II.A Baseband Transmission (Definitions & Modulation types)

Pulse Amplitude Modulation (PAM)
- Natural sampled PAM
- Instantaneous sampled PAM
- Time division multiplexing (TDM)
- Intersymbol interference (ISI)

Pulse Width Modulation (PWM)

Pulse Position Modulation (PPM)

Pulse Code Modulation (PCM)
- Definition
- Quantization noise issues
- Signal-to-Quantization Noise ratio (SNR_q)
- Nonlinear quantization
- Pre-emphasis & de-emphasis
- Application to speech signal type
- μ-law & A-law quantization for speech types
- TDM for digital signals

Delta modulation

Adaptive Delta modulation

Receivers
- PAM, PPM, PWM receivers

Digital Baseband

Signal format & power spectrum concepts

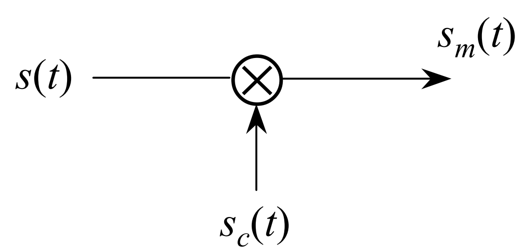
Potential problems with NRZ transmissions

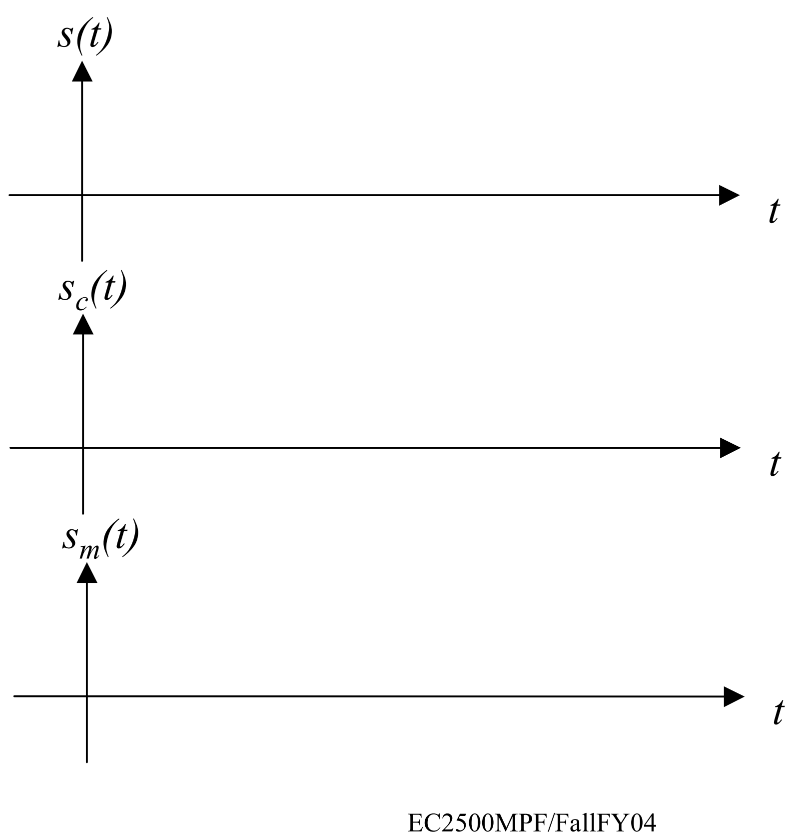
II. Baseband Transmission

- Goal: Investigate information transmission using low frequencies

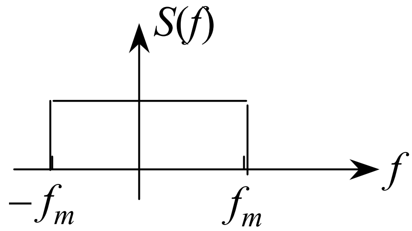
1) Pulse Amplitude Modulation (PAM)

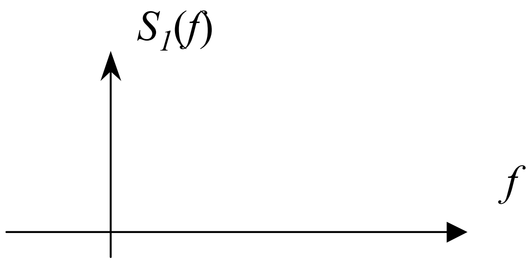
- <u>Natural-sampled PAM</u>

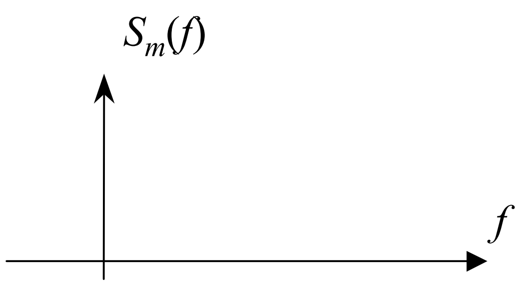




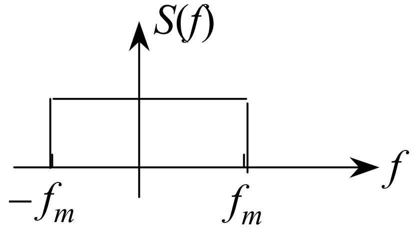
• <u>Natural Sampled PAM from the frequency side</u>

