Microcontrollers

Syllabus: *Microcontrollers: Introduction to Microcontrollers, 8051 Microcontroller Architecture and an example of Microcontroller based stepper motor control system (only Block Diagram approach).*
(5 Hours)

Introduction to Microcontrollers

A microcontroller is a small computer on a single integrated circuit (IC) containing a processor (CPU), memory and programmable input/output ports. A microcontroller is also referred to as a ***system on a chip.*** Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, household appliances, power tools, toys and other embedded systems.

Difference between Microprocessors and Microcontrollers

Fig. 1 gives a comparison of a microprocessor system and a microcontroller system.

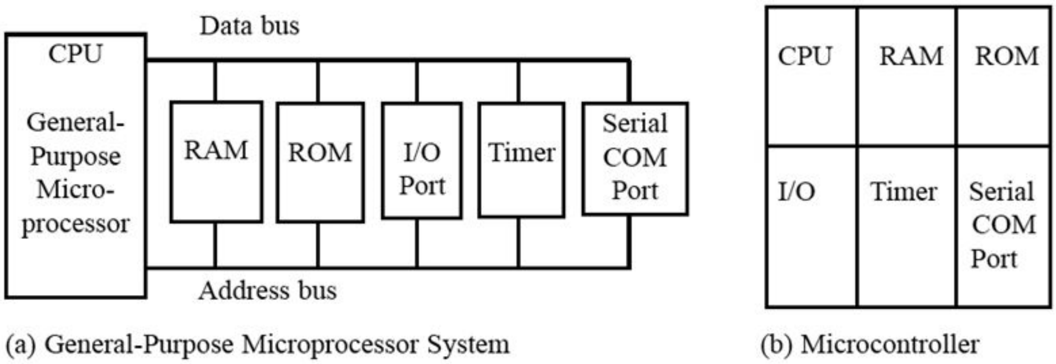

Fig. 1 Microprocessor system contrasted with microcontroller system.

A microprocessor is a multipurpose, programmable, clock-driven, register-based electronic device that reads binary instructions from a storage device called memory, accepts binary data as input and processes data according to those instructions, and provides results as output. A microprocessor is a ***general-purpose*** device and it does not contain RAM, ROM or I/O ports. To make it functional, memory and I/O ports have to be connected to the microprocessor externally.

A microcontroller has a CPU in addition to a fixed amount of RAM, ROM, I/O ports and a timer all on a single chip. Since the processor, memory and I/O ports are on a single chip, microcontroller systems take lesser space than microprocessor systems. Microcontrollers are used mostly in embedded systems, where cost and space are critical. Microcontroller based systems are specific-purpose systems which perform a single task. For example, a printer is used only for a single purpose, that is, getting the data and printing it.

Table 1 summarizes the differences between microprocessor and microcontroller.

Table 1 Differences between microprocessor and microcontroller

Microprocessor	Microcontroller
Microprocessor contains ALU, general purpose registers, stack pointer, program counter, clock and timing circuit and interrupt circuit	Microcontroller contains the circuitry of microprocessor and in addition it has built-in memory (ROM and RAM), I/O devices, timers and counters
It has many instructions to move data between memory and CPU	It has one or two instructions to move data between memory and CPU
It has one or two bit handling instructions	It has many bit handling instructions
Access times for memory and I/O devices are more	Less access times as memory and I/O are built-in
Microprocessor based system requires more hardware	Microcontroller based system requires less hardware reducing PCB size and increasing the reliability
Microprocessor based system is more flexible in design point of view	Less flexible in design point of view
It has single memory map for data and code	It has separate memory map for data and code
Less number of pins are multifunctioned	More number of pins are multifunctioned

8051 Microcontroller

In 1981, Intel Corporation introduces an 8-bit controller called the 8051. The 8051 has 128 bytes of RAM, 4k bytes of on-chip ROM, one serial port and four 8-bit ports all on a single chip. The 8051 is an ***8-bit processor***, which means 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.

