Baseband Digital System (5)

LC 3-7, 3-8, 6-8

Lecture 16, 2008-11-11

Contents

- Differential Pulse Code Modulation
- Delta Modulation
- Eye Pattern
- Matched Filter
- Results for White Noise

Differential Pulse Code Modulation

- When audio or video signals are sampled, it is usually found that adjacent samples are close to the same value. This means that there is a lot of redundancy in the signal samples and, consequently, that the bandwidth and the dynamic range of a PCM system are wasted. One way to minimize redundancy is to transmit PCM signals corresponding to the difference in adjacent sample values. This, crudely speaking, is differential pulse code modulation (DPCM).

- Moreover, the present value can be estimated from the past values by using a prediction filter. Such a filter can be realized by using a tapped delay line to form a transversal filter. When the tap gains are set so that the filter output will predict the present value from past values, the filter is said to be a linear prediction filter. The output samples are

$$z(nT_s) = \sum_{l=1}^{K} a_l y(nT_s - lT_s) \quad \text{or} \quad z(n) = \sum_{l=1}^{K} a_l y(n-l)$$

Linear Prediction Filter

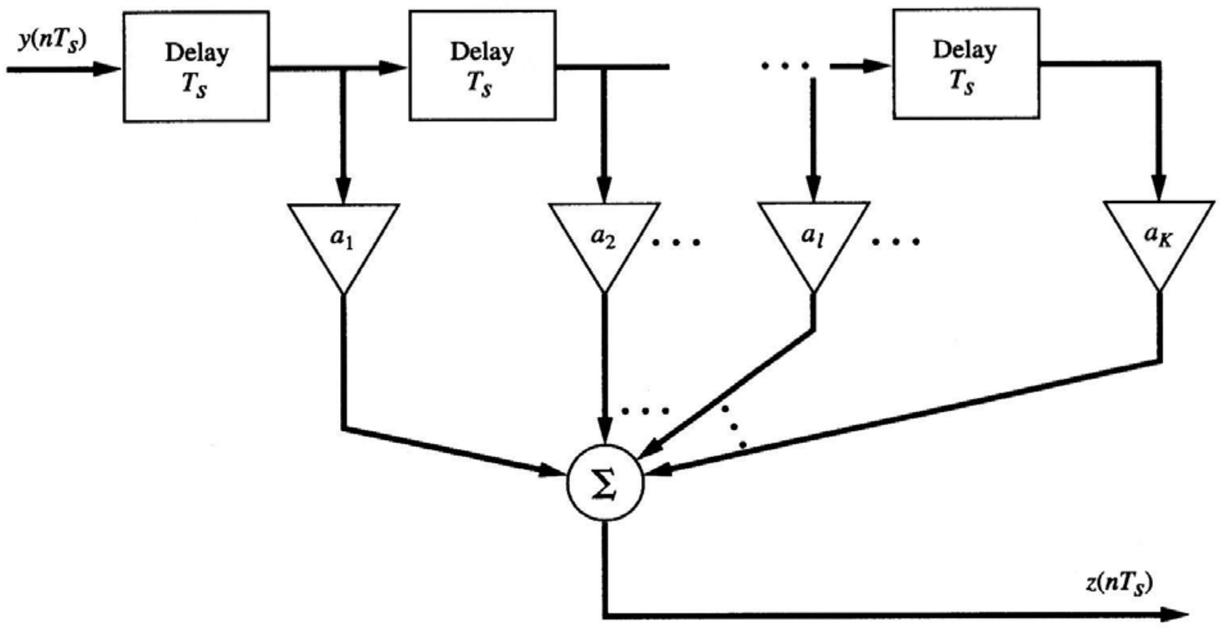


Figure 3–28 Transversal filter.

