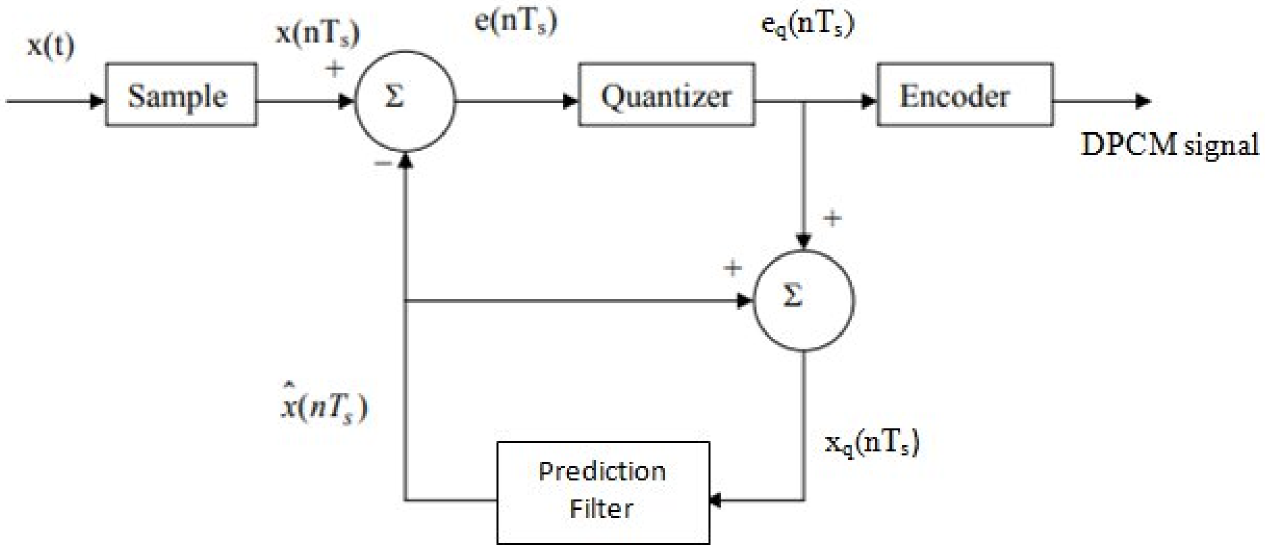
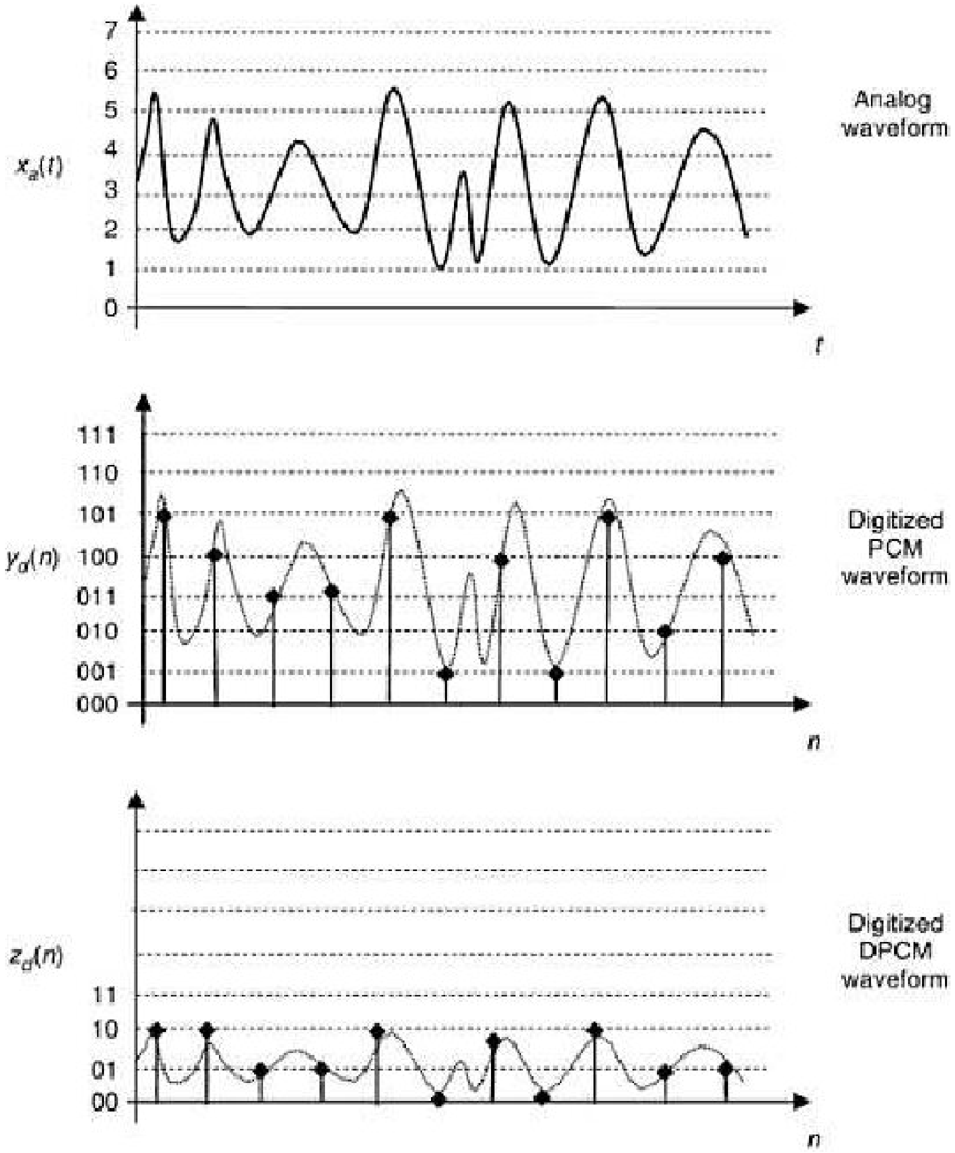
DPCM can be treated as a variation of PCM; it also involves the three basic steps of PCM, namely, sampling, quantization and coding. But, in the case of DPCM, what is quantized is the difference between the actual sample and its *predicted* value, as explained below.