Salient Features

The 8051 has following salient features:

- 8-bit CPU with 8-bit registers A (accumulator) and B
- 8-bit data bus and 16-bit address bus
- 128 bytes of internal data memory (RAM)
- 4096 bytes (4k bytes) of internal program memory (ROM)
- Four register banks: R0, R1, R2 and R3, each containing 8 registers
- 32 bidirectional I/O lines organized as four 8-bit ports: P0, P1, P2 and P3
- Two multiple mode 16-bit timers/counters: T0 and T1
- 128 user-defined software flags

- One microsecond (1 µs) instruction cycle with 12 MHz crystal
- Full duplex asynchronous serial transmitter/receiver
- Two external and three internal interrupt sources

Architecture

Fig. 2 shows the block diagram of 8051 microcontroller. It consists of a CPU, two kinds of memory – RAM and ROM, input/output ports, serial port, two 8-bit timers/counters, interrupt control and bus control logic.

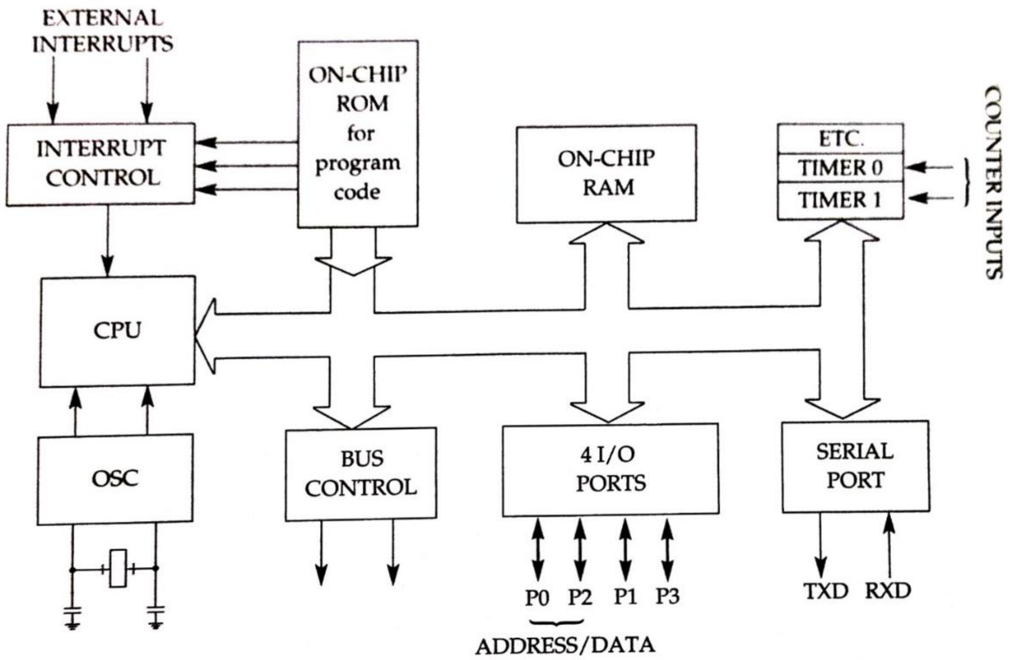

Fig. 2 Block diagram of 8051 microcontroller

Fig. 3 shows the architectural block diagram of 8051.

Central Processing Unit (CPU)

The CPU of 8051 consists of 8-bit arithmetic and logic unit (ALU) with associated registers like accumulator (A), B, program status word (PSW), stack pointer (SP), program counter (PC) and data pointer (DPTR) registers.

Register A (Accumulator)

It is an 8-bit register used in arithmetic and logic operations. It holds the source operand and receives the result of the arithmetic instructions.

Register B

Register B is a general purpose register which is also used during multiply and divide operations.

Data Pointer (DPTR)

The data pointer consists of two 8-bit registers – a high byte (DPH) and a low byte (DPL). It is used as base register while calculating address in certain instructions.

