

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

- ⇒ Explain the purpose of each pin of the 8051 microcontroller
- ⇒ List the 4 ports of the 8051
- ⇒ Describe the dual role of port 0 in providing both data and addresses
- ⇒ Code Assembly language to use the ports for input or output
- ⇒ Explain the use of port 3 for interrupt signals
- ⇒ Code 8051 instructions for I/O handling
- ⇒ Code bit-manipulation instructions in the 8051

This chapter describes the 8051 pins and then shows I/O port programming of the 8051 with many examples.

SECTION 4.1: PIN DESCRIPTION OF THE 8051

Although 8051 family members (e.g., 8751, 89C51, DS5000) come in different packages, such as DIP (dual in-line package), QFP (quad flat package), and LLC (leadless chip carrier), they all have 40 pins that are dedicated for various functions such as I/O, \overline{RD} , \overline{WR} , address, data, and interrupts. It must be noted that some companies provide a 20-pin version of the 8051 with a reduced number of I/O ports for less demanding applications. However, since the vast majority of developers use the 40-pin DIP package chip, we will concentrate on that.

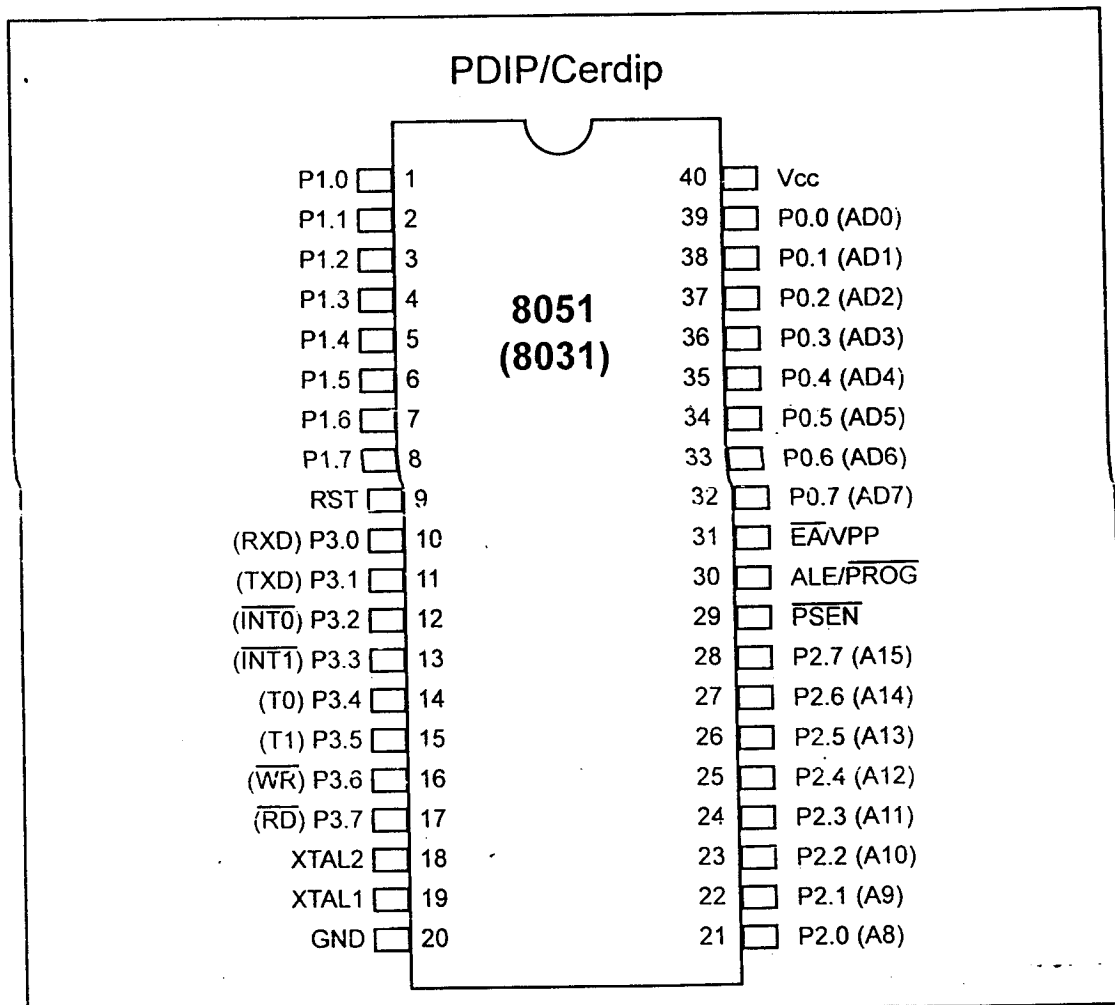


Figure 4-1. 8051 Pin Diagram

Examining Figure 4-1, note that of the 40 pins, a total of 32 pins are set aside for the four ports P0, P1, P2, and P3, where each port takes 8 pins. The rest of the pins are designated as V_{CC} , GND, XTAL1, XTAL2, RST, \overline{EA} , \overline{PSEN} . Of these 8 pins, six of them (V_{CC} , GND, XTAL1, XTAL2, RST, and \overline{EA}) are used by all members of the 8051 and 8031 families. In other words, they must be connected in order for the system to work, regardless of whether the microcontroller is of

