MODULE 2
ACHITECTURE OF 8051

2.1 Introduction :

The 8051 microcontroller family, introduced by Intel in 1980, has evolved over the years with several variants and improvements from different manufacturers. Here's a comparison of some notable members:

1. **Intel 8051**:
   - The original microcontroller introduced by Intel.
   - Generally operates at a clock speed of up to 12 MHz.
   - Limited on-chip peripherals and memory (128 bytes of RAM, 4 KB of ROM).
2. **Intel 8031/8052**:
   - Variants of the original 8051 with additional features.
   - Intel 8031 has 128 bytes of RAM and 1 KB of ROM.
   - Intel 8052 has 256 bytes of RAM and 8 KB of ROM.
3. **Atmel AT89 Series**:
   - Atmel (now Microchip Technology) produced a wide range of 8051-compatible microcontrollers under the AT89 series.
   - AT89C51, AT89C52, AT89S52 are popular variants.
   - They offer expanded memory options (up to 64 KB of Flash) and additional features like UART, timers/counters, and ADC.
4. **Silicon Labs C8051F Series**:
   - Silicon Labs (formerly Cygnal Integrated Products) enhanced the 8051 architecture with the C8051F series.
   - These microcontrollers offer higher clock speeds (up to 25 MHz), more on-chip peripherals (UARTs, ADCs, DACs), and larger memory options (up to 64 KB of Flash).
5. **STMicroelectronics STC89 Series**:
   - STMicroelectronics produces several variants of 8051-compatible microcontrollers under the STC89 series.
   - They offer features similar to other variants, with options for different memory sizes and peripherals.
6. **NXP (formerly Philips) P89V51RD2**:
   - NXP's variant of the 8051 includes features like dual data pointers, extended RAM (1 KB), and large Flash memory (64 KB).
   - It also supports in-system programmability and a wide range of communication interfaces.

Comparison Summary:

- **Clock Speed**: Ranges from 12 MHz in older models to up to 25 MHz in newer variants like the Silicon Labs C8051F.

- **Memory**: Ranges from as low as 128 bytes of RAM and 1 KB of ROM in older models to 1 KB of RAM and up to 64 KB of Flash in newer models.
- **Peripherals**: Basic UART, timers, and GPIOs in older models; newer models include advanced peripherals like ADCs, DACs, and multiple UARTs.
- **Manufacturer**: Intel, Atmel (Microchip), Silicon Labs, STMicroelectronics, NXP (Philips), and others produce different variants with varying features and specifications

The 8051 microcontroller and its various family members, including the 8052 and 8031, offer a range of features suited for different applications. Here's a breakdown of their key characteristics and uses:

Key Characteristics Comparison

Characteristic	8051	8052	8031
RAM	128 bytes	256 bytes	128 bytes
ROM (on-chip)	4 KB	8 KB	0 KB
Number of Timers	2	3	2
Interrupt Sources	6	8	6
Serial Port	1	1	1
Number of I/O Ports	32	32	32

Uses of Comparison

1. **Selecting the Appropriate Microcontroller:** Engineers can choose based on the specific needs of their application. For example, if more RAM or ROM is required, the 8052 might be preferred. If no on-chip ROM is needed, the 8031 could be suitable.
2. **Code Migration:** Understanding the similarities in instruction set and pinout allows engineers to migrate code between different members of the 8051 family. This facilitates reusability and compatibility across projects.
3. **Upgrading Existing Systems:** Engineers can assess whether upgrading from an 8051-based system to a newer family member like the 8052 or 8031 would benefit their application. This includes evaluating additional features such as more timers or interrupt sources.
4. **Learning and Development:** Students and hobbyists can explore different members to understand microcontroller architecture and determine which

features are most relevant for their projects. This knowledge aids in developing new applications.

5. Developing New Applications: By leveraging the additional features of newer family members (e.g., on-chip flash memory, expanded interrupt structure), engineers can create more sophisticated embedded systems that meet specific requirements.

