Communication Engg.

MODULE - III

PCM SYSTEM

(PULSE CODE MODULATION)

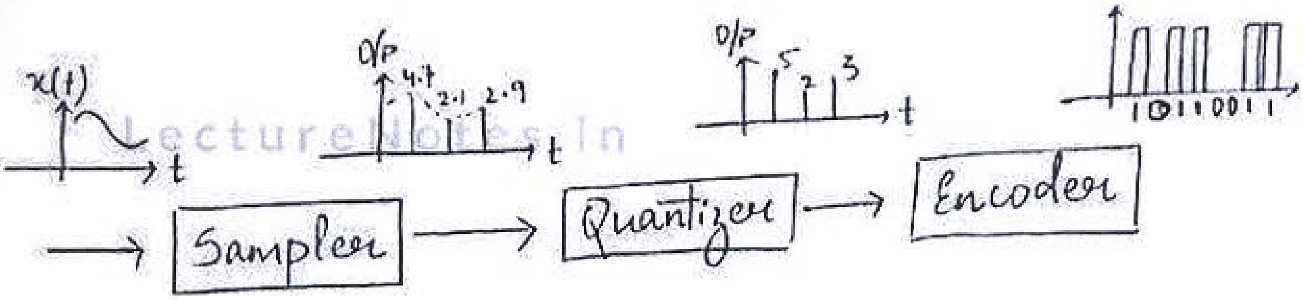


Fig (a) PCM TRANSMITTER

→ Fig (a) shows a PCM Transmitter, here baseband signal is sampled by sampler at Nyquist rate.

→ The sampled pulses are then Quantized in the quantizer.

→ The Encoder encodes these quantized pulses into bits, which are then transmitted over the channel

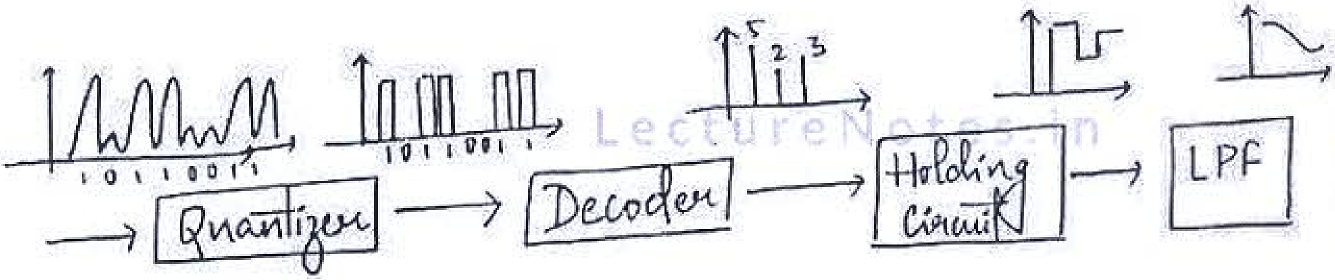


Fig (b) PCM RECEIVER

→ Fig (b) shows a PCM Receiver, here first block is again a quantizer. But this quantizer differs from the transmitter quantizer because it has to take a decision about the presence or absence of a pulse. Thus, there are only two quantization levels.

→ The output of the quantizer goes to the decoder that performs the inverse operation of the encoder. The decoder output is a sequence of quantized pulse.

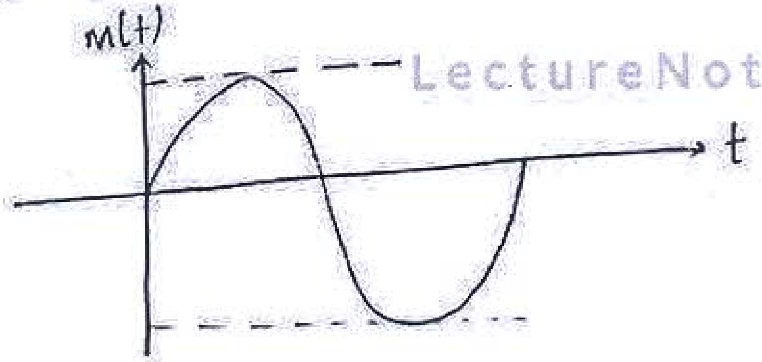
→ The Original Baseband signal is reconstructed in the holding circuit and LPF.