X(nTs)	X'(nTs)	e(nTs)	eq(nTs)	Xq(nTs)
1.1	0	1.1	1	0+1=1
1.2	1	0.2	0	1+0=1
1.3	1	0.3	0	1+0=1
1.6	1	0.6	1	1+1=2

Differential Pulse Code Modulation (DPCM)

The sampled signal is denoted by $x(nT_s)$ and predicted signal is denoted by $x\hat{}(nT_s)$. The comparator finds out the difference between the actual sample value $x(nT_s)$ and predicted sample value $x\hat{}(nT_s)$. This is known as prediction error and it is denoted by $e(nT_s)$. The predicted value is produced by using a prediction filter. It can be defined as ,

$$\mathbf{e(nT_s) = x(nT_s) - x\hat{}(nT_s)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)}$$

The quantizer output signal gap $e_q(nT_s)$ and previous prediction is added and given as input to the prediction filter. This signal is called $x_q(nT_s)$. This makes the prediction more and more close to the actual sampled signal. We can observe that the quantized error signal $e_q(nT_s)$ is very small and can be encoded by using small number of bits. Thus number of bits per sample are reduced in DPCM. The quantizer output can be written as ,

$$\mathbf{e_q(nT_s) = e(nT_s) + q(nT_s)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)}$$

Here, $q(nT_s)$ is the quantization error.

As shown in fig.2, the prediction filter input $x_q(nT_s)$ is obtained by sum $x\hat{}(nT_s)$ and quantizer output. i.e.,

$$\mathbf{x_q(nT_s) = x\hat{}(nT_s) + e_q(nT_s)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)}$$