Issues to Consider

1. **Compatibility Challenges:** While most family members are largely compatible, slight variations in features or pinout could impact code migration. Careful evaluation and testing are necessary.
2. **Development Tools:** Different development tools could be needed for different microcontrollers. For effective development, interoperability with programmers, debuggers, and compilers is essential.
3. **Availability and Cost:** Availability and pricing can vary between different family members and manufacturers. Engineers should consider these factors alongside their project requirements.
4. **Training and Support:** Adequate resources for training and technical support are essential, particularly for less commonly used variants. This ensures smooth development and troubleshooting.
5. **Power Consumption:** Although the 8051 series is recognized for having low power consumption, subsequent models may require more power due to added functionalities. Assessing power usage is essential for battery-powered devices.

2.2 8051 ARCHITECTURE

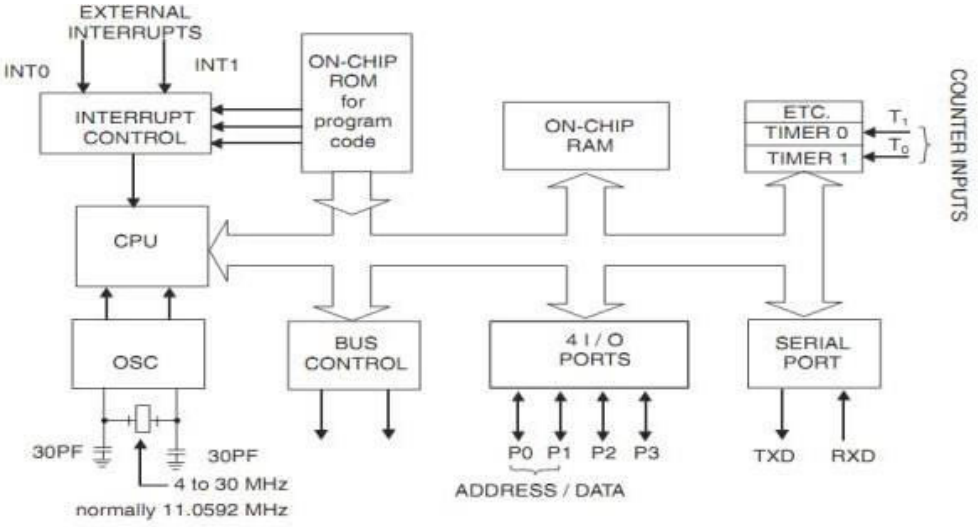


Fig 2.2.1 Block Diagram of 8051

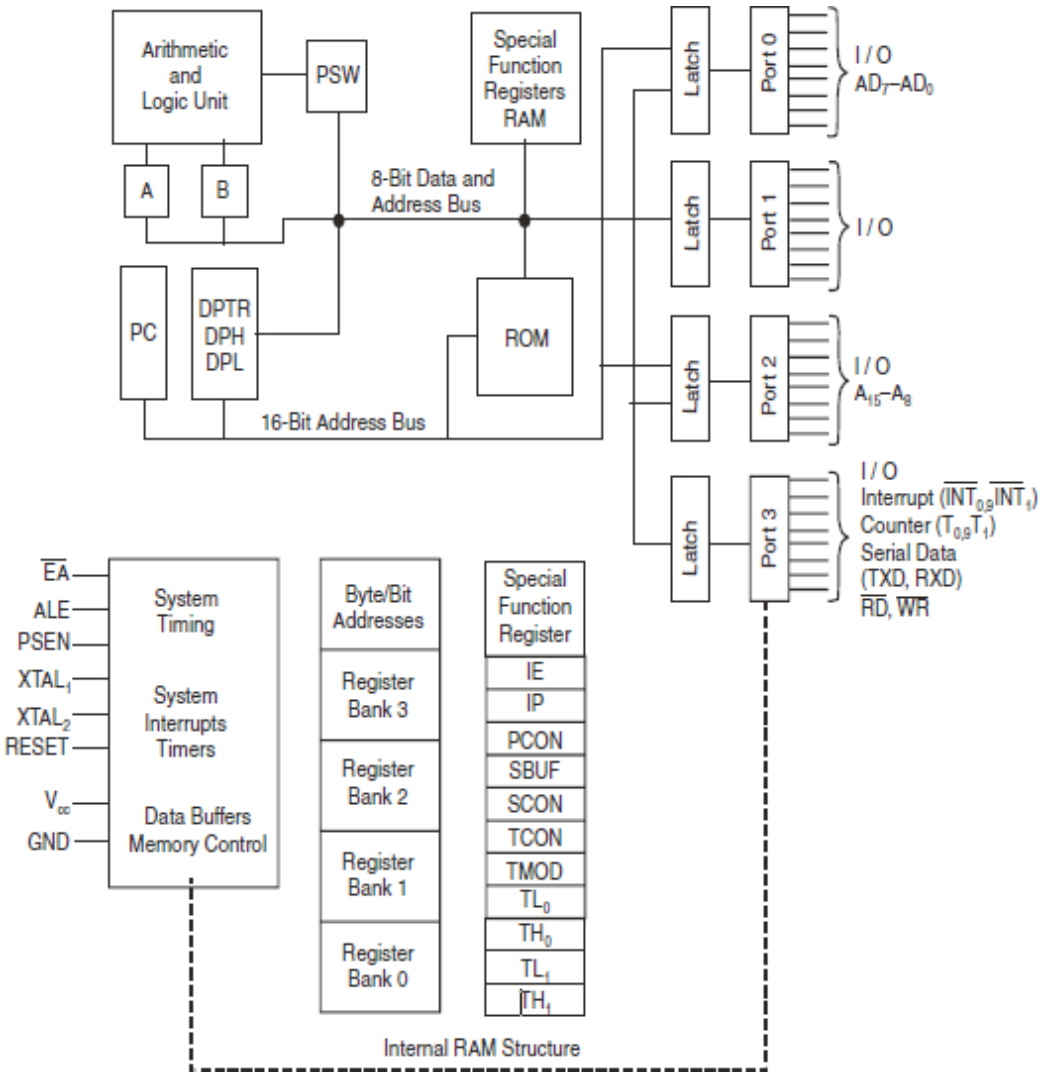


Fig 2.2.2 Architectural block diagram of microcontroller 8051

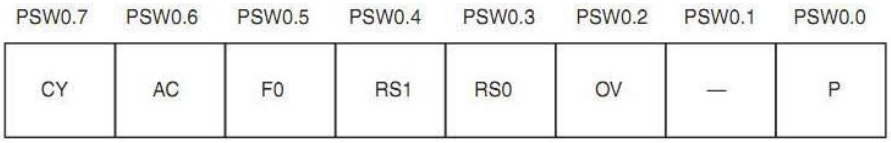