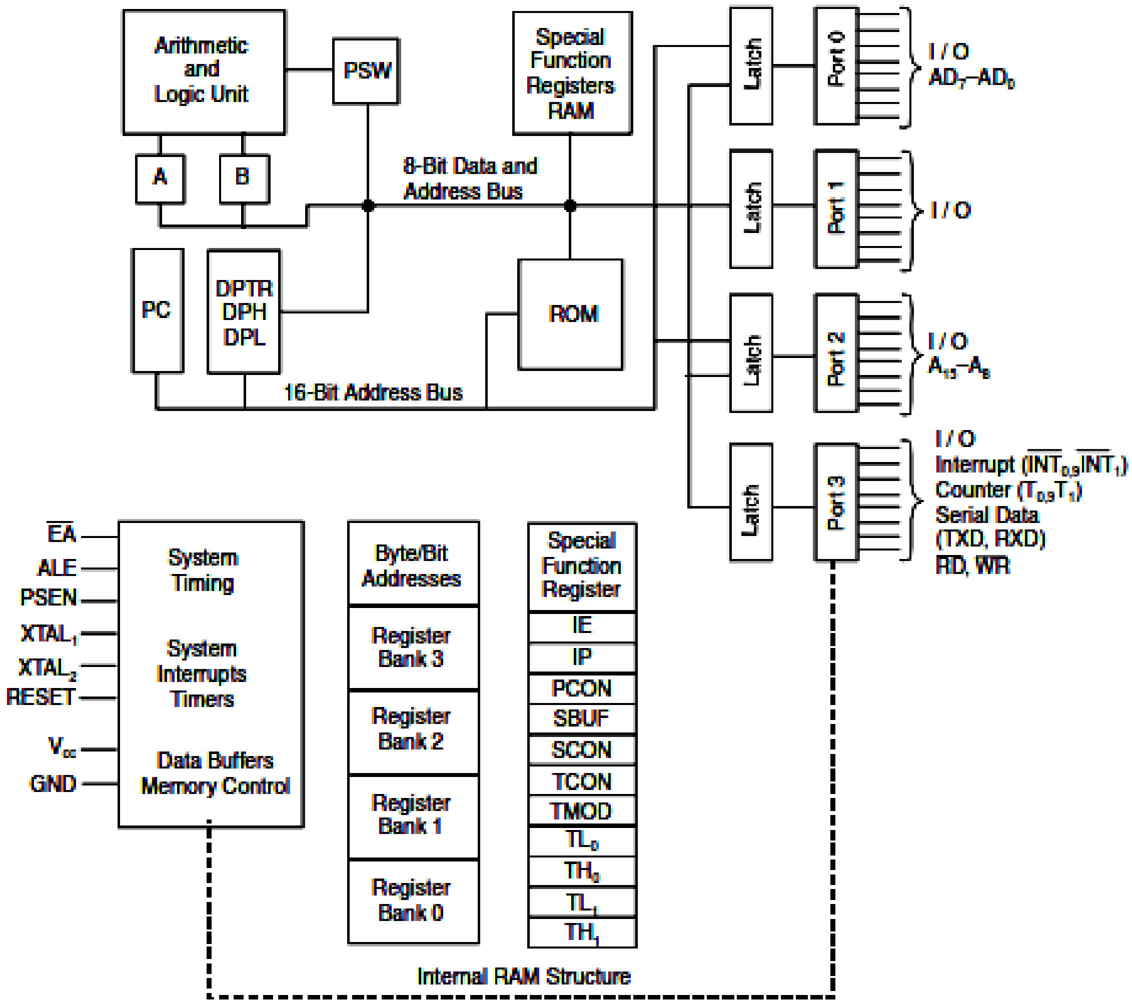

Fig. 3 Architectural block diagram of 8051

Program Counter (PC)

It is a 16-bit register which holds the address of next instruction to be executed.

Program Status Word (PSW)

It is an 8-bit register which holds the present status of 8051 CPU. Fig. 4 shows the contents of the PSW of 8051 with explanation of each bit.