the 8051 or 8031 family. The other two pins, $\overline{\text{PSEN}}$ and ALE , are used mainly in 8031-based systems. We first describe the function of each pin. Ports are discussed separately.

V_{CC}

Pin 40 provides supply voltage to the chip. The voltage source is +5V.

GND

Pin 20 is the ground.

XTAL1 and XTAL2

The 8051 has an on-chip oscillator but requires an external clock to run it. Most often a quartz crystal oscillator is connected to inputs XTAL1 (pin 19) and XTAL2 (pin 18). The quartz crystal oscillator connected to XTAL1 and XTAL2 also needs two capacitors of 30 pF value. One side of each capacitor is connected to the ground as shown in Figure 4-2 (a).

It must be noted that there are various speeds of the 8051 family. Speed refers to the maximum oscillator frequency connected to XTAL . For example, a 12-MHz chip must be connected to a crystal with 12 MHz frequency or less. Likewise, a 20-MHz microcontroller requires a crystal frequency of no more than 20 MHz. When the 8051 is connected to a crystal oscillator and is powered up, we can observe the frequency on the XTAL2 pin using the oscilloscope.

If you decide to use a frequency source other than a crystal oscillator, such as a TTL oscillator, it will be connected to XTAL1 ; XTAL2 is left unconnected, as shown in Figure 4-2 (b).

RST

Pin 9 is the RESET pin. It is an input and is active high (normally low). Upon applying a high pulse to this pin, the microcontroller will reset and terminate all activities. This is often referred to