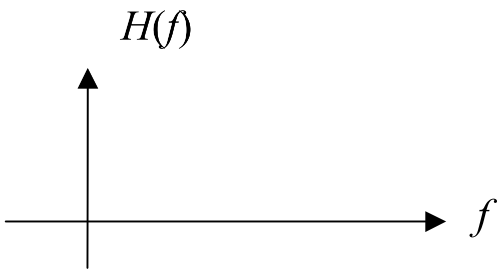


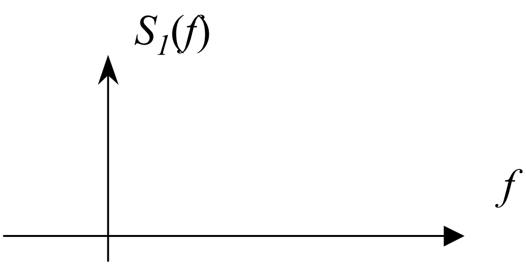




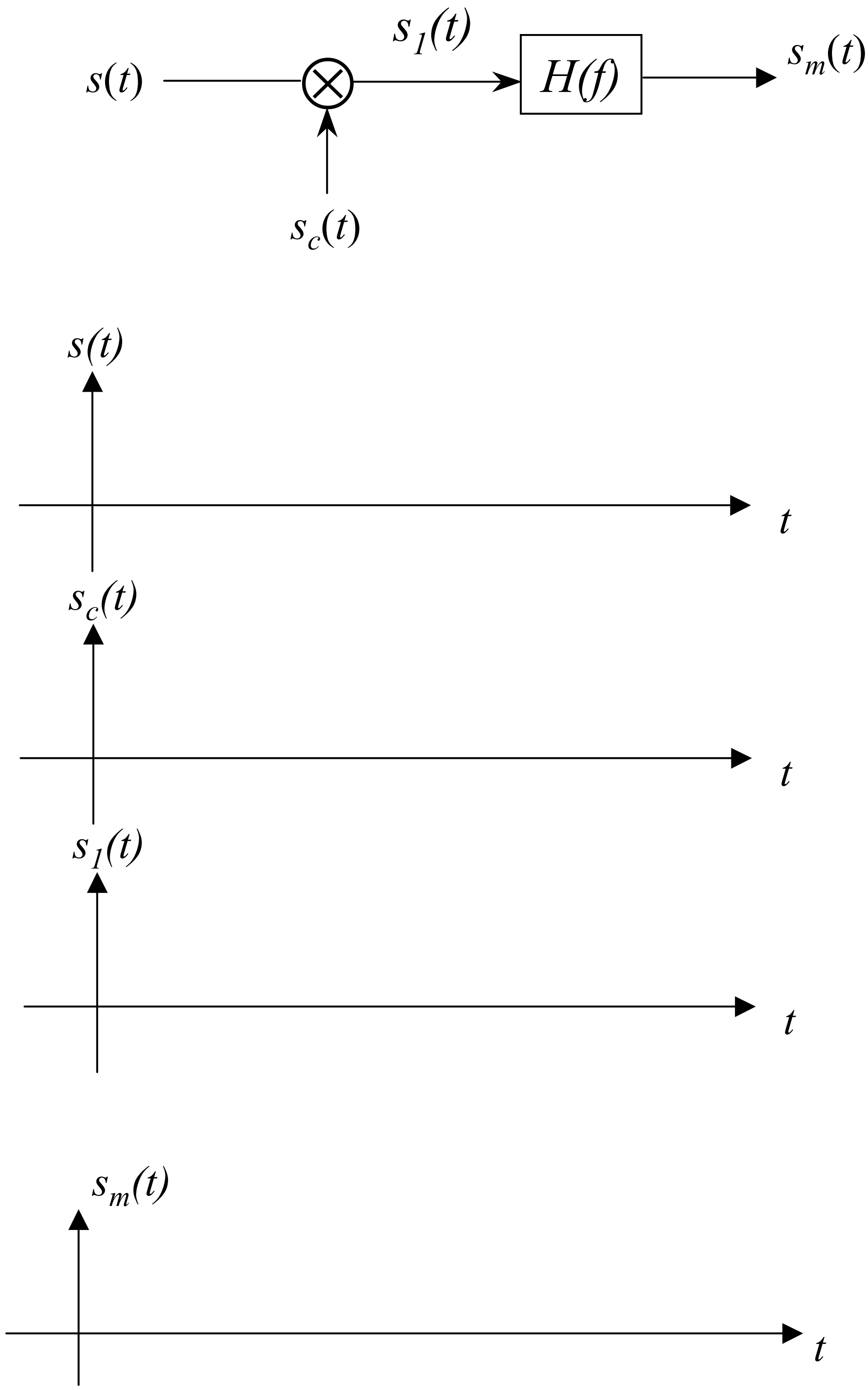
• <u>Natural Sampled PAM from the frequency side</u>



