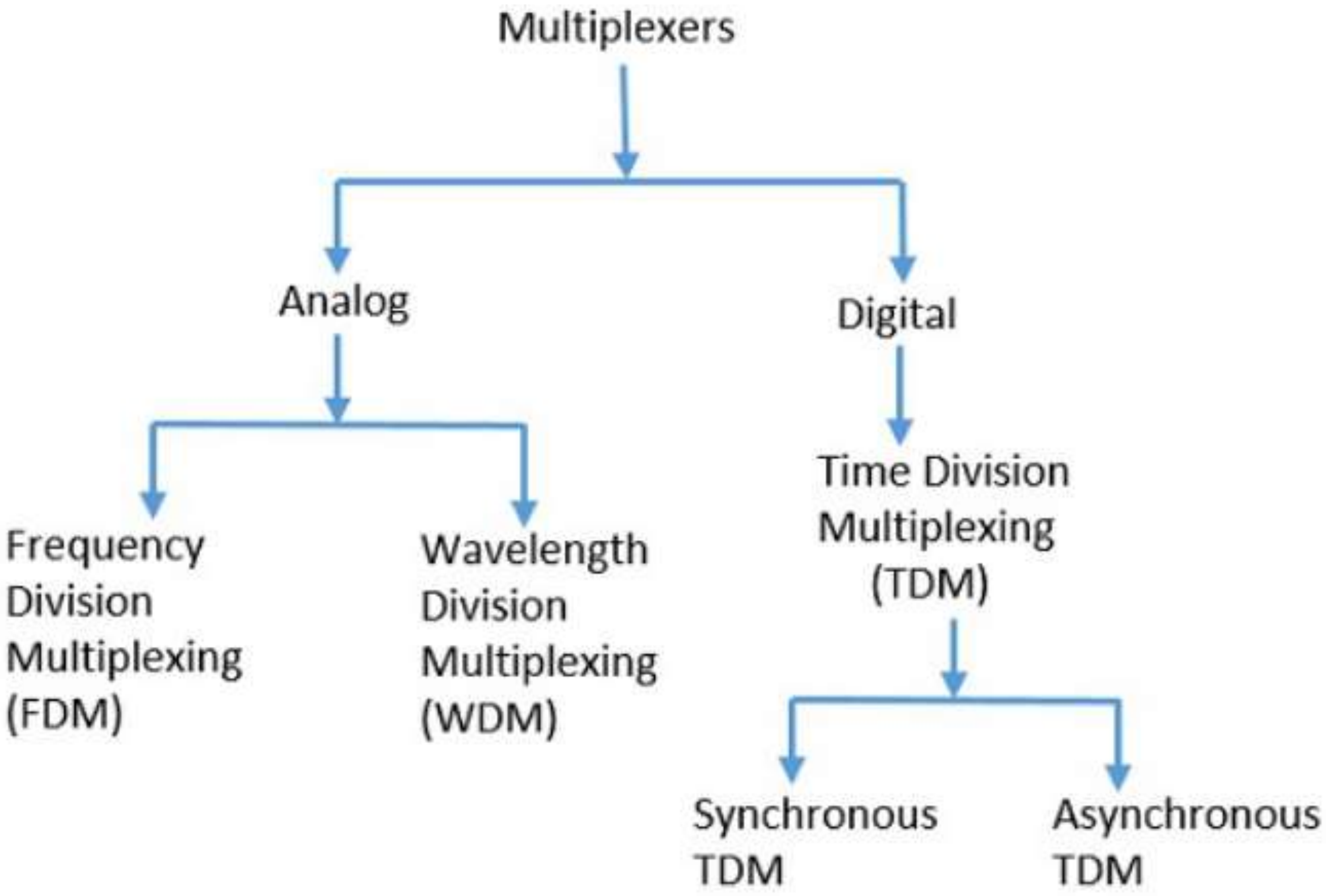
Digital modulation Techniques

Multiplexing and Demultiplexing

- **Multiplexing** is the process of combining multiple signals into one signal, over a shared medium.
- The process is called as **analog multiplexing** if these signals are analog in nature.
- If digital signals are multiplexed, it is called as **digital multiplexing**.
- The process of multiplexing divides a communication channel into several number of logical channels, allotting each one for a different message signal or a data stream to be transferred.
- The device that does multiplexing, can be called as a Multiplexer or **MUX**.
- The reverse process, i.e., extracting the number of channels from one, which is done at the receiver is called as **demultiplexing**.
- The device which does demultiplexing is called as Demultiplexer or **DEMUX**.

Types of Multiplexers



Analog Multiplexing techniques

Involve signals which are analog in nature. The analog signals are multiplexed according to their frequency (FDM) or wavelength (WDM).

- Frequency Division Multiplexing (FDM) is the most used technique. It uses various frequencies to combine streams of data, for sending them on a communication medium, as a single signal.
    - **Example** − A traditional television transmitter, which sends a number of channels through a single cable uses FDM.
- Wavelength Division Multiplexing (WDM): many data streams of different wavelengths are transmitted in the light spectrum. If the wavelength increases, the frequency of the signal decreases. A prism which can turn different wavelengths into a single line, can be used at the output of MUX and input of DEMUX.
    - **Example** − Optical fiber Communications use the WDM technique, to merge different wavelengths into a single light for the communication.

Digital Multiplexing

Is in form of discrete bits of information. The available data is in the form of frames or packets.

- Time Division Multiplexing (TDM): the time frame is divided into slots. Signals are transmitted over a single communication channel, by allotting one slot for each message (signal).
- Two main types of TDM are Synchronous TDM and Asynchronous TDM

In Synchronous TDM, the input is connected to a frame. If there are ‘n’ number of connections, then the frame is divided into ‘n’ time slots. One slot is allocated for each input line.

- In this technique, the sampling rate is common for all signals and hence the same clock input is given. The MUX allocates the **same slot** to each device at all times.

In Asynchronous TDM, the sampling rate is different for each of the signals and a common clock is not required. If the allotted device, for a time slot transmits nothing and sits idle, then that slot is **allotted to another** device, unlike synchronous.

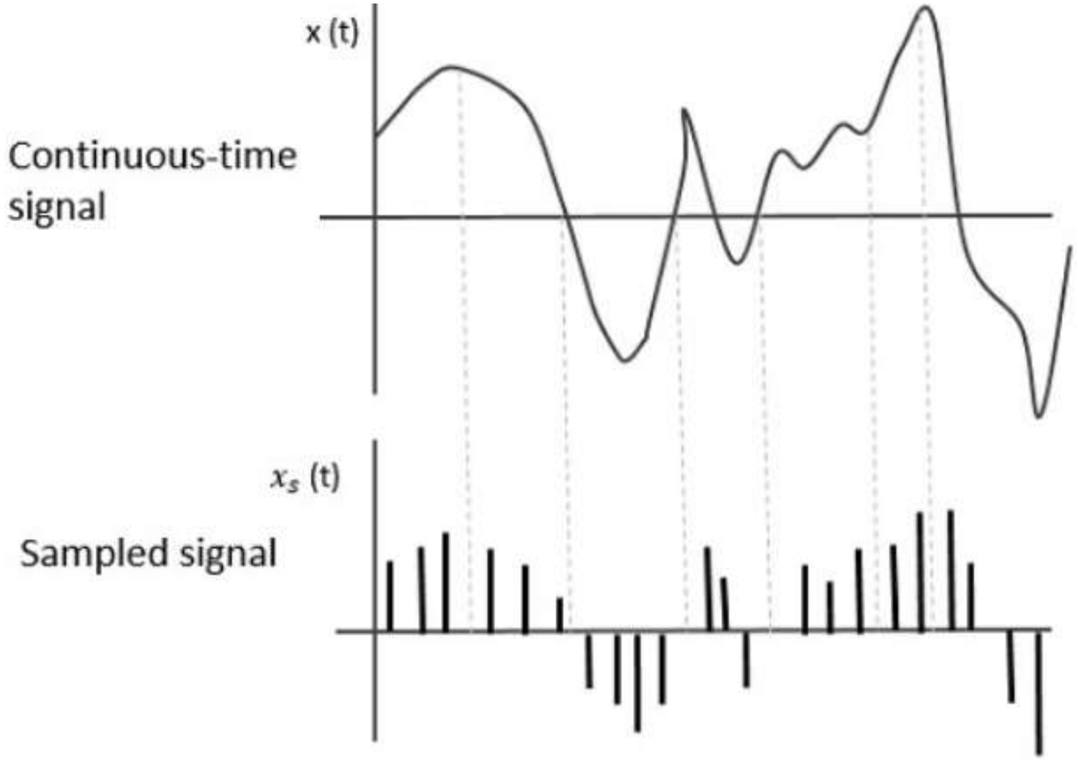
- This type of TDM is used in Asynchronous Transfer Mode networks.