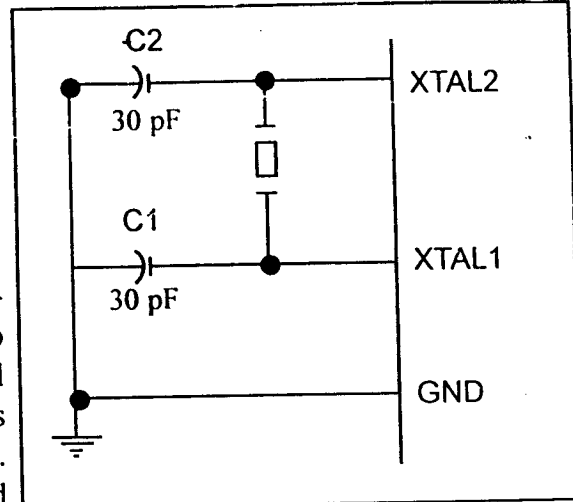


Figure 4-2 (a). XTAL Connection to 8051

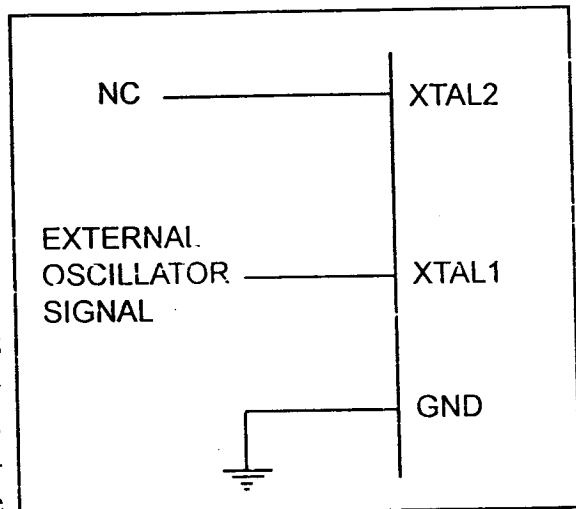


Figure 4-2 (b). XTAL Connection to an External Clock Source

Table 4-1: RESET Value of Some 8051 Registers

Register	Reset Value
PC	0000
ACC	0000
B	0000
PSW	0000
SP	0007
DPTR	0000

as a *power-on reset*. Activating a power-on reset will cause all values in the registers to be lost. Table 4-1 provides a partial list of 8051 registers and their values after power-on reset.

Notice that the value of the PC (program counter) is 0 upon reset, forcing the CPU to fetch the first opcode from ROM memory location 0000. This means that we must place the first line of source code in ROM location 0 because that is where the CPU wakes up and expects to find the first instruction. Figure 4-3 shows two ways of connecting the RST pin to the power-on reset circuitry.

In order for the RESET input to be effective, it must have a minimum duration of 2 machine cycles. In other words, the high pulse must be high for a minimum of 2 machine cycles before it is allowed to go low.

In the 8051, a machine cycle is defined as 12 oscillator periods, as discussed in Chapter 3, as shown again in Example 4-1.

\overline{EA}

The 8051 family members, such as the 8751, 89C51, or DS5000, all come with on-chip ROM to store programs. In such cases, the \overline{EA} pin is connected to V_{CC} . For family members such as the 8031 and 8032 in which there is no on-chip ROM, code is stored on an external ROM and is fetched by the 8031/32. Therefore, for the 8031 the \overline{EA} pin must be connected to GND to indicate that the code is stored externally. \overline{EA} , which stands for “external access,” is pin number 31 in the DIP packages. It is an input pin and must be connected to either V_{CC} or GND. In other words, it cannot be left unconnected.

In Chapter 14, we will show how the 8031 uses this pin along with \overline{PSEN} to access programs stored in ROM memory located outside the 8031. In 8051 chips with on-chip ROM, such as the 8751, 89C51, or DS5000, \overline{EA} is connected to V_{CC} , as we will see in the next section.