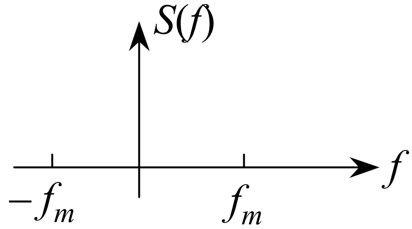


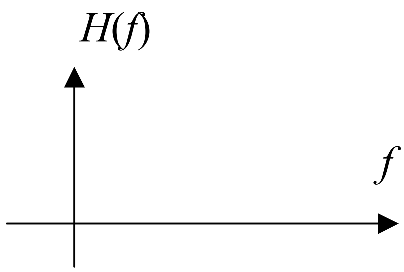


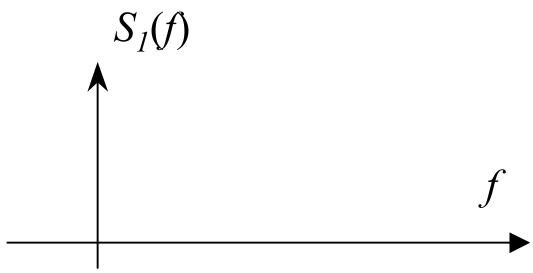
• Instantaneous-sampled PAM

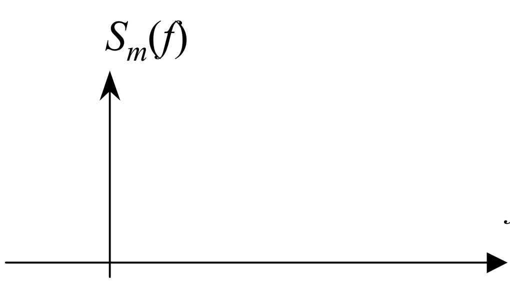


• <u>Instantaneous Sampled PAM from the frequency side</u>



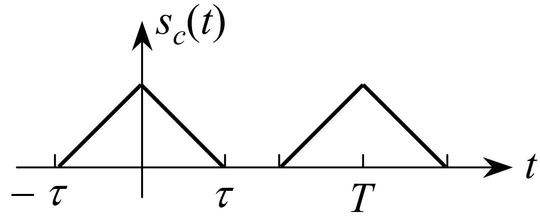


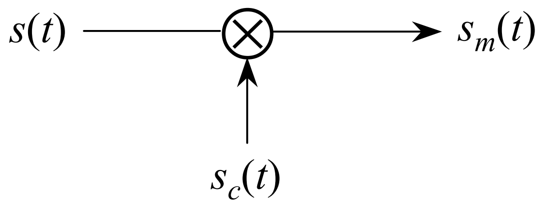




- Example

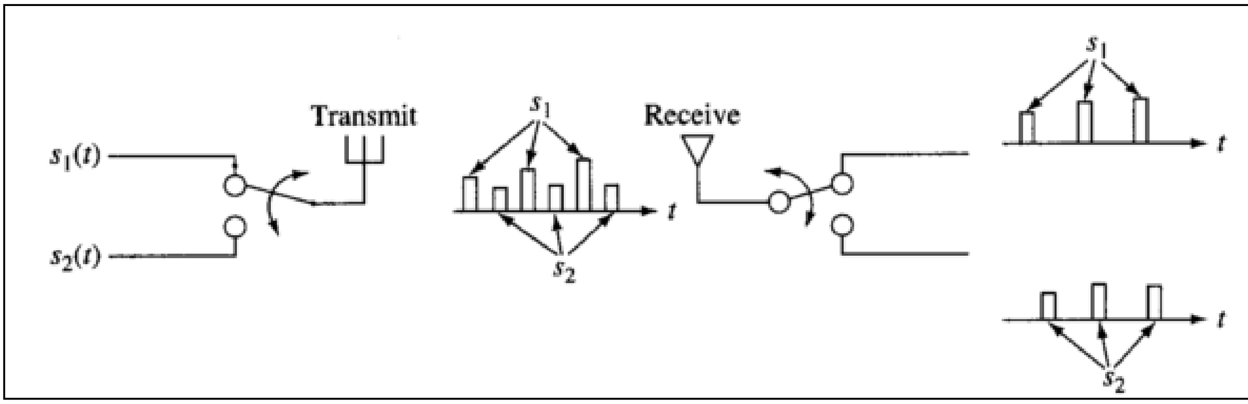
$$s(t) = \frac{\sin \pi t}{\pi t}$$



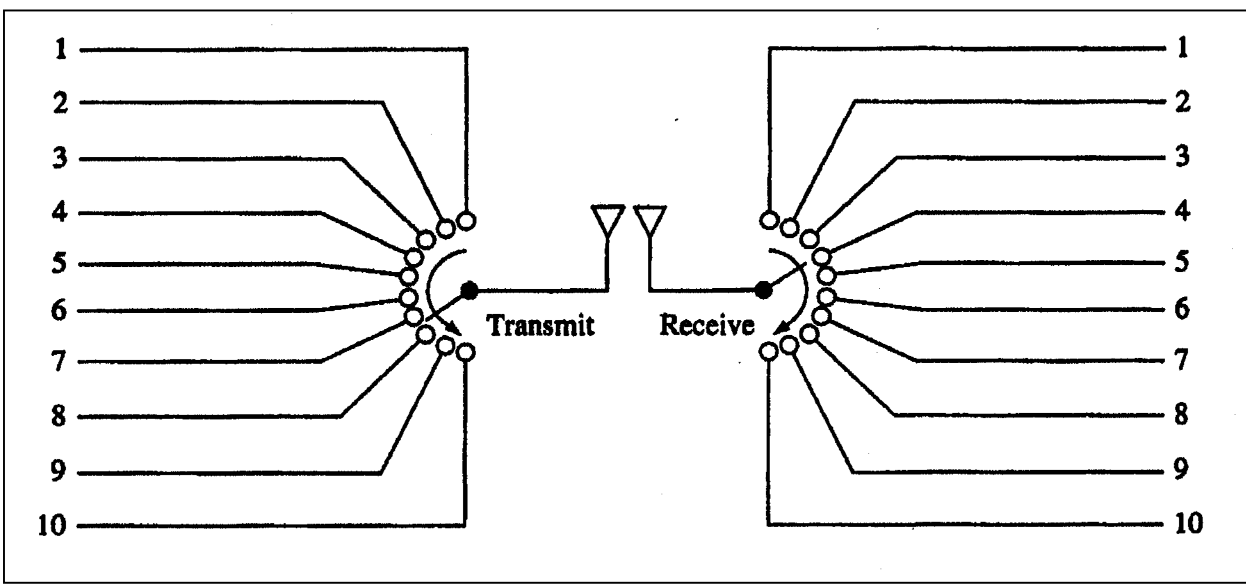


Compute the Fourier transform for $s_m(t)$

2) Time Division Multiplexing (TDM)



Multiplexing of 2 channels



Multiplexing of 10 channels

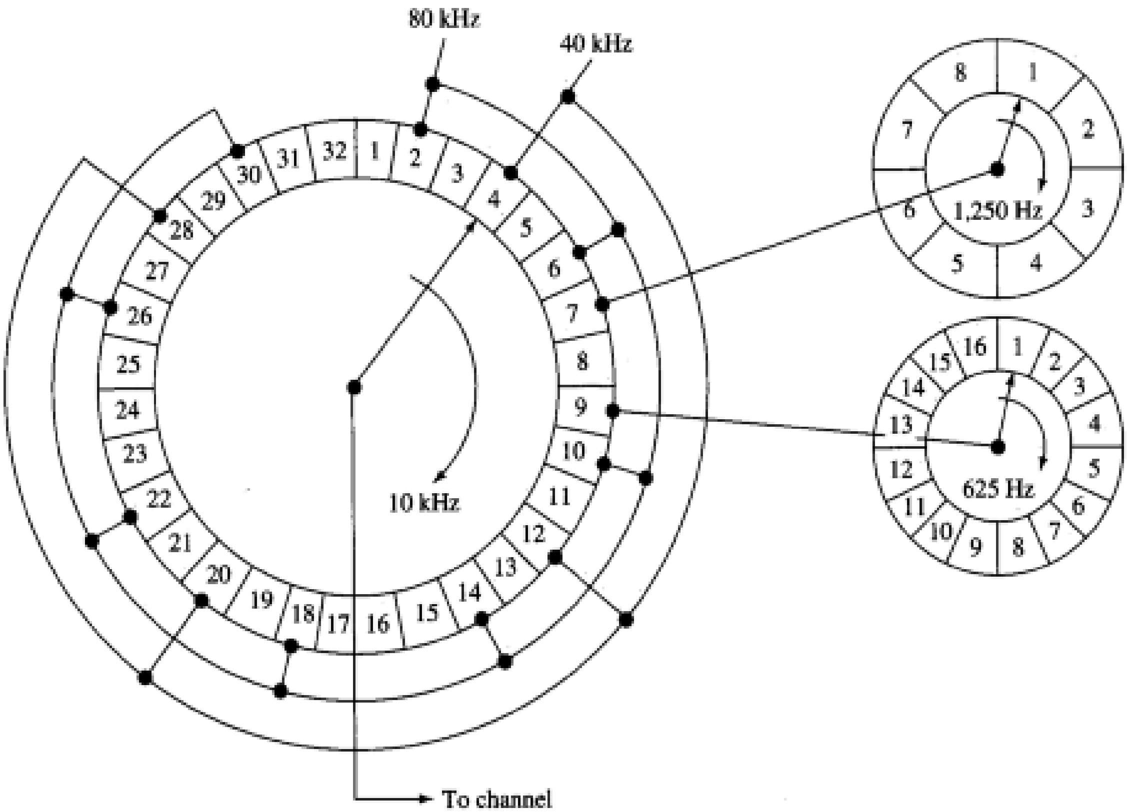


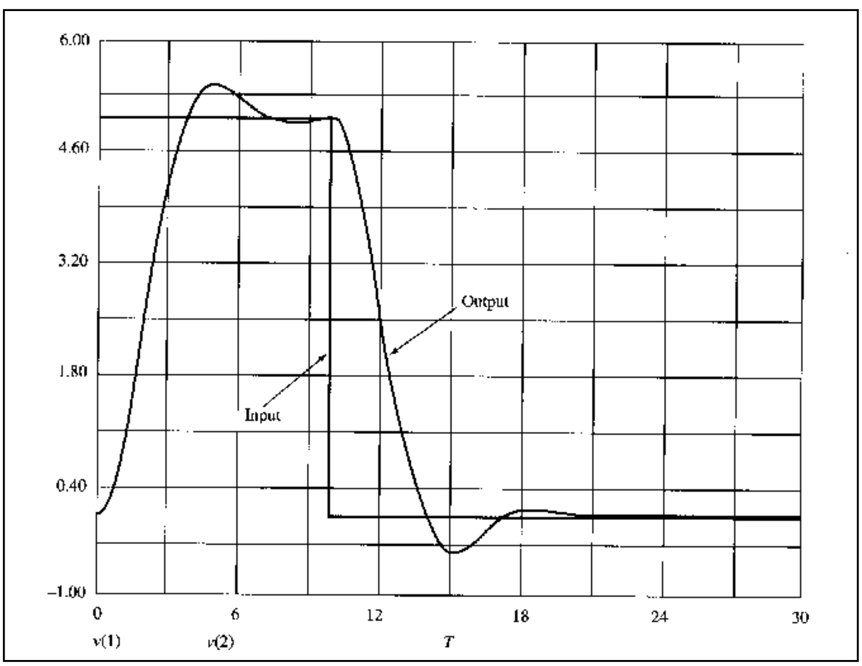
Figure 2.14 - Sub- and Super-Commutation

3) Intersymbol Interference (ISI)

- What is it ?

Interaction between multiple poles due to transmission channel distortions.