Demultiplexer

- Demultiplexers are used to connect a single source to multiple destinations. This process is the reverse of multiplexing. As mentioned previously, it is used mostly at the receivers. DEMUX has many applications. It is used in receivers in the communication systems. It is used in arithmetic and logical unit in computers to supply power and to pass on communication, etc.
- Demultiplexers are used as serial to parallel converters. The serial data is given as input to DEMUX at regular interval and a counter is attached to it to control the output of the demultiplexer.
- Both the multiplexers and demultiplexers play an important role in communication systems, both at the transmitter and receiver sections.

Sampling

- The process of converting continuous time signals into equivalent discrete time signals, can be termed as **Sampling**.
- A certain instant of data is continually sampled in the sampling process.
- The following figure indicates a continuous-time signal **x(t)** and a sampled signal $\mathbf{x_s(t)}$. When **x(t)** is multiplied by a periodic impulse train, the sampled signal $\mathbf{x_s(t)}$ is obtained.



- A **sampling signal** is a periodic train of pulses, having **unit amplitude**, sampled at equal intervals of time $\mathbf{T_s}$, which is called as the **Sampling time**.
- This data is transmitted at the time instants $\mathbf{T_s}$ and the carrier signal is transmitted at the remaining time

Wave Coding Techniques

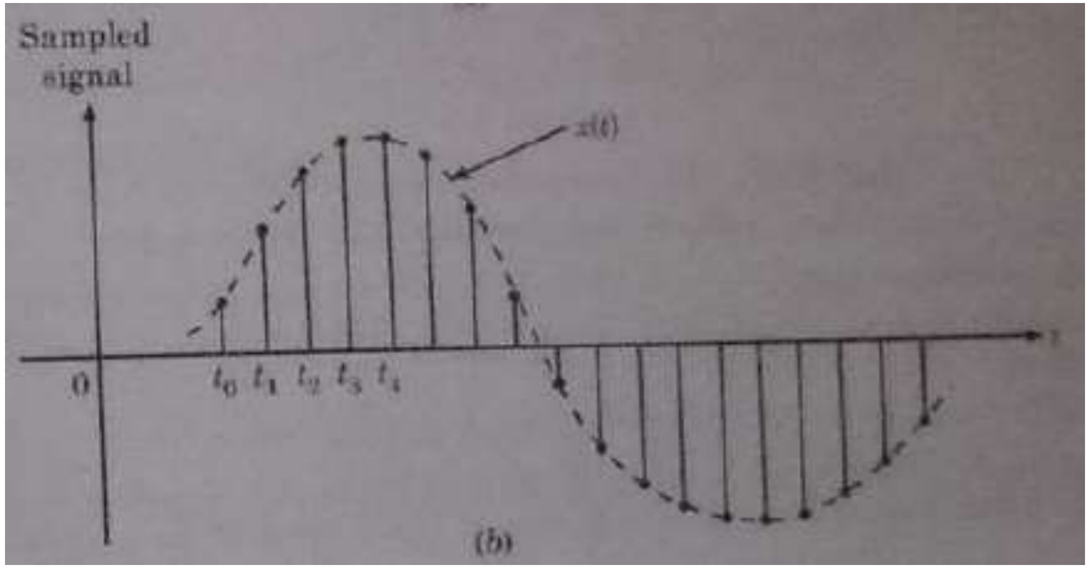
- Digital communication offer advantages over analogue communication:
  - Ruggedness to channel noise and external interference
  - Flexible operation of the system
  - Integration of diverse sources of information into a common format
  - Security of information during transmission

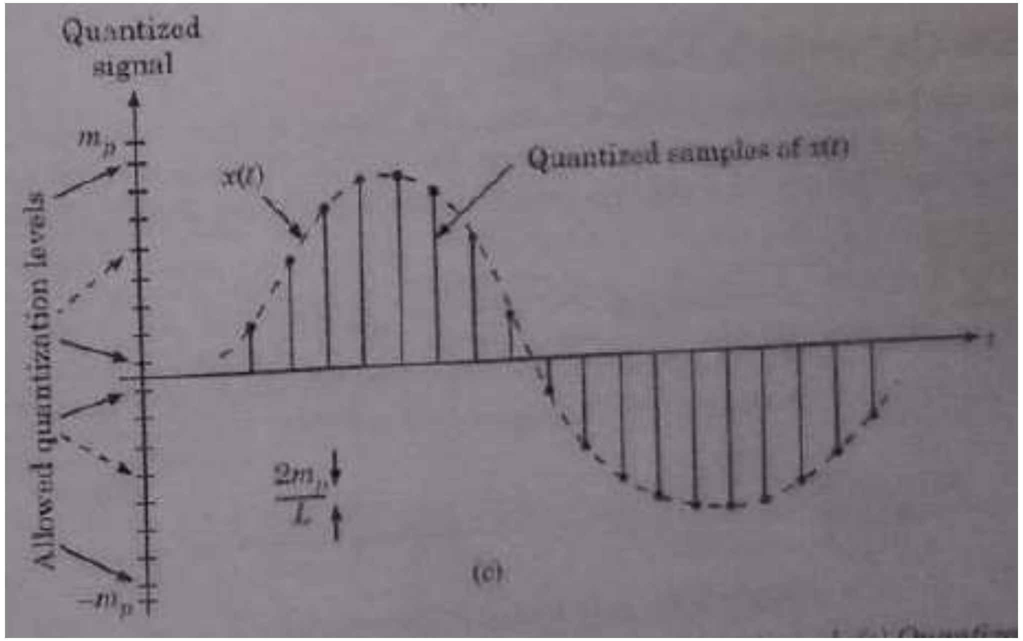
- To handle transmission of analogue signals e.g. voice and video, by digital means we need to convert the analogue signal to digital signals.
- Using wave coding techniques, we convert the analogue Pulse Amplitude Modulation (PAM) signal into digital signals.
- This resulting digital signal is in the form of a train of binary digits.
- After sampling an analogue signal the next step in its transmission is to generate its digital representation thus (coded version)
- One method is by Pulse Code Modulation (PCM)

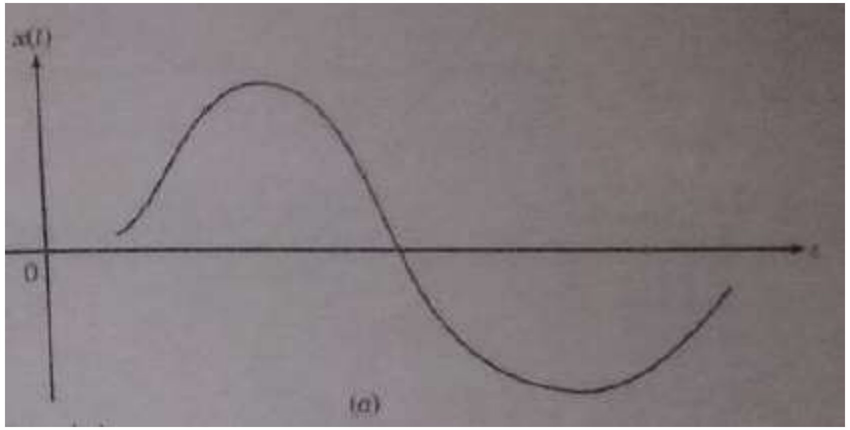
Pulse Code Modulation (PCM)

- In PCM, the message signal is sampled and its amplitude approximated (quantized) to the nearest one of a finite set of discrete values.
- This is the simplest form of pulse digital modulation technique.
- In PCM, the time and pulse parameter (usually amplitude) is represented in discrete form and digital coded form respectively. This process is called discretization.
- PCM is also known as Digital Pulse Modulation technique.

