achieved through companding.

3.14. Companding in PCM

As discussed earlier, the quantization error depends upon the step size 'δ'. Thus, when the steps are uniform in size, the small amplitude signals would have a poorer signal to quantization noise ratio than the large amplitude signals, since in both the cases the denominator (*i.e.*, quantization noise) is the same whereas the numerator order is quite small for small amplitude signals and large for large amplitude signals. Now, since 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 manner that the ratio remain constant. This means that the step size must be small for small amplitude signals and large for large amplitude signals.

The effect of an adaptive step size may also be achieved in a more feasible way by distorting the signal before the quantization process. An inverse distortion has to be introduced at the receiver to make the overall transmission distortionless.

Therefore the signal is amplified at low signal levels and attenuated at high signal levels. After this process, uniform quantization is used. This is equivalent to more step size at low signal levels and small step size at high signal levels. At the receiver a reverse process is done. That is signal is attenuated at low signal levels and amplified at high signal levels to get original signal. Thus the compression of signal at transmitter and expansion at receiver is called combinely as *companding*. Fig 3.9 shows compression and expansion curves.

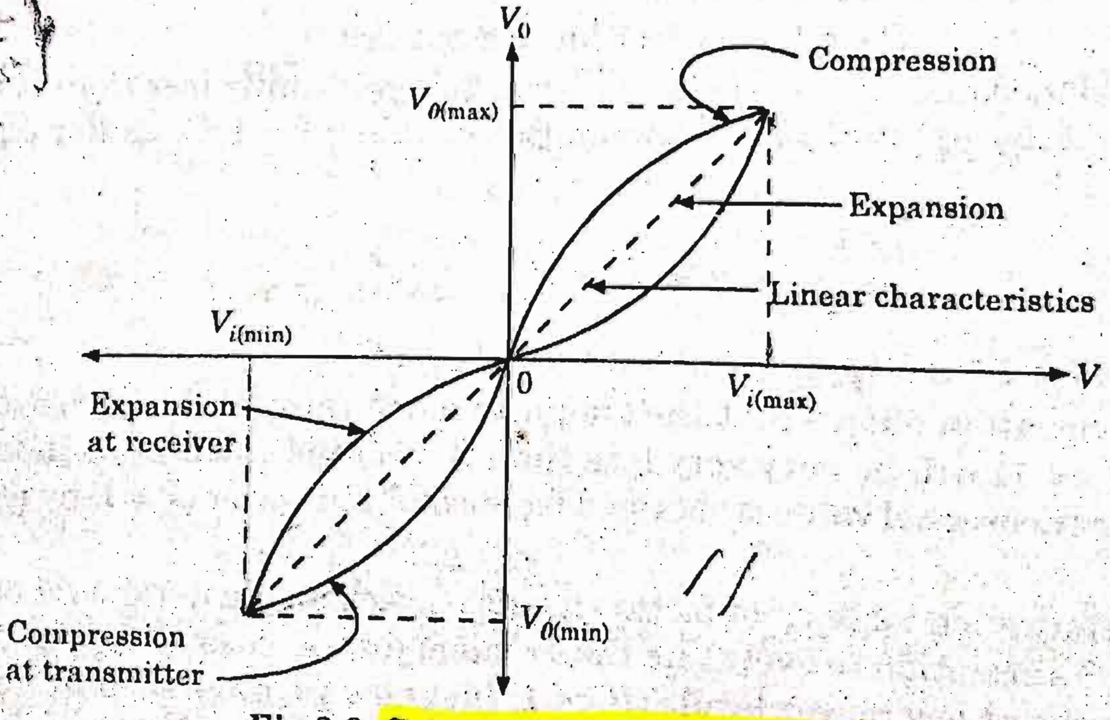

Fig 3.9. *Companding curves for PCM.*

As can be seen form Fig 3.9, at the receiver, the signal is expanded exactly opposite to compression curve at transmitter to get original sigal. A dotted line in the Fig. 3.9 shows uniform quantization. The compression and expansion is obtained by passing the signal through the amplifier having non-linear transfer characteristic as shown in Fig. 3.9. That is non-linear transfer characteristic means compression and expansion curves.