<u>Quantization Process</u> :-

Process in which the amplitude domain is discretized is known as <u>Quantization Process</u>

<u>Quantization of Signal</u> :-

The Process in which amplitude domain of given signal is discretized is known as Quantization of Process. Here we will discuss how the analog signal is discretized.



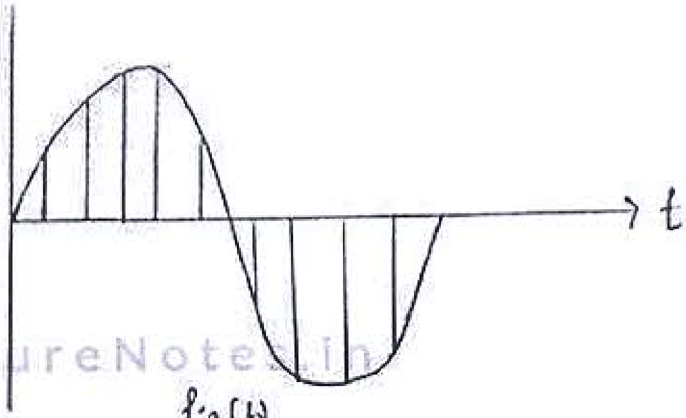
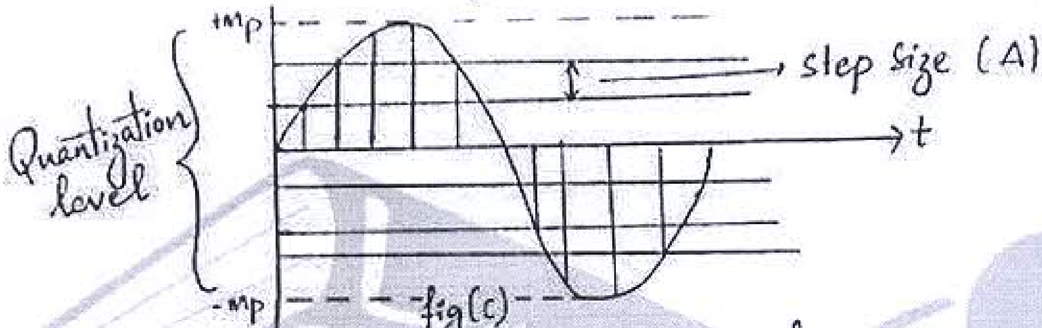


fig (b)



fig(c)

Practical v/s Quantized signal

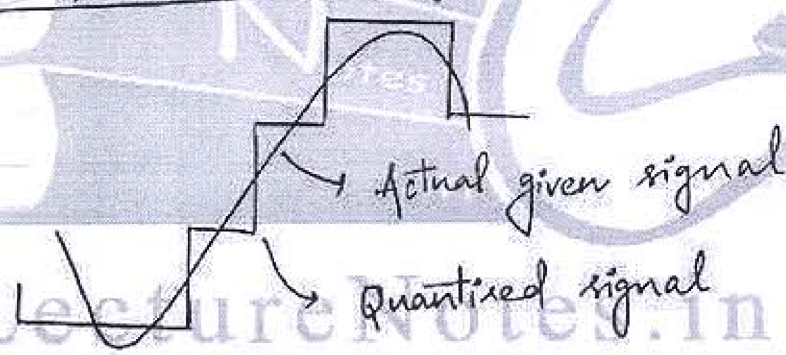


fig (d)

→ fig (d) shows the quantized signal approaches the actual signal very closely in stair case format

→ The advantage of quantization process is the quantized signal is totally separable from the additive white

→ The gap between quantization level is called step size $(\Delta) = \frac{2M_p}{q}$

$\therefore$ $M_p = A_m$

M_p = peak value of given signal

$$\boxed{q = 2^{\nu}}$$

q = no of quantization levels

ν = no of bits produced by encoder block

→ The accuracy level of quantized signal can be increased by increasing no. of quantization levels, which results in decreasing step size.