- Fig a: an analogue signal
- Fig b: a sampled discrete time signal
- Fig c: a quantized signal



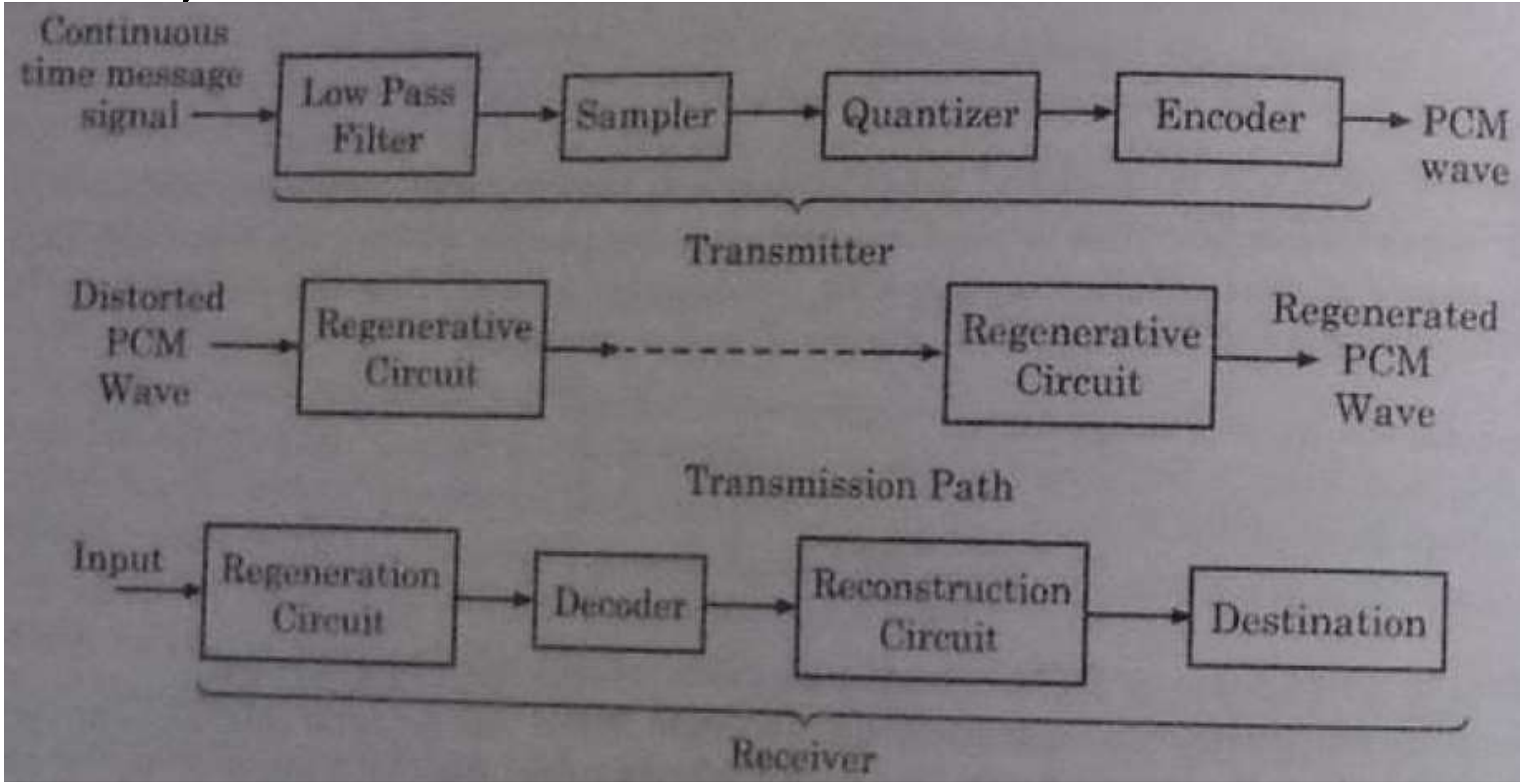




A PCM system

- Has three main parts as shown below and as shown in the next slide:
- Fig a: transmitter: consist of sampling, quantizing and encoding. Quantizing and encoding are performed by a circuit known as analogue-to-digital converter.
- Fig b; transmission path: has regenerative repeaters used to reconstruct the transmitted sequence of pulses to eliminate signal distortion and noise.
- Fig c: Receiver: essential operations are regeneration of impaired signals, decoding and demodulation of the train of quantized samples. These are performed by a circuit known as digital-to-analogue converter (DAC)

A PCM system

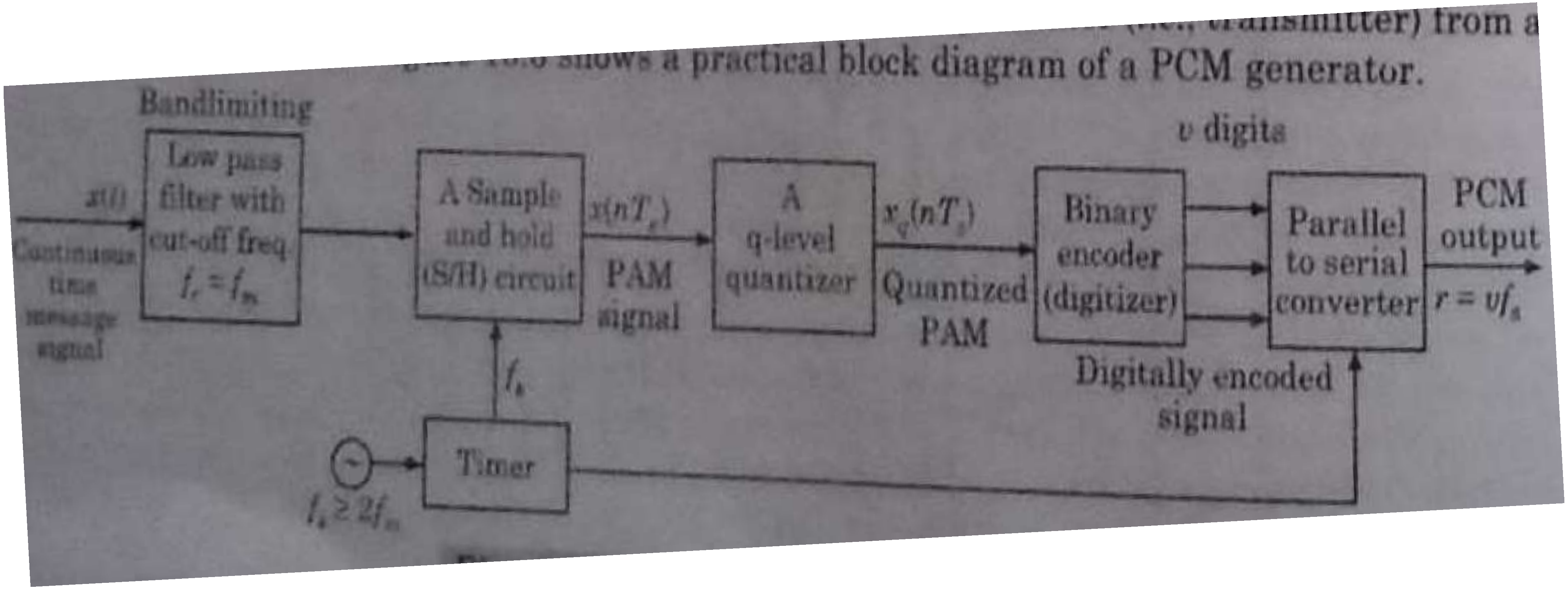


Continuous time message signal
Low Pass Filter
Sampler
Quantizer
Encoder
PCM wave
Transmitter
Distorted PCM Wave
Regenerative Circuit
Regenerative Circuit
Regenerated PCM Wave
Transmission Path
Input
Regeneration Circuit
Decoder
Reconstruction Circuit
Destination
Receiver

Quantization

- A continuous time signal is converted to digital by a process below:
  - By getting the samples according to sampling theorem thus the magnitude of the signal is measured at equal time intervals: t0, t1, t2, t3 etc. hence signal is now in discrete-time form. But still in analogue since the amplitude is taking any value in a continuous range ($-m_p$ to $+m_p$)
  - This is solved by quantization. Where the range is divided into finite standard levels. Say L intervals each of magnitude $\Delta v=2m_p/L$. Now each sample is approximated to one of the L numbers hence digitized.
  - Note that the more the L numbers the more accurate the approximation.