- <u>Overlap of signals into adjacent time slots</u>



Pulse through LPF

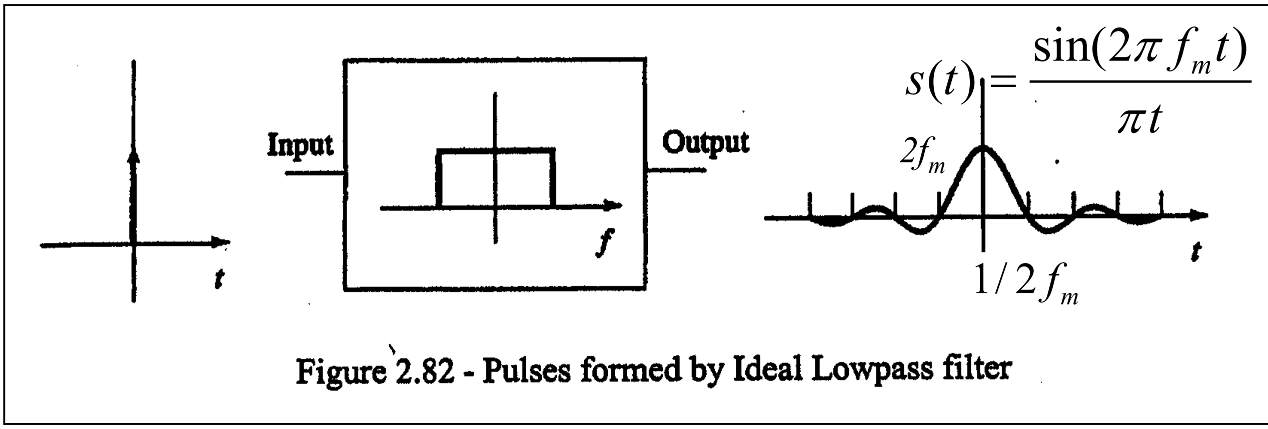
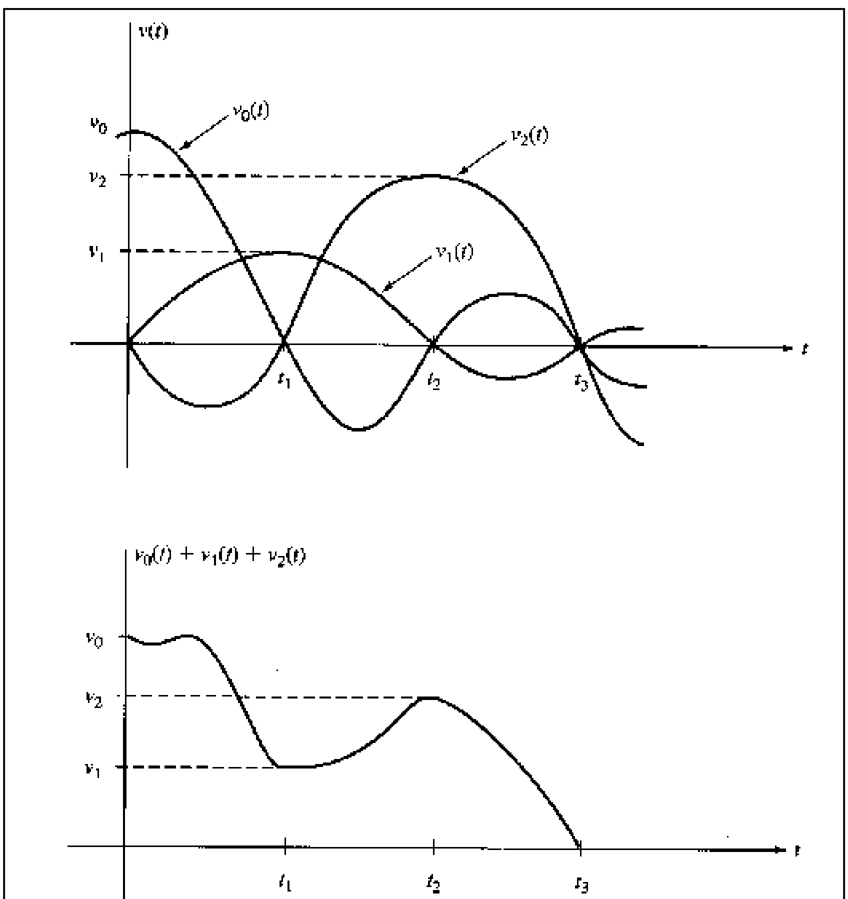


Figure 2.82 - Pulses formed by Ideal Lowpass filter

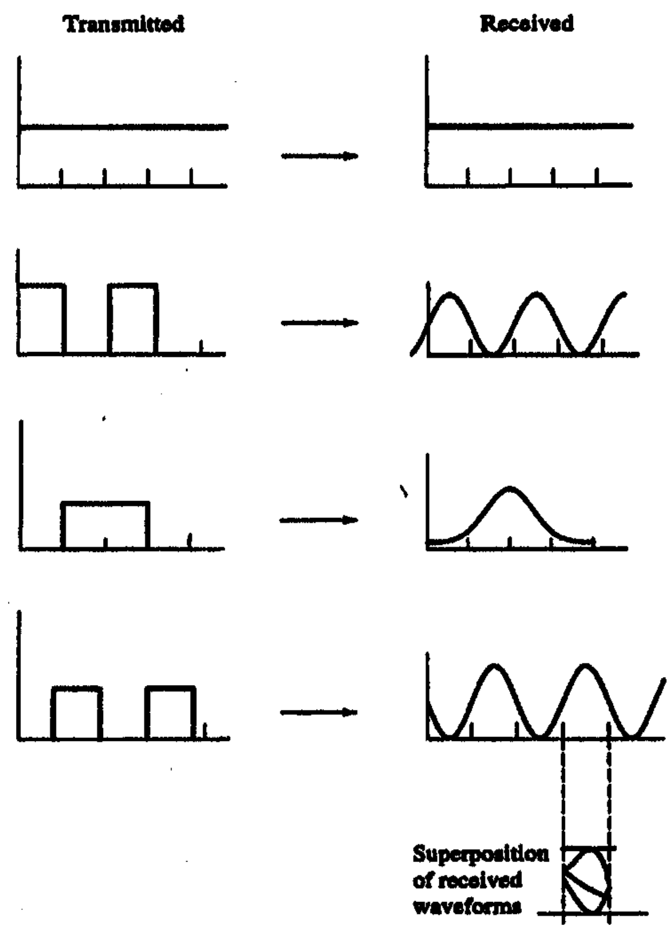
Pulse shaping by the Channel



Ideal LPF Shaping

- How is ISI evaluated ?

    =>Through eye pattern generation.



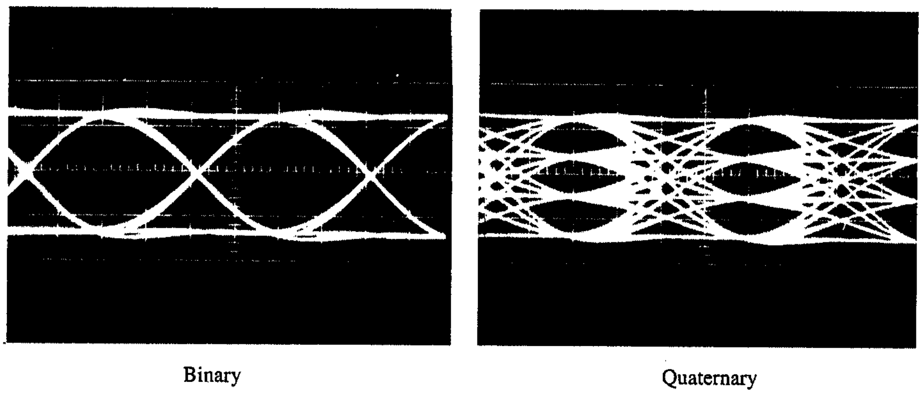


Figure 6.15 Examples of eye patterns for binary and quaternary amplitude shift keying (or PAM)