→ Types of quantization Process

(i) Uniform quantization Process

(ii) Non Uniform quantization Process

Uniform quantization process :-

In this process the step size is fixed or remain constant throughout the i/p range of given signal.

Non-Uniform quantization process :-

In this process the step size varies according to type of i/p signals

Bandwidth of the PCM system :-

Assume that there are n channels, each bandlimited to fm, to be time division multiplexed let ν be the length of PCM code, so that there are $2^{\nu} = q$ quantization levels

The Bandwidth of PCM system depends on the bit duration (bit time slot) which is calulated as follows

$$\text{Sampling frequency } (f_s) = 2 f_m$$

$$\text{Sampling period} = \frac{1}{2 f_m}$$

As there are n channels and ν bits per sample and one synchronizing bit, the total no of bits / sampling period (or frame)

$$= n\nu + 1$$

$$\text{Bit duration} = \frac{\text{Sampling period}}{\text{total number of bits}}$$

$$T_b = \frac{1}{(n\nu+1)\,2 f_m} \text{ sec}$$

$$\text{Bandwidth} = \frac{1}{T_b}$$

$$BW = (n\vartheta + 1)\, 2 f_m \text{ Hz}$$

if $\vartheta >> 1$ and $n >> 1$

$$BW = 2n\vartheta f_m \text{ Hz}$$

Example :-

24 telephone channels each bandlimited to 3.4 KHz are to be time division multiplexed by using PCM. Calculate the bandwidth of the PCM system for 128 quantization levels and an 8 KHz sampling frequency.

$$n = 24$$

$$q = 128$$

$$2^{\vartheta} = 128$$

$$\vartheta = 7$$

$$f_s = 2f_m = 8000$$

$$BW = [(24 \times 7) + 1]\, 8000 \text{ Hz}$$

$$= 1.352 \text{ MHz}$$

<u>Q</u>:- find out Transmission BW of PCM system?

From above explanation we know that

$$q = 2^{\vartheta}$$

Since, each sample of given ~~syn~~ signal is approximated / rounded off to the nearest quantization level. So the no of bits required for each of the sample = v

No of samples per sec = f_s

then, no of "bits per sec" for pcm system is

no of bits per sec (r) = $v f_s$

$$\text{unit} = \frac{\text{bits}}{\text{sample}} \times \frac{\text{sample}}{\text{sec}} = \text{bits/sec}$$

Above eq is known as signalling rate, bit rate, data rate.

→ Transmission BW required for PCM system is given as 1/2 signalling rate

$r = v f_s$

$$= \frac{1}{2}(r)$$

$$= \frac{1}{2} v f_s$$

$$= \frac{1}{2} v \, 2 f_m$$

$$= v f_m$$

$$(BW)_{PCM} = \frac{1}{2} v f_s \geq v f_m$$

$$(BW)_{PCM} \geq v f_m$$

Q:- A tv signal having BW of 4.2 MHz is transmitted using binary PCM system given that the no of quantization levels is 512. Determine the no of bits required by encoder system

(i) Determine transmission BW

(ii) Determine r

$q = 512$

$2^{v} = q = 512$

$v = 9$

$BW = v.f_m = 9 \times 4.2 \times 10^6$

$= 37.8\ MHz$

$r = vf_s$

$= v \times 2f_m$

75.6×10^6

$r = 75.6$ mega bits/sec

Noise in PCM system

Quantization error:

Due to quantization process, there is a deviation of the quantized signal from the actual signal. due to this deviation an error is generated in the PCM system known as quantization error.