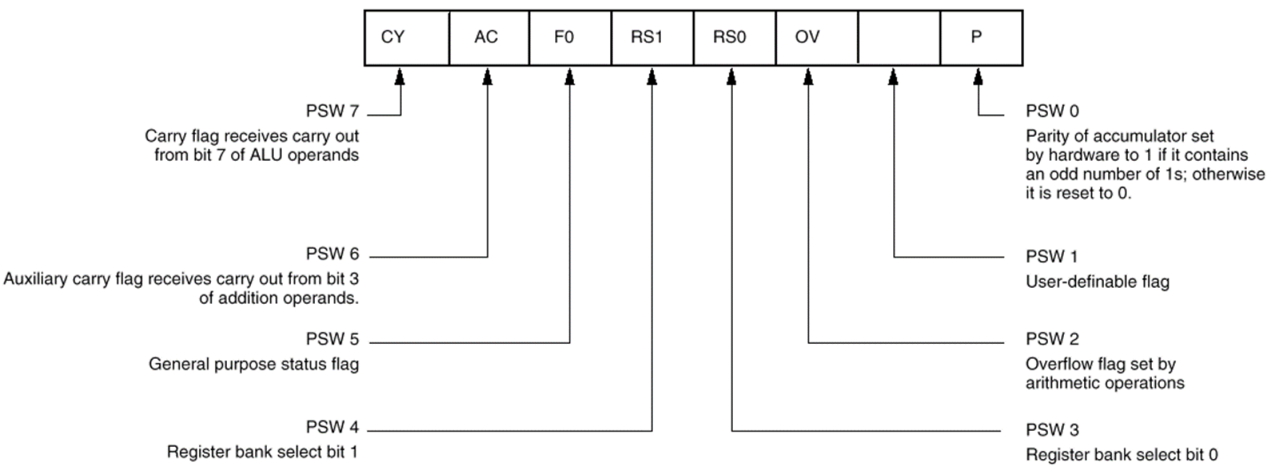

Fig. 4 Program status word in 8051

Stack Pointer (SP)

It is an 8-bit register which contains the address of the data item on the top of the stack.

Memory

The 8051 has 4k bytes of internal program/code memory (ROM) and 128 bytes of internal data memory (RAM). The program memory is used to hold the startup program that will be executed when 8051 is powered up. The data memory is organized into three parts: four register banks, bit addressable RAM and general purpose RAM.

In addition to internal memory, 64k bytes of external ROM and RAM can be connected to the 8051 if required. Fig. 5 shows the memory organization in 8051.