It seems like you've provided a detailed overview of various components and features of the 8051 microcontroller. Here's a breakdown and summary of the main components and their functions:

Components of 8051 Microcontroller

1. **ALU (Arithmetic Logical Unit)**
   - Performs arithmetic and logical operations.
2. **A-Accumulator**

- 8-bit register for arithmetic operations.
- Bit-addressable for individual bit manipulation.

3. **B-Register**
   - Used specifically in MUL AB and DIV AB instructions.
   - Bit-addressable and 8-bit register.
4. **PC-Program Counter**
   - 16-bit register pointing to the next instruction in ROM.
   - Address range from 0000H to FFFFH (64KB).
   - Initialized using ORG directive.
   - Automatically incremented after each instruction.
5. **PSW Register (Program Status Word)**
   - Contains flags indicating arithmetic conditions.
   - Bit-addressable and 8-bit wide.
   - Flags include Carry (CY), Auxiliary Carry (AC), Overflow (OV), and others.



PSW0.7	PSW0.6	PSW0.5	PSW0.4	PSW0.3	PSW0.2	PSW0.1	PSW0.0
CY	AC	F0	RS1	RS0	OV	—	P

FLAG Register

PSW Register Description

CY	PSW0.7	Carry Flag
AC	PSW0.6	Auxiliary Carry Flag
F0	PSW0.5	Flag 0 available for general purpose.
RS1	PSW0.4	Register Bank select bit 1
RS0	PSW0.3	Register bank select bit 0
OV	PSW0.2	Overflow flag
---	PSW0.1	User definable flag
P	PSW0.0	Parity flag .set/cleared by hardware.

