Differential Pulse Code Modulation (DPCM)

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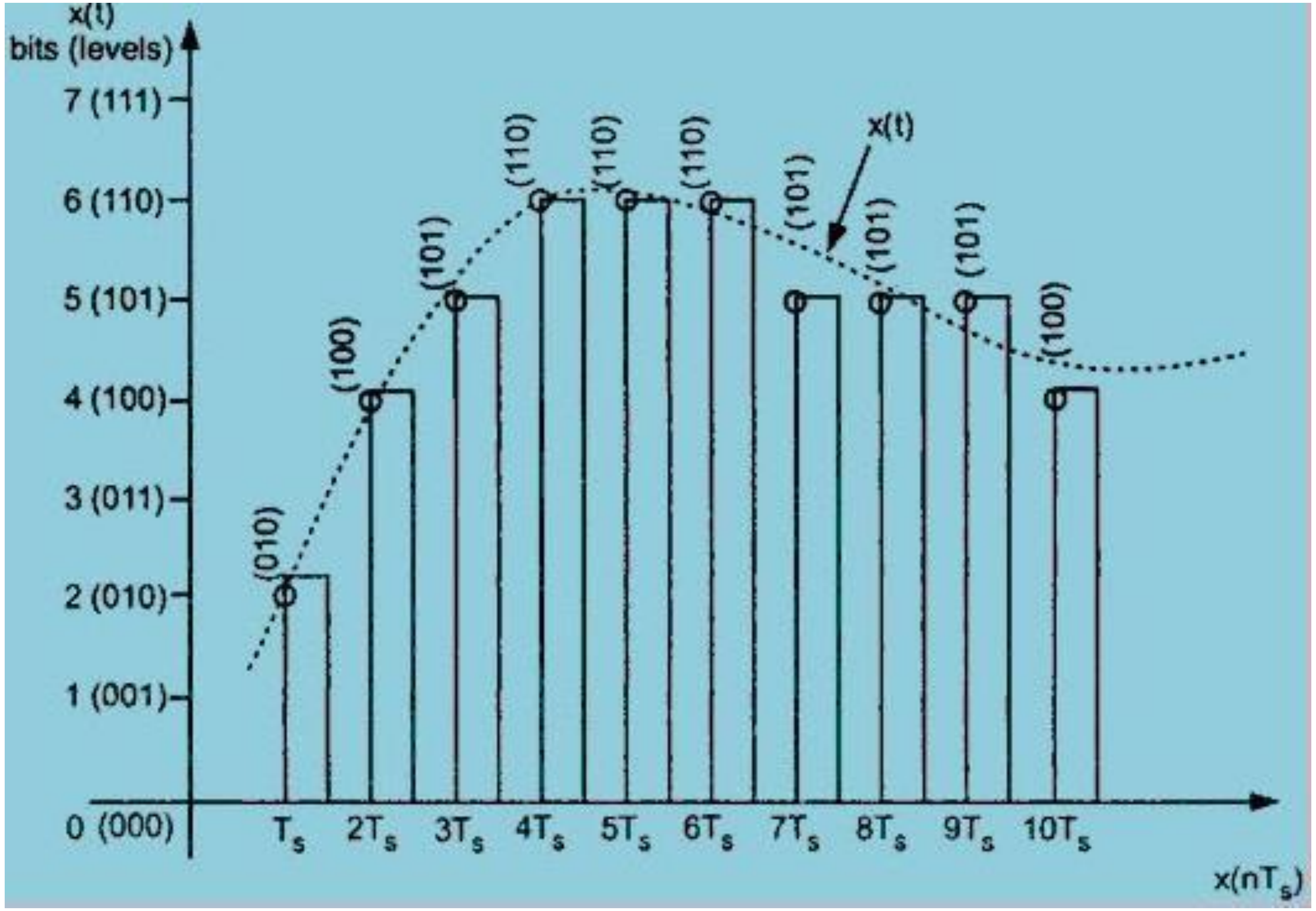
- It may be observed that the samples of a signal are highly correlated with each other.
- This is due to the fact that any signal does not change fast.
  - Which means, its value from present sample to next sample does not vary by a large amount.
- The adjacent samples of the signal carry the same information with a little difference.
- When these samples are encoded by a standard **PCM system**, the resulting encoded signal contains some redundant information.
- These effects can be seen in voice and video signals encoded with PCM system.