3.14.1. Model of a Non-unif

remains almost constant with companding.

3.15. Delta Modulation

We have observed in PCM that it transmits all the bits which are used to code the sample. Hence signaling rate and transmission channel bandwidth are large in PCM. To overcome this problem, Delta Modulation is used.

Delta modulation transmits only one bit per sample. Here, the present sample value is compared with the previous sample value and this result whether the amplitude is increased or decreased is transmitted. Input signal $x(t)$ is approximated to step signal by the delta modulator. This step size is kept fixed. If the difference between the input signal $x(t)$ and staircase approximated signal confined to two levels, *i.e.*, $+\delta$ and $-\delta$. Now, if the difference is positive, then approximated signal is increased by one step, *i.e.*, 'δ'. If the difference is negative, then approximated signl is reduced by 'δ'. When the step is reduced, '0' is transmitted and if the step is increased, '1' is transmitted. Thus for each sample, only one binary bit is transmitted. Fig 3.14 shows the analog signal $x(t)$ and its staircase approximated signal by the delta modulator.

Thus, The principle of delta modulation can be explained by the following equations.

The error between the sampled value of $x(t)$ and last approximated sample is given as,

$$e(nT_s) = x(nT_s) - \hat{x}(nT_s) \quad \text{...(3.45)}$$

Here, $e(nT_s)$ = error at present sample

$x(nT_s)$ = Sampled signal of $x(t)$

$\hat{x}(nT_s)$ = Last sample approximation of the staircase waveform.

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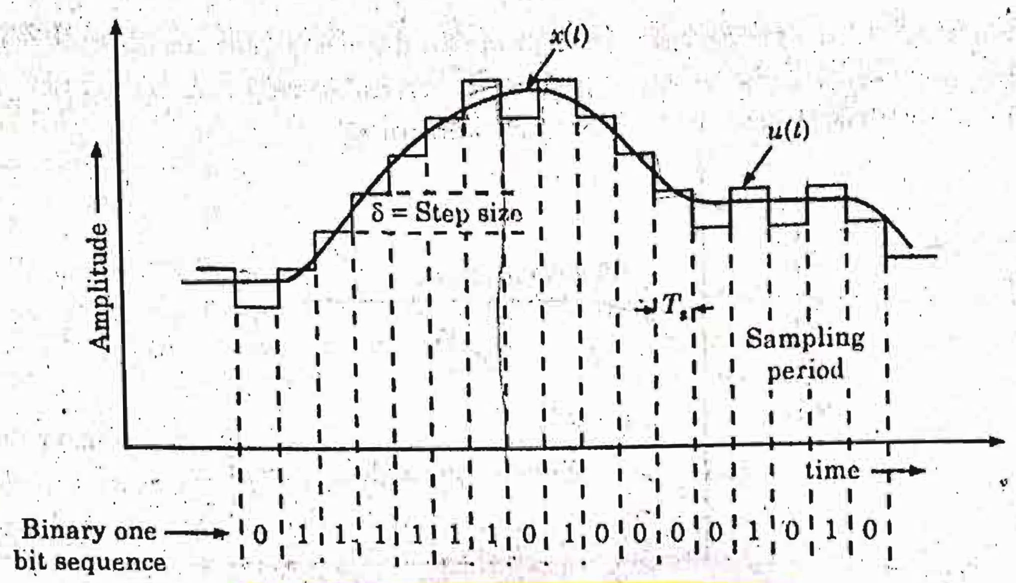

Fig 3.14. Delta modulation waveform.

If we assume $u(nT_s)$ as the present sample approximation of staircase output,

then, $u[(n-1)T_s] = \hat{x}(nT_s)$ ...(3.46)

= Last sample approximation of staircase waveform

Let us define a quantity $b(nT_s)$ in such a way that,

$$b(nT_s) = \delta \, sgn \, [e(nT_s)] \quad ...(3.47)$$

This means that depending on the sign of error $e(nT_s)$, the sign of step size δ is decided. In other words, we can write

$$b(nT_s) = +\delta \quad \text{if } x(nT_s) \geq \hat{x}(nT_s)$$

$$= -\delta \quad \text{if } x(nT_s) < \hat{x}(nT_s) \quad ...(3.48)$$

Also, If $b(nT_s) = +\delta$; a binary '1' is transmitted

and if $b(nT_s) = -\delta$; a binary '0' is transmitted.

