ADC & DAC

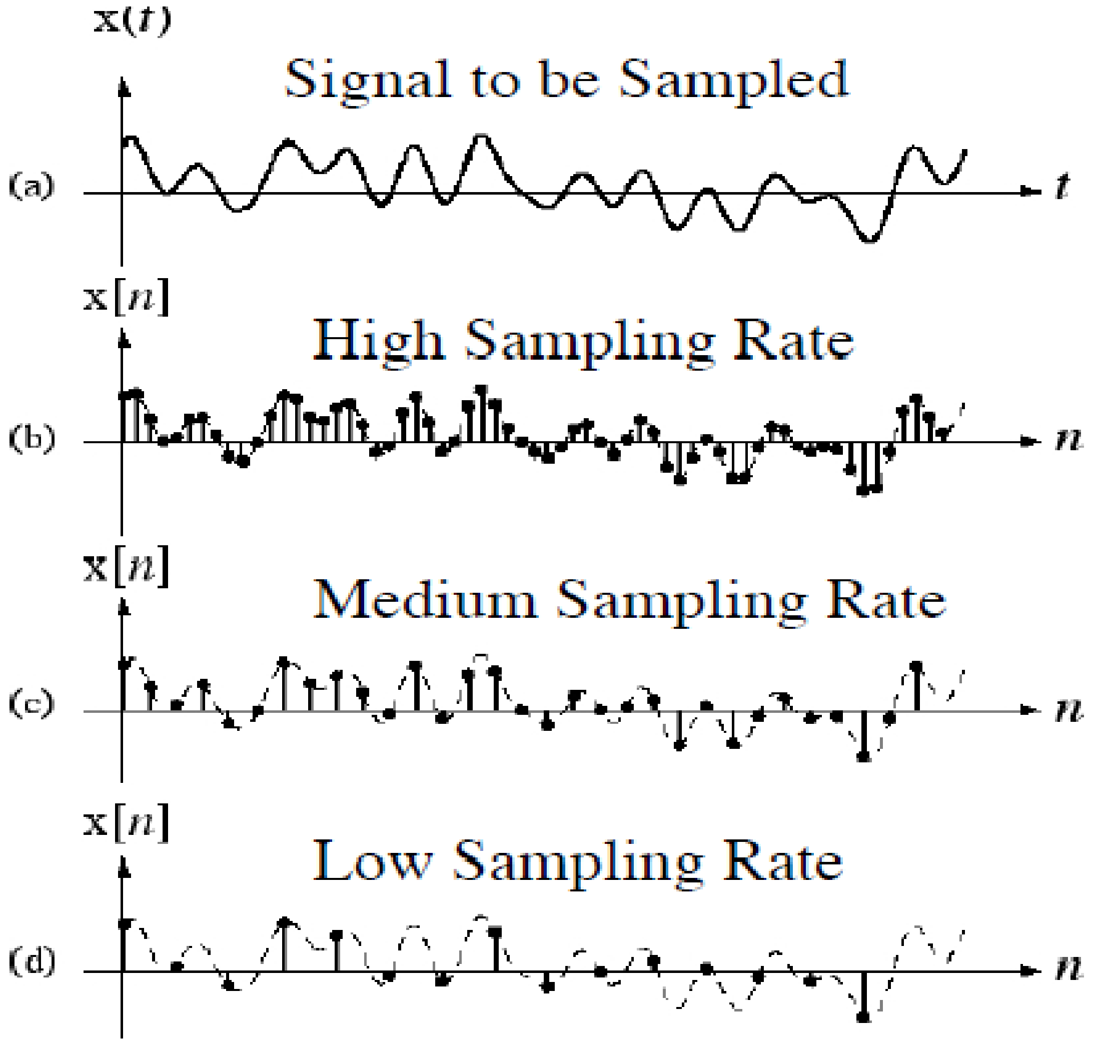
- The analog signals produced by various sensors and transducers have one characteristics called Bandwidth.
- The analog signal can be converted into digital format in two stages:
  - Sampling
  - Quantization

Sampling

- **Sampling** converts a time-varying signal into a discrete-time signal, a sequence of real numbers.
- To obtain signal values from the continuous signal at regular time-intervals.
- The analog signal is sampled every T_s s, where T_s is the sample interval or period.
- The inverse of the sampling interval is called the **sampling rate** or sampling frequency and denoted by f_s where $f_s=1/ T_s$.

Sampling

The fundamental consideration in sampling is how fast to sample a signal to be able to reconstruct it.