Differential Pulse Code Modulation (DPCM)

- **Redundant Information in PCM**



Differential Pulse Code Modulation (DPCM)

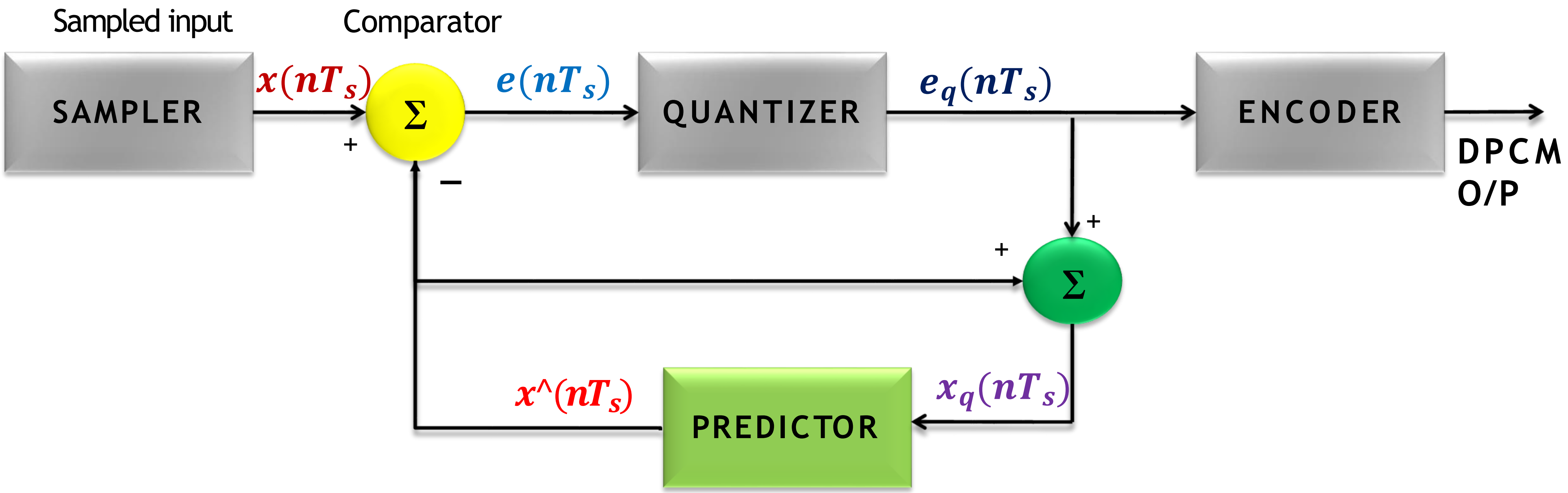
- To process this redundant information and to have a better output,
- DPCM quantizes the difference of the actual sample and predicted value.
- Such a process is called as **Differential Pulse Code Modulation (DPCM)**.

Working Principle

- The differential pulse code modulation works on the principle of prediction.
- The value of the present sample is predicted from the past samples.
- The prediction may not be exact but it is very close to the actual sample value.

Differential Pulse Code Modulation (DPCM)

Transmitter of D PCM system

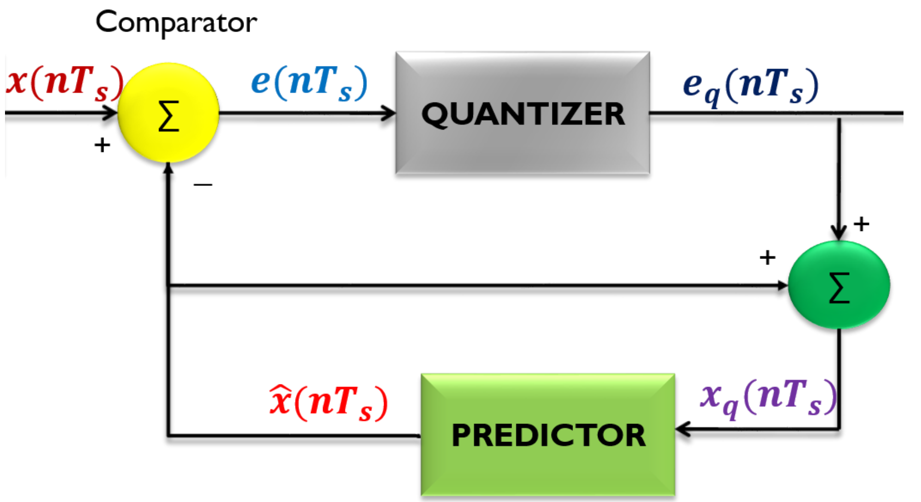


Differential Pulse Code Modulation (DPCM)