- The bits PSW3 and PSW4 are denoted as RS0 and RS1 and these bits are used to select the bank registers of the RAM location.
- **P (Parity flag)** → PSW 0.0
  - 1 – odd number of 1 in ACC
  - 0 – even number of 1 in ACC
- **OV (overflow flag)** → PSW 0.2
  - This is used to detect error in signed arithmetic operation.
  - This is similar to carry flag but difference is only that carry flag is used for unsigned operation.
- **The selection of the register Banks** and their addresses are given below.

6. **Register banks**

RS1	RS0	Register Bank	Address
0	0	0	00H-07H
0	1	1	08H-0FH
1	0	2	10H-17H
1	1	3	18H-1FH

- Initially by default always Bank 0 is selected.

- **F0 → user definable bit**
- **AC (Auxiliary carry flag)** → PSW0.6
  - When carry is generated from D3 to D4, it is set to 1, it is used in BCD arithmetic.
- **CY (carry flag)** → PSW0.7
  - Affected after 8 bit addition and subtraction.
  - It is used to detect error in unsigned arithmetic operation.
  - It can be used as single bit storage.
    - SETB C → for cy = 1
    - CLR C → for cy = 0

Stack and Stack Pointer (SP)

- RAM locations 08H to 1FH used as stack.
- Stack operates on Last In, First Out (LIFO) principle.
- SP is an 8-bit register pointing to the current top of stack.
- Initialized to 07H, increments with PUSH, decrements with POP.

6. **DPTR (Data Pointer)**
- 16-bit register for accessing program and external data memory.
- Consists of DPH (high byte) and DPL (low byte).

7. **I/OPorts (P0, P1, P2, P3)**
- Four 8-bit ports for general-purpose I/O.
- P0 and P2 can serve dual purposes as address/data buses when interfacing with external memory.
- P3 has additional functions like serial communication (RXD, TXD), interrupts (INT0, INT1), and memory control signals (RD, WR).

8. **Oscillator**
- Provides clock signal to the microcontroller.
- Typically uses a crystal oscillator ranging from 4MHz to 30MHz.
- Determines the operating speed and baud rate.

9. **Interrupts**
- Special events that can interrupt normal program flow.
- Handled by Interrupt Service Routines (ISR).
- External interrupts INT0 and INT1 are associated with P3 pins.

10. **Timers and Counters**
- T0 and T1 are 16-bit timers/counters.
- Used for generating delays or counting external events.
- Controlled by TMOD (Timer Mode) and TCON (Timer Control) registers.
- TH0/TL0 and TH1/TL1 used for loading timer values.

11. **Serial Port**
- TXD and RXD pins for serial communication.
- SBUF register holds serial data.
- SCON register controls serial port operation.

The 8051 microcontroller is a versatile 8-bit architecture with a rich set of features suitable for embedded systems. Its components include arithmetic units, registers for data manipulation, program control through PC and PSW, flexible I/O ports, stack management, timers/counters for timing and event counting, and serial communication capabilities. Understanding these components and their functionalities helps in effectively designing and programming applications on the 8051 family of microcontrollers.

❖ **Memory organization:**

The 8051 microcontroller features 4kB of on-chip ROM and 128 bytes of internal RAM.

o Another name for RAM is data memory, and another name for ROM is program memory.

o Code memory is another name for program memory.

o This code memory contains the actual 8051 software that has to be executed.

o The 8051 has a meager 64K of memory.

o Code memory is found in on-chip ROMs and EPROMs. Alternatively, and this is the more common option, it can be retained completely off-chip in an external EPROM or ROM.