→ quantization error can be generated mathematically as,

$\epsilon_e = x(t) - x_q(t)$

within this range ($-\Delta/2$ to $+\Delta/2$), the PDF (Probability distribution function) of the uniformly distributed random variable is given in fig (b)

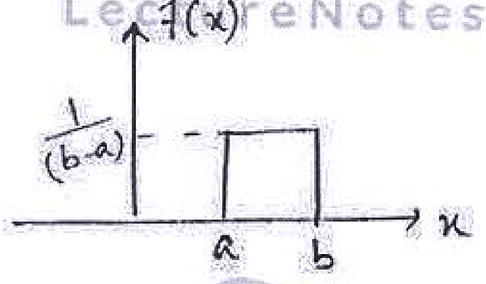


fig (a)

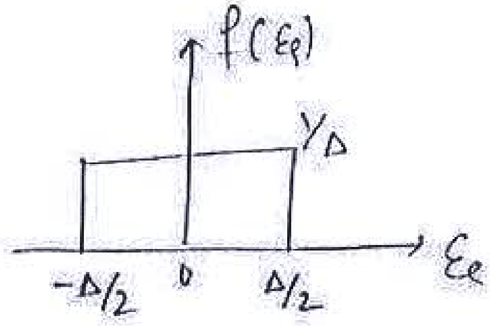


fig (b)

This PDF is given as $f(\varepsilon_e) = \begin{cases} 1/\Delta & -\Delta/2 \le \varepsilon_e \le \Delta/2 \\ 0 & \text{elsewhere} \end{cases}$

from fig (b) it is also observed that mean value / average value of quantization error is 0

i.e $M_{\varepsilon_e} = 0$

$M_{\varepsilon_e} \rightarrow$ Mean / avg value

→ It is assumed that the i/p signal is a voltage signal, then normalized noise power (Quantization error)

$$\text{power} = \frac{V^2_{noise}}{R} \qquad R = 1\,\Omega$$

$$\text{power} = V^2_{noise}$$

ε_e → quantization error

$x(t)$ → actual signal

$x_q(t)$ → quantized signal

→ The i/p signal / actual signal which is applied to i/p of uniform quantizer is a continuous time domain signal ranging in the range from peak to peak ($-m_p$ to m_p)

→ If the uniform quantizer provides q no of quantization level then, the step size is

$$\Delta = \frac{2M_p}{q} = S$$

→ If we want to increase or to improve the degree of accuracy level of uniform quantizer then we have to increase the no. of quantization levels as a result of which the step size reduces.

→ If step size is two small, then quantization error is assumed to be treated as special type of random variable known as Uniformly distributed random variable.

→ As we know that max^m value of quantisation error $\varepsilon_{max} = \pm \Delta/2$

....

As, we have to use a fixed number of quantization levels, the only way to have a uniform signal to quantization noise ratio is to adjust the step size in such a way that the ratio remains constant. Thus, the step size should be small for small amplitude signals and large for large amplitude signals.

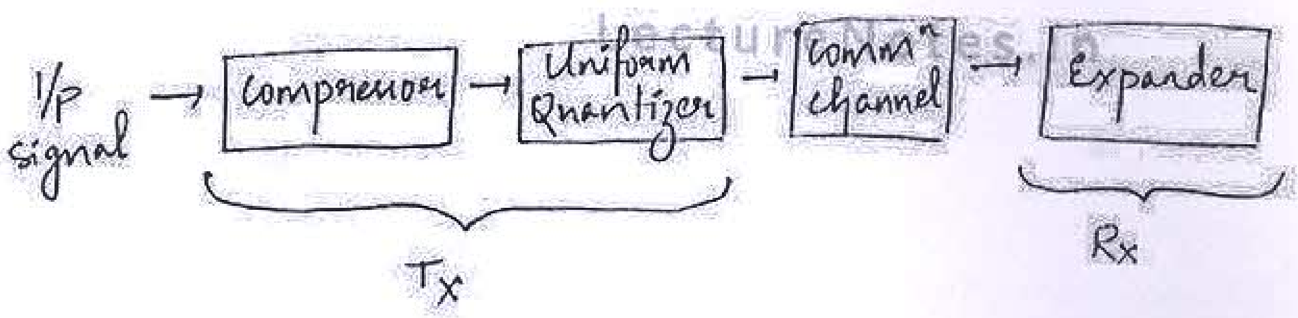
→ This is achieved technically in the comm^n system by compressing the signals at the transmitting end and reverse operation should be operated i.e expansion of signal at receiver side

→ The compression of signals means low amp signal should be amplified by the amplifier and high amp signal should be attenuated by the attenuator.