Using Prediction from Samples of Input Signal

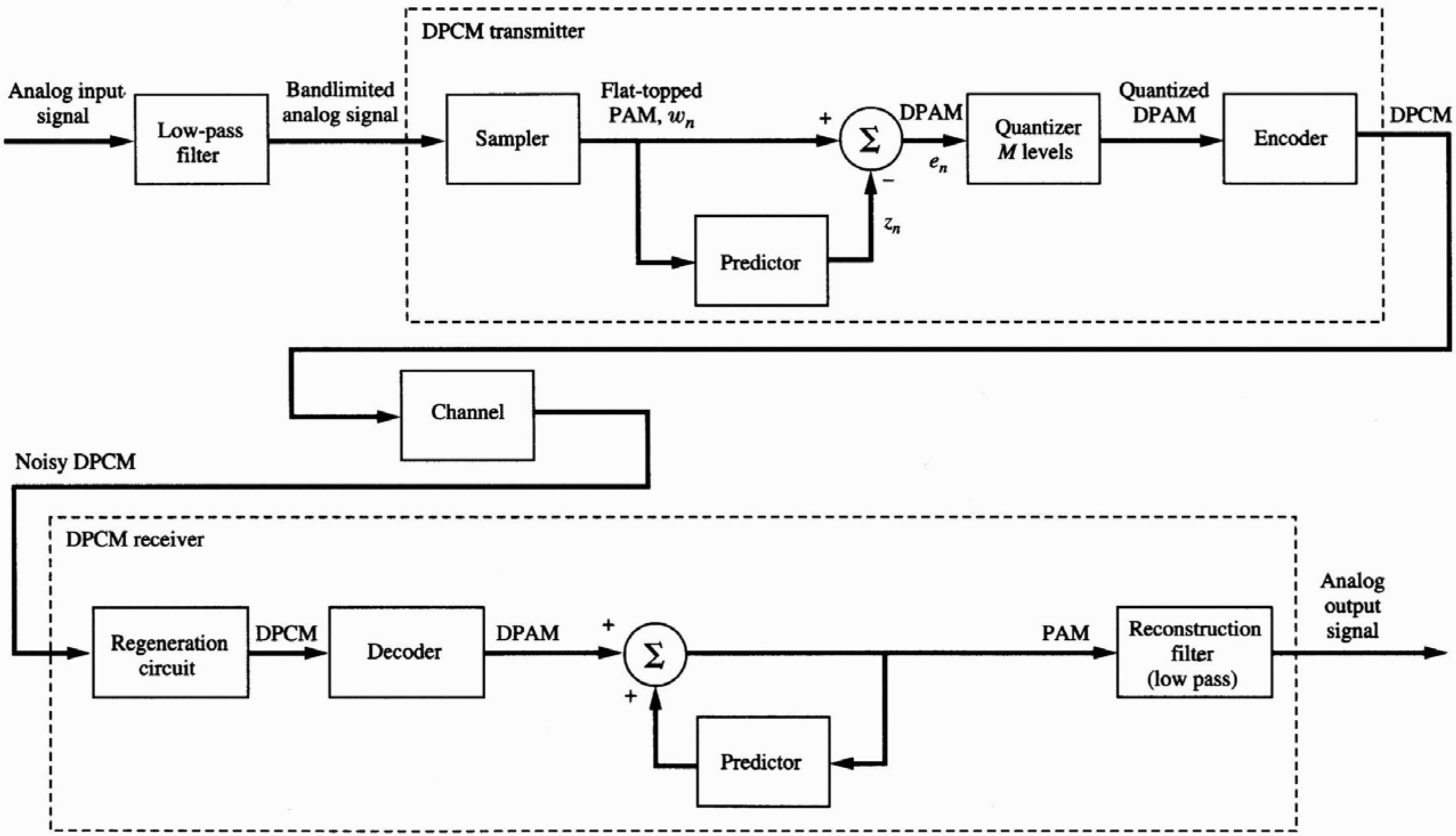


Figure 3–29 DPCM, using prediction from samples of input signal.