The 8051 has only 128 bytes of internal RAM, however it can support 64kB of external RAM. As the name suggests, external RAM is any random access memory that is not on-chip. The 8051 microcontroller has 128 bytes of internal RAM and 4kB of on-chip ROM.

o The RAM is also known as data memory and the. This code memory

contains the actual 8051 software that has to be executed.
o The 8051's memory is located off-chip.
o For example, increasing a position by one in Internal RAM requires only one instruction and one instruction cycle, while increasing a 1-byte value stored in External RAM requires four instructions and seven instruction cycles.
As a result, this external memory operates seven times slower.

- **Internal RAM OF 8051:**
- The 8051's internal RAM is located on-chip.

o As a result, it is the quickest RAM on the market and offers the greatest flexibility for reading, writing, and editing data.
o Because internal RAM is volatile, it is cleared during an 8051 reset.
o The internal 128 bytes Bank0, Bank1, Bank2, and Bank 3 are the four register banks, each with
eight bits (a total of 32 bytes). Bank0 is the default bank registration. The RS0 and RS1 bits of
the PSW Register are used to assist choose the remaining Banks.
As seen in the diagram, there are 16 bytes of bit addressable area and 80 bytes of general
purpose area (Scratch pad memory). The microcontroller additionally uses this space as a
storage place for o The 8051's internal RAM is located on-chip.
o As a result, it is the quickest RAM on the market and the most adaptable in terms of reading the
operating system.
o Working registers, arranged into four banks of eight registers each, are created using the 32
bytes of RAM from address 00 H to 1FH.
o R0-R7 is the name of the registries. Either the RAM address or the register name can be used to
address each one.

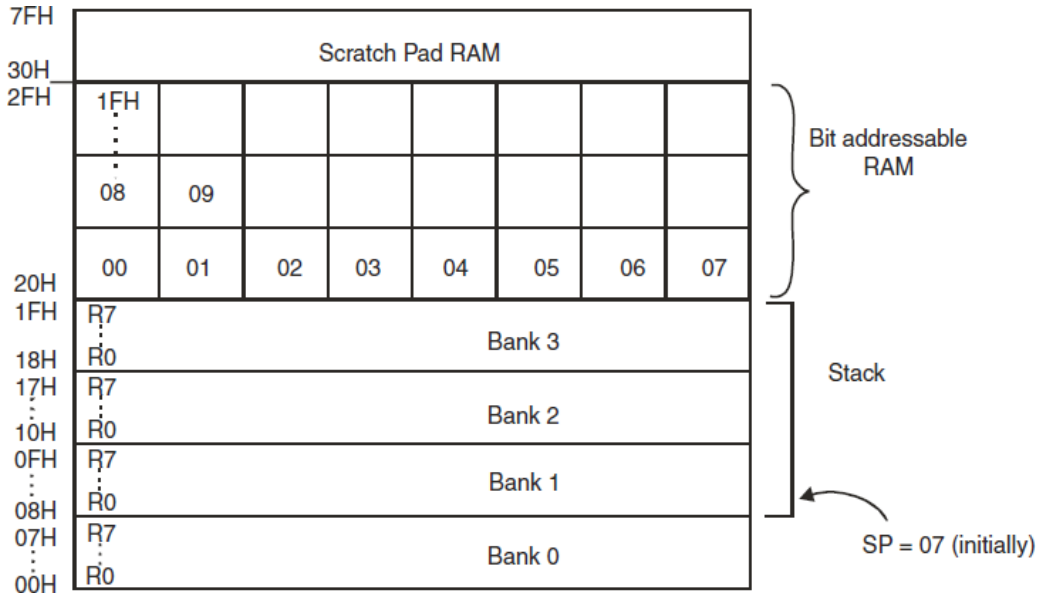


Fig2.2.3 Structure of RAM

The 8051 has 4KB of read-only memory (ROM) that can be used to store programs.

o Permanent data storage is done here. or the data that is kept unchanged while being processed, such as an algorithm or program designed for a particular use.