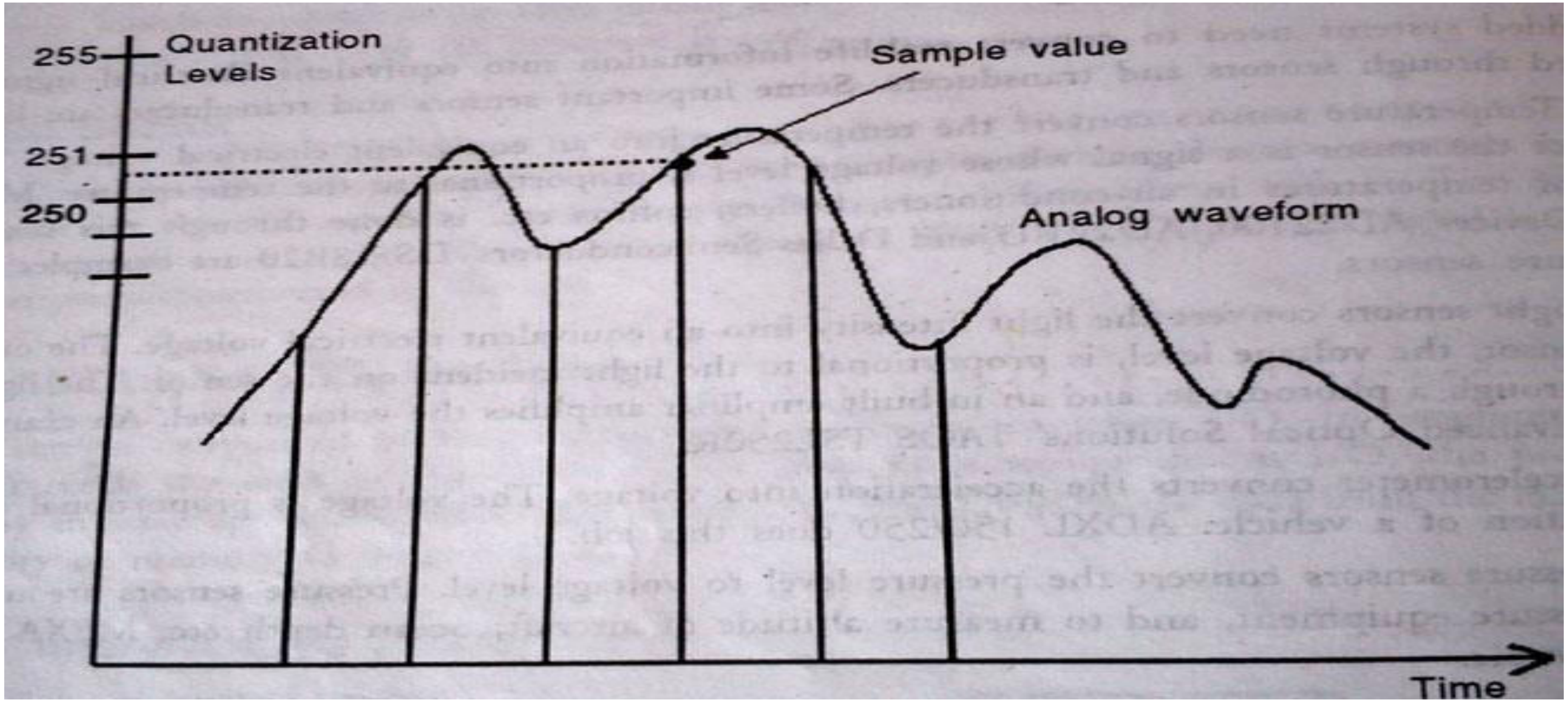


Nyquist Theorem

- How many samples are needed to correctly represent an analog signal ?
- According to the Nyquist theorem, the sampling rate must be at least 2 times the highest frequency contained in the signal.

- If the bandwidth of a signal is B Hz, the number of samples required per second(called the sampling rate) should be at least 2B. So, for the voice signals with a bandwidth of 4 kHz, the minimum sampling rate is 8000 samples per second.

• In quantization, the sampled value is converted into a number,



Quantization

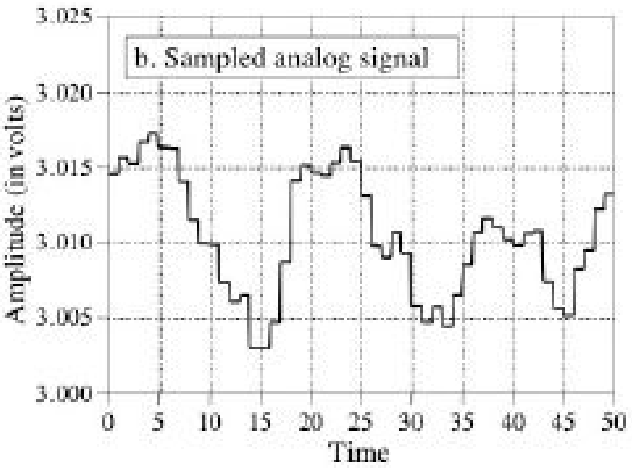
- After the sampling we have a sequence of numbers which can theoretically take on any value (In y-axis).

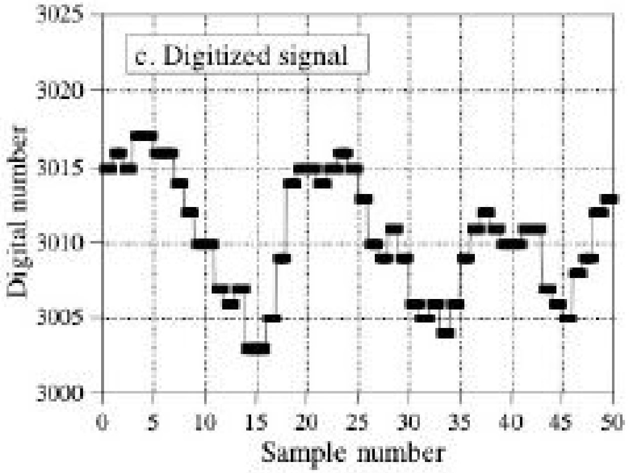
- In order to be able to represent each number from such a range, we would need an infinite number of digits .
- We must represent the numbers with a finite number of digits, so now we need to convert these discrete numbers into digital numbers.
- **Quantization** replaces each real number with an approximation from a finite set of discrete values.

Quantization

Quantization:

Each flat region in the sampled signal is "rounded-off" to the nearest member of a set of discrete values (e.g., nearest integer)