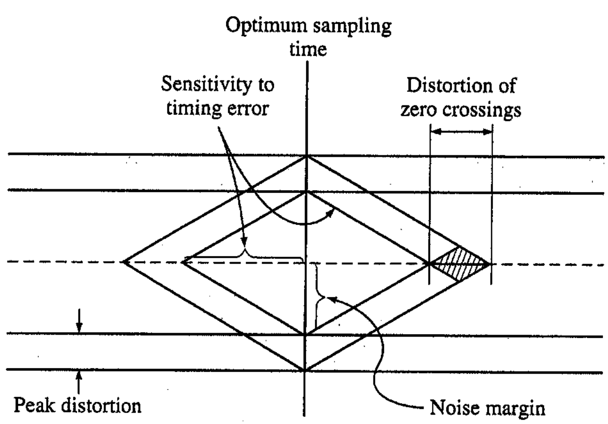


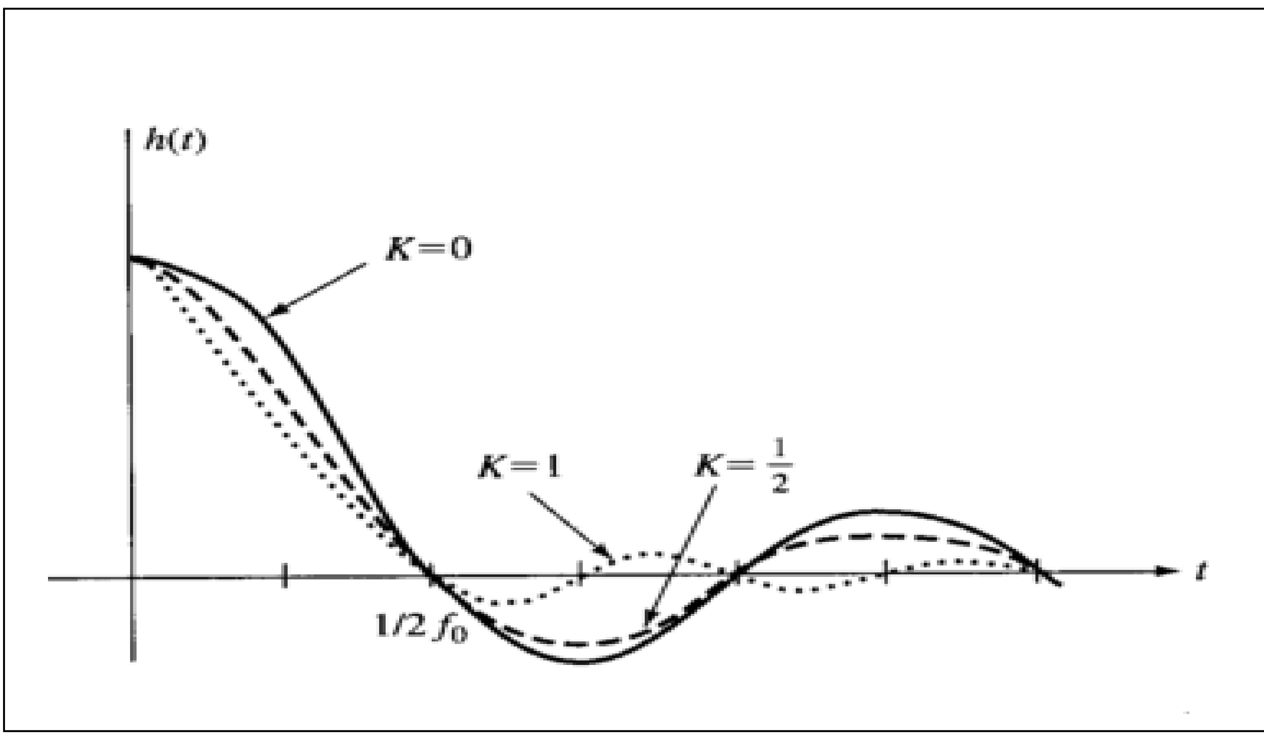
Figure 6.16 Effect of intersymbol interference on eye opening

- How to fix the problem ?

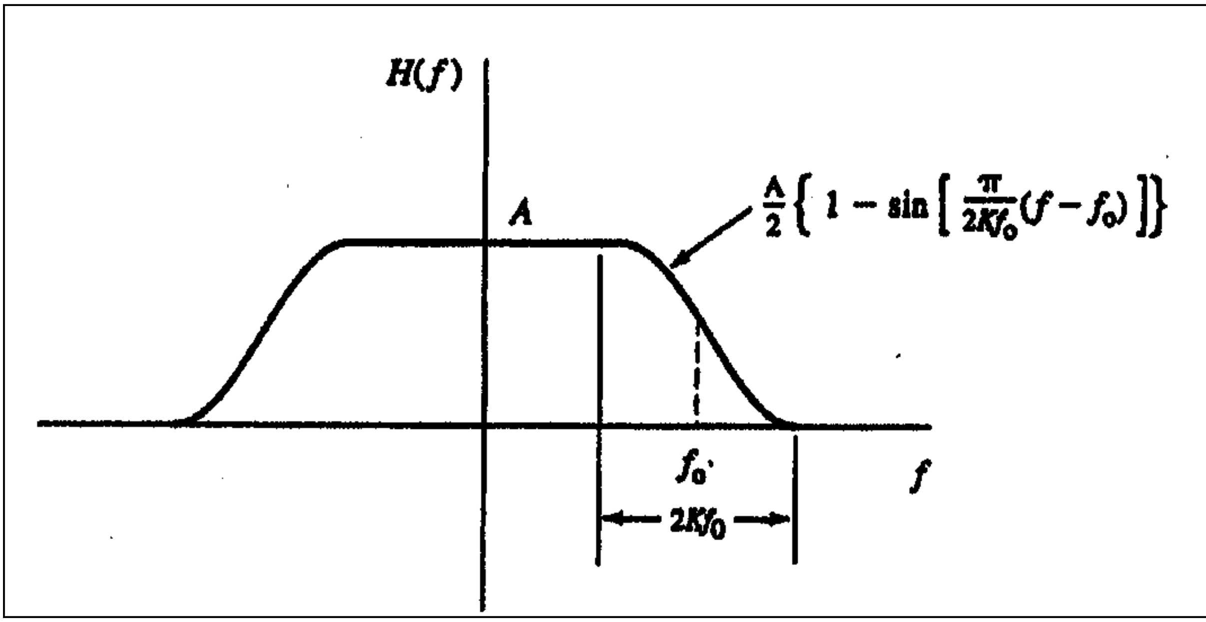
==> Raised cosine filter

$$h(t) = A\frac{\sin(2\pi f_0 t)}{2\pi f_0 t}\frac{\cos(2\pi KTf_0)}{1-(8K^2 f_0 t^2/\pi)}$$

