Delta Modulation (DM):

It converts or encodes any message signal into a sequence of binary digits or symbols. These binary symbols are represented by a train of positive and negative impulses. The basic advantage of delta modulation is the extreme simplicity modulation and demodulation circuit as compared to conventional A to D converter.

Block diagram of Delta modulation:

Delta modulator is shown in figure 1. The input message signal $m(t)$ is compared with the reference signal $m_s(t)$, which is coming from the feedback path. A comparator subtracts this two input signal, generating a positive output when the difference is positive and a negative output when the difference is negative. An amplitude limiter is needed for doing this operation. A +V is generated when the input to the amplitude limiter is positive and a –V is generated when the input to the amplitude limiter is negative.

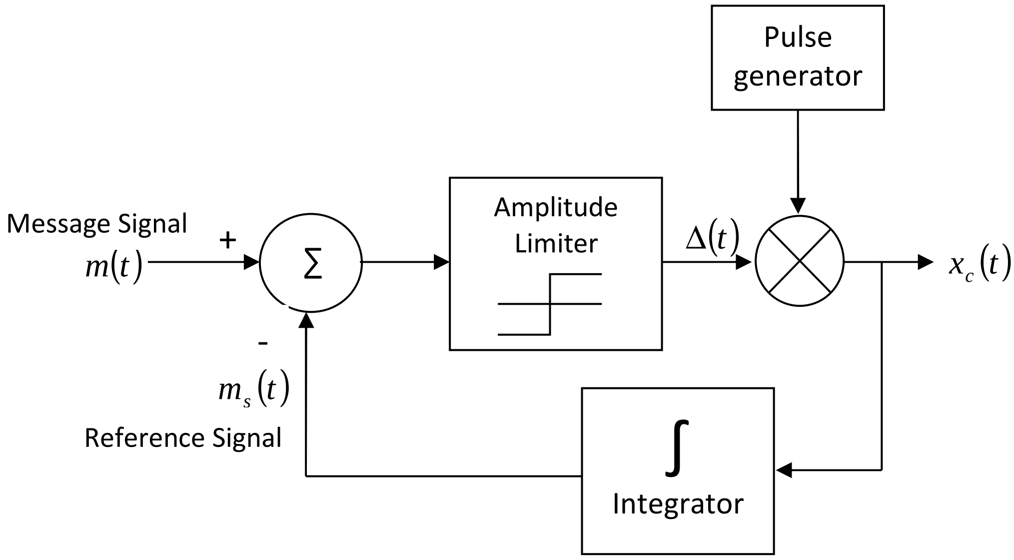


Figure 1: Delta modulator

The output of limiter is the quantized representation of symbols. Quantization output is $\Delta(t)$. It is modulated or multiplied with a train of impulse signals $\sum \delta(t - nT_s)$. The output of the modulator is $x_c(t)$,

$$x_c(t) = \Delta(t) \bullet \sum \delta(t - nT_s)$$

Using the shifting property of impulse function, the above equation can be written as,

$$x_c(t) = \sum \Delta(nT_s)\delta(t - nT_s)$$

The nature of $x_c(t)$ is a series of impulses with positive and negative polarity depending on the sign of the difference signal.

Reference signal:

It is obtained by passing $x_c(t)$ through an integrator. i.e. reference signal may be obtained when $x_c(t)$ is integrated.