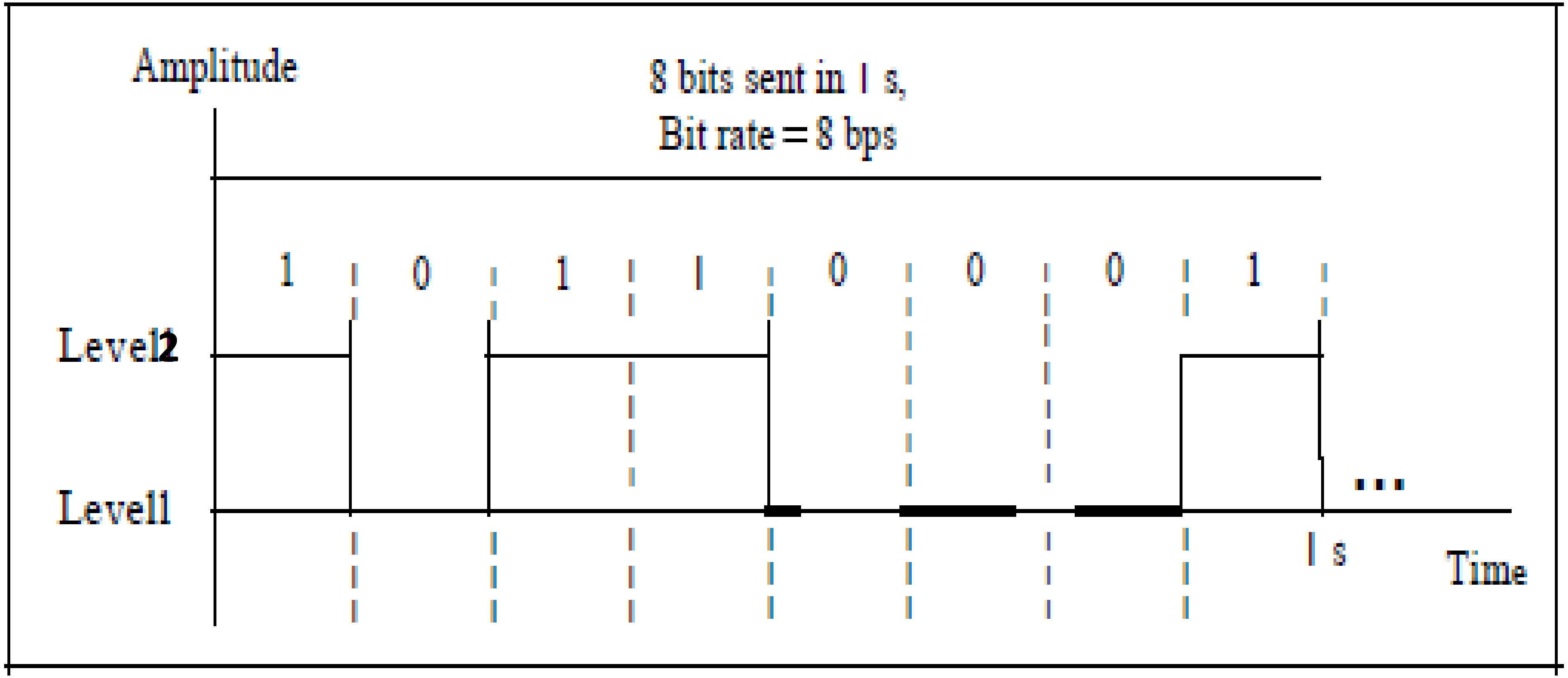
Before: $t \in \{0, 0.1, \ldots 50\}$,

$y_A(t) \in (3000, 3025)$,

After quantization: $t \in \{0, 0.1, \ldots 50\}$,

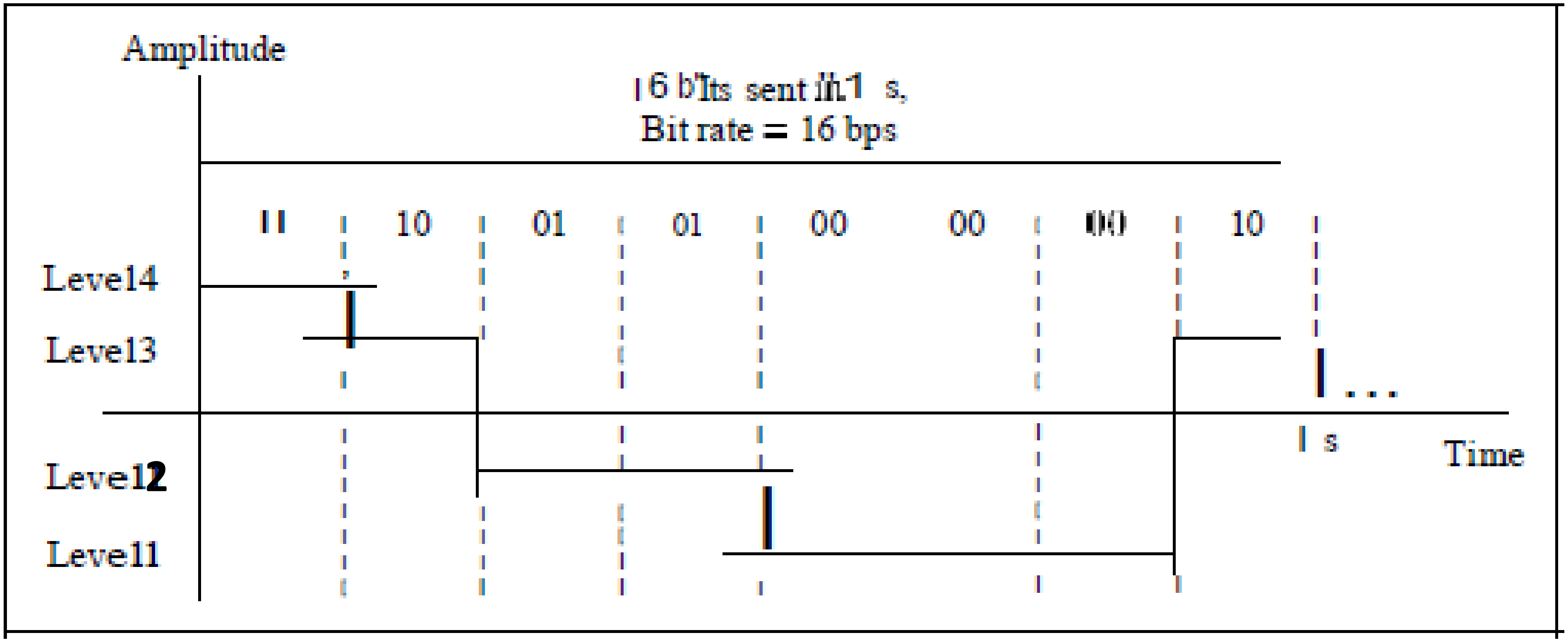
$y_Q(t) \in \{3000, 3001, \ldots, 3025\}$

A digital signal can have more than two levels.



a. A digital signal with two levels

A digital signal can have more than two levels.



b. A digital signal with four levels

Example 3.16

A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the formula

$$\text{Number of bits per level} = \log_2 8 = 3$$

Each signal level is represented by 3 bits.