T_s = Sampling interval.

Fig 3.15(a) shows the transmitter ($i.e.$, generation of Delta Modulated signal) based upon equations (3.47) to (3.49).

The summer in the accumulator adds quantizer output (± δ) with the previous sample approximation. This gives present sample approximation. $i.e.$,

$$u(nT_s) = u(nT_s - T_s) + [\pm \delta]$$

or $$u(nT_s) = u[(n-1)T_s] + b(nT_s) \quad ...(3.49)$$

The previous sample approximation $u[(n-1)T_s]$ is restored by delaying one sample period T_s. The sampled input signal $x(nT_s)$ and staircase approximated signal $\hat{x}(nT_s)$ are subtracted to get error signal $e(nT_s)$.

Thus, depending on the sign of $e(nT_s)$, one bit quantizer generates an output of + δ or − δ. If the step size is + δ, then binary '1' is transmitted and if it is − δ, then binary '0' is transmitted.

At the receiver shown in Fig 3.15(b), the accumulator and low-pass filter are used. The accumulator generates the staircase approximated signal output and is delayed by one sampling period T_s. It is then added to the input signal. If input is binary '1' then it adds + δ step to the previous output (which is delayed). If input is binary '0' then one step 'δ' is subtracted from the delayed signal. The low-pass filter has the cutoff frequency equal to highest frequency in $x(t)$. This filter smoothens the staircase signal to reconstruct $x(t)$.