Using Prediction from Quantized Differential Signal

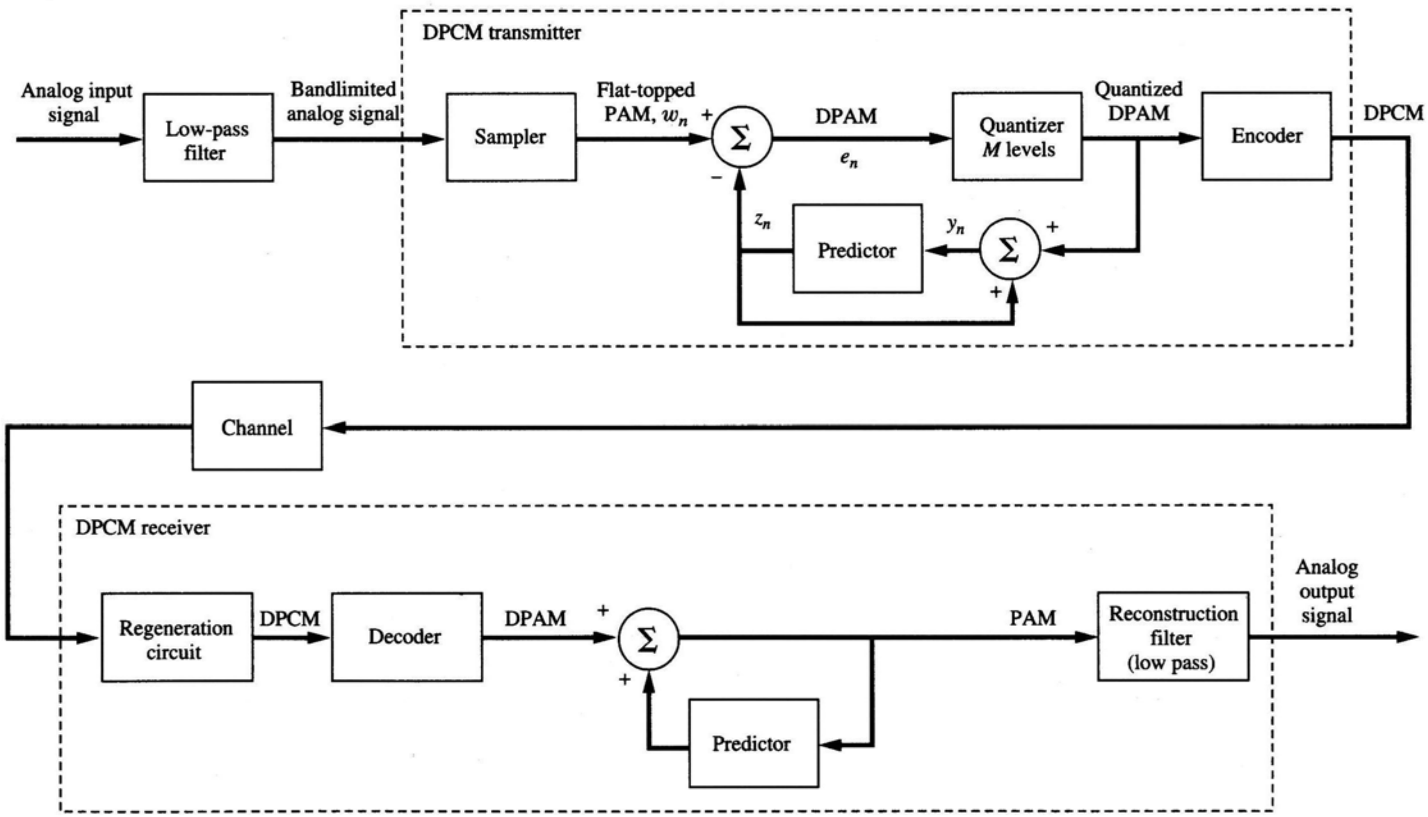
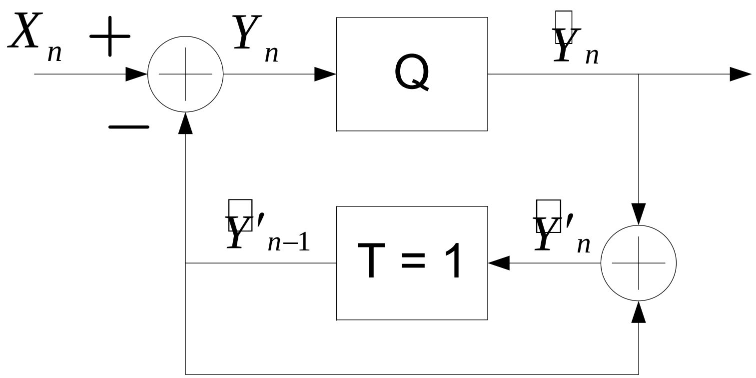
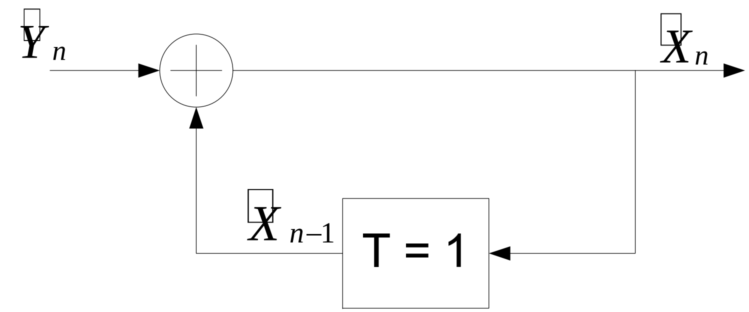


Figure 3–30 DPCM, using prediction from quantized differential signal.

A Simple DPCM System





$$Y_n = X_n - \hat{Y}'_{n-1}$$

$$\boxed{\hat{Y}'_n = \hat{Y}_n + \hat{Y}'_{n-1}}$$

$$\hat{Y}_n - Y_n = \hat{Y}_n - (X_n - \hat{Y}'_{n-1})$$

$$= \hat{Y}_n - X_n + \hat{Y}'_{n-1} = \hat{Y}'_n - X_n$$

$$\boxed{\hat{X}_n = \hat{Y}_n + \hat{X}_{n-1}}$$

$$\underline{\hat{Y}_n - Y_n = \hat{X}_n - X_n}$$

The range of variation of Y_n is usually much smaller than that of X_n and, therefore, Yn can be quantized with fewer bits.

- The DPCM, like PCM, follows the 6-dB rule

$$\left(\frac{S}{N}\right)_{dB} = 6.02n + \alpha$$

where

$$-3 < \alpha < 15 \quad \text{for DPCM speech}$$

For μ-law companded PCM with $\mu = 255$

$$\alpha \approx 4.77 - 20\log[\ln(1+\mu)] \approx -10.11\,\text{dB}$$

$$\text{SNR improvement} \approx 25\,\text{dB} \Leftrightarrow 25/6.02 \approx 4 \text{ fewer bits per sample}$$

- The CCITT (ITU-T) has adopted a 32-kbits/s DPCM standard that uses 4-bit quantization at 8-ksamples/s rate for encoding 3.2-kHz bandwidth VF signals.
- Moreover, a 64-kbits/s DPCM CCITT standard (4-bit quantization and 16k samples/s rate) has been adopted for encoding audio signals that have a 7-kHz bandwidth.