Resolution =3 bits.

Example

Consider the voice signals again. In telephone networks, the voice signals are considered to have a bandwidth of 4 KHz and the resolution is 8 bits. In CD audio, the bandwidth is considered to be 44.1 KHz and 16-bit resolution is used and hence the quality of CD audio is very high. In DVD audio, the bandwidth is considered as 48 KHz, and the resolution is 24 bits.

- Analog-to-digital conversion introduces error because each sample value is rounded off to its nearest quantization level. This error is known as **quantization error**.

ADC

Many micro-controllers have on-chip ADC. If the on-chip ADC does not serve your purpose, you can have an external ADC. An example of ADC is MAX 1245. MAX 525 is a 12-bit DAC. Analog Devices AD 9772 is an example of high-end ADC with a sampling rate of 150 Mega Samples Per Second (MSPS) and 14-bit resolution.

Example in Arduino

Example in Arduino

- Arduino board has six ADC channels, as show in figure below. Among those any one or all of them can be used as inputs for analog voltage.
- The **Arduino Uno ADC** is of 10 bit resolution (so the integer values from (0-(2^10) 1023)).
- This means that it will map input voltages between 0 and 5 volts into integer values between 0 and 1023.
- So for every (5/1024= 4.9mV) per unit.

Sensors and Transducers

- Embedded Systems need to convert real-life information into equivalent electrical signals.
- This is achieved through sensors and transducers.
- What ever we sense, everything are analog signals. Their amplitude varies continuously with time.
- So we must use ADC chips to convert it into digital signals

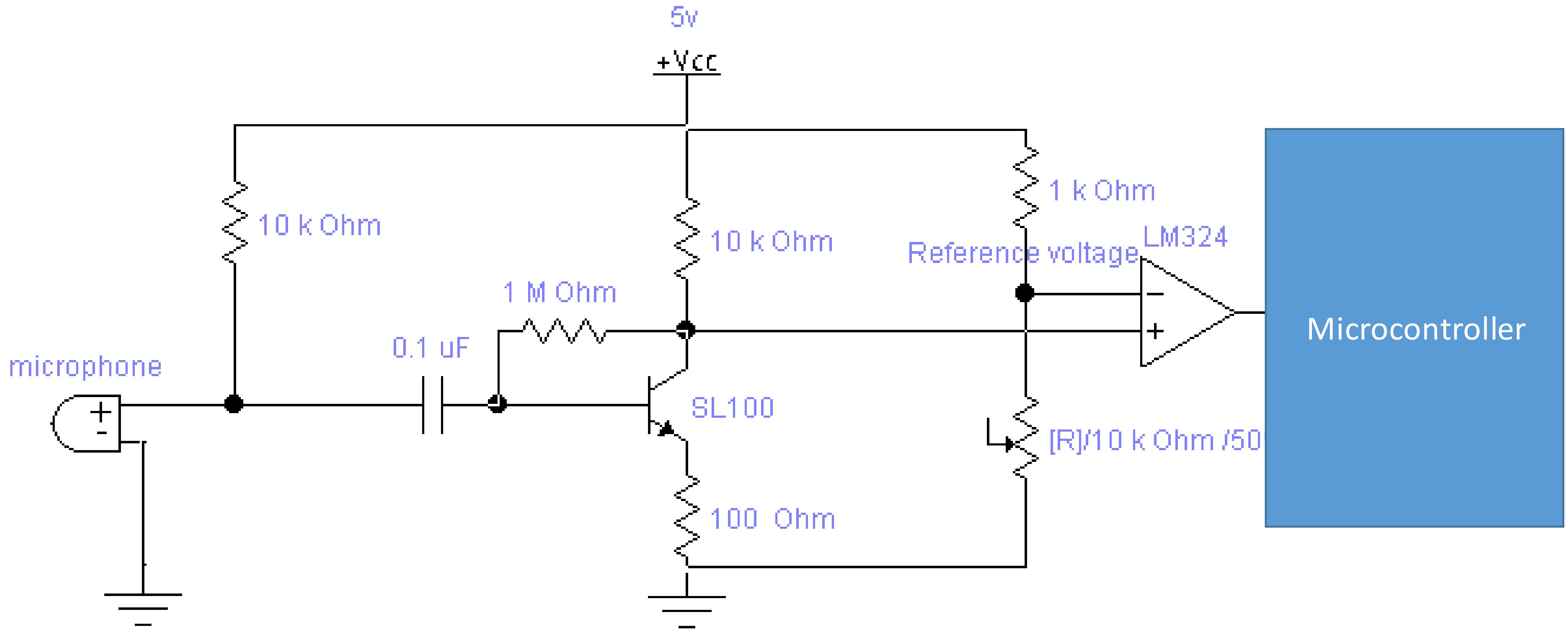
Sensors and Transducers

- Temperature sensors convert the temperature into an equivalent electrical voltage. The output of the sensor is a signal whose voltage level is proportional to the temperature. Measurement of temperatures in air-conditioners, boilers, coffins etc. is done through this sensor. Analog Devices' AD22100, AD22103 and Dallas Semiconductors' DS 18B20 are examples of temperature sensors.
- Light sensors convert the light intensity into an equivalent electrical voltage. The output of the sensor, the voltage level, is proportional to the light incident on the sensor. The light is sensed through a photodiode, and an in-built amplifier amplifies the voltage level. An example is Texas Advanced Optical Solutions' TAOS TSL250R.