$$m_s(t) = \sum \Delta(nT_s)\int_0^t \delta(\alpha - nT_s)d\alpha$$

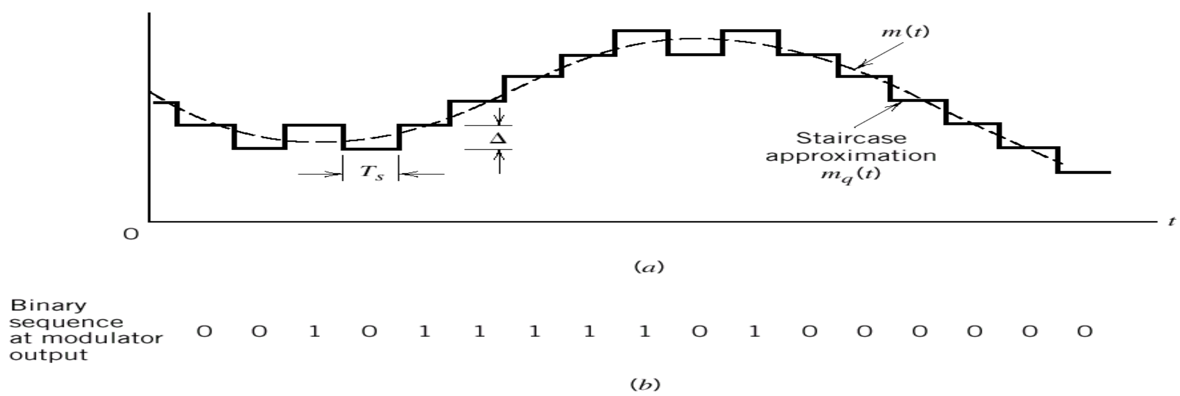
The output is step signal, when the impulse signal is integrated.

$$\therefore \quad m_s(t) = \sum \Delta(nT_s)u(t - nT_s)$$

i.e. The Output of integrator creates a staircase approximation of message signal.

In delta modulation, reference signal is the staircase approximation to actual signal and this way a series of positive and negative pulses are generated.

Figure 2 shows the operation of delta modulation.



Demodulator of Delta modulation:

Demodulator is very simple in circuit. It consists of an integrator followed by a low pass filter, which is shown in figure 3.

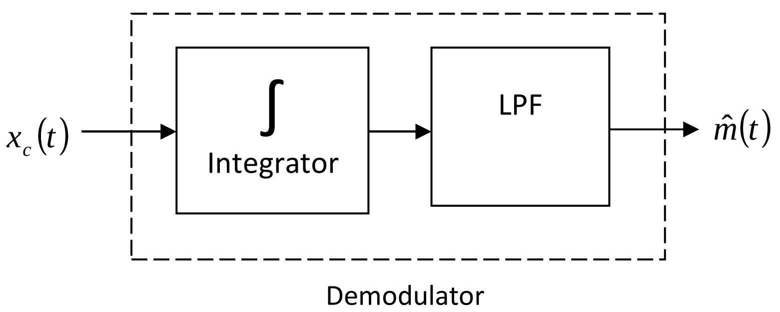


Figure 3: Demodulation circuit

Limitations of delta modulation:

i) Slope overload distortion:

Staircase approximation cannot track the rapid changes happening in a message signal, when the input message signal changes rapidly. The staircase approximation is increased or decreased by size S for every T_s sec.

The staircase wave can predict at a rate of S/T_s when there is any sudden change of signal.

Therefore, whenever message signal $m(t)$ has a slope greater than S/T_s, staircase approximation of message signal cannot predict the message signal $m(t)$.

The condition for avoiding slope overload distortion:

Consider a sinusoidal message signal $m(t) = A \sin 2\pi f_m t$

The maximum slope of the signal is,

$$\frac{dm(t)}{dt} = 2\pi A f_m \cos 2\pi f_m t$$

i.e. $S/T_s \geq 2\pi A f_m$

The above equation gives the condition for avoiding slope overload distortion.

ii) Granular noises:

The second problem with delta modulation is that the output signal must always either increase by a step, or decrease by a step, and cannot stay at a single value. This means that if the input signal is level or changes very slow, the output signal could potentially be oscillatory. That is, the output signal would appear to be a wave, as it would go up and down regularly. This phenomena is called **Granular Noise**.

When step size S is too large it is unable to track very slow or small amplitude variations in the signal. This kind of situation is Granular noise condition.