Delta modulation

- Delta modulation(DM) is a special case of DPCM in which there are two quantization levels

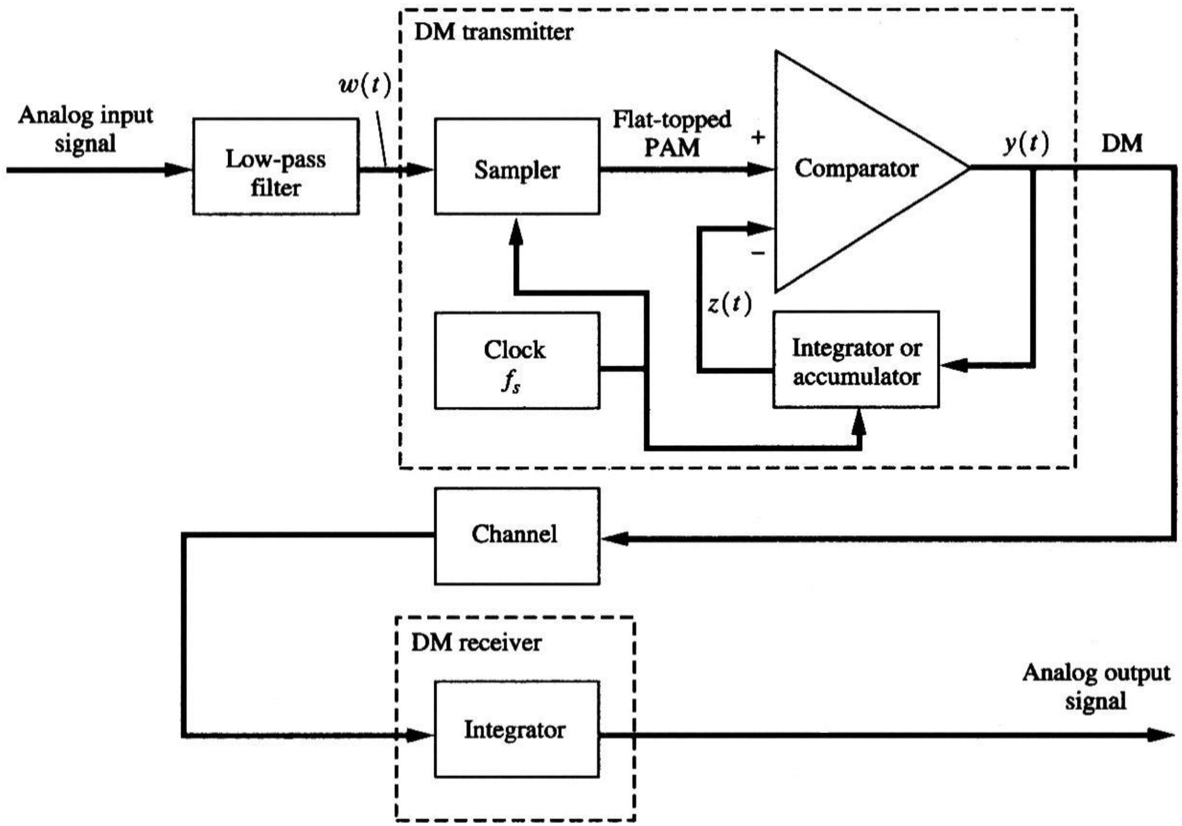
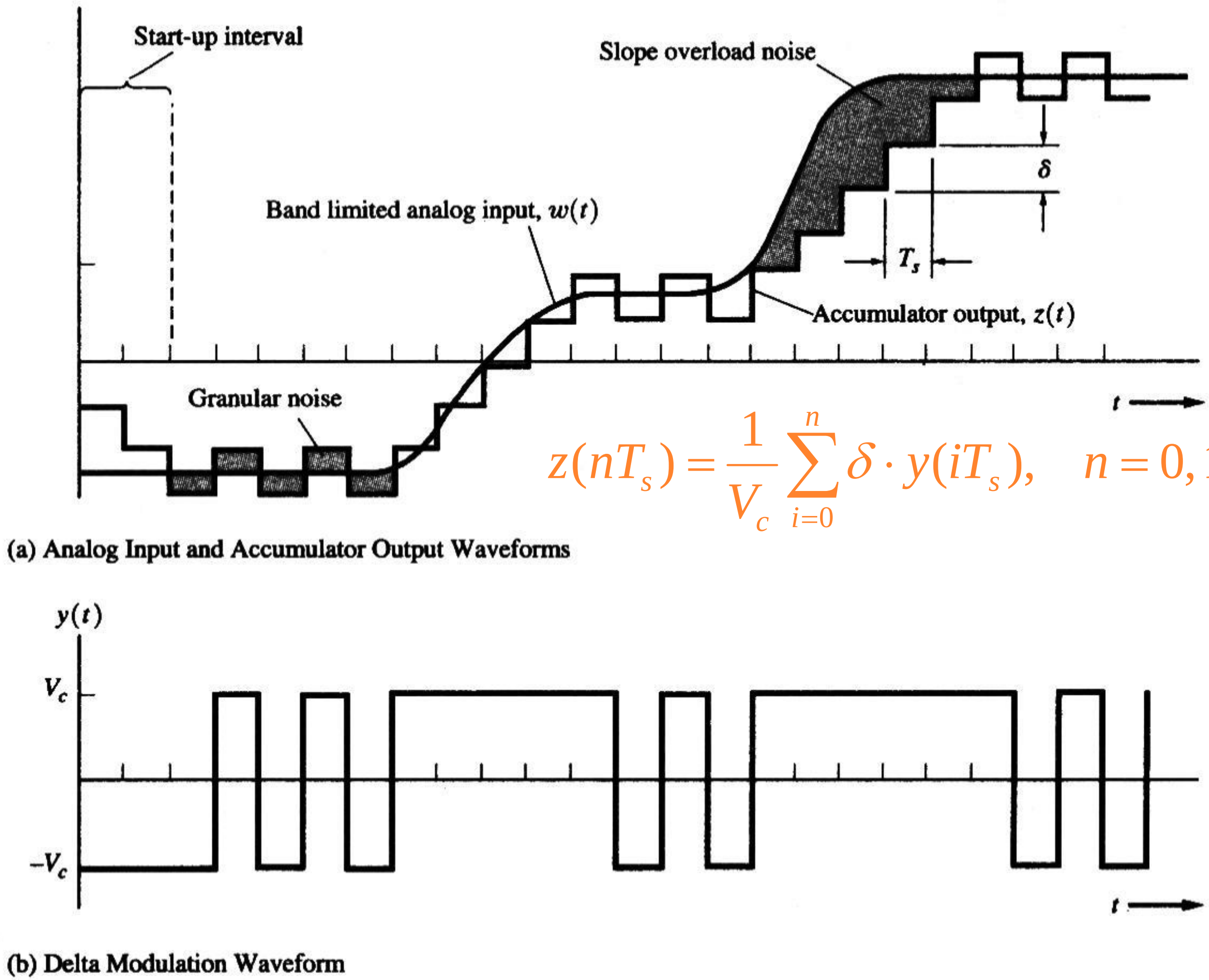