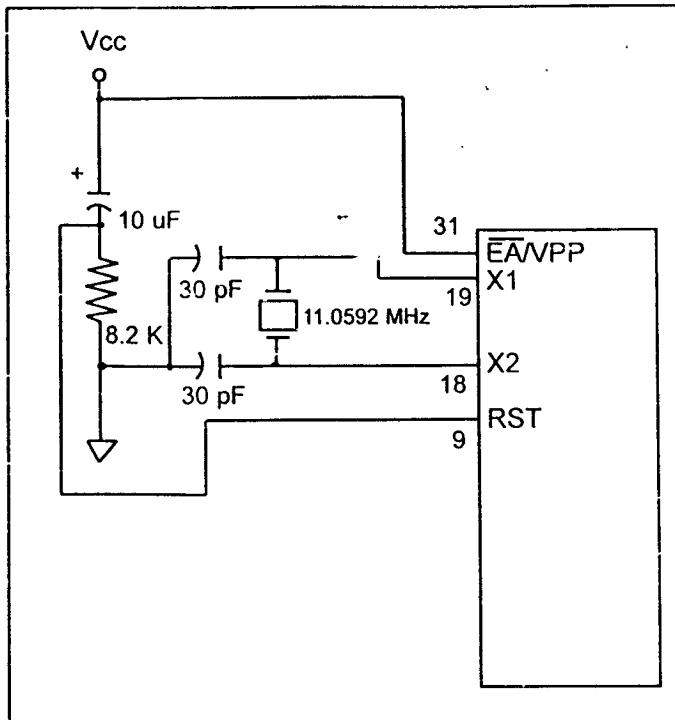


Figure 4-3 (a). Power-On RESET Circuit

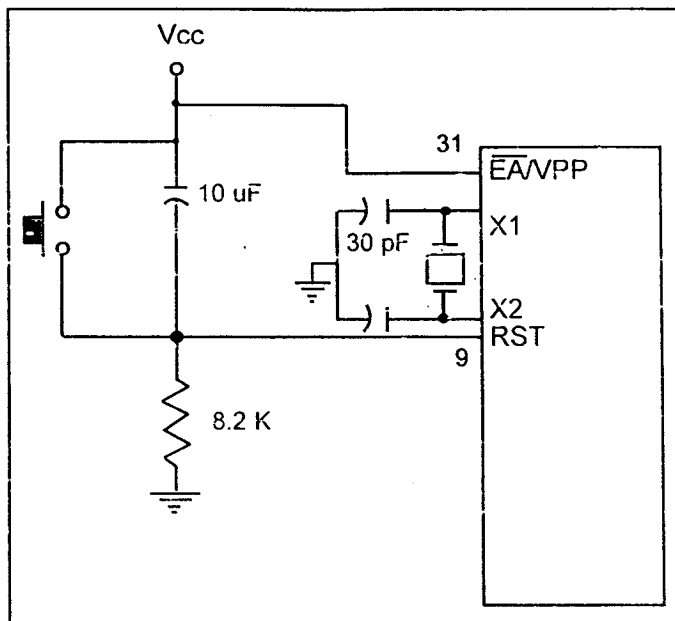


Figure 4-3 (b). Power-On RESET with Debounce

Example 4-1.

Find the machine cycle for (a) XTAL = 11.0592 MHz (b) XTAL = 16 MHz.

Solution:

- (a) $11.0592 \text{ MHz} / 12 = 921.6 \text{ kHz}$;
machine cycle = $1 / 921.6 \text{ kHz} = 1.085 \mu\text{s}$
- (b) $16 \text{ MHz} / 12 = 1.333 \text{ MHz}$;
machine cycle = $1 / 1.333 \text{ MHz} = 0.75 \mu\text{s}$

The pins discussed so far must be connected no matter which family member is used. The next two pins are used mainly in 8031-based systems and are discussed in more detail in Chapter 14. The following is a brief description of each.

PSEN

This is an output pin. PSEN stands for "program store enable." In an 8031-based system in which an external ROM holds the program code, this pin is connected to the OE pin of the ROM. See Chapter 14 to see how this is used.

ALE

ALE (address latch enable) is an output pin and is active high. When connecting an 8031 to external memory, port 0 provides both address and data. In other words, the 8031 multiplexes address and data through port 0 to save pins. The ALE pin is used for demultiplexing the address and data by connecting to the G pin of the 74LS373 chip. This is discussed in detail in Chapter 14.

I/O port pins and their functions

The four ports P0, P1, P2, and P3 each use 8 pins, making them 8-bit ports. All the ports upon RESET are configured as output, ready to be used as output ports. To use any of these ports as an input port, it must be programmed, as we will explain throughout this section. First, we describe each port.

Port 0

Port 0 occupies a total of 8 pins (pins 32 - 39). It can be used for input or output. To use the pins of port 0 as both input and output ports, each pin must be connected externally to a 10K ohm pull-up resistor. This is due to the fact that P0 is an open drain, unlike P1, P2, and P3, as we will soon see. *Open drain* is a term used for MOS chips in the same way that *open collector* is used for TTL chips. In any system using the 8751, 89C51, or DS5000 chips, we normally connect P0 to pull-up resistors. See Figure 4-4. In this way we take advantage of port 0 for both input and output. With external pull-up resistors connected upon reset, port 0 is configured as an output port. For example, the following code will continuously send out to port 0 the alternating values 55H and AAH.

```
BACK:    MOV     A, #55H
         MOV     P0, A
         ACALL  DELAY
         CPL    A
         SJMP   BACK
```

Port 0 as input

With resistors connected to port 0, in order to make it an input, the port must be programmed by writing 1 to all the bits. In the following code, port 0 is configured first as an input port by writing 1s to it, and then data is received from that port and sent to P1.