Sensors and Transducers

- Accelerometer converts the acceleration into voltage. The voltage is proportional to the acceleration of a vehicle. ADXL 150/250 does this job.
- Pressure sensors convert the pressure level to voltage level. Pressure sensors are used in blood pressure equipment, and to measure altitude of aircraft, ocean depth etc. MPXA 6115A is an example.
- **Microphone and speakers:** Microphone converts the acoustic energy into a voltage signal. When you speak into a microphone, the output of the microphone is an electrical signal with continuously varying amplitude. The speakers convert the electrical signal back into acoustic waves.

Example



5v
+Vcc
10 k Ohm
10 k Ohm
1 k Ohm
Reference voltage
LM324
1 M Ohm
0.1 uF
microphone
SL100
[R]/10 k Ohm /50
100 Ohm
Microcontroller

Example

- Figure shows the Sound Sensor circuit diagram of the project .It contains Microphone which is used to convert acoustic energy into electrical energy. The condenser microphone is used as transducer in this circuit diagram.
- The electrical signal coming from microphone is too low. So, we need to amplify our electrical signal coming from MIC. Transistor (SL 100) is used to amplify that signal. Resistances are used for amplification adjustment. Capacitor is used to decouple microphone from transistor.
- Sound sensor is designed to give it the ability to respond to sounds ,claps, whistles ,etc. Output of the sound sensor is given to LM324 Comparator.
- At last, comparator (LM324) compares the signal with reference voltage. If the signal coming from microphone is greater than the threshold voltage, then it sends logic 1 otherwise 0.
- This is the general working principle of this Sound sensor.

Chip Select

- If there is need to connect several devices to the same set of input wires (i.e., a computer bus), but retain the ability to send data or commands to each device independently of the others on the bus, they can use a **chip select.**
- The chip select is a command pin on most ICs which connects the input pins on the device to the internal circuitry of that device.

Serial Peripheral Interface(SPI)

- Developed by Motorolla, It is used for short distance communication between different peripherals.
- Peripheral Devices such as memory chips, ADC/DAC, etc are provided with SPI interface so that they can be interface with the processor
- SPI is a synchronous data transmission protocol. In synchronous data transmission, the sender and receiver share a clock with one another.
- This interface is widely used in embedded system.

Serial Peripheral Interface(SPI)

-SPI devices communicate in full duplex mode using a master-slave architecture with a single master.

-The master device originates the frame for reading and writing.

-Multiple slave-devices are supported through selection with individual slave select (SS), sometimes called chip select (CS), lines.

-SPI Signals(Uses 4 types of signals for interfacing peripherals to processor)

1. Master Out Slave In (MOSI)

-Master sends byte to slave, and slave reads

2. Master In Slave Out (MISO)

-Slave sends it's register content, master reads

3.Serials Clock (SCLK)

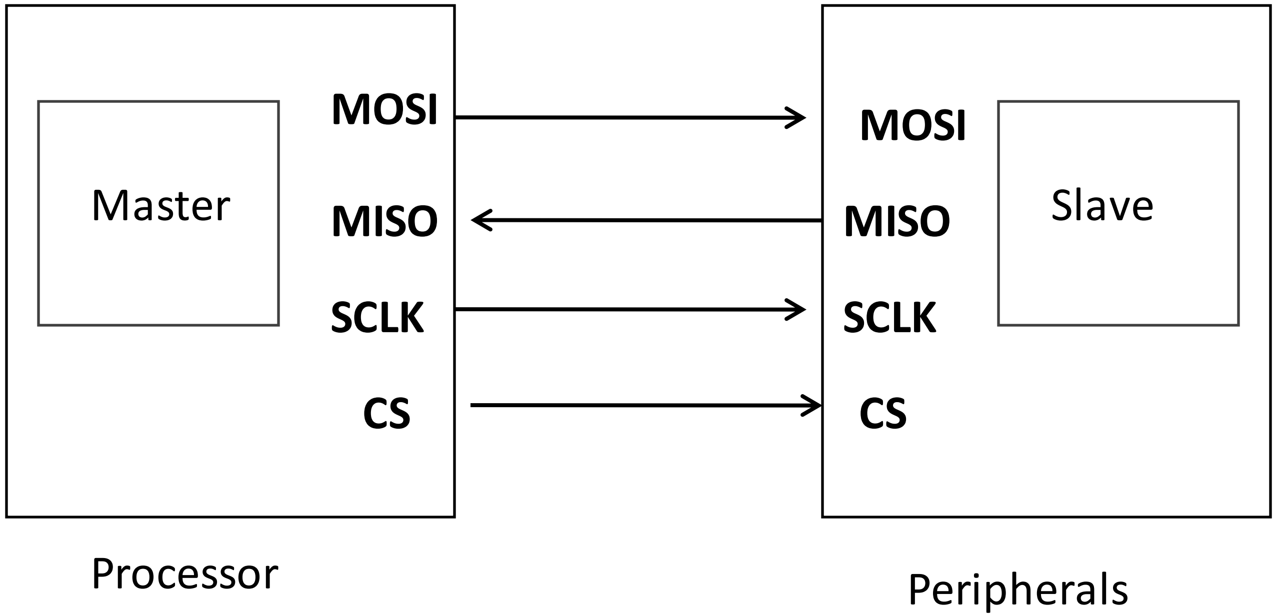
-O/p from Master(generates the clock & synchronize peripherals)

4. Chip Select (CS)

-O/p from Master

Serial Peripheral Interface(SPI)

-In SPI interface, devices works in Master/Slave mode.