Figure 3–31 DM system.

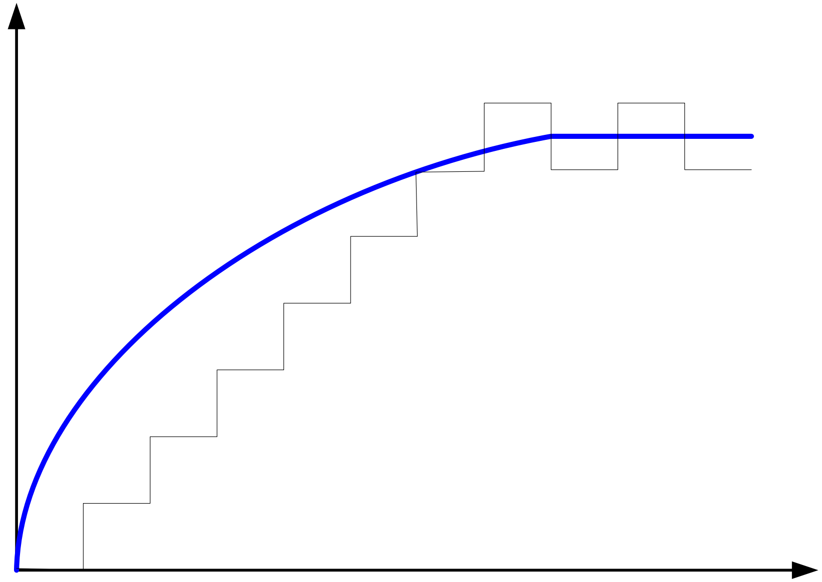
DM system waveforms



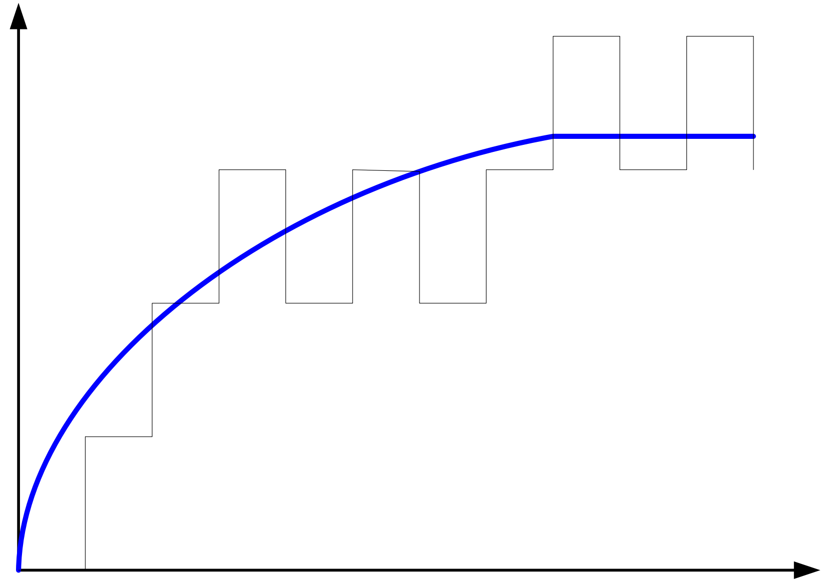
$$z(nT_s) = \frac{1}{V_c}\sum_{i=0}^{n} \delta \cdot y(iT_s), \quad n = 0, 1, \cdots$$

Figure 3–32 DM system waveforms.

Noise in DM (1)



Small delta and Slope overload noise



Large delta and granular noise

Noise in DM (2)

- Slope overload noise occurs when the step size is too small for the accumulator output to follow quick changes in the input waveform.
- Granular noise occurs for any step size, but is smaller for a small step size.

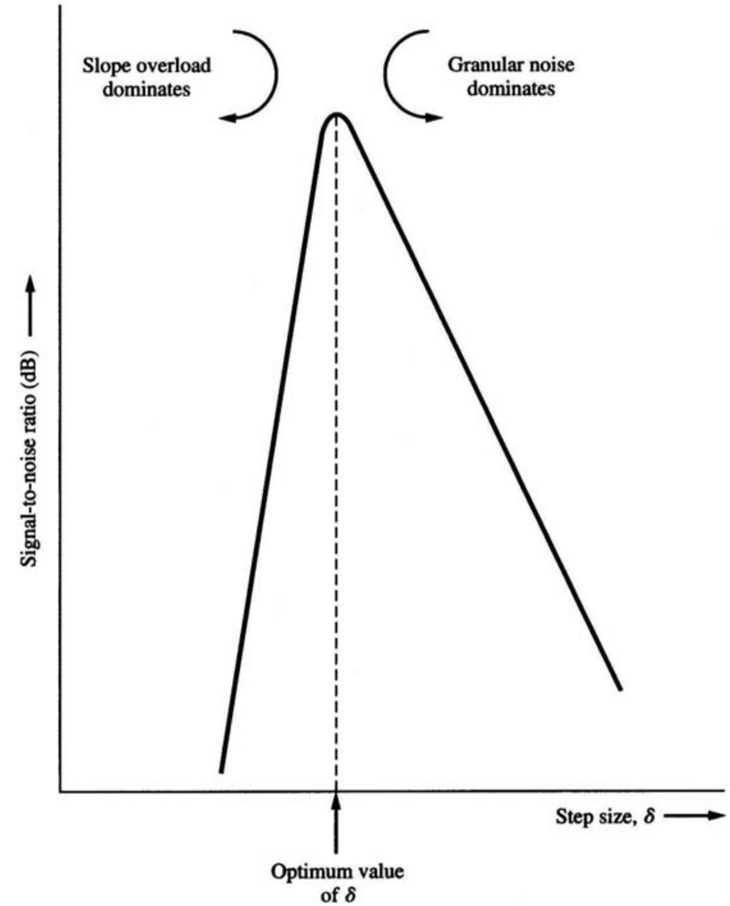


Figure 3–33 Signal-to-noise ratio out of a DM system as a function of step size.

SNR of DM (1)

- SNR out of a DM system with a sinusoid test signal

The granular noise is uniformly distributed over $|g| \le \delta$

$$P = < g^2 > = \overline{g^2} = \int_{-\delta}^{\delta} g^2 \frac{1}{2\delta} dg = \frac{\delta^2}{3}$$

The spectrum of the granular noise is uniformly distributed over $|f| \le f_s$

$$P_n(f) = \frac{P}{2 f_s} = \frac{\delta^2}{6 f_s}$$

The granular noise power in the analog signal band, $|f| < B$, is

$$N = < n^2 > = \int_{-B}^{B} P_n(f) df = \frac{B}{3 f_s} \delta^2 = \frac{B}{3 f_s} \left(\frac{2\pi f_a A}{f_s} \right)^2 = \frac{4\pi^2 A^2 f_a^2 B}{3 f_s^3}$$

$$\left(\frac{S}{N} \right)_{out} = \frac{< w^2(t) >}{N} = \frac{A^2 / 2}{N} = \frac{3}{8\pi^2} \frac{f_s^3}{f_a^2 B}$$

SNR of DM (2)