A practical PCM generator or transmitter

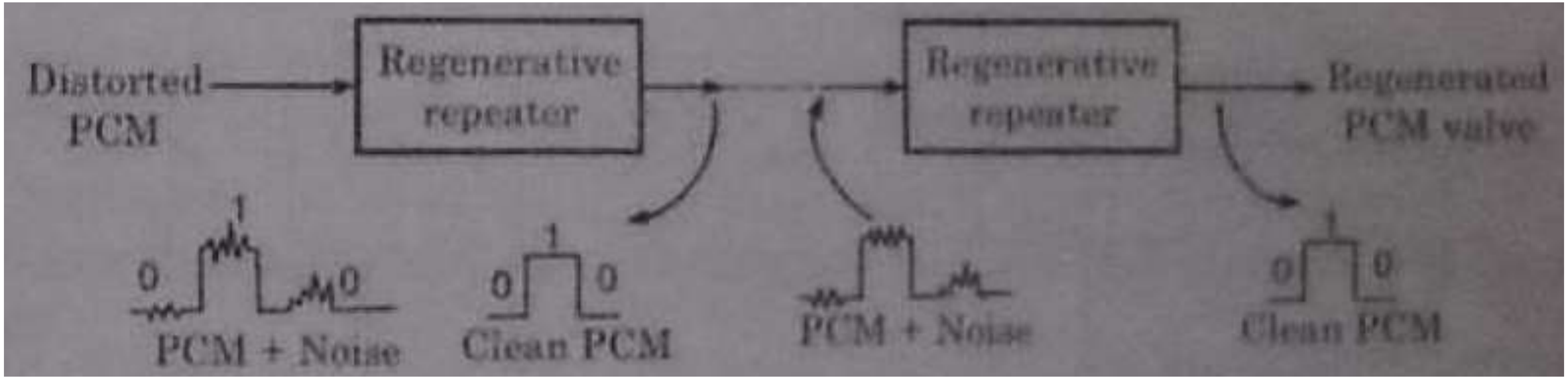


- The signal x(t) is first passed through a low-pass filter with a cut-off frequency f_m Hz.
- This low-pass filter blocks all the frequency components above f_m Hz
- Signal x(t) is now bandlimited to f_m Hz.
- This bandlimited signal is then sampled at the rate of f_s above nyquist frequency to avoid aliasing. i.e. $f_s > 2f_m$
- The output of the sample and hold $x(nT_s)$ is discrete in time and continuous in amplitude.

- A q-level quantizer compares input $x(nT_s)$ with fixed digital levels and assigns the approximated digital $x_q(nT_s)$ which results in minimum distortion.
- The difference between the levels of $x(nT_s)$ and $x_q(nT_s)$ is called quantization error
- Signal $x_q(nT_s)$ is then encoded in binary format containing 'v' binary bits. This is called a digitizer.

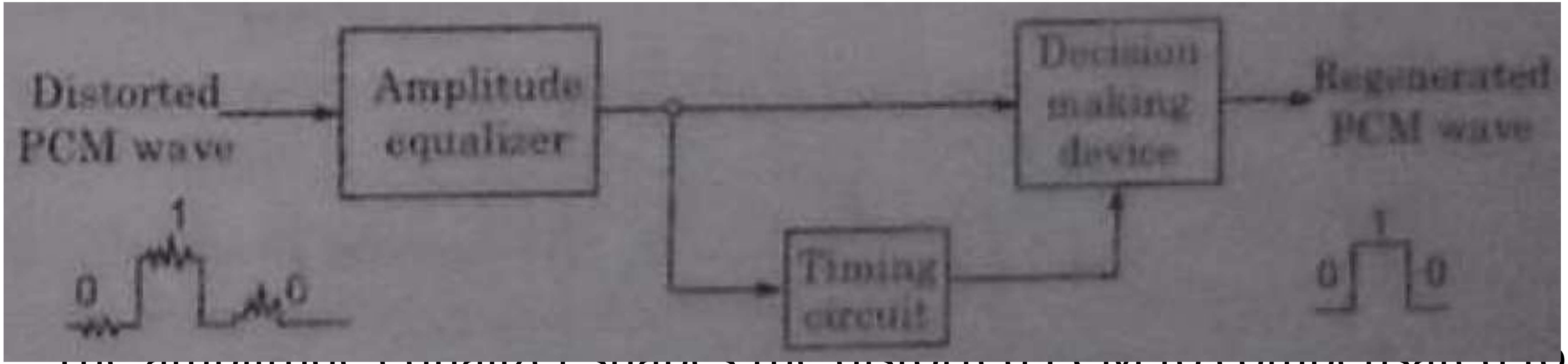
- For purposes of transmission the ‘v’ binary digits are converted to serial bit stream to generate a single baseband signal.
- This is accomplished by a shift register.
- An oscillator generates the clocks for sample and hold circuit and parallel to serial converter.

PCM Transmission Path



- Is the path travelled by PCM signal from the transmitter to the receiver.
- It controls the effects of distortion and noise.
- This is done by using a chain of PCM regenerative repeater.
- The regeneration performs three basic operations: equalization, timing and decision making.

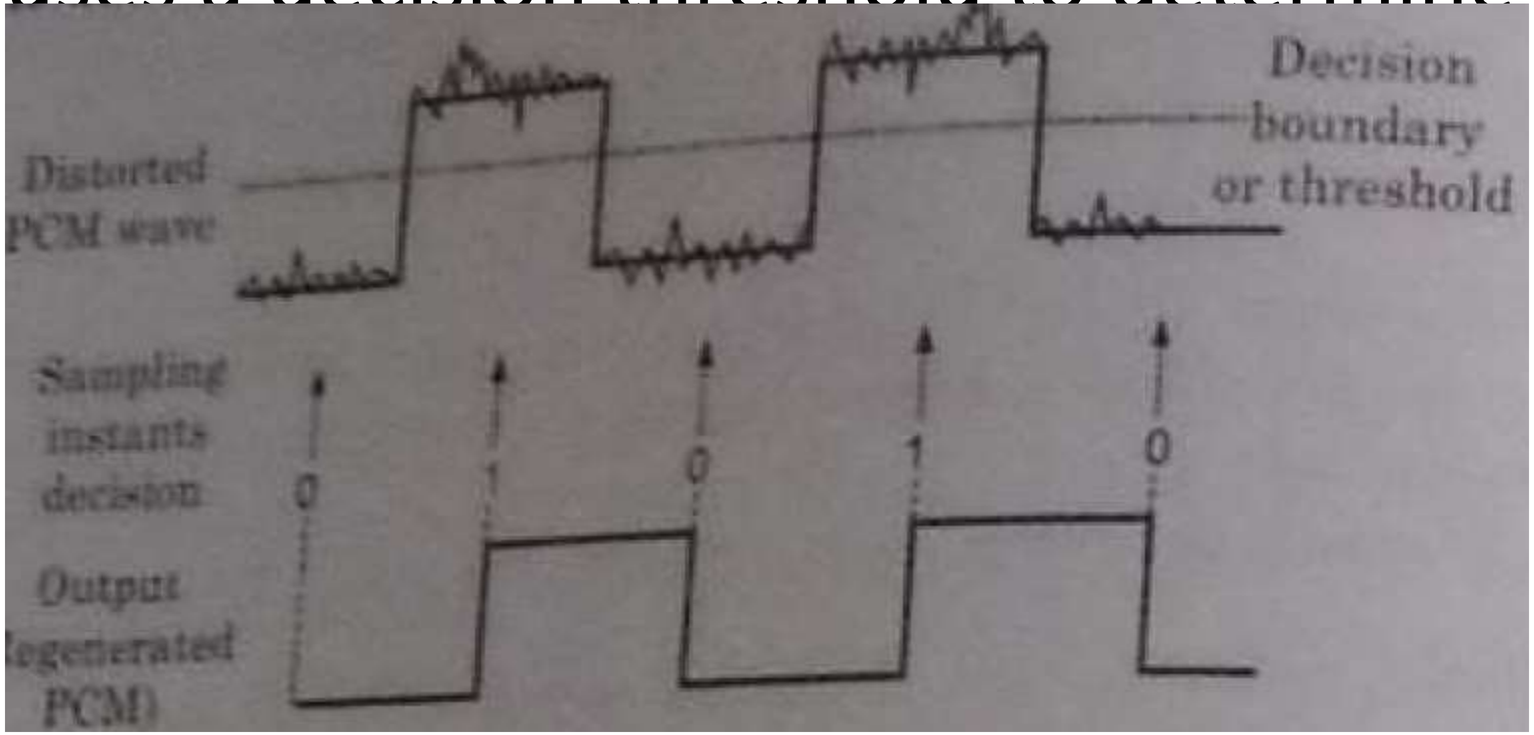
Block diagram of a PCM regenerative repeater