Serial Peripheral Interface(SPI)

SPI can be configured in 2 ways

1. Independent Slave Configurations
2. Daisy chain configuration

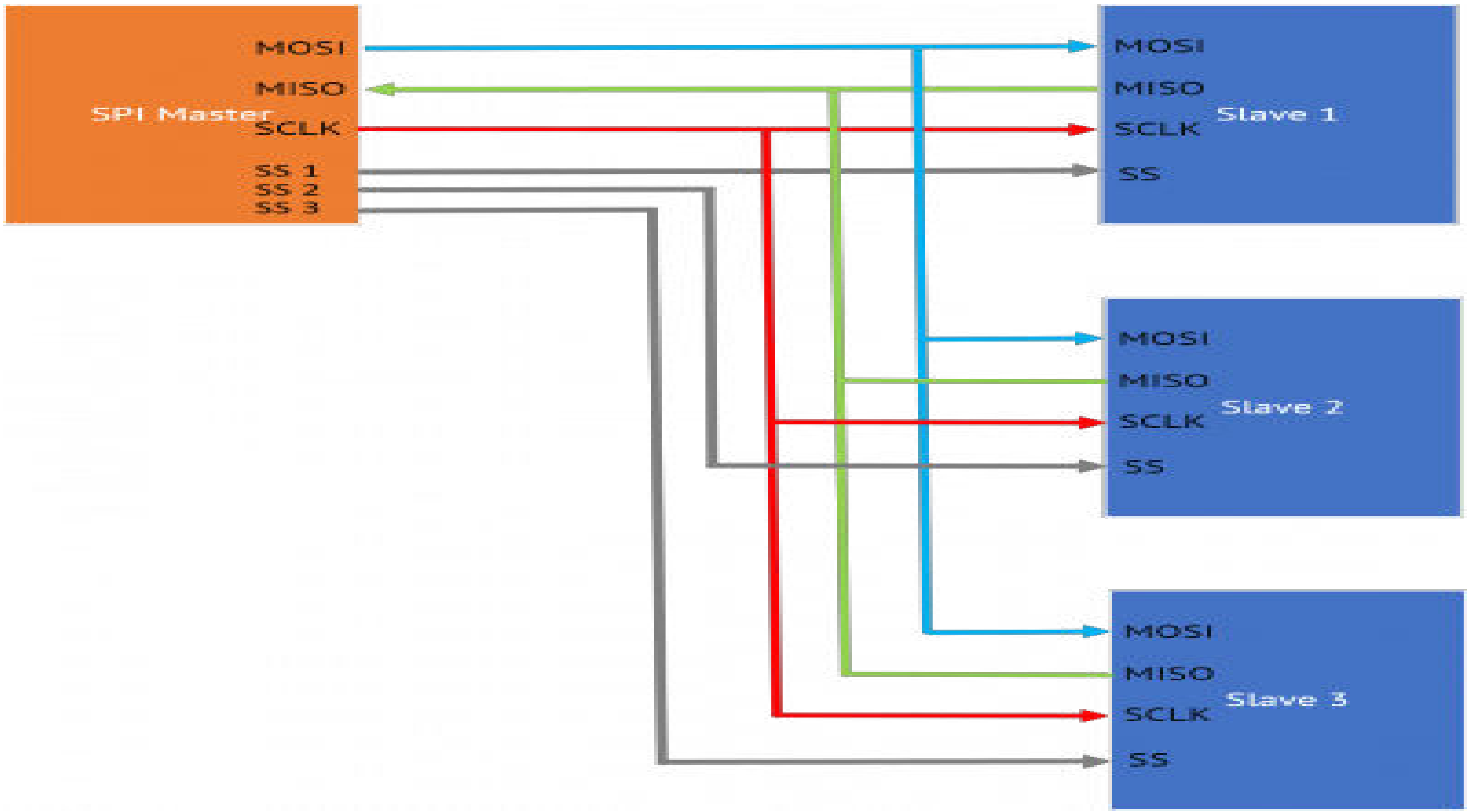
Independent Slave Configurations

- In the independent slave configuration, there is an independent chip select line for each slave.
- The master asserts only one chip select at a time.
- The MISO line, MOSI lines and clock lines of all the devices are connected together.
- But the chip select pin of each peripheral is connected to separate slave select pins of the master.

Independent Slave Configurations

- In the independent slave configuration, there is an independent chip select line for each slave.
- The master asserts only one chip select at a time.
- The MISO line, MOSI lines and clock lines of all the devices are connected together.
- But the chip select pin of each peripheral is connected to separate slave select pins of the master.