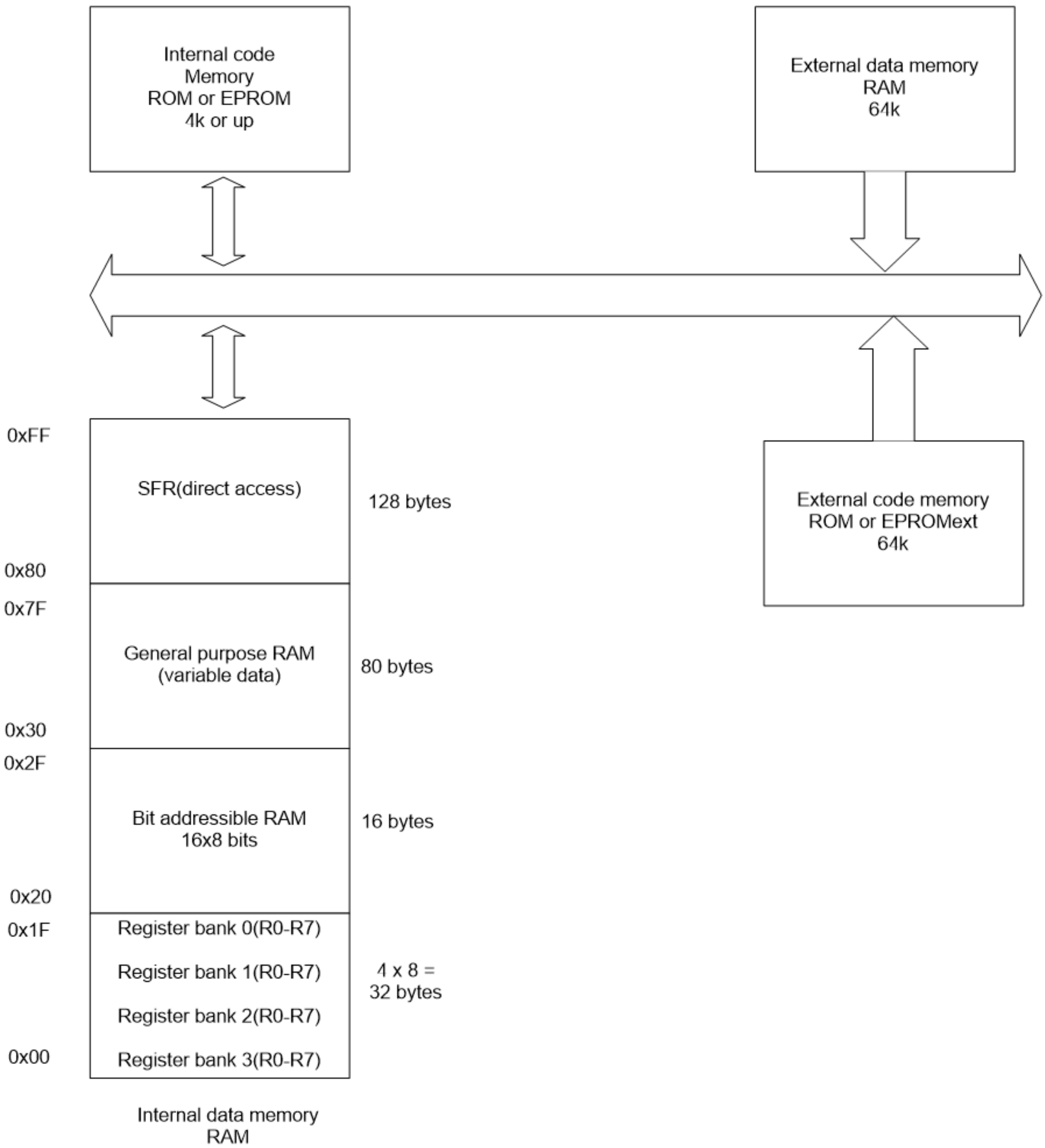

Fig. 5 Memory organization in 8051

Special Function Registers

The group of registers that are located immediately above the 128 bytes of RAM and perform special functions are called special function registers (SFRs). The SFRs are a sort of control table used for running and monitoring the operation of the microcontroller. There are 21 SFRs. The most frequently used SFRs to control and configure 8051 operations are:

- TCON (Timer control)
- TMOD (Timer mode)
- TH0/TH1 and TL0/TL1 (Timer's high and low bytes)
- SCON (Serial port control)
- IP (Interrupt Priority)
- IE (Interrupt Enable)

Input/Output Ports

The 8051 contains four 8-bit parallel ports P0, P1, P2 and P3. Ports can be used to send or receive data. Each bit of the port can be configured as an input or an output port pin.

The port 0 is used as low order address and data pins, port 2 I used as high order address pins and port 3 is used by timers, serial ports, external interrupt and for sending control signals for external data memory.

Pin Diagram

Fig. 6 gives the pin description of 8051. The pins are explained as below:

Vcc (Pin 40): It is connected to +5V power supply.

GND (Pin 20): It is connected to ground

XTAL1 and XTAL2 (Pin 19 and 18): The 8051 has an on-chip oscillator but requires an external clock to run it. A quartz crystal oscillator is connected to the inputs XTAL1 and XTAL2.

RST (Pin 9): When a high pulse is applied to this pin, the microcontroller is ***reset*** and terminates all the activities. Table 2 gives the values of some 8051 registers when reset.