Substituting the value of $e_q(nT_s)$ from eq.(2) in the above eq. (3) , we get,

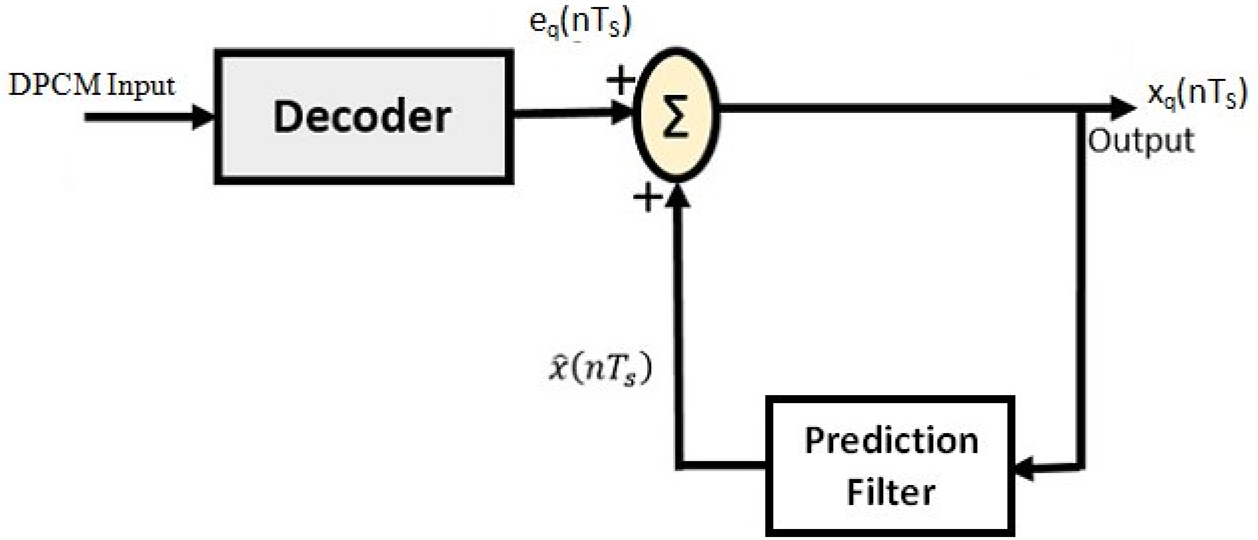
$$\mathbf{x_q(nT_s) = x\hat{}(nT_s) + e(nT_s) + q(nT_s)\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)}$$

eq.(1) is written as, $e(nT_s) = x(nT_s) - x\hat{}(nT_s)$ thus ∴ $e(nT_s) + x\hat{}(nT_s) = x(nT_s)$

Therefore, substituting the value of $e(nT_s) + x\hat{}(nT_s)$ from the above equation into eq. (4), we get,

$$\mathbf{x_q(nT_s) = x(nT_s) + q(nT_s)\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)}$$

The decoder first reconstructs the quantized error signal from incoming binary signal.
The prediction filter output and quantized error signals are summed up to give the quantized version of the original signal. Thus the signal at the receiver differs from actual signal by quantization error $q(nT_s)$, which is introduced permanently in the reconstructed signal.



Advantages of DPCM

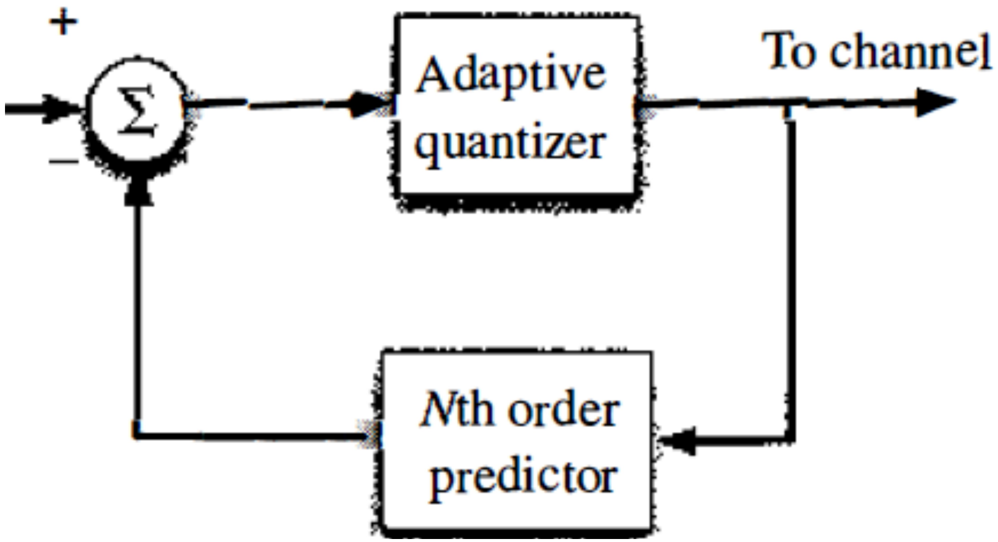
1. As the difference between x(nTs) and x^(nTs) is being encoded and transmitted by the DPCM technique, a small difference voltage is to be quantized and encoded.
2. This will require less number of quantization levels and hence less number of bits to represent them.
3. Thus signalling rate and bandwidth of a DPCM system will be less than that of PCM.