- The amplitude equalizer shapes the distorted PCM to compensated to amplitude and phase distortions.
- The timing circuit generates a train of pulses derived from the input PCM pulses.
- Which are then applied to the decision making device to sample the quantized PCM pulses at instances where signal to noise ratio is high.

Waveforms of a regenerative repeater

- The input and output of the decision making unit. It uses a decision threshold to determine whether the

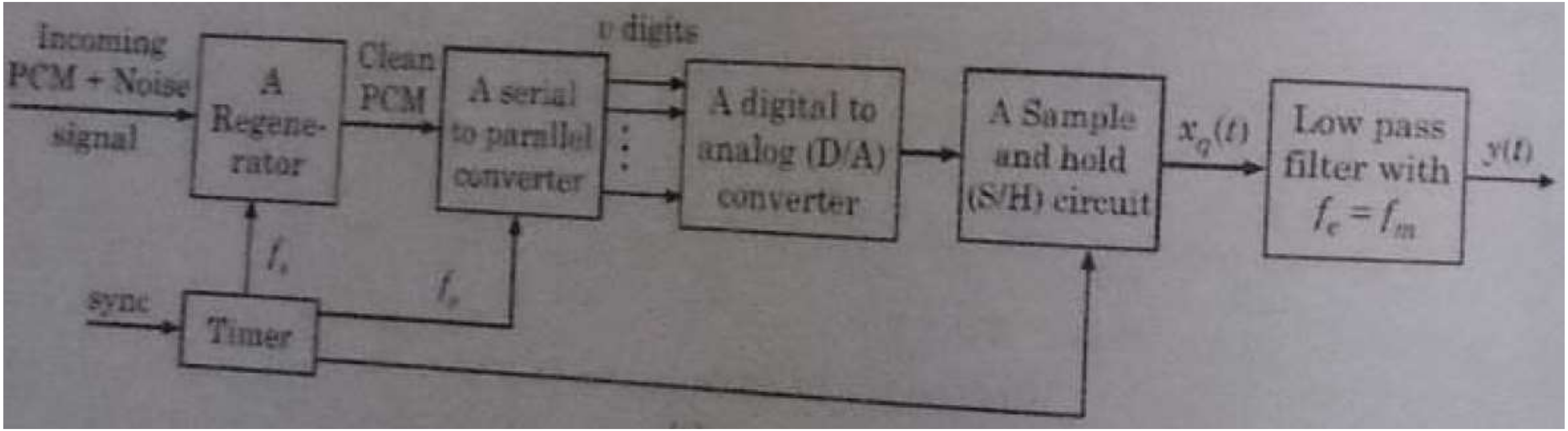


A practical PCM Receiver

- A regenerator receives and reshapes the pulses to remove noise.
- Then the signal is converted to parallel digital words for each sample.
- Sample and hold converts digital words to their analogue values $x_q(t)$.
- $x_q(t)$ is passed to a low-pass reconstruction filter to obtain its original message $y(t)$.

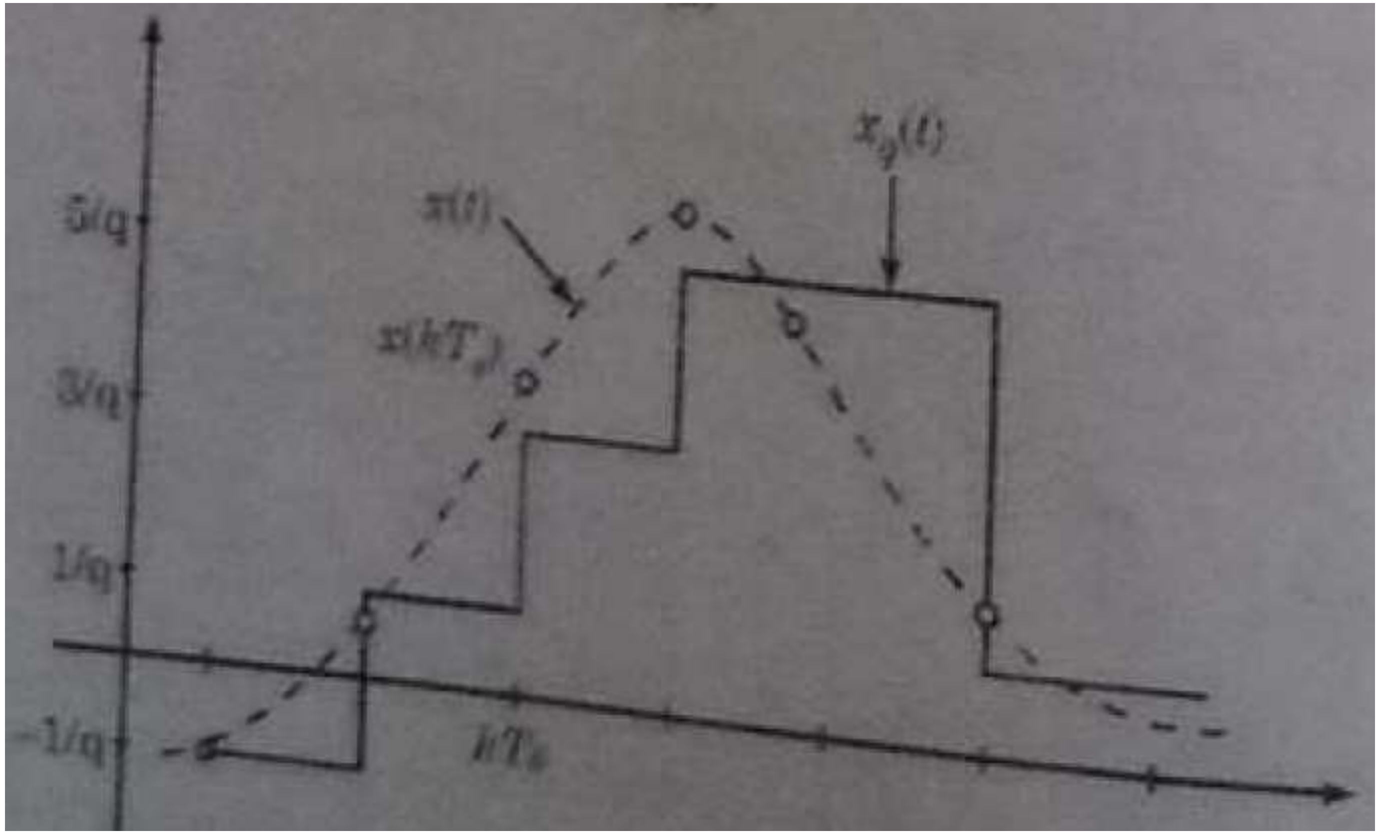
A block diagram of a practical PCM receiver

- A practical PCM receiver.



A reconstructed waveform

- As compared to the original waveform, it can be seen that it is impossible to reconstruct the original waveform.
- This is due to quantization error introduced during the quantization stage after sampling.