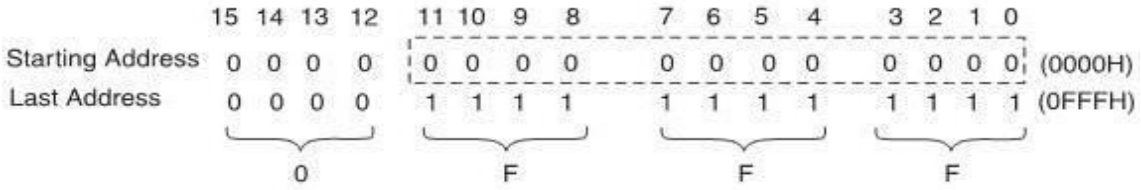
This memory is volatile, meaning that even in the event of a power outage, the data stored inside remains intact.

If the application is substantial, we can interface up to 64KB of ROM memory externally.

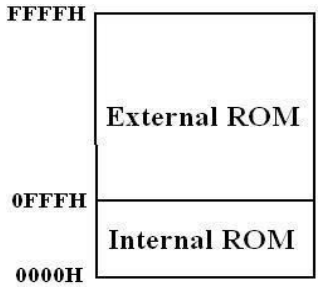
o The companies have varying specifications for these sizes.

o PC Address Range: The program counter on a PC, which indicates the next command to be executed, can be moved between various locations based on its address range, or the program can be saved from one location to another. It is possible to compute the address range in the same way just like the RAM which is discussed in previous section

$$4\text{KB} = 2^2 \cdot 2^{10}\,\text{B} \left(\text{since } 1\text{KB} = 2^{10}\,\text{B}\right)$$
$$= 2^{12}\,\text{Byte}$$



- Address range of PC is 0000H to 0FFFH means total 4KB locations are available from 0000H to 0FFFH.



❖ **SPECIAL FUNCTION REGISTERS (SFRs):**

A few registers on the 8051 microcontroller use RAM addresses between 80h and FFh and are designed for specific purposes.

o These registers are referred to as special function registers, or SFRs.

o Some of these registers are also bit addressable. The list of SFRs and their functional names are displayed below. These SFRs fall into three groups: those linked to I/O ports (P0, P1, P2, and P3), those meant for control activities (TCON, SCON, PCON, etc.), and the other SFRs, which are auxiliary in nature and do not directly configure the 8051.

Table : SFRs of 8051 Microcontroller

S.No	Symbol		Name of SFR	Address (Hex)
1	ACC*		Accumulator	**E0**
2	B*		B-Register	**F0**
3	PSW*		Program Status word register	**DO**
4	SP		Stack Pointer Register	**81**
5	DPTR	DPL	Data pointer low byte	**82**
		DPH	Data pointer high byte	**83**
6	P0*		Port 0	**80**
7	P1*		Port 1	**90**
8	P2*		Port 2	**0A**
9	P3*		Port 3	**0B**
10	IP*		Interrupt Priority control	**B8**
11	IE*		Interrupt Enable control	**A8**
12	TMOD		Timer mode register	**89**
13	TCON*		Timer control register	**88**
14	TH0		Timer 0 Higher byte	**8C**
15	TL0		Timer 0 Lower byte	**8A**
16	TH1		Timer 1Higher byte	**8D**
17	TL1		Timer 1 lower byte	**8B**
18	SCON*		Serial control register	**98**
19	SBUF		Serial buffer register	**99**
20	PCON		Power control register	**87**

The * indicates the bit addressable SFRs

2.3 PIN DIAGRAM OF 8051:

The 8051 microcontroller operates at +5 volts DC and is available as a 40 pin DIP chip.
VCC → 5V power source
XTAL2/XTALI are for oscillator input. VSS → GND
Ports 0 through 32 to 39, which correspond to AD0/AD7 and P0.0 to P0.7; Ports 1 through 8; 21 to 28; P2.0 to P2.7 and A 8 to A15; Port 3 through 10 to 17; P3.0 to P3.7; P 3.0 – RXD – Serial data input – SBUF; and P 3.1 – TXD – Serial data output – SBUF
P 3.2 - INT0 - External interrupt 0 - TCON 0.1 P 3.3 - INT1 - External interrupt 1 - TCON 0.3 P 3.4 - T0 - External timer 0 input - TMOD