Table 2 Values of 8051 registers when reset

Register	Reset Value (hex)
PC	0000
DPTR	0000
ACC	00
PSW	00
SP	07
B	00
P0-P3	FF

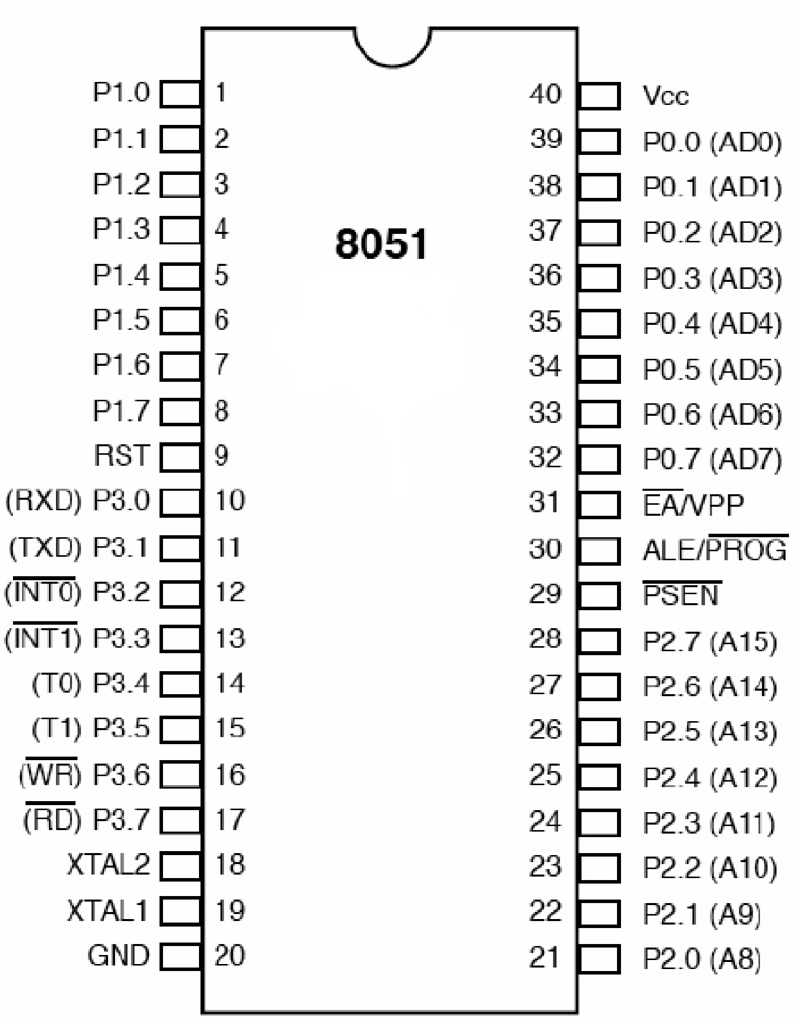

Fig. 6 Pin diagram of 8051

$\overline{\text{EA}}$ (Pin 31): If this pin is high, it selects internal program memory for address 0000H to 0FFFFH. Beyond this address (1000H to FFFFH), it selects external program memory. If this pin is low, it selects only external program memory for address 0000H to FFFFH.

$\overline{\text{PSEN}}$ (Pin 29): Program strobe enable (PSEN) is an output pin. When fetching internal program memory, this pin is low and during internal program execution, this pin is high.

ALE (Pin 30): Address latch enable (ALE) is an output pin. This is used to latch low order address from the multiplexed bus (AD0-AD7) and generate a separate set of eight address lines A0-A7.

Port 0 (Pins 32-39): It is a bidirectional 8-bit I/O port. It is also designated as AD0-AD7 and is used for both address and data. When ALE=0, it provides data D0-D7 and when ALE=1, it has address A0-A7.

Port 1 (Pins 1-8): It is a bidirectional 8-bit I/O port. It has no dual functions.

Port 2 (Pins 21-28): It is also a bidirectional 8-bit I/O port. It serves as high order address bus (A8-A15) for external memory.

Port 3 (Pins 10-17): It is also a bidirectional 8-bit I/O port. It has additional function of providing some important signals. The alternate functions of port 3 are listed in Table 3.