Multiplexing

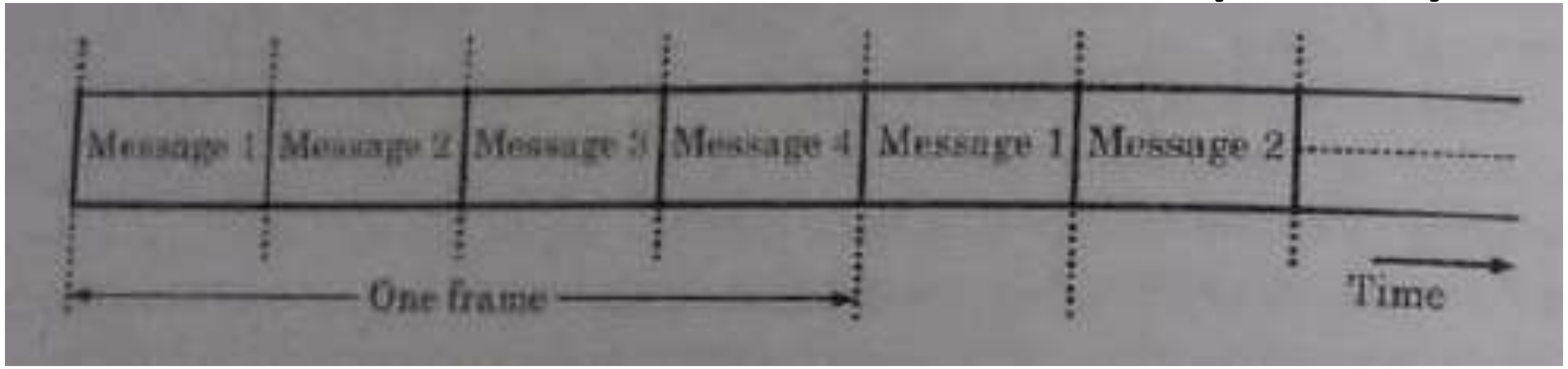
- A technique that allows many users to share a common communication channel simultaneously.
- there are two major types of multiplexing:
  i. Frequency Division Multiplexing (FDM)
  ii. Time Division Multiplexing (TDM)

i) Frequency Division Multiplexing (FDM)

- The whole frequency bandwidth is subdivided into smaller fixed frequency band and allocated to every user.
- Signals share different frequency slots but are transmitted simultaneously (thus at the same time).
- E.g. 1MHz is divided into ten bands for 10 users, thus 100kHz for each user.
- FDM is suitable for modulated signals since they can be placed in any frequency by simply varying the carrier frequency.

ii) Time Division Multiplexing

- The signal to be multiplexed are transmited sequentially one after the other.
- Each signal is given a different time slot from the rest. Thus signals are isolated from each other by time domain but share the same frequency.



Advantages of TDM

- Full available channl bandwidth can be utilized for each channel.
- Intermodulation distortion is absent.
- TDM circuitry is not very complex
- The problem of crosstalk is not severe.

Disadvantages of TDM

- Synchronisation is essential for proper operation.
- Due to slow narrowband fading, all the TDM channels may get wiped out.

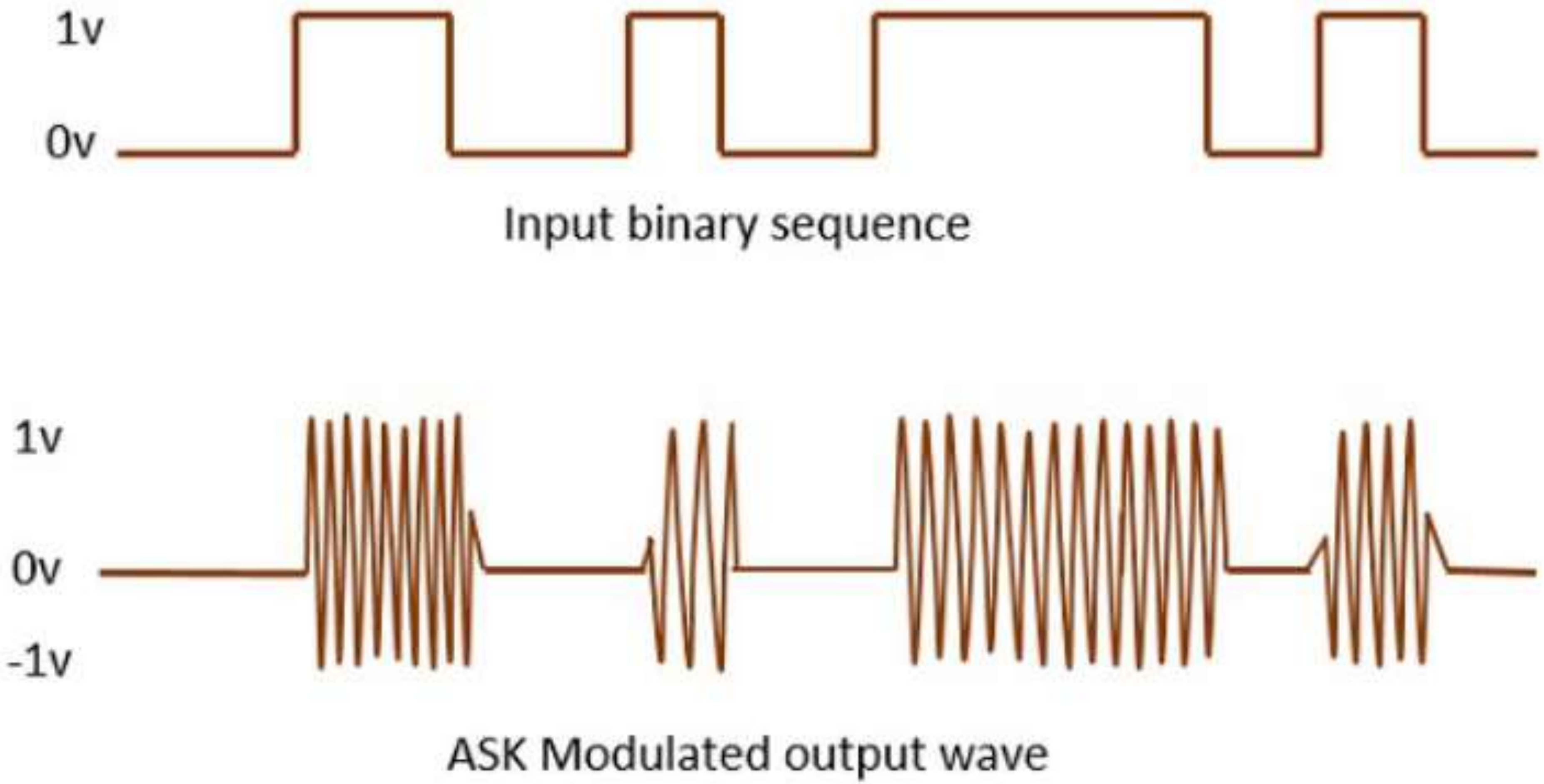
Digital modulation techniques

- Digital Modulation provides more information capacity, high data security, quicker system availability with great quality communication. Hence, digital modulation techniques have a greater demand, for their capacity to convey larger amounts of data than analog ones.
- There are many types of digital modulation techniques and we can even use a combination of these techniques as well.

Amplitude Shift Keying

- The amplitude of the resultant output depends upon the input data whether it should be a zero level or a variation of positive and negative, depending upon the carrier frequency.
- **Amplitude Shift Keying (ASK)** is a type of Amplitude Modulation which represents the binary data in the form of variations in the amplitude of a signal.
- Following is the diagram for ASK modulated waveform along with its input.
- Any modulated signal has a high frequency carrier. The binary signal when ASK is modulated, gives a zero value for LOW input and gives the carrier output for HIGH input.