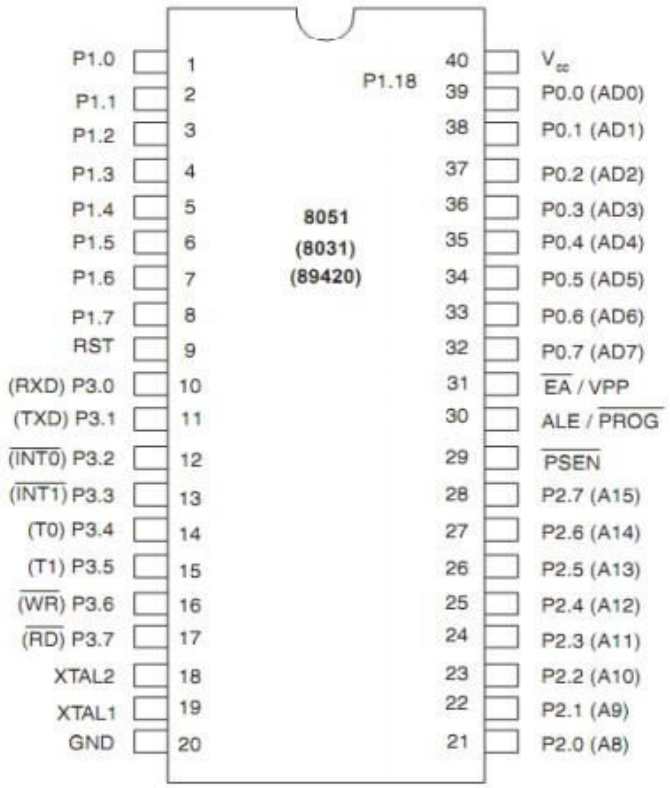
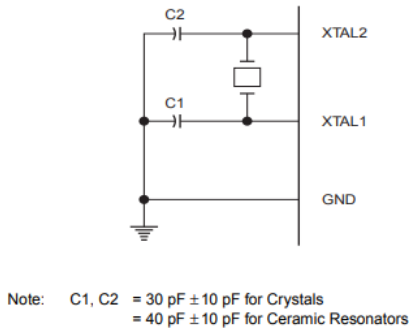


Fig 2.3.1 Pin Diagram of 8051

XTAL1,XTAL2:

The on-chip oscillator is powered by a quartz crystal oscillator, which is coupled to these two pins.
- o As seen in figure 2.3.2, the quartz crystal oscillator is connected to the two pins together with a 30 pF capacitor.
- o As illustrated in figure 2.3.3, if a source other than the crystal oscillator is used, it will be connected to XTAL1 and XTAL2 will remain disconnected.



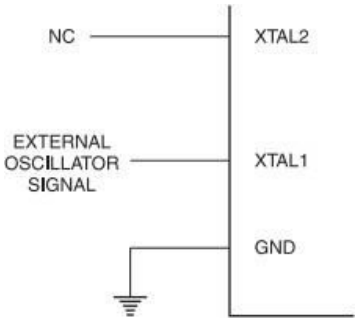


Fig 2.3.2 Crystal Oscillator as Source **Fig 2.3.3 External Clock Source**

- **P0.0- P0.7(AD0-AD7) :**
  - o Address and data pins were multiplexed with port 0 pins.
  - o These pins serve as address/data pins when the microcontroller is accessing external memory; otherwise, they are utilized as Port 0 pins.
- **P2.0- P2.7(A8-A15) :**

  The higher order address pins are multiplexed with the port 2 pins.
  - o These pins function as Port 2 pins while the microcontroller is not accessing external memory; otherwise, they give the higher order address byte.
- **P1.0- P1.7:**
  - These 8-pins are dedicated for Port1 to perform input or output port operations.
- **P3.0- P3.7:**
  - These 8-pins are meant for Port3 operations and also for some control operations like Read, Write, Timer0, Timer1, INT0, INT1, RxD and TxD
- **RST:**