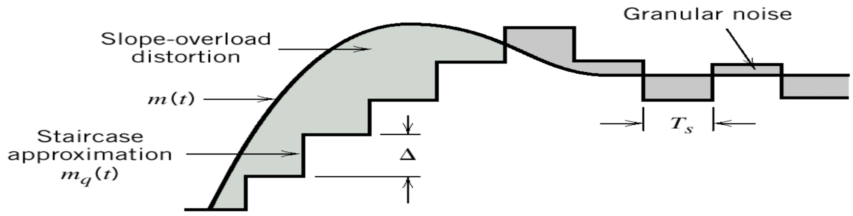


Figure 4: Slope overload and Granular noise condition

Adaptive Delta Modulation:

We need adaptive delta modulation for solving slope overload distortion and granular noise.

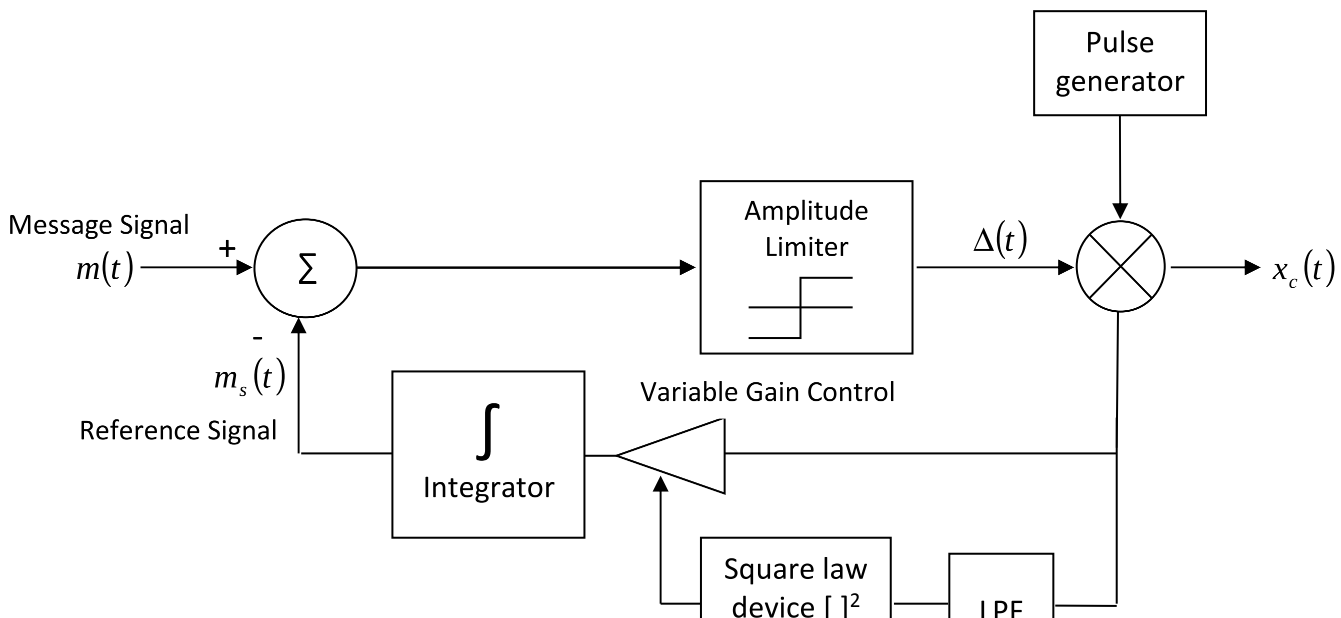
We should be able to increase the step size in the slope overload condition and minimize the step size for granular noise condition.

A continuous positive output may be obtained indicating or symptomizing for slope overload condition. In a similar manner, getting a positive impulse followed by a negative one is a symptom of granular noise condition. Therefore, we must able to monitor the output nature of delta modulation and immediately take corrective action. This is the principle of adaptive delta modulation. Figure 3 shows the adaptive delta modulation circuit.

Therefore we need a variable gain amplifier at the feedback path. This is shown in the figure. This amplifier becomes a variable gain amplifier by modifying the step size through amplifications of signals. Gain of the amplifier is controlled by a square law device and low pass filter.