- 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 $\hat{x}(nT_s)$
- This is known as prediction error and it is denoted by $e(nT_s)$.
- It can be defined as ,

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

- The predicted value is produced by using a prediction filter.

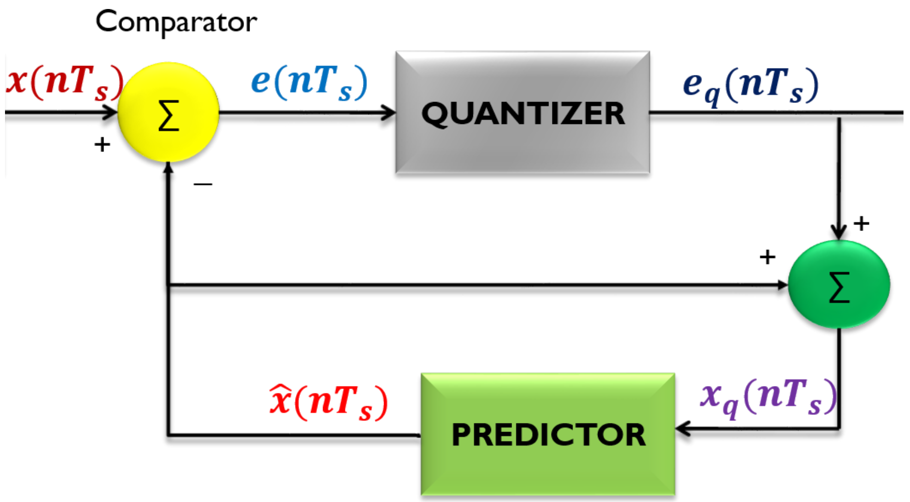


Differential Pulse Code Modulation (DPCM)

- 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 $x_q(nT_s)$.
- If prediction is well performed then the variance of $e(nT_s)$ will be much smaller than the variance of $x(nT_s)$
- Then it may lead to smaller levels of quantization of $e(nT_s)$ (using small number of bits).
- Thus number of bits per sample are reduced in DPCM.
- The quantizer output can be written as,

$$e_q(nT_s) = e(nT_s) + q(nT_s)$$

  - Where, $q(nT_s)$ is the quantization error



Differential Pulse Code Modulation (DPCM)

- The prediction filter input $x_q(nT_s)$ is obtained by sum of $\hat{x}(nT_s)$ and quantizer output. $e_q(nT_s)$ i.e.,

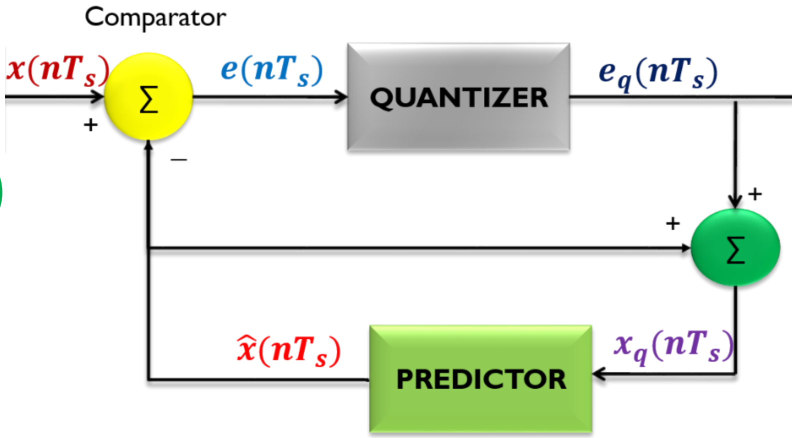
$$x_q(nT_s) = \hat{x}(nT_s) + e_q(nT_s)$$