K represents flat portion width of the frequency transform

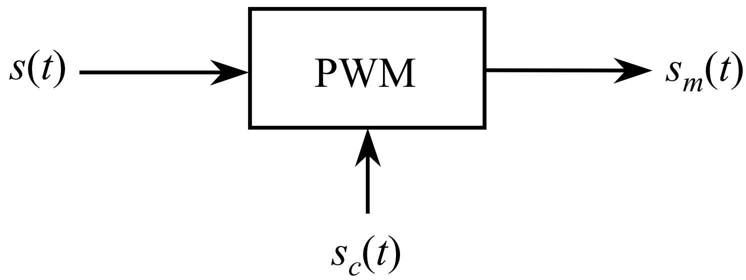


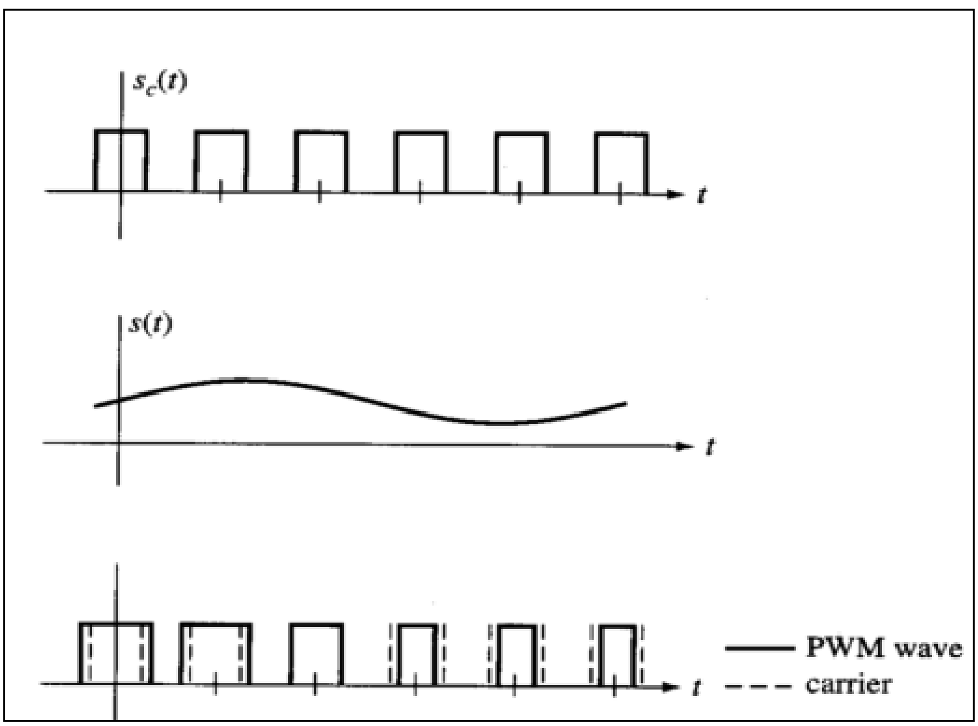
Raised Cosine Impulse Response



Raised Cosine Frequency Characteristic

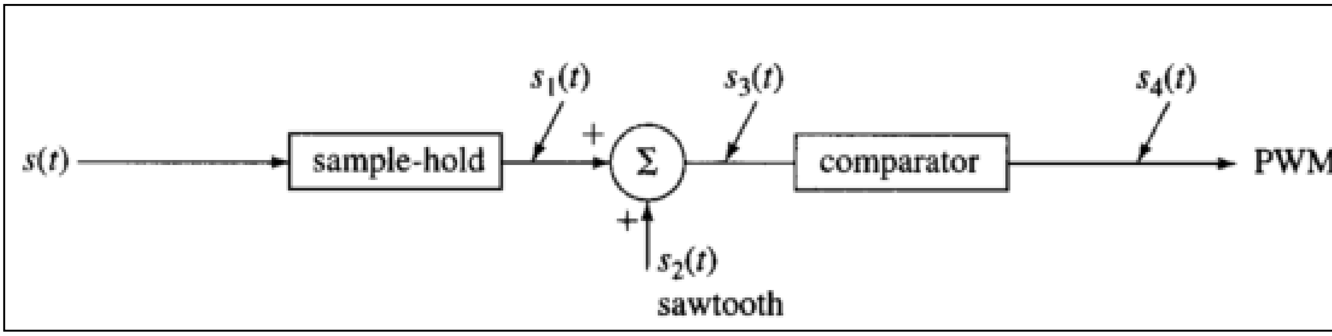
4) Pulse Width Modulation (PWM)