For example, when there is a slope overload condition, too many positive or negative impulses are coming (i.e. large positive slope or large negative slope) at the output side. During this period, output of low pass filter is the average DC value. When the magnitude of average value of low pass filter is large, gain requires increase. Therefore step size also increases to follow the message signal.

Similarly, during the granular noise condition, positive impulses are obtained followed by negative impulses. Hence the output of low pass filter is very small. (Low pass filter produces average DC value). Therefore step size are decreases.



Differential Pulse Code Modulation (DPCM):

In sampling the signal at the rate of $f_s \geq 2 f_h \; Hz$ is required in PCM. The resulting sampled signal is found to be a high correlation between adjacent samples. i.e. signals not change rapidly from one sample to another. In other words variance between the samples are small.

When these highly correlated samples are encoded by the PCM system, encoded information contains a lot of redundant information. A more efficient coded signal can be obtained by removing this redundancy before encoding. Such type of coding is referred to as Differential pulse code modulation (DPCM).

The schematic of DPCM transmitter is shown in figure 1.

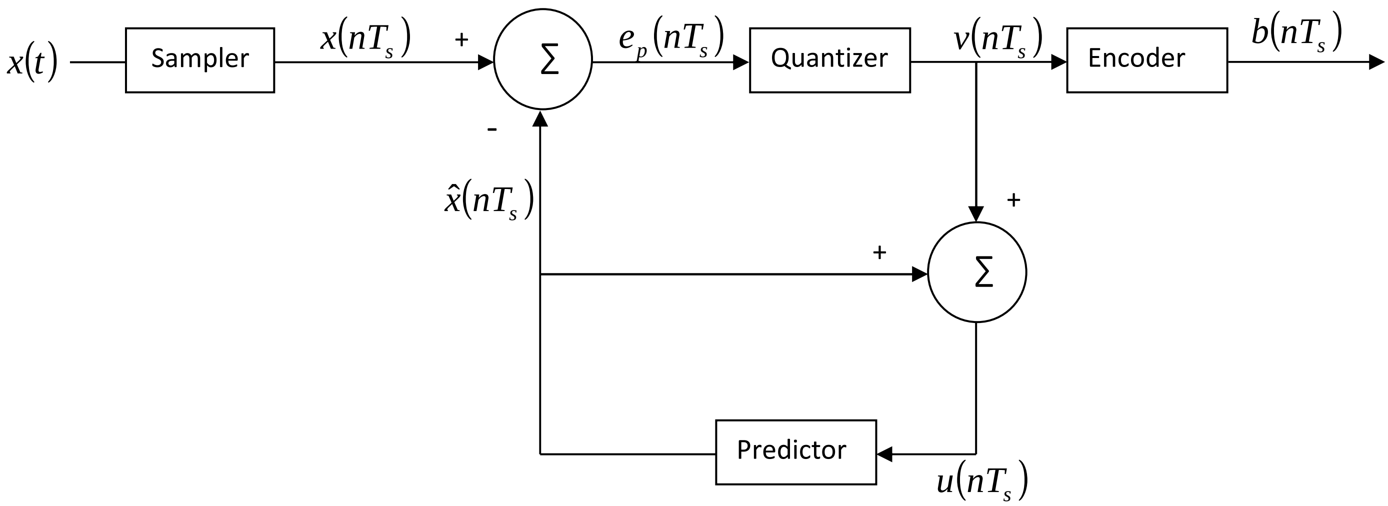


Figure 1. DPCM Transmitter

The operation DPCM can be explained through the following examples.