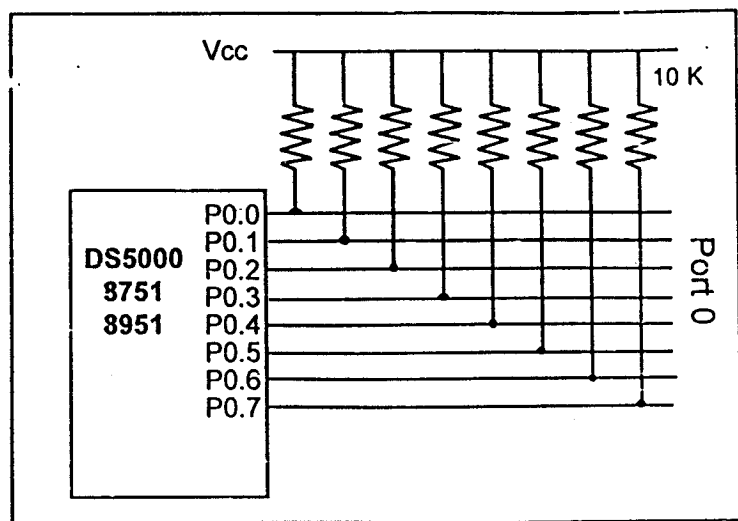


Figure 4-4. Port 0 with Pull-Up Resistors

```
                MOV  A,#0FFH    ;A = FF hex
                MOV  P0,A        ;make P0 an input port
                                ;by writing all 1s to it
BACK:           MOV  A,P0        ;get data from P0
                MOV  P1,A        ;send it to port 1
                SJMP BACK       ;keep doing it
```

Dual role of port 0

As shown in Figure 4-1, port 0 is also designated as AD0 - AD7, allowing it to be used for both address and data. When connecting an 8051/31 to an external memory, port 0 provides both address and data. The 8051 multiplexes address and data through port 0 to save pins. ALE indicates if P0 has address or data. When ALE = 0, it provides data D0 - D7, but when ALE = 1 it has address A0 - A7. Therefore, ALE is used for demultiplexing address and data with the help of a 74LS373 latch, as we will see in Chapter 14.

Port 1

Port 1 occupies a total of 8 pins (pins 1 through 8). It can be used as input or output. In contrast to port 0, this port does not need any pull-up resistors since it already has pull-up resistors internally. Upon reset, port 1 is configured as an output port. For example, the following code will continuously send out to port 1 the alternating values 55H and AAH.

```
                MOV  A,#55H
BACK:           MOV  P1,A
                ACALL DELAY
                CPL  A
                SJMP BACK
```

Port 1 as input

To make port 1 an input port, it must be programmed as such by writing 1 to all its bits. The reason for this is discussed in Appendix C.2. In the following code, port 1 is configured first as an input port by writing 1s to it, then data is received from that port and saved in R7, R6, and R5.

```
MOV  A, #0FFH    ;A=FF hex
MOV  P1, A       ;make P1 an input port
                          ;by writing all 1s to it
MOV  A, P1       ;get data from P1
MOV  R7, A       ;save it in reg R7
ACALL DELAY      ;wait
MOV  A, P1       ;get another data from P1
MOV  R6, A       ;save it in reg R6
ACALL DELAY      ;wait
MOV  A, P1       ;get another data from P1
MOV  R5, A       ;save it in reg R5
```

Port 2

Port 2 occupies a total of 8 pins (pins 21 through 28). It can be used as input or output. Just like P1, port 2 does not need any pull-up resistors since it already has pull-up resistors internally. Upon reset, port 2 is configured as an output port. For example, the following code will send out continuously to port 2 the alternating values 55H and AAH. That is, all the bits of P2 toggle continuously.

```
MOV  A, #55H
BACK: MOV  P2, A
      ACALL DELAY
      CPL  A
      SJMP BACK
```