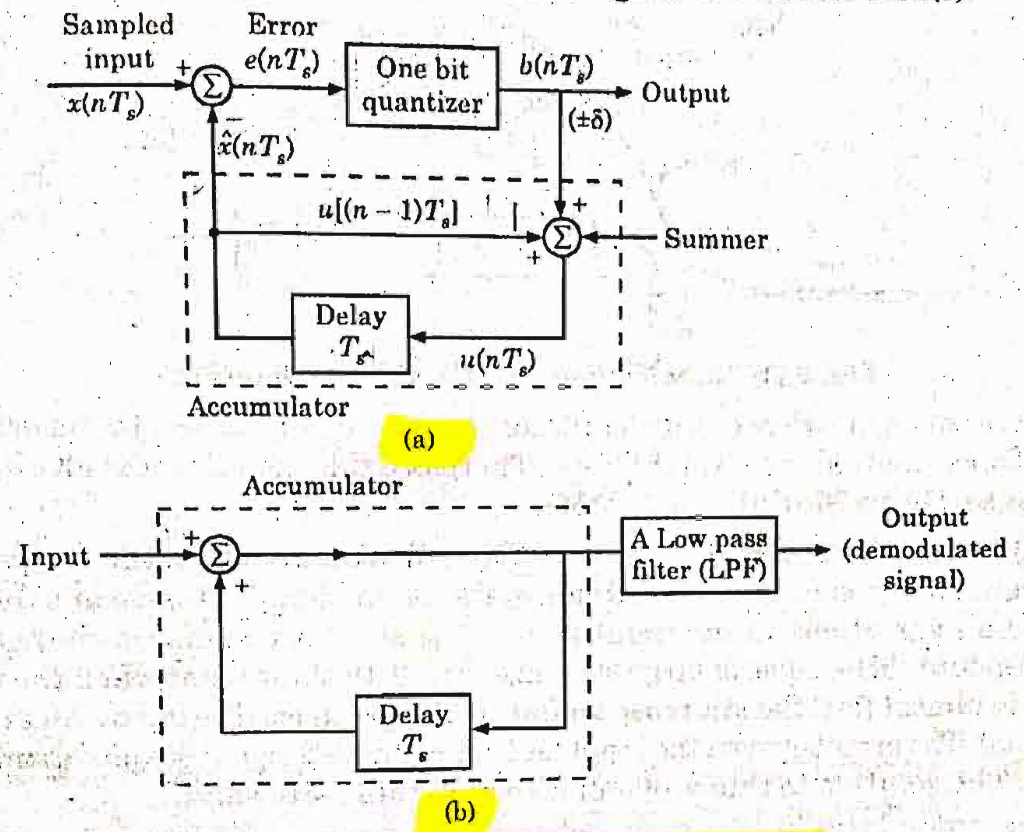

***Fig. 3 15.** (a) A Delta modulation transmitter*
(b) A Delta modulation receiver

Advantages of Delta Modulation

The delta modulation has certain advantages over PCM as under :

1. Since, the delta modulation transmits only one bit for one sample, therefore the signaling rate and transmission channel bandwidth is quite small for delta modulation compared to PCM.
2. The transmitter and receiver implementation is very much simple for delta modulation. There is no analog to digital converter required in delta modulation.

Disadvantges of Delta Modulation

The delta modulation has two major drawbacks as under :

(*i*) Slope overload distortion,

(*ii*) Granular or Idle noise

Now, let us discuss these two drawbacks in detail.

(*i*) Slope Overload Distortion. This distortion arises because of large dynamic range of the input signal.

As can be observed from Fig 3.16, the rate of rise of input signal $x(t)$ is so high that the staircase signal cannot approximate it, the step size 'δ' becomes too small for staircase signal $u(t)$ to follow the step segment of $x(t)$. Hence, there is a large error between the staircase approximated signal and the original input signal $x(t)$. This error or noise is known as **slope overload distortion.** To reduce this error, the step size must be increased when slope of signl $x(t)$ is high.

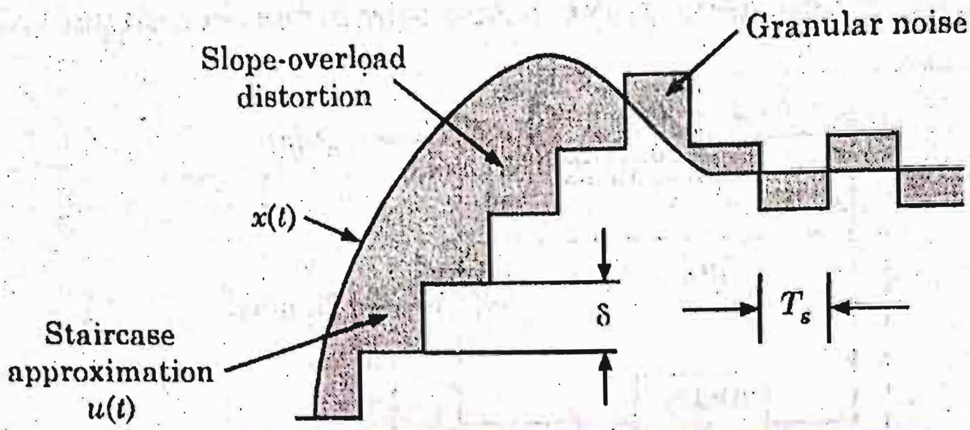

Fig. 3.16. *Quantization errors in delta modulation.*

Since the step size of delta modulator remains fixed, its maximum or minimum slopes occur along straight lines. Therefore this modulator is also known as **Linear Delta Modulator (LDM).**

***(ii)* Granular Noise.** Granular or Idle noise occurs when the step size is too large compared to small variations in the input signal. This means that for very small variations in the input signal, the staircase signal is changed by large amount (δ) because of large step size. Fig. 3.16 shows that when the input signal is almost flat, the staircase signal $u(t)$ keeps on oscillating by $\pm\delta$ around the signal. The error between the input and approximated signal is called **granular noise.** The solution to this problem is to make step size small.

Therefore, large step is required to accommodate wide dynamic range of the input signal (to reduce slope overload distortion) and small steps are required to reduce granular noise. Infact, Adaptive delta modulation is the modification to overcome these errors.