Table 3 Alternate functions of Port 3

Port Pin	Pin No.	Alternate Function
P3.0	10	RXD (serial input port)
P3.1	11	TXD (serial output port)
P3.2	12	$\overline{INT0}$ (external interrupt 0)
P3.3	13	$\overline{INT1}$ (external interrupt 1)
P3.4	14	T0 (timer/counter 0 external input)
P3.5	15	T1 (timer/counter 1 external input)
P3.6	16	$\overline{WR}$ (external data memory write strobe)
P3.7	17	$\overline{RD}$ (external data memory read strobe)

Microcontroller Based Stepper Motor Control System

Stepper Motors

A stepper motor is a widely used device that translates electrical pulses into mechanical movement. Stepper motors have a permanent magnet rotor (or shaft) surrounded by a stator as shown in Fig. 7. The most common stepper motors have four stator windings that are paired with a center-tapped common as shown in Fig. 8. This type of stepper motor is commonly referred to as a ***four-phase*** or ***unipolar stepper motor.*** The center tap allows a change of current direction in each of two coils when a winding is grounded, thereby resulting in a polarity change of the stator.

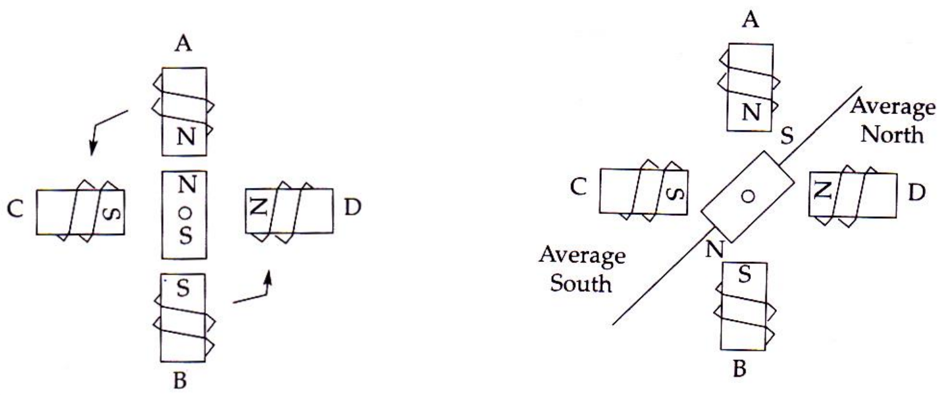

Fig. 7 Rotor alignment

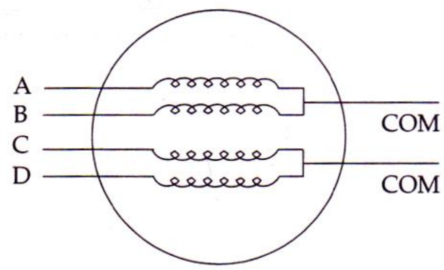

Fig. 8 Stator winding configuration

Principle of Operation

The stepper motor shaft moves in a fixed repeatable increment and hence can be moved to a precise position. This repeatable fixed movement is possible as a result of basic magnetic theory where ***poles of same polarity repel and opposite poles attract***. The direction of the rotation is determined by the stator poles. The stator poles are determined by the current sent through the wire coils. As the direction of the current is changed, the polarity is also changed, causing the reverse motion of the rotor.

The stepper motor discussed here has 6 leads – 4 leads representing the four stator windings and 2 commons for the center-tapped leads. As the sequence of power is applied to each stator winding, the rotor will rotate. Table 4 shows a 2-phase, 4-step stepping sequence.

Table 4 Normal 4-step sequence

Clockwise ↓

Step No.	Winding A	Winding B	Winding C	Winding D
1	1	0	0	1
2	1	1	0	0
3	0	1	1	0
4	0	0	1	1

Counter-Clockwise ↑

Step Angle

The step angle is the minimum degree of rotation associated with a single step. Table 5 shows the step angles for various motors and corresponding steps per revolution.