- Substituting the value of $e_q(nT_s)$,

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

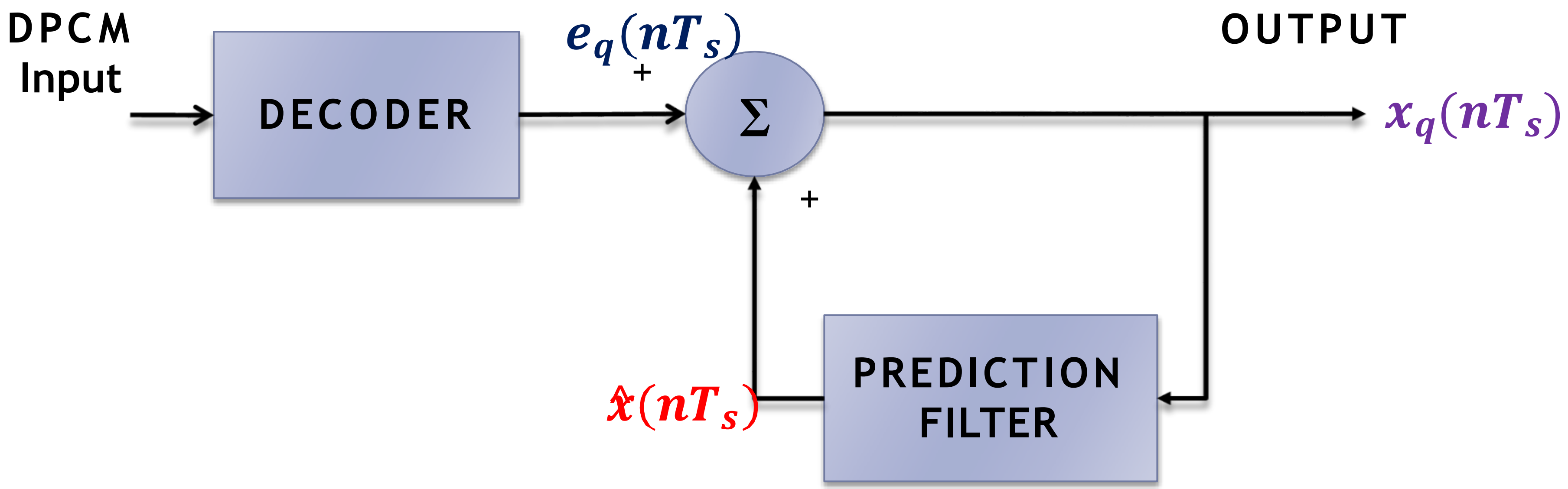
- We know that $e(nT_s) = x(nT_s) - \hat{x}(nT_s) \rightarrow x(nT_s) = e(nT_s) + \hat{x}(nT_s)$
- **Therefore,**

$$x_q(nT_s) = x(nT_s) + q(nT_s)$$



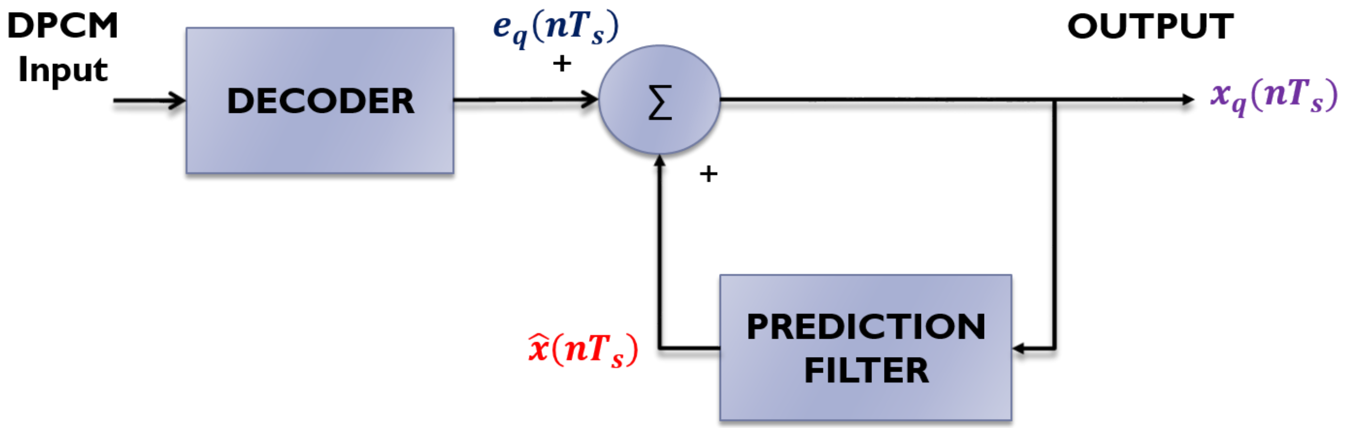
Differential Pulse Code Modulation (DPCM)

Receiver of D PCM system



Differential Pulse Code Modulation (DPCM)

- 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.