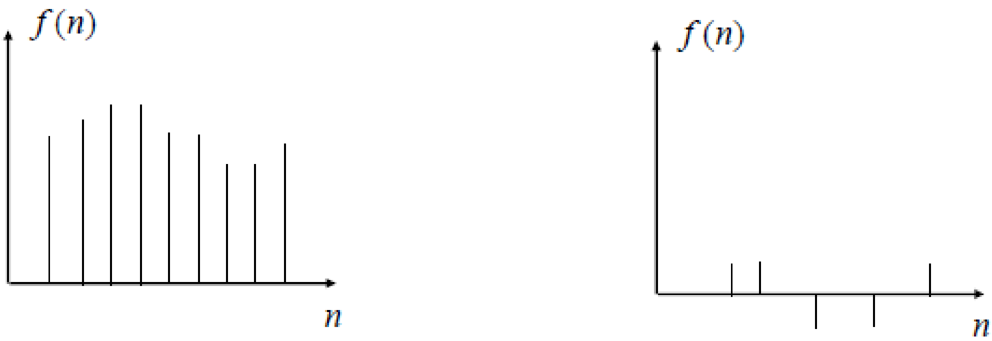
Let us assume figure 2 shows the original samples.

First input:

Let us take the first sample as 156, (During this stage $\hat{x}(nT_s) = 0$) the output of the comparator is 156. (i.e. 156-0=156). It is given to the quantizer, now output of the quantizer is 156 and it is encoded by the encoder.

Now consider the second sample as 157, now the inputs to the comparator are current input sample 157 and 156. {(Obtained from predictor block. ($v(nT_s)=156$ and $\hat{x}(nT_s)=0$; $u(nT_s)=v(nT_s)+\hat{x}(nT_s)=156$. After predicting, $\hat{x}(nT_s)=156$)}. Output of the comparator was 1 (i.e.157-156=1), given to the quantizer. Quantizer output was 1 and encoded by the encoder. During this time, the input to the predictor is 157. (Since $u(nT_s)=v(nT_s)+\hat{x}(nT_s)=1+156=157$, after predicting, $\hat{x}(nT_s)=157$. Consider the third input sample as 158, another input to the comparator was 157, therefore the output of the comparator was 1. (158-157=1). Now the output of the comparator 1 is quantized and encoded by the encoder. During this time, input to the predictor is 158. (since $u(nT_s)=v(nT_s)+\hat{x}(nT_s)=1+157=158$. After predicting, $\hat{x}(nT_s)=158$. This operation is repeated for all the sample inputs. Input and output samples are given in figure 2.

Sample values in PCM are encoded by the encoder, whereas, in DPCM, the difference between the two samples is encoded. Hence it is called differential pulse code modulation. In this way, redundant information's are removed in the original samples.



$_{\text{INPUT}} = 156, 157, 158, 158, 156, 156, 154, 154, 155$

$_{\text{INPUT TO ENCODER}} = 156, 1, 1, 0, -1, 0, -1, 0, 1$

Figure 2. DPCM Operation

Mathematical Analysis:

Prediction error $e_p(nT_s)$ is given by the expression,

$$e_p(nT_s)=x(nT_s)-\hat{x}(nT_s) \qquad (1)$$

where $\hat{x}(nT_s)$ is a predicted value of $x(nT_s)$ and $e_p(nT_s)$ is the prediction error of the n^{th} sample.

The output of the quantizer is given by the expression,

$$v(nT_s)=Q[e_p(nT_s)]=e_p(nT_s)+q(nT_s) \qquad (2)$$

where Q is the transfer characteristic of the quantizer and $q(nT_s)$ indicates the quantization error of the n^{th} sample arising as a result of the quantization operation.

Further, the input to the predictor is given by,

$$u(nT_s) = v(nT_s) + \hat{x}(nT_s) \qquad (3)$$

Sub. value of $v(nT_s)$ from eq. 2 to eq. 3,

$$u(nT_s) = v(nT_s) + \hat{x}(nT_s)$$

$$u(nT_s) = e_p(nT_s) + q(nT_s) + \hat{x}(nT_s) \qquad (4)$$

As we know from eq. (1)

$$e_p(nT_s) = x(nT_s) - \hat{x}(nT_s)$$

$$e_p(nT_s) + \hat{x}(nT_s) = x(nT_s)$$

Hence eq. 4 can modified into following format,

$$u(nT_s) = x(nT_s) + q(nT_s) \qquad (5)$$