Port 2 as input

To make port 2 an input, it must be programmed as such by writing 1 to all its bits. In the following code, port 2 is configured first as an input port by writing 1s to it. Then data is received from that port and is sent to P1 continuously.

```
MOV  A, #0FFH    ;A=FF hex
MOV  P2, A       ;make P2 an input port by
                          ;writing all 1s to it
BACK: MOV  A, P2   ;get data from P2
      MOV  P1, A   ;send it to Port 1
      SJMP BACK   ;keep doing that
```

Dual role of port 2

In systems based on the 8751, 89C51, and DS5000, P2 is used as simple I/O. However, in 8031-based systems, port 2 must be used along with P0 to pro-

vide the 16-bit address for the external memory. As shown in Figure 4-1, Port 2 is also designated as A8 - A15, indicating its dual function. Since an 8031 is capable of accessing 64K bytes of external memory, it needs a path for the 16 bits of the address. While P0 provides the lower 8 bits via A0 - A7, it is the job of P2 to provide bits A8 - A15 of the address. In other words, when the 8031 is connected to external memory, P2 is used for the upper 8 bits of the 16-bit address, and it cannot be used for I/O. This is discussed in detail in Chapter 14.

From the discussion so far, we conclude that in systems based on 8751, 89C51, or DS5000 microcontrollers, we have three ports, P0, P1, and P2, for I/O operations. This should be enough for most microcontroller applications. That leaves port 3 for interrupts as well as other signals, as we will see next.

Port 3

Port 3 occupies a total of 8 pins, pins 10 through 17. It can be used as input or output. P3 does not need any pull-up resistors, the same as P1 and P2 did not. Although port 3 is configured as an output port upon reset, this is not the way it is most commonly used. Port 3 has the additional function of providing some extremely important signals such as interrupts. Table 4-2 provides these alternate functions of P3. This information applies to both 8051 and 8031 chips.

Table 4-2: Port 3 Alternate Functions

P3 Bit	Function	Pin
P3.0	RxD	10
P3.1	TxD	11
P3.2	$\overline{\text{INT0}}$	12
P3.3	$\overline{\text{INT1}}$	13
P3.4	T0	14
P3.5	T1	15
P3.6	$\overline{\text{WR}}$	16
P3.7	$\overline{\text{RD}}$	17

P3.0 and P3.1 are used for the RxD and TxD serial communications signals. See Chapter 10 to see how they are connected. Bits P3.2 and P3.3 are set aside for external interrupts, and are discussed in Chapter 11. Bits P3.4 and P3.5 are used for timers 0 and 1, and are discussed in Chapter 9 where timers are discussed. Finally, P3.6 and P3.7 are used to provide the $\overline{\text{WR}}$ and $\overline{\text{RD}}$ signals of external memories connected in 8031-based systems. Chapter 14 discusses how they are used in 8031-based systems. In systems based on the 8751, 89C51, or DS5000, pins 3.6 and 3.7 are used for I/O while the rest of the pins in Port 3 are normally used in the alternate function role.

Review Questions

1. A given 8051 chip has a speed of 16 MHz. What is the range of frequency that can be applied to the XTAL1 and XTAL2 pins?
2. A 16-MHz 8051 system has a machine cycle of _____.
3. Which pin is used to inform the 8051 that the on-chip ROM contains the program?
4. There are total of _____ ports in the 8051 and each has _____ bits.
5. True or false. All of the 8051 ports can be used for both input and output.
6. Upon power up, the program counter (PC) has a value of _____.
7. Upon power up, the 8051 fetches the first opcode from ROM address location _____.
8. Which of the 8051 ports need pull-up resistors to function as an I/O port?

SECTION 4.2: I/O PROGRAMMING; BIT MANIPULATION

In this section we further examine 8051 I/O instructions. We pay special attention to I/O bit manipulation since it is a powerful and widely used 8051 feature. A detailed discussion of I/O ports of the 8051 is given in Appendix C.2.

Different ways of accessing the entire 8 bits

In the following code, as in many previous I/O examples, the entire 8 bits of Port 1 are accessed.

```
BACK:    MOV    A, #55H
          MOV    P1, A
          ACALL DELAY
          MOV    A, #0AAH
          MOV    P1, A
          ACALL DELAY
          SJMP   BACK
```

The above code toggles every bit of P1 continuously. We have seen a variation of the above program before. Now we can rewrite the above code in a more efficient manner by accessing the port directly without going through the accumulator. This is shown next.

```
BACK:    MOV    P1, #55H
          ACALL DELAY
          MOV    P1, #0AAH
          ACALL DELAY
          SJMP   BACK
```

We can write another variation of the above code by using a technique called *read-modify-write*. This is shown next.