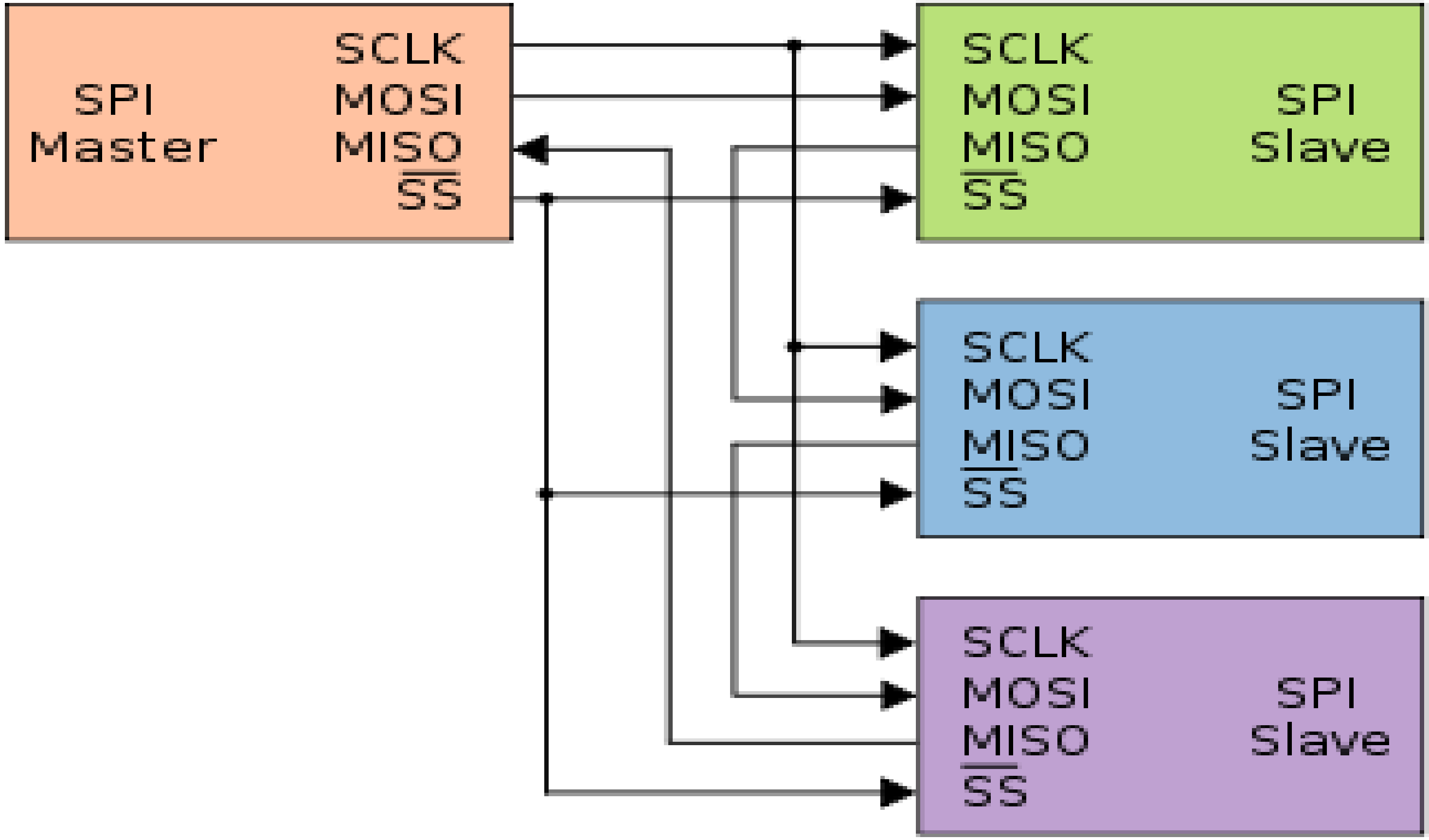
Independent Slave Configurations



Daisy Chain Configuration

- In cascaded or daisy chain configuration, the clock lines and chip select lines of all devices are connected together.
- The data from the master flows through each peripheral and returns to the master.
- Used while relaying information in each devices.
- The data output of the preceding slave device is attached to the data in of the next device. Only a single SS line is required by the master.

Daisy Chain Configurations



SPI Interface

SPI is a widely used protocol, so it is included in most of the microcontroller families.

Some of the chips using SPI are listed below.

- Flash memories and EEPROMs, e.g: Microchip SST25VF080
- SD/MMC Cards
- Real Time Clock chips, e.g: Maxim DS1347
- Analog to Digital converters, e.g: Microchip MCP3008
- Battery management ICs, e.g: TI BQ76PL536
- TFT LCD display drivers, e.g: ILI9341

SPI Interface

Advantages of SPI

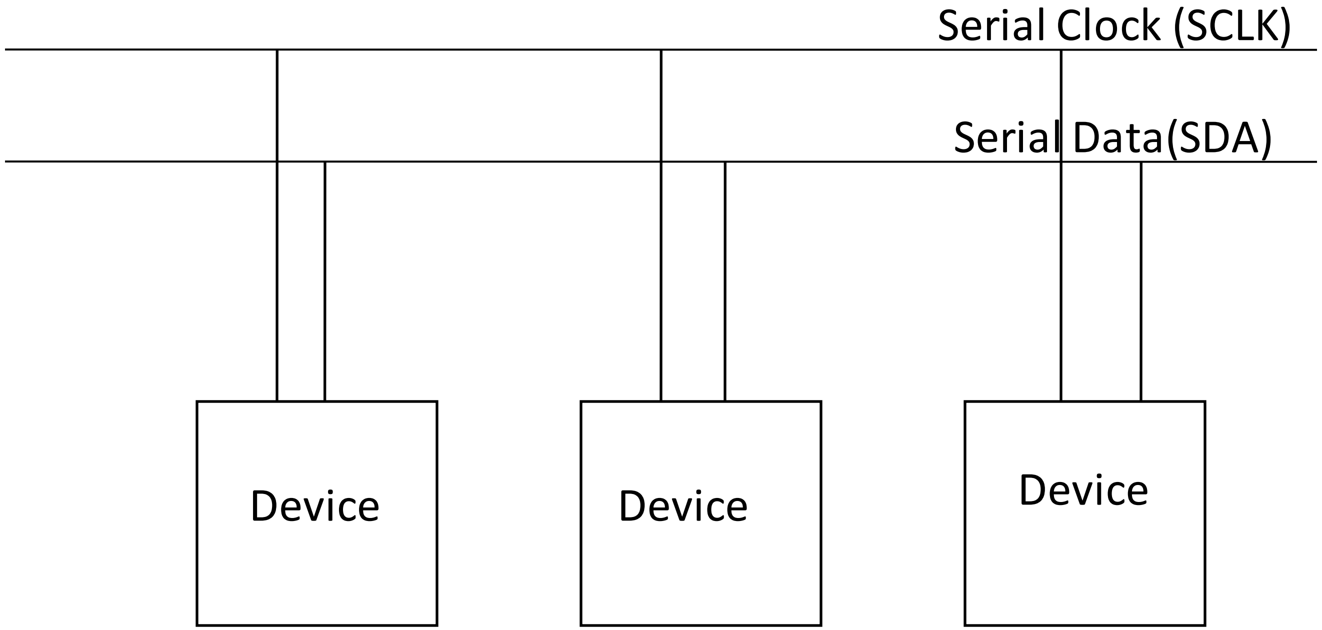
- Supports multiple slave devices
- Full duplex communication, transfer data in and out at the same time.
- Significantly high data rates (in megabits/second) as compared to other serial communication stands, sometimes in megahertz range.
- Simple protocol and easy to implement for single-master single-slave applications
- Less complex circuitry and there is no need of external transceivers, so it is a very easy interfacing.