  The RESET pin is an active high pin that is used as an input.
  - o This pin will receive a high pulse, which will cause the microcontroller to reset and stop operating.
  - o All of the registers, with the exception of the PC, will reset to 0000 value and the PC register to 0007 value upon reset.
- $\overline{EA}$ **(External Access):** Active Low Pin

  This pin is connected to Vcc when the microcontroller is accessing program code that is stored in on-chip memory and to ground when it is accessing program code that is stored in external memory. Don't leave this pin disconnected.
- $\overline{PSEN}$ **(Program Store Enable):** Active Low Pin

  This pin is linked to the external ROM's OE (Output Enable) pin so that the microcontroller can access the program code stored there.
- **ALE (Address latch enable):** an active high pin. Port 0 multiplexes address and data, delivering both address and data, when it is connected to an external memory device.
  - o This ALE pin will be used to demultiplex the address and data busses.
  - o When the pin is high, the AD bus acts as the address bus; otherwise, it acts as the data bus.

2.4 PARALLEL I/O PORTS:

In the context of microcontrollers like the 8051, parallel I/O (Input/Output) ports play a fundamental role in interfacing with external devices and peripherals. The 8051 microcontroller specifically has four parallel I/O ports, namely P0, P1, P2, and P3, each of which is 8 bits wide. Here's an overview of parallel I/O ports and their significance:

Parallel I/O Ports in 8051 Microcontroller

1. **P0 (Port 0):**
   - **Address:** 80h
   - **Functionality:**
     - Port 0 is an 8-bit bidirectional I/O port.
     - It can be used for general-purpose digital I/O.
     - Additionally, it has alternate functions related to address and data bus multiplexing.
2. **P1 (Port 1):**
   - **Address:** 90h
   - **Functionality:**
     - Port 1 is another 8-bit bidirectional I/O port.
     - It is used primarily for general-purpose digital I/O operations.
     - It may also have additional alternate functions depending on specific applications.
3. **P2 (Port 2):**
   - **Address:** A0h
   - **Functionality:**
     - Port 2 is also an 8-bit bidirectional I/O port.
     - It is often used for interfacing with higher-order address lines (A8-A15) when external memory is used.
     - Like other ports, it supports general-purpose digital I/O.
4. **P3 (Port 3):**
   - **Address:** B0h
   - **Functionality:**
     - Port 3 is an 8-bit bidirectional I/O port.
     - It has dual functions:
     - General-purpose digital I/O.
     - Special functions for external interrupt handling (INT0, INT1), serial communication (TXD, RXD), and control signals (RD, WR).

Features and Usage

- **Bidirectional Operation:** Each port can be configured as either an input or output port under program control.
- **General-Purpose I/O:** Used for connecting and controlling external devices such as LEDs, switches, sensors, and actuators.
- **Address and Data Bus Multiplexing:** P0 and P2 can serve dual roles by multiplexing address and data lines when interfacing with external memory.

- **Interrupts and Special Functions:** Port 3 (P3) includes pins dedicated to external interrupts (INT0, INT1), serial communication (TXD, RXD), and memory control signals (RD, WR), making it versatile for various system-level tasks.

Programming Considerations

- **Configuring Ports:** Ports are configured using appropriate control and data direction registers.
- **Bit-Level Access:** Some ports (P0, P1, P3) are bit-addressable, allowing individual bits to be manipulated directly.
- **Interrupt Handling:** Port 3 pins for interrupts require proper configuration of interrupt enable registers (IE) and interrupt priority registers (IP).

Applications

- **Embedded Systems:** Used extensively in embedded systems for interfacing with sensors, actuators, displays, and other peripherals.
- **Industrial Automation:** Controls and monitors various devices and processes through digital I/O operations.
- **Communication Interfaces:** Handles communication protocols via UART (Universal Asynchronous Receiver/Transmitter) using P3 (TXD, RXD).

Understanding the parallel I/O ports of the 8051 microcontroller is essential for designing and implementing efficient control and interfacing solutions in embedded systems applications. Each port's flexibility and features contribute to its versatility in a wide range of electronic projects and industrial applications.