Read-modify-write feature

The ports in the 8051 can be accessed by the read-modify-write technique. This feature saves many lines of code by combining in a single instruction all three actions of (1) reading the port, (2) modifying it, and (3) writing to the port. The following code first places 01010101 (binary) into port 1. Next, the instruction "XLR P1, #0FFH" performs an XOR logic operation on P1 with 1111 1111 (binary), and then writes the result back into P1.

```
          MOV    P1, #55H           ;P1=01010101
AGAIN:    XLR    P1, #0FFH         ;EX-OR P1 with 1111 1111
          ACALL DELAY
          SJMP   AGAIN
```

Notice that the XOR of 55H and FFH gives AAH. Likewise, the XOR of AAH and FFH gives 55H. Logic instructions are discussed in Chapter 7.

Single-bit addressability of ports

There are times that we need to access only 1 or 2 bits of the port instead of the entire 8 bits. A powerful feature of 8051 I/O ports is their capability to access individual bits of the port without altering the rest of the bits in that port. For example, the following code toggles the bit P1.2 continuously.

```
BACK:    CPL P1.2           ;complement P1.2 only
         ACALL DELAY
         SJMP BACK
```

```
;another variation of the above program follows
AGAIN:  SETB P1.2          ;change only P1.2=high
         ACALL DELAY
         CLR P1.2          ;change only P1.2=low
         ACALL DELAY
         SJMP AGAIN
```

Notice that P1.2 is the third bit of P1, since the first bit is P1.0, the second bit is P1.1, and so on. Table 4-3 shows the bits of 8051 I/O ports. See Example 4-2 for an example of bit manipulation of I/O bits. Notice in Example 4-2 that unused portions of Ports 1 and 2 are undisturbed. This single-bit addressability of I/O ports is one of most powerful features of the 8051 microcontroller.

Table 4-3: Single-Bit Addressability of Ports

P0	P1	P2	P3	Port Bit
P0.0	P1.0	P2.0	P3.0	D0
P0.1	P1.1	P2.1	P3.1	D1
P0.2	P1.2	P2.2	P3.2	D2
P0.3	P1.3	P2.3	P3.3	D3
P0.4	P1.4	P2.4	P3.4	D4
P0.5	P1.5	P2.5	P3.5	D5
P0.6	P1.6	P2.6	P3.6	D6
P0.7	P1.7	P2.7	P3.7	D7

Example 4-2

Write a program to perform the following.

- Keep monitoring the P1.2 bit until it becomes high,
- When P1.2 becomes high, write value 45H to port 0, and
- Send a high-to-low (H-to-L) pulse to P2.3.

Solution:

```

         SETB P1.2           ;make P1.2 an input
         MOV A, #45H         ;A=45H
AGAIN:  JNB P1.2, AGAIN     ;get out when P1.2=1
         MOV P0, A           ;issue A to P0
         SETB P2.3          ;make P2.3 high
         CLR P2.3           ;make P2.3 low for H-to-L
```

In this program, instruction "JNB P1.2, AGAIN" (JNB means jump if no bit) stays in the loop as long as P1.2 is low. When P1.2 becomes high, it gets out of the loop, writes the value 45H to port 0, and creates a H-to-L pulse by the sequence of instructions SETB and CLR.

Review Questions

1. Upon reset, the 8051 ports are configured as
(a) input (b) output (c) both input and output.
2. True or false. The instruction "SETB P2.1" makes pin P2.1 high while leaving other bits of P2 unchanged.
3. Why do we use 55H and AAH to test the bits of the port?
4. Is the following a valid instruction: "MOV P1, #99H"? Explain your answer.
5. Using the instruction "JNB P2.5, HERE" assumes that bit P2.5 is an _____ (input, output).