Example: For broadcast quality black and white pictures, DPCM with $M=8= 2^3$ gives acceptable video signal reproduction, where as PCM must have $M= 256=2^8$ levels thus DPCM reduces the transmission BW by a factor of 3/8.

Adaptive DPCM (ADPCM)

Adaptive differential pulse-code modulation (ADPCM) is a variant of differential pulse-code modulation (DPCM) that varies the size of the quantization step, to allow further reduction of the required data bandwidth for a given SNR.

ADPCM refers to DPCM coders that adapt **Δ** and/or the predictor. SNR can be increased in DPCM if step size **Δ** may change dynamically. The improvements in SNR are additive with the differential process and by adapting **Δ** to match the quantizer input.



Compared with DPCM, ADPCM can further compress the number of bits needed for a signal waveform. For example, it is very common in practice for an 8-bit PCM sequence to be encoded into a 4-bit ADPCM sequence at the same sampling rate. This easily represents a 2: 1 bandwidth or storage reduction with virtually no loss.

Difference between PCM and ADPCM

Difference between PCM and DPCM and ADPCM?

1. DPCM requires fewer levels for the quantization process as compared to the PCM (Pulse Code Modulation) process. ADPCM requires **fewer numbers of levels** as compared to both the DPCM and PCM. It means that ADPCM provides better bandwidth reduction than DPCM and PCM. The numbers of levels are directly proportional to the bandwidth. The fewer the levels, the lesser the bandwidth will be.

2. In ADPCM, difference between two consecutive samples is used to represent the signal, whereas sample values are directly used in PCM.

3. In PCM, the size of the interval between two samples is fixed, whereas it can be varied in ADPCM.

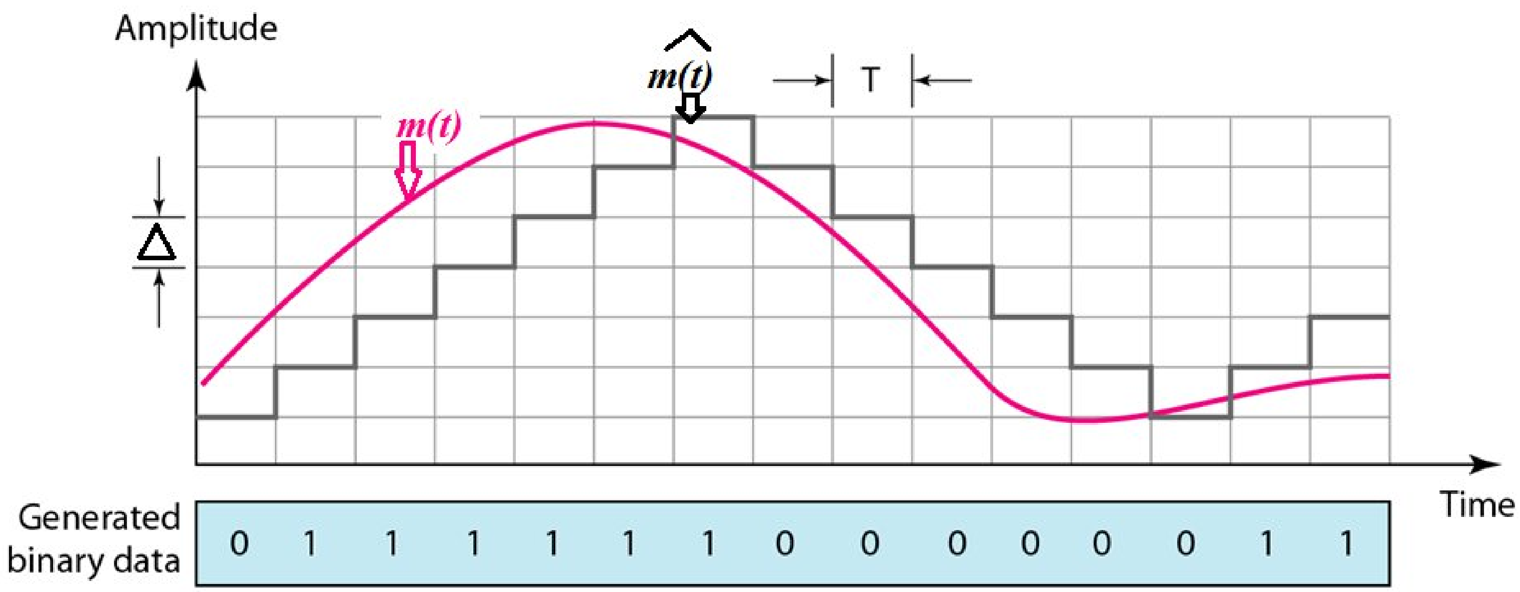
4. ADPCM needs a less amount of bits to represent a signal compared to PCM.