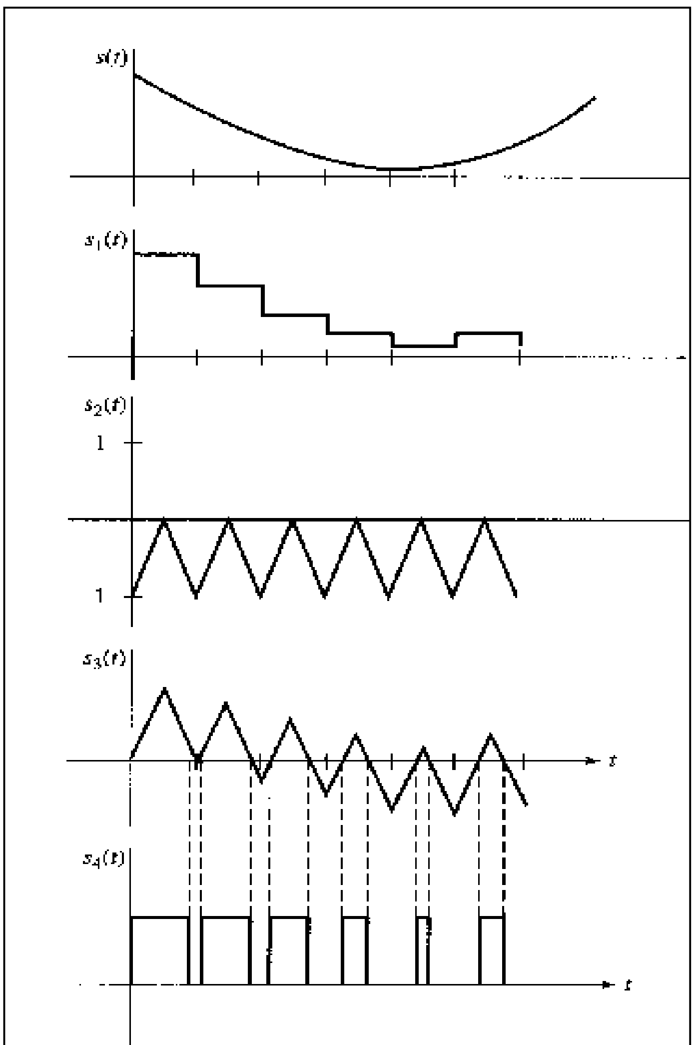




PWM

• <u>PWM Generator</u>

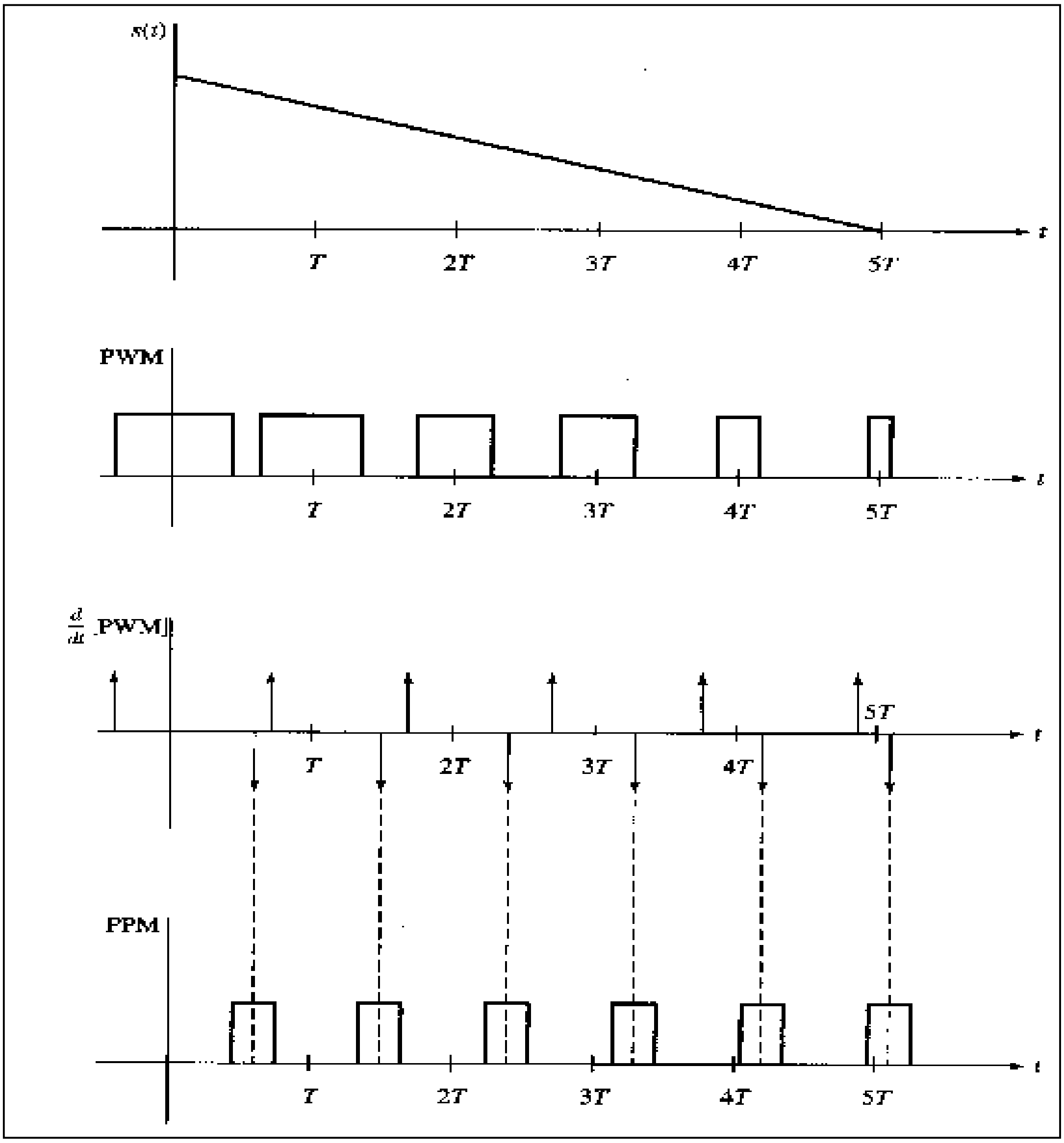




(b)

5) Pulse Position Modulation (PPM)

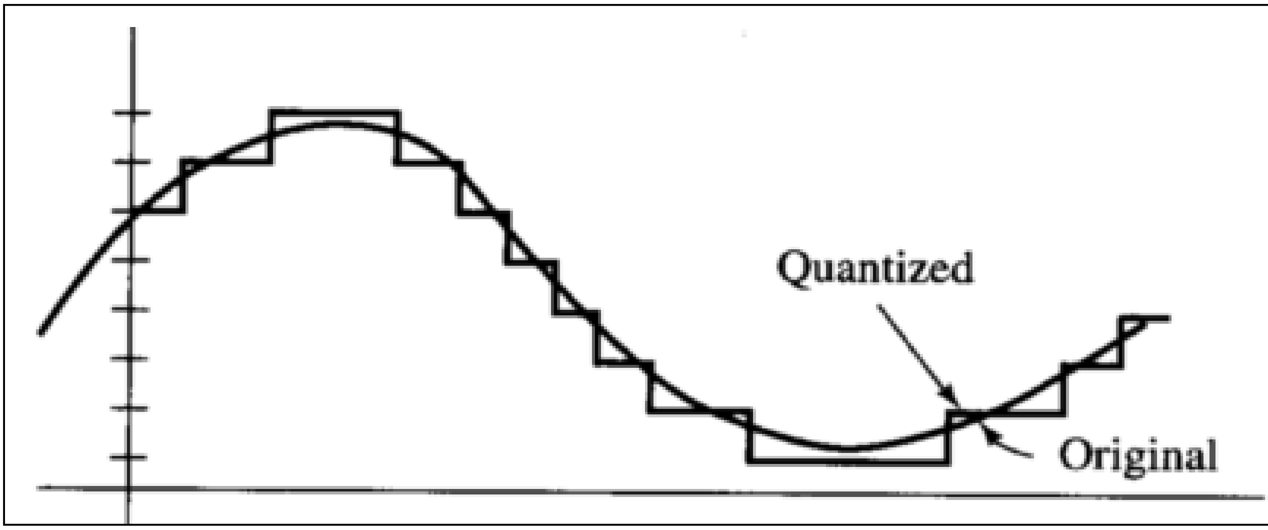
- PPM can be derived from PWM



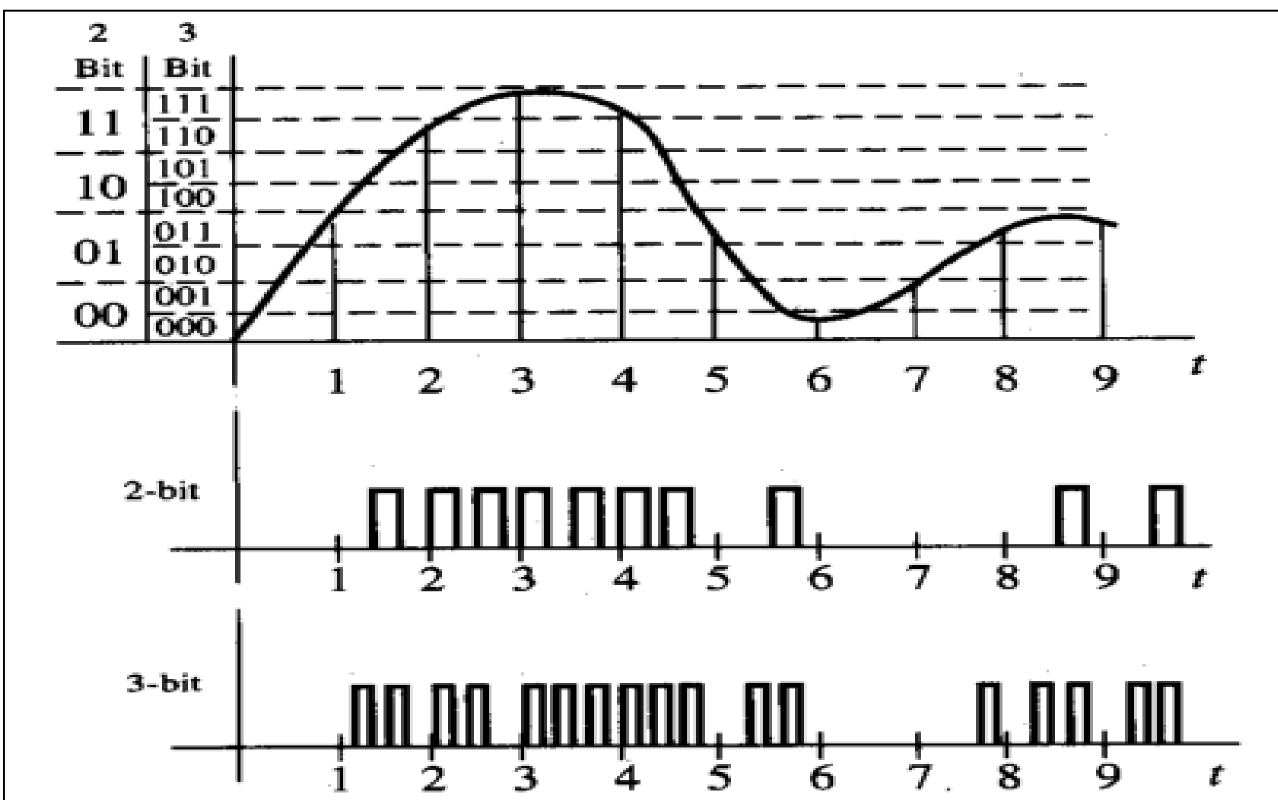
PWM to PPM

6) Pulse Code Modulation (PCM)