Table 5 Stepper motor step angles

Step Angle	Steps per Revolution
0.72	500
1.8	200
2.0	180
2.5	144
5.0	72
7.5	48
15	24

Interfacing 8051 to a Stepper Motor

Fig. 9 shows the connections for interfacing 8051 microcontroller to a stepper motor.

- An ohmmeter is used to measure the resistance of the leads. This identifies which COM leads are connected to which winding leads.
- The common wires are connected to the positive side of the motor's power supply. In many motors, +5V is sufficient.

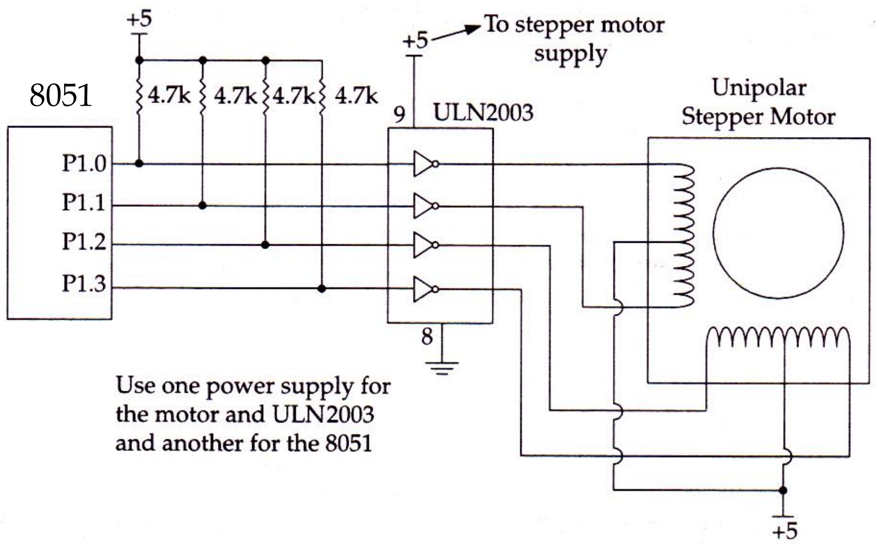

Fig. 9 8051 connection to stepper motor

- The four leads of the stator winding are controlled by four bits of the 8051 port (P1.0 – P1.3).
- Since 8051 lacks sufficient current to drive the motor, a driver such as ULN2003 is used to energize the stator.
- The same power supply (+5V) used for the motor is used as a supply for the driver.

Applications of Stepper Motors

Stepper motors are used in various applications which require controlled step-wise rotation such as ***robotics, dot matrix printers, disk drives, scanners, plotters, etc.***

Questions

1. Define microcontrollers. Write their important applications. ***(Dec '16 – 5M)***
2. List the differences between microprocessor and microcontroller.
(Dec '17 – 4M, Jun '17 – 8M, Jun '16 – 5M, Dec '15 – 5M, Jun '15 – 8M, MQP '14 – 5M)
3. List the features of 8051 microcontroller. ***(Jun '16 – 5M)***
4. With a neat block diagram, explain the architecture of 8051 microcontroller.
(Dec '17 – 10M, Jun '17 – 8M, Dec** '16 **– 8M, Jun '15 – 6M, Dec '15 – 10M, Dec '14 – 9M, MQP '15 – 6M)
5. Explain flag register of 8051 microcontroller. ***(Dec '16 – 5M)***
6. Explain the logic pinout and signals of 8051 microcontroller.
7. What is stepper motor? With a neat block diagram, explain the working principle of microcontroller based stepper motor control system.
(Dec '17 – 10M, Jun '17 – 8M, Dec '16 – 6M, Jun '16 - 8M, Dec '15 – 8M, MQP '15 – 6M)

References

1. Muhammad Ali Mazidi, Janice Gillispie Mazidi, Rolin D. McKinlay ***"The 8051 Microcontroller and Embedded Systems using Assembly and C"***, Second Edition, Pearson India, 2011.
2. Kenneth J. Ayala, ***"The 8051 Microcontroller Architecture, Programming & Applications"***, Second Edition, Thomson Learning, 2005.