5. Decoding a PCM signal is easier than an ADPCM signal.

Delta Modulation (DM)

PCM is a very complex technique. Other techniques have been developed to reduce the complexity of PCM. The simplest is delta modulation (DM). PCM finds the value of the signal amplitude for each sample; Delta modulation (DM) finds the change from the previous sample.

Note that there are no code words here; bits are sent one after another. The main advantages of DM are simplicity and low cost.



compares the value of the analog signal with the last value of the staircase signal

The transmitted output is a binary stream of $\pm\Delta$ pulses at fs. It gives a stepwise approximation $\hat{m}(t)$ to $\boldsymbol{m(t)}$.

Modulator

The modulator is used at the sender site to create a stream of bits from an analog signal. The process records the small positive or negative changes, called ***delta Δ***. If the delta is positive, the process records a **1**; if it is negative, the process records a **0**. However, the process needs a base against which the analog signal is compared. The modulator builds a second signal that resembles a staircase

The present sample is compared with previous sample value and 1/0 is transmitted if it is greater/less than the previous sample value.

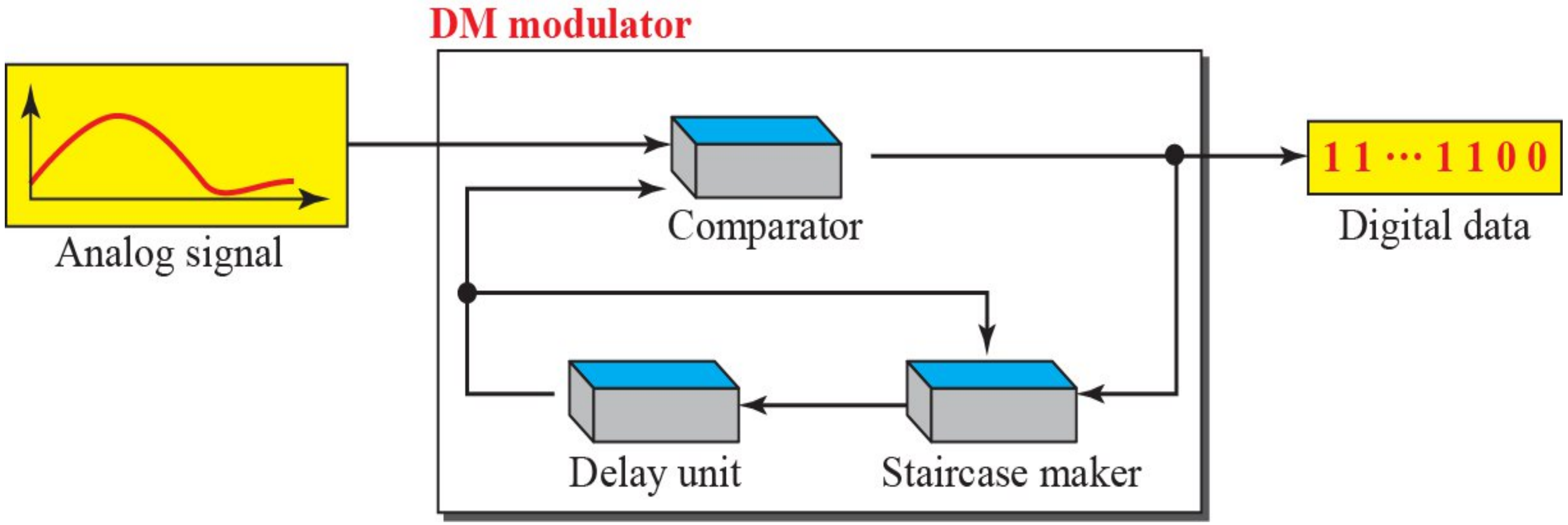
- Bandwidth requirement of DM is less on compared to PCM.
- DM needs simple circuity compared to PCM
- Quantization error is more.