Disadvantages of SPI

- Required number of pins are high as compared to other serial protocols
- Absence of in-chip addressing, it needs separate chip select of each devices

Inter Integrated Cicuit(I^2 C)

-It also use Master Slave Protocol.



Inter Integrated Cicuit(I^2 C)

-It uses 2 lines(bidirectional) for connecting devices.

SDA (Serial Data) – The line for the master and slave to send and receive data

SCL (Serial Clock) – The line that carries the clock signal.

-It is a multi-master bus, more than one device can act as master.

-Same line is used for master transmission and slave response.

-It is a Half Duplex Communication

Inter Integrated Cicuit(I^2 C)

- I2C is also serial communication protocol, so data is transferred bit by bit along a single wire (the SDA line).
- Like SPI, I2C is synchronous, so the output of bits is synchronized to the sampling of bits by a clock signal shared between the master and the slave. The clock signal is always controlled by the master.

Debug Port

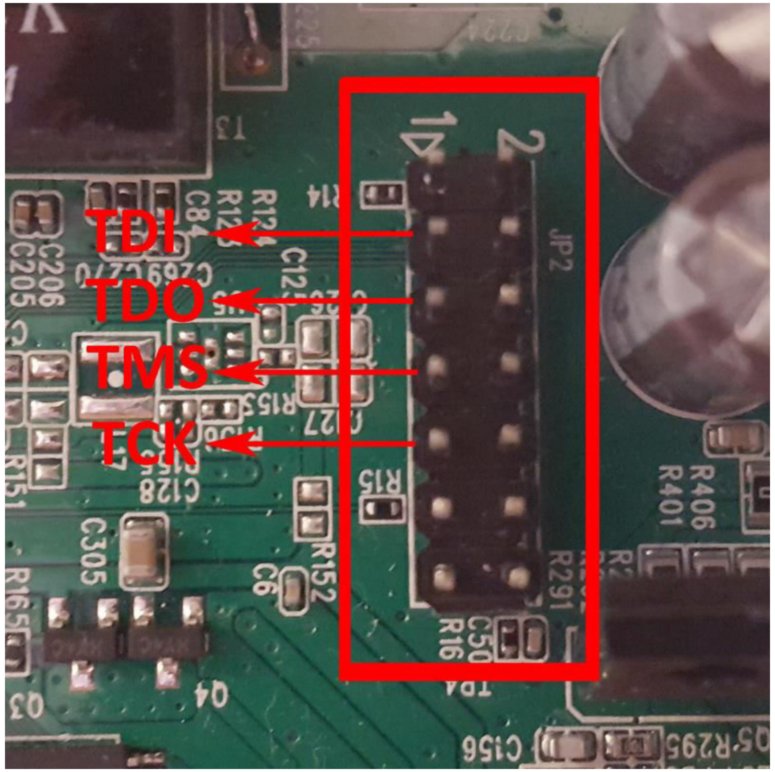
- Debugging port is used to find bugs or defects in any electronic hardware.

- Joint Test Access Group standardized the mechanism for providing debugging through a port called JTAG port.

- JTAG port can also be used to download software onto the embedded system.

Debug Port

- JTAG port consists of 4 signals
  - Test Data Input (TDI)
  - Test Data Output (TDO)
  - Test Mode Select (TMS)
  - Test Clock (TCK)

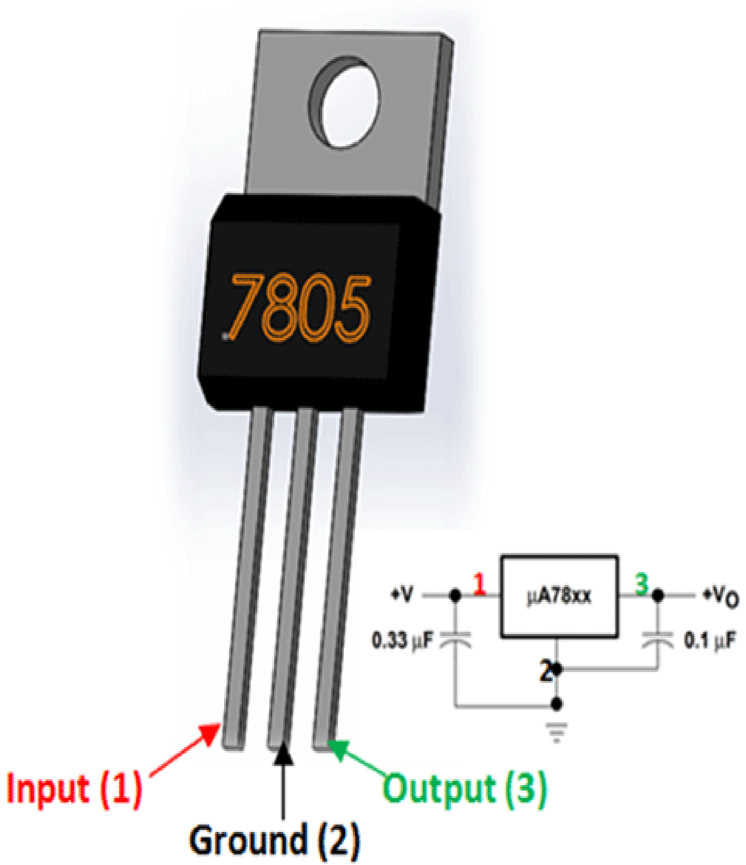


- JTAG port is like a synchronous serial interface. JTAG port can also be used to download the software onto the embedded system.

Power Supply Unit

- The components in Embedded System uses DC voltage.(Ranging from +12 volt to -12 volt).
- So, DC to DC converter are widely used in embedded system. The 2 types of DC- DC converters are
  - Linear Regulator
    - Output Voltage is less than Input Voltage.
    - Less efficient and wastes more power.
  - Switching Regulator
    - Step Up/ Step Down the input voltage.
    - More efficient and waste less power during conversion.

Power Supply Unit



Voltage regulators are very common in electronic circuits. They provide a constant output voltage for a varied input voltage. In 7805 IC it provides 5V as output.