Companding is mixing of 2 words

Compression + Expansion

Block diagram of non-uniform Quantizer



V^2_{noise} represents, the mean square value of the quantization error

Mathematically $V^2_{noise} = E[\varepsilon_e^2]$
↓
Exception

$V^2_{noise} = \overline{\varepsilon_e^2}$ → term is variance

$$V^2_{noise} = \int_{-\infty}^{\infty} \varepsilon_e^2 f(\varepsilon_e)\, d\varepsilon_e$$

$$\int_{-\Delta/2}^{\Delta/2} \varepsilon_e^2 + \frac{1}{\Delta}\, d\varepsilon_e = \frac{1}{\Delta}\left[\frac{\varepsilon_e^3}{3}\right]_{-\Delta/2}^{\Delta/2}$$

$$= \frac{1}{\Delta}\left[\frac{\Delta^3}{24} - \frac{1}{3}\left(-\frac{\Delta}{2}\right)^3\right]$$

$$= \frac{\Delta^2}{12} = N_q$$

N_q = quantization Noise power

Companding (concept of Non-Uniform Quantizer)

lets consider 2 types of signals available to communication system

(i) Weak / low amp signal

(ii) High Amp signal

— As we ~~have~~ Known the quantization error depends upon the stepsize. When the steps are uniform in size, the small amplitude signals will have a poorer Signal to quantization noise ratio than the large amplitude signal

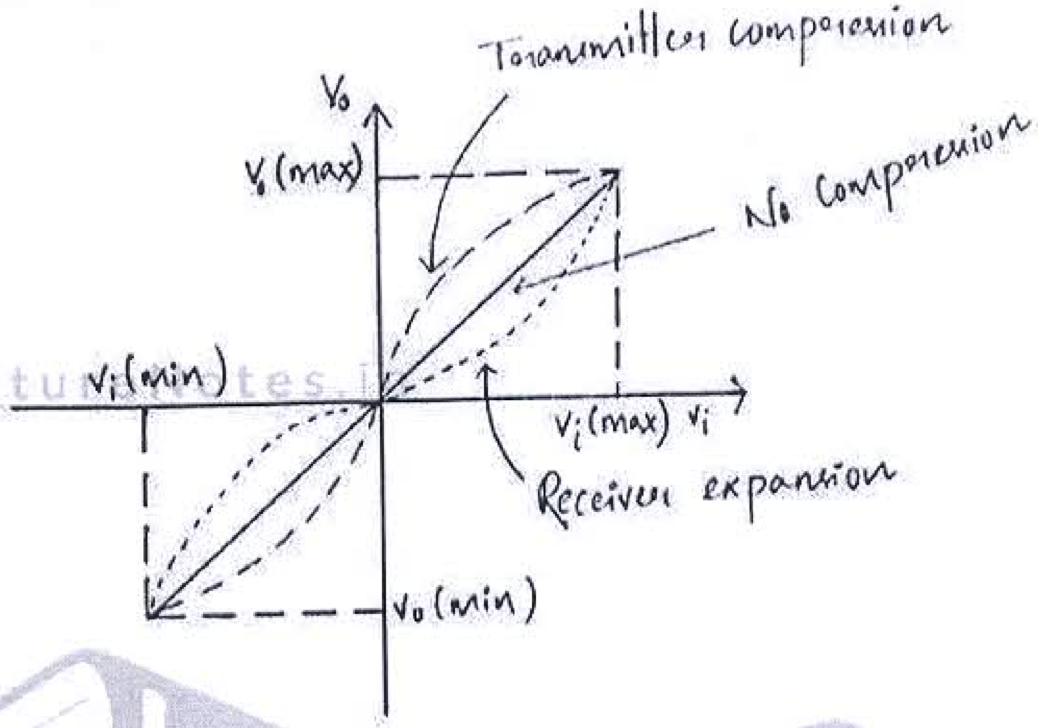
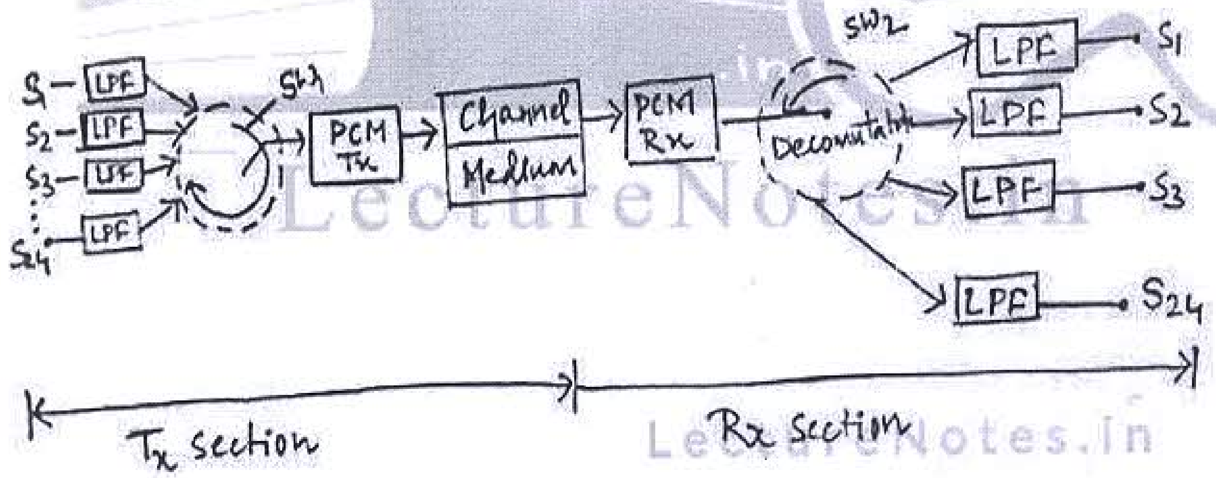