SUMMARY

This chapter began by describing the function of each pin of the 8051. The four ports of the 8051, P0, P1, P2, and P3, each use 8 pins, making them 8-bit ports. These ports can be used for input or output. Port 0 can be used for either address or data. Port 3 can be used to provide interrupt and serial communication signals. Then I/O instructions of the 8051 were explained, and numerous examples were given.

PROBLEMS

SECTION 4.1: PIN DESCRIPTION OF THE 8051

1. The 8051 DIP package is a _____-pin package.
2. Which pins are assigned to V_{CC} and GND?
3. In the 8051, how many pins are designated as I/O port pins?
4. The crystal oscillator is connected to pins _____ and _____.
5. If an 8051 is rated as 25 MHz, what is the maximum frequency that can be connected to it?
6. Indicate the pin number assigned to RST in the DIP package.
7. RST is an _____ (input, output) pin.
8. The RST pin is normally _____ (low, high) and needs a _____ (low, high) signal to be activated.
9. What are the contents of the PC (program counter) upon RESET of the 8051?
10. What are the contents of the SP register upon RESET of the 8051?
11. What are the contents of the A register upon RESET of the 8051?
12. Find the machine cycle for the following crystal frequencies connected to X1 and X2.
(a) 12 MHz (b) 20 MHz (c) 25 MHz (d) 30 MHz
13. \overline{EA} stands for _____ and is an _____ (input, output) pin.
14. For 8051 family members with on-chip ROM such as the 8751 and the 89C51, pin \overline{EA} is connected to _____ (V_{CC} , GND).
15. \overline{PSEN} is an _____ (input, output) pin.
16. ALE is an _____ (input, output) pin.
17. ALE is used mainly in systems based on the _____ (8051, 8031).
18. How many pins are designated as P0 and what are those in the DIP package?

19. How many pins are designated as P1 and what are those in the DIP package?
20. How many pins are designated as P2 and what are those in the DIP package?
21. How many pins are designated as P3 and what are those in the DIP package?
22. Upon RESET, all the bits of ports are configured as _____ (input, output).
23. In the 8051, which port needs a pull-up resistor to be used as I/O?
24. Which port of the 8051 does not have any alternate function and can be used solely for I/O?
25. Write a program to get 8-bit data from P1 and send it to ports P0, P2, and P3.
26. Write a program to get an 8-bit data from P2 and send it to ports P0 and P1.
27. In P3, which pins are for RxD and TxD?
28. At what memory location does the 8051 wake up upon RESET? What is the implication of that?
29. Write a program to toggle all the bits of P1 and P2 continuously
(a) using AAH and 55H (b) using the CPL instruction.
30. What is the address of the last location of on-chip ROM for the 8751?

SECTION 4.2: I/O PROGRAMMING; BIT MANIPULATION

31. Which ports of the 8051 are bit-addressable?
32. What is the advantage of bit-addressability for 8051 ports?
33. When P1 is accessed as a single bit port, it is designated as _____.
34. Is the instruction "CPL P1" a valid instruction?
35. Write a program to toggle P1.2 and P1.5 continuously without disturbing the rest of the bits.
36. Write a program to toggle P1.3, P1.7, and P2.5 continuously without disturbing the rest of the bits.
37. Write a program to monitor bit P1.3. When it is high, send 55H to P2.
38. Write a program to monitor the P2.7 bit. When it is low, send 55H and AAH to P0 continuously.
39. Write a program to monitor the P2.0 bit. When it is high, send 99H to P1.
40. Write a program to monitor the P1.5 bit. When it is high, make a low-to-high-to-low pulse on P1.3.

ANSWERS TO REVIEW QUESTIONS

SECTION 4.1: PIN DESCRIPTION OF THE 8051

1. From 0 to 16 MHz, but no more than 16 MHz.
2. $1/12$ th of 16 MHz is 1.33 MHz. and the machine cycle is = 0.75 μ s
3. EA 4. 4, 8 5. True
6. PC = 0000 7. 0000 8. Port 0

SECTION 4.2: I/O PROGRAMMING; BIT MANIPULATION

1. (b) 2. True 3. They are the complement of each other.
4. Yes. This is called immediate addressing mode (discussed in Chapter 5).
5. input