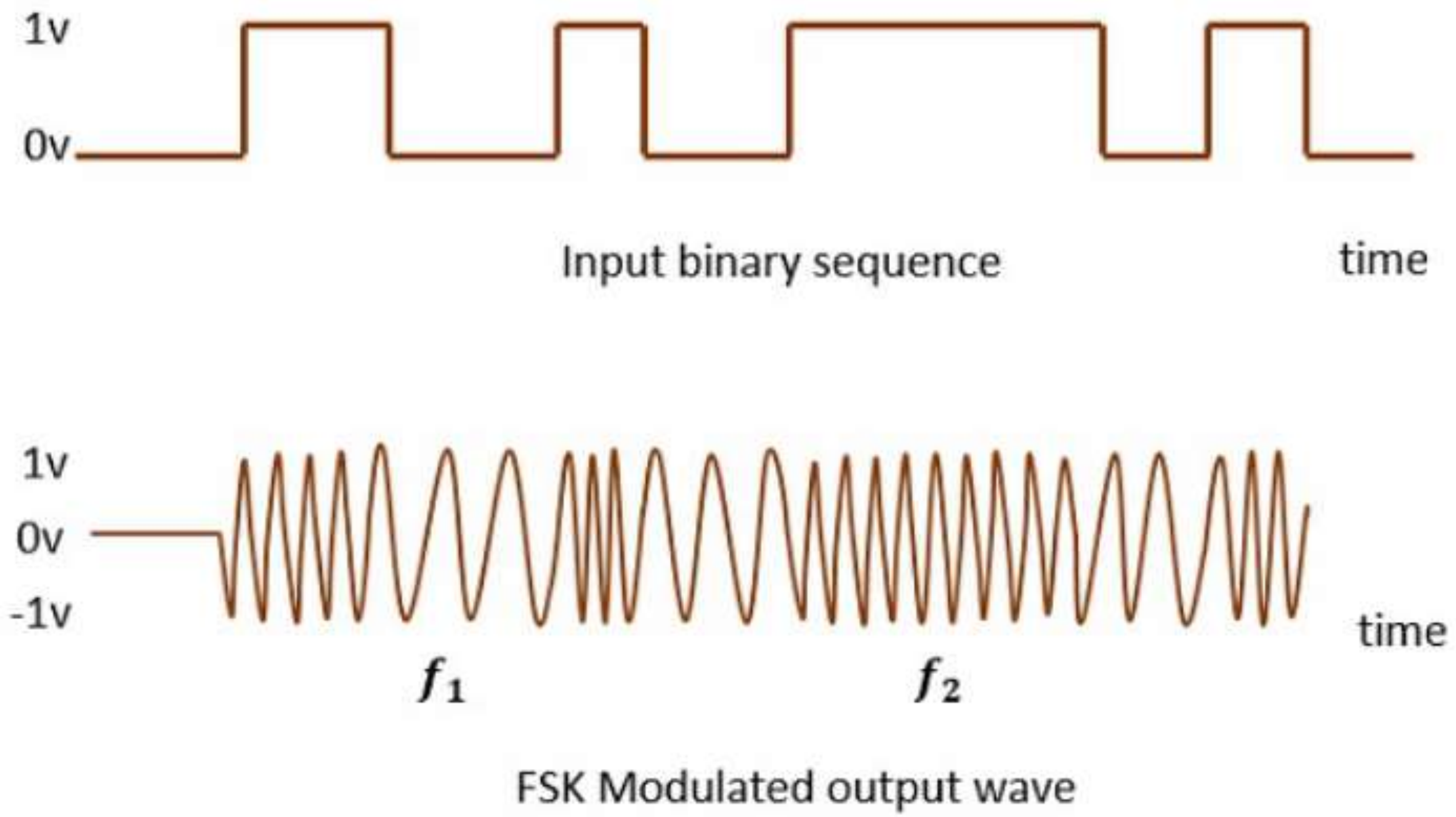
Amplitude Shift Keying (ASK)



Frequency Shift Keying

- The frequency of the output signal will be either high or low, depending upon the input data applied.
- **Frequency Shift Keying (FSK)** is the digital modulation technique in which the frequency of the carrier signal varies according to the discrete digital changes. FSK is a scheme of frequency modulation.
- The output of a FSK modulated wave is high in frequency for a binary HIGH input and is low in frequency for a binary LOW input. The binary 1s and 0s are called **Mark** and **Space frequencies**.
- Diagram for FSK modulated waveform along with its input is shown in the next slide.

Frequency Shift Keying

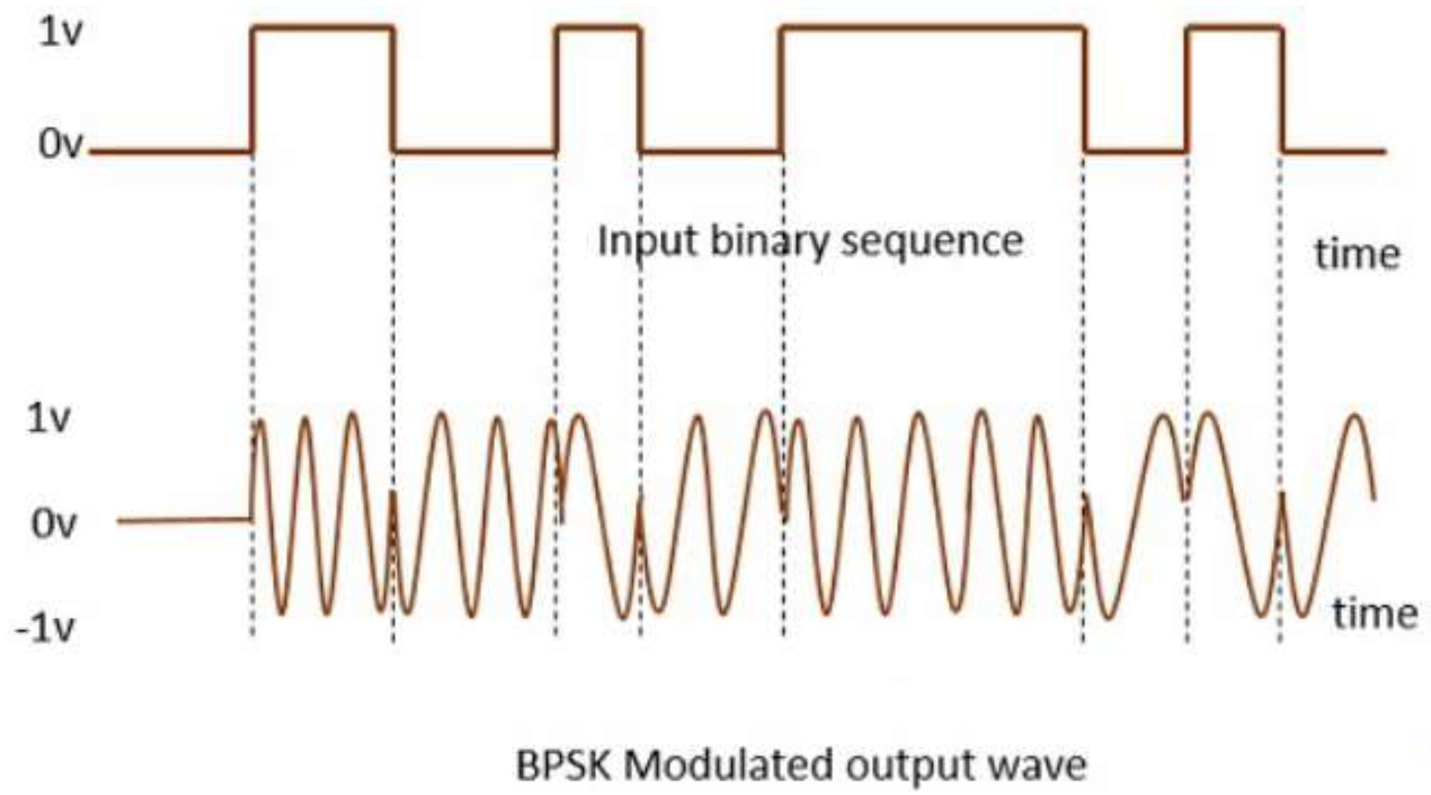


Phase Shift Keying

- The phase of the output signal gets shifted depending upon the input. These are mainly of two types, namely BPSK and QPSK, according to the number of phase shifts. The other one is DPSK which changes the phase according to the previous value.
- **Phase Shift Keying (PSK)** is the digital modulation technique in which the phase of the carrier signal is changed by varying the sine and cosine inputs at a particular time. PSK technique is widely used for wireless LANs, bio-metric, contactless operations, along with RFID and Bluetooth communications.