Fig : Companding

Time Division Multiplexing of the PCM signal



Tx - Transmitted side
Rx - Receiver side

→ Basically PCM - TDM system is classified into 2 types:

(i) Synchronous TDM system

(ii) Asynchronous TDM system

→ When all the available voice signals are bandlimited to same frequency range then the sampling frequency is also same and this type of TDM system is known as <u>Synchronous TDM system</u>.

→ When all the available voice signals are band limited to different frequency components then the sampling frequencies are also different and this type of TDM system is known as <u>Asynchronous TDM system</u>

Synchronous TDM system

(i) Bit interleaving synchronous TDM

(ii) Word interleaving synchronous TDM

In Bit interleaving synchronous TDM the 1st bit of 1st sample is transmitted followed by 1st bit of 2nd sample and followed by 1st bit of 3rd sample and so on

(ii) In Word interleaving Synchronous TDM, All the bits of 1st sample is transmitted followed by all the bits of 2nd sample and so on.

Asynchronous TDM system

In this case all the voice signals are bandlimited to different frequencies components hence, their sampling frequency are also different

→ Since the sampling frequency are different. So their recording rate is also different which means all are being transmitted with different speeds. So that the o/p sample rate of each of the device is same

Applications of PCM

→ In telephony (with the advent of fibre optic cables)

→ In the space communication, space craft transmits signals to earth. Here, the transmitted power is very low (10 or 15 W) and distance are huge (a few million km). still due to the high noise immunity, only PCM system can be used in such applications

Advantages of PCM

→ Very high noise immunity.

→ Due to digital nature of the signal, repeaters can be placed between the transmitter and the receivers. The repeaters actually regenerate the received PCM signal

→ It is possible to store the PCM signal due to its digital nature

→ It is possible to use various coding techniques so that only the desired person can decode the received signal.

Disadvantages of PCM

→ The encoding, decoding and quantizing circuitory of PCM is complex.

→ PCM requires a large bandwidth as compared to the ~~oth~~ other systems.