- SNR out of a DM system with a VF signal

The granular noise is uniformly distributed over $|g| \le \delta$

$$P = \langle g^2 \rangle = \overline{g^2} = \int_{-\delta}^{\delta} g^2 \frac{1}{2\delta} dg = \frac{\delta^2}{3}$$

The spectrum of the granular noise is uniformly distributed over $|f| \le f_s$

$$P_n(f) = \frac{P}{2f_s} = \frac{\delta^2}{6f_s}$$

The granular noise power in the analog signal band, $|f| < B$, is

$$N = \langle n^2 \rangle = \int_{-B}^{B} P_n(f)df = \frac{B}{3f_s}\delta^2 = \frac{B}{3f_s}\left(\frac{2\pi 800 W_p}{f_s}\right)^2 = \frac{(1600\pi)^2 W_p^2 B}{3f_s^3}$$

$$\left(\frac{S}{N}\right)_{out} = \frac{\langle w^2(t) \rangle}{N} = \frac{3f_s^3}{(1600\pi)^2 B}\frac{\langle w^2(t) \rangle}{W_p^2}$$

Example

$$\left(\frac{S}{N}\right)_{out\ dB} = 30\text{ dB},\ B = 4\text{ kHz},\ \frac{<w^2(t)>}{W_p^2} = \frac{1}{2}$$

$$\left(\frac{S}{N}\right)_{out} = 10^{\frac{30}{10}} = 1000 = \frac{3f_s^3}{(1600\pi)^2 B}\frac{<w^2(t)>}{W_p^2} = \frac{3f_s^3}{(1600\pi)^2 4000}\frac{1}{2}$$

$$f_s = \sqrt[3]{(1600\pi)^2 \cdot 4000 \cdot 2 \cdot 1000/3} \approx 40691\text{ Hz} \approx 10.2B$$

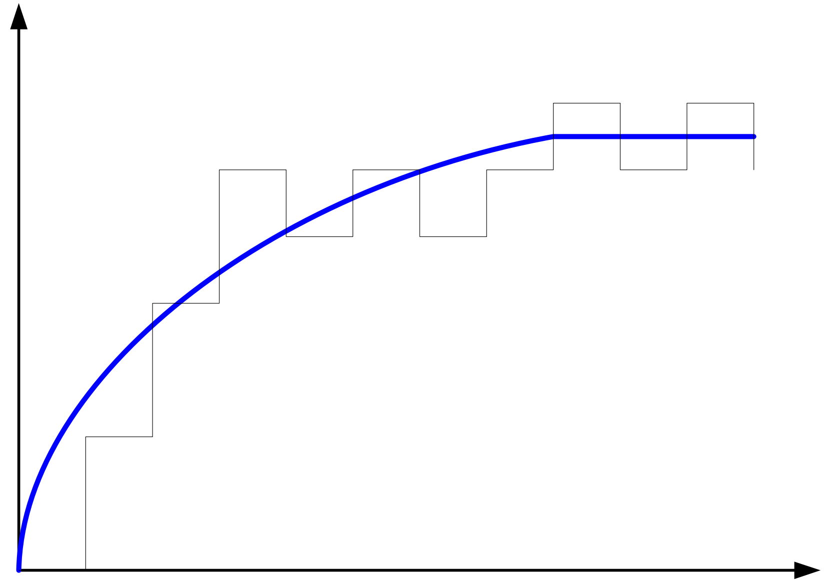
Compare this DM system with a PCM system that has the same bandwidth (i.e., bit rate)

$$R = n(2B) \Rightarrow n = \frac{R}{2B} \approx \frac{10.2B}{2B} \approx 5\text{ bits} \Rightarrow SNR \approx 6.02n \approx 30.1\text{dB}$$

- If an SNR larger than 30 dB were desired, the PCM system would have a larger SNR than that of the DM system of the same bandwidth; If an SNR less than 30 dB were sufficient, the DM system would have a larger SNR than that of the PCM system of the same bandwidth.

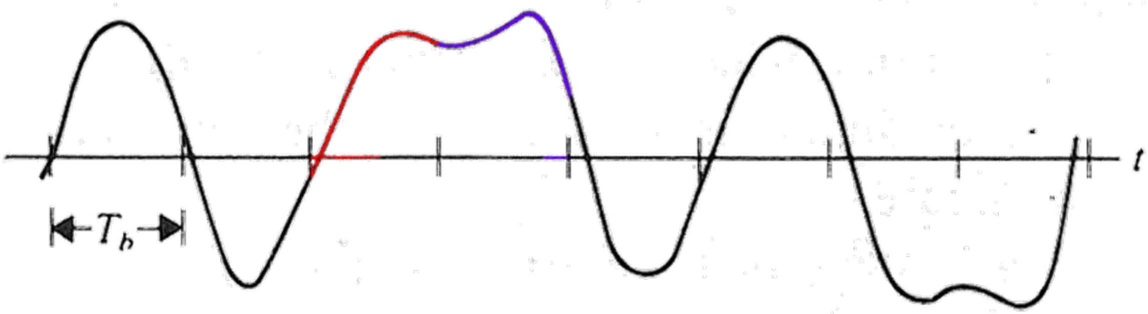
Adaptive DM

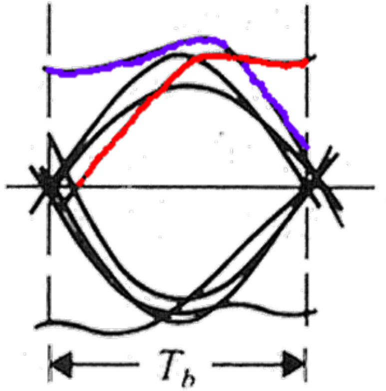
- Change the step size according to changes in the input.