The process of delta modulation

1. Find the change from the previous sample
2. Modulator - to record the positive or negative change, delta Δ
3. If Δ is positive, record a 1.
4. If Δ is negative, record a 0.
5. Need a base

Delta Modulation components

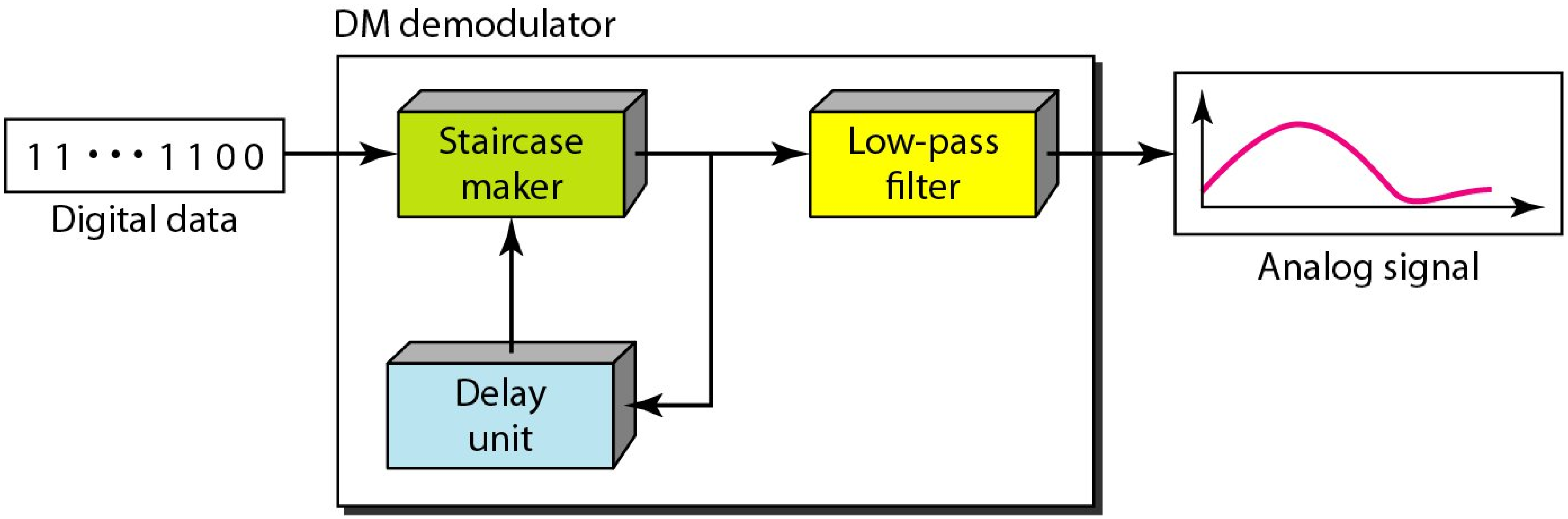
DM Characteristics:
◆ There are only two quantizing levels
◆ Only one bit is transmitted per sample.



The modulator, at each sampling interval, **compares the value of the analog signal with the last value of the staircase signal.** A single-bit PCM code to achieve digital transmission of analog.
Logic ‘0’ is transmitted if current sample is smaller than the previous sample.
Logic ‘1’ is transmitted if current sample is larger than the previous sample.
Note that we need a delay unit to hold the staircase function for a period between two comparisons.

Demodulator

The demodulator takes the digital data and, using the staircase maker and the delay unit, creates the analog signal. The created analog signal, however, needs to pass through a low-pass filter for smoothing. Figure below shows the schematic diagram



Delta Demodulation components

Delta modulation requires a **sampling rate much greater than the Nyquist rate** (commonly four or five times the Nyquist rate).