Differential Pulse Code Modulation (DPCM)

Advantages of DPCM

1. As the difference between $x(nT_s)$ and $\hat{x}(nT_s)$ 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 signaling rate and bandwidth of a DPCM system will be less than that of PCM.

Differential Pulse Code Modulation (DPCM)

SNR improvement in DPCM

- Consider a signal $x(t)$ of peak amplitude $\boldsymbol{x_p}$ applied to both PCM and DPCM systems.
- The signal power in both the systems are assumed to be same.
- The quantizer in the PCM system quantizes the signal $x(t)$
- The quantizer in the DPCM system quantizes the signal $e(t)$ with peak amplitude of $\boldsymbol{e_p}$
- If the number of levels 'L' in both the cases are same, then the step size in DPCM is reduced by the factor of $\frac{\boldsymbol{x_p}}{\boldsymbol{e_p}}$

Differential Pulse Code Modulation (DPCM)

- So the quantization noise error is reduced by the factor of $\left(\frac{x_p}{e_p}\right)^2$
- So the SNR of DPCM increases by the same factor over the SNR of PCM.
- Processing gain of DPCM is

$$G_p = \left(\frac{x_p}{e_p}\right)^2 = \frac{\overline{x^2}}{\overline{e^2}}$$

- The mean square error of prediction is

$$\overline{\left(x(nT_s) - \hat{x}(nT_s)\right)^2} = \overline{e^2(n)}$$

Differential Pulse Code Modulation (DPCM)

Slope Overload Noise in DPCM

- If the signal $x(t)$ changes so fast that the predicted signal $\hat{x}(t)$ cannot follow it, the system noise increases which is called slope overloading.

$$\left(\frac{d\hat{x}(t)}{dt}\right)_{max} = \pm f_s(N-1)\Delta$$

  - Where, N is the past number of samples.

- The slop overload can be prevented of the sampling frequency is chosen greater than the threshold value given below,

$$f_s \geq \frac{2\pi A_m f_m}{(N-1)\Delta}$$

Differential Pulse Code Modulation (DPCM)

- Using Mid riser quantizer, find the DPCM output for the given input sequence. (Assume first order prediction filter)

$$\{0, 0.3, 1.5, 0.7, 1, 2.3\}$$

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X(n)	X^(n)=Xq(n-1)	e(n)	eq(n)	Xq(n)

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X(n)	X^(n)=Xq(n-1)	e(n)	eq(n)	Xq(n)
0	0	0	0.5	0.5
0.3	0.5	-0.2	-0.5	0
1.5	0	1.5	1.5	1.5
0.7	1.5	-0.8	-0.5	1
1	1	0	0.5	1.5
2.3	1.5	0.8	0.5	2

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eq(n)	X^(n)=Xq(n-1)	Xq(n)
0.5	0	0.5
-0.5	0.5	0
1.5	0	1.5
-0.5	1.5	1
0.5	1	1.5
0.5	1.5	2

Differential Pulse Code Modulation (DPCM)

- Consider the input sample values {2.1,2.2,2.3,2.6,2.7,2.8}. Explain about the process of DPCM encoding and decoding . Assume first order prediction filter and Mid tread quantizer.

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X(n)	X^(n)=Xq(n-1)	e(n)	eq(n)	Xq(n)
2.1	0	2.1	2	2
2.2	2	0.2	0	2
2.3	2	0.3	0	2
2.6	2	0.6	1	3
2.7	3	-0.3	0	3
2.8	3	-0.2	0	3

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eq(n)	X^(n)=Xq(n-1)	Xq(n)
2	0	2
0	2	2
0	2	2
1	2	3
0	3	3
0	3	3