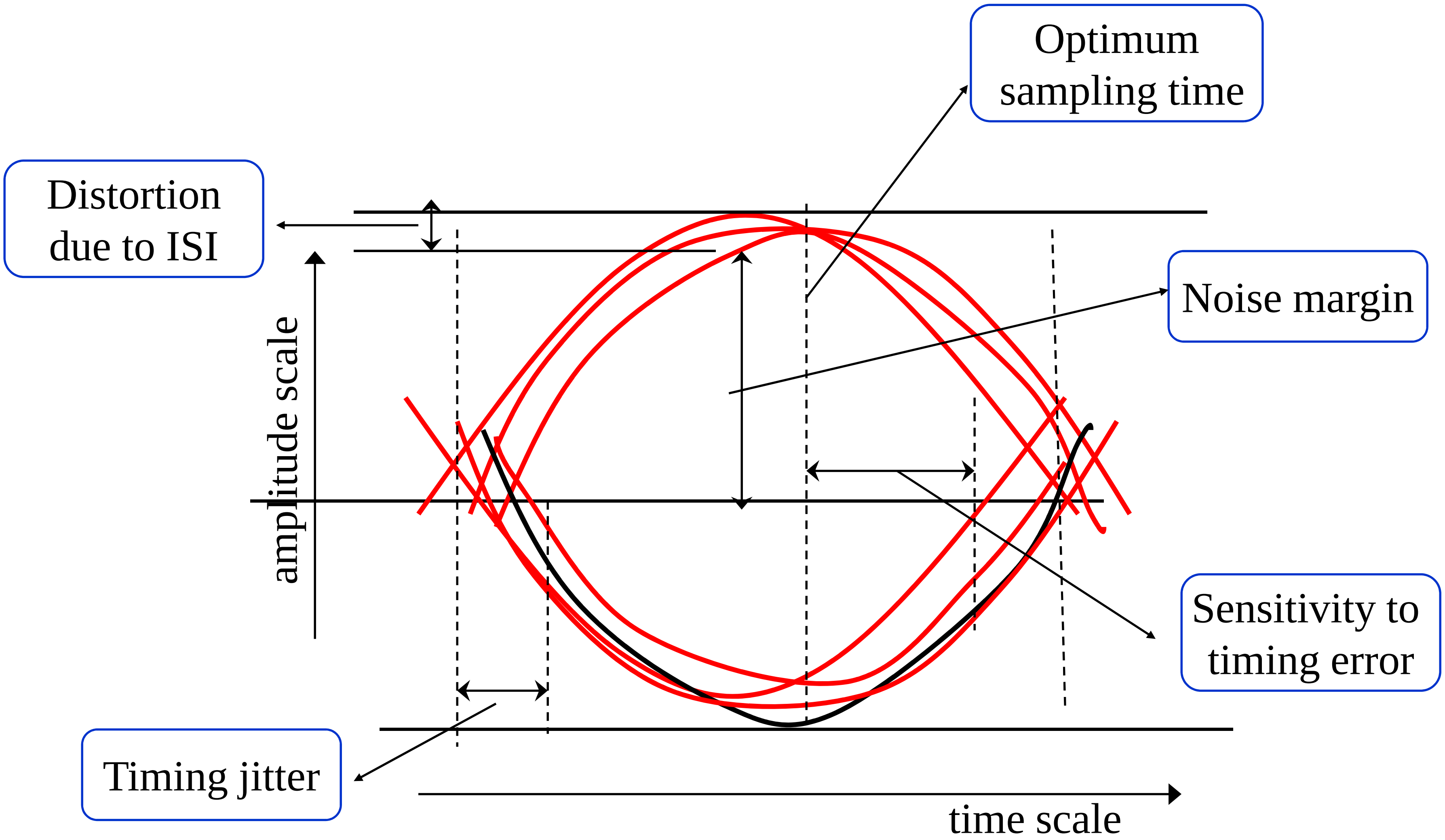
Eye Pattern

- Display on an oscilloscope which sweeps the system response to a baseband signal at the rate $1/T_b$ (T_b symbol duration) , Plot the received signal periodically (with progress step T_b) on the same time scale





Characterization of System Quality



Measurement

- Eye-open: small ISI, low error rate, reliable
- Eye-closed: large ISI, high error rate, unreliable