- PSK is of two types, depending upon the phases the signal gets shifted. They are −
- Binary Phase Shift Keying (BPSK)
- This is also called as **2-phase PSK** (or) **Phase Reversal Keying**. In this technique, the sine wave carrier takes two phase reversals such as 0° and 180°.
- BPSK is basically a DSB-SC (Double Sideband Suppressed Carrier) modulation scheme, for message being the digital information.
- Following is the image of BPSK Modulated output wave along with its input.

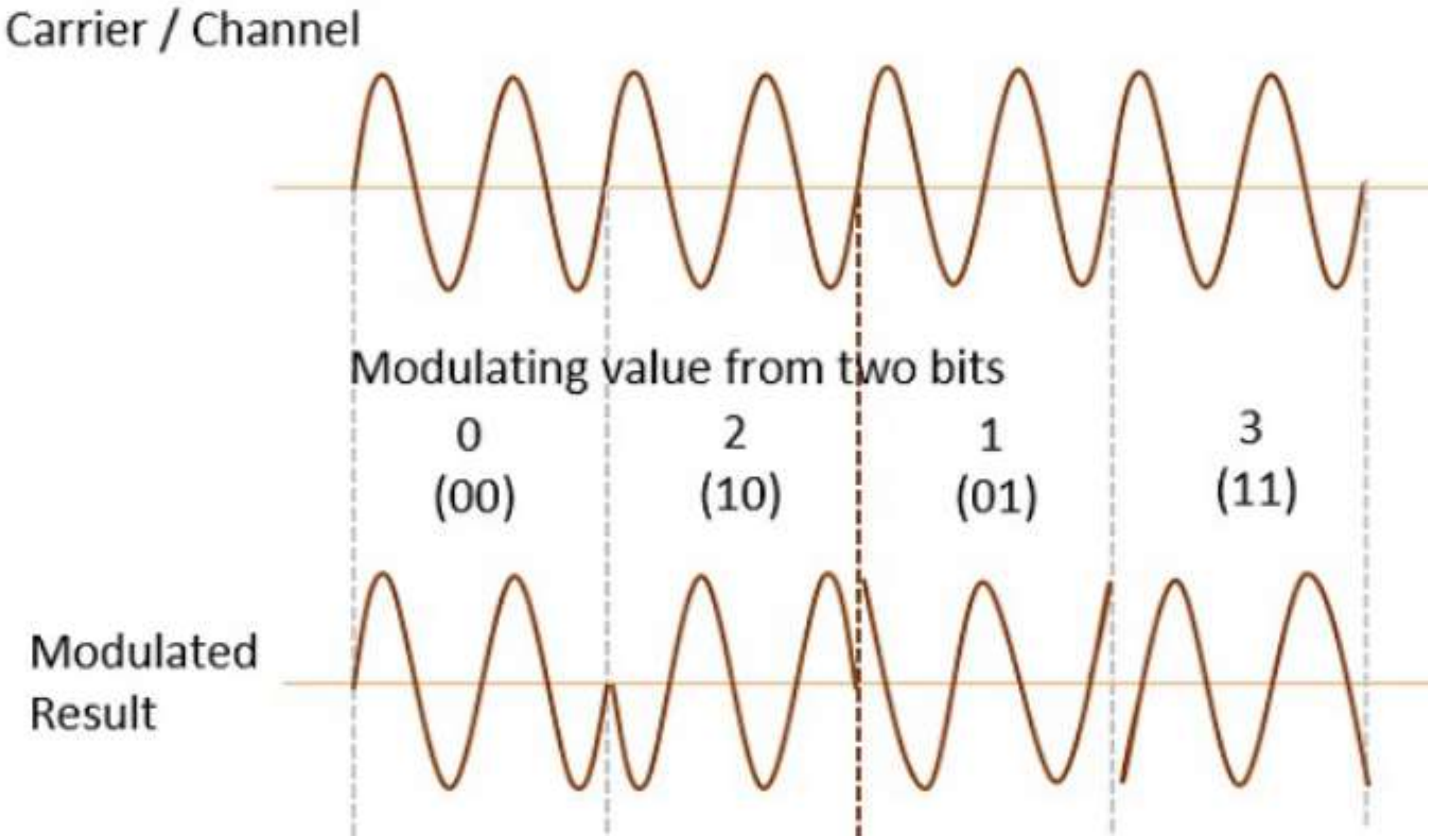
Binary Phase Shift Keying (BPSK)



Quadrature Phase Shift Keying (QPSK)

- This is the phase shift keying technique, in which the sine wave carrier takes four phase reversals such as 0°, 90°, 180°, and 270°.
- If this kind of techniques are further extended, PSK can be done by eight or sixteen values also, depending upon the requirement. The following figure represents the QPSK waveform for two bits input, which shows the modulated result for different instances of binary inputs.
- QPSK is a variation of BPSK, and it is also a DSB-SC (Double Sideband Suppressed Carrier) modulation scheme, which send two bits of digital information at a time, called as **bigits**.
- Instead of the conversion of digital bits into a series of digital stream, it converts them into bit-pairs. This decreases the data bit rate to half, which allows space for the other users.

Quadrature Phase Shift Keying (QPSK)



Differential Phase Shift Keying (DPSK)

- In DPSK (Differential Phase Shift Keying) the phase of the modulated signal is shifted relative to the previous signal element. No reference signal is considered here. The signal phase follows the high or low state of the previous element. This DPSK technique doesn’t need a refe
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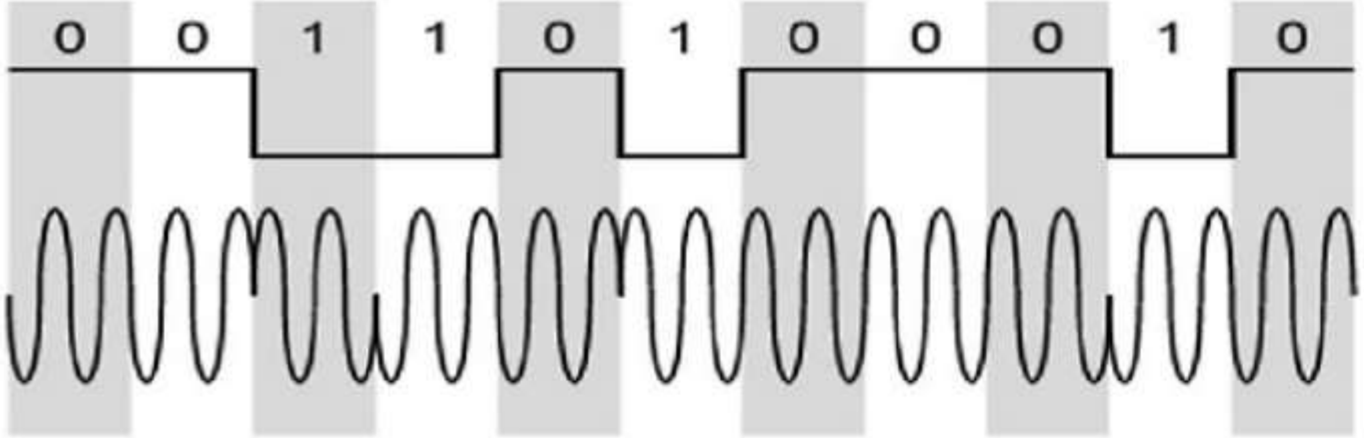

- It is seen from the above figure that, if the data bit is LOW i.e., 0, then the phase of the signal is not reversed, but is continued as it was. If the data is HIGH i.e., 1, then the phase of the signal is reversed, as with NRZI, invert on 1 (a form of differential encoding).
- If we observe the above waveform, we can say that the HIGH state represents an **M** in the modulating signal and the LOW state represents a **W** in the modulating signal.

Exercise

- Distinguish the differences amongst the following digital modulation techniques: ASK, PSK and FSK.
- Discuss the following digital modulation techniques:
    i. Synchronous Time Division Multiplexing
    ii. Asynchronous Time Division Multiplexing.
- Describe the main functional blocks of a PCM transmitter.

Exercise

- An input binary signal is given as 01110010. Sketch the corresponding output signal when this input is modulated using:
    i. Binary Phase Shift Keying
    ii. Quadrature Phase Shift Keying
- An input binary signal is given as 10011011. Sketch the corresponding output signal when this input is modulated using:
    i. Binary Phase Shift Keying
    ii. Quadrature Phase Shift Keying