- Signal format



- From analog to digital



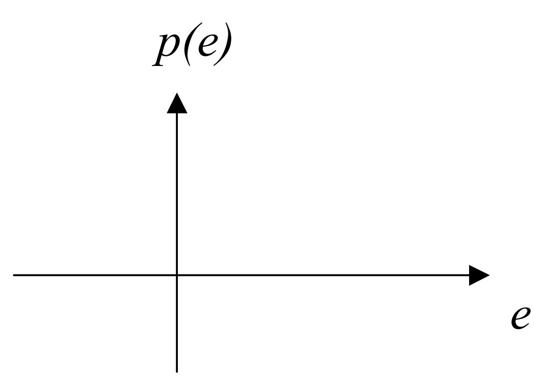
• **Quantization noise issues**

- Quantization error is a measure of effectiveness of a quantization scheme

- Quantization noise level is directly related to the number of quantization levels

- Assume quantization error *e(n)* to be equally likely to occur in the range D

pdf of *e*



- $\underline{e(n)}$ statistics

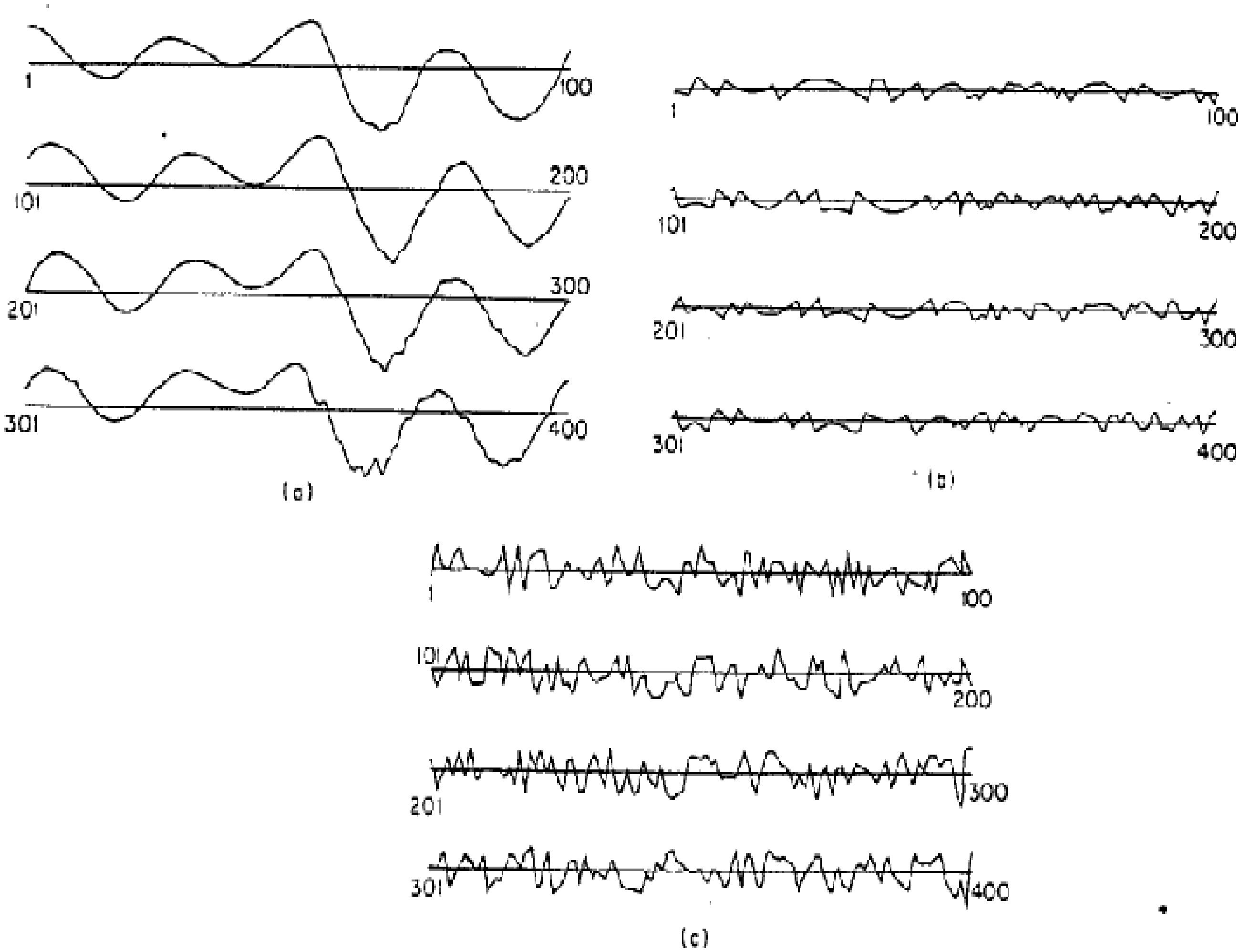


Fig. 5.11 (a) Speech waveform; (b) quantization error for 3-bit quantization (same scale as in (a)); (c) quantization error for 8-bit quantization (magnified 66 times with respect to (a)).

- SNR level due to quantization noise

$$SNR_q = \frac{\sigma_s^2}{\sigma_e^2} = \frac{E\left[s^2(n)\right]}{E\left[e^2(n)\right]}$$

- Example

$$s(t) = 2\cos(500\pi t)$$

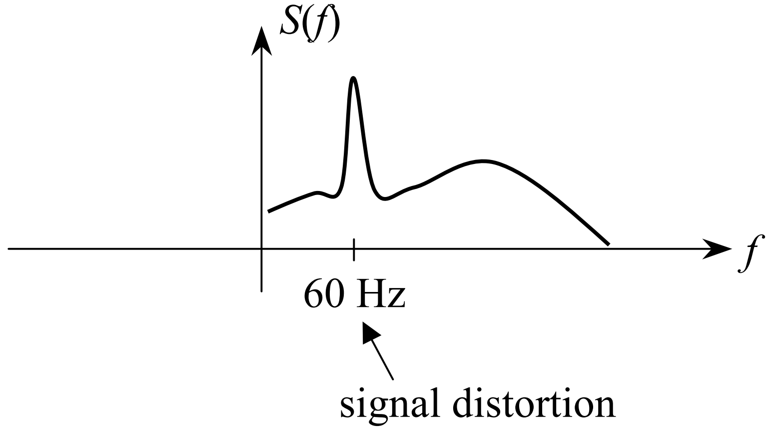
1) Compute SNR_q when using 8-bit PCM
2) Compute the minimum number of bits needed to get $SNR_q \geq 20$ dB

- Non-linear quantization

  (pre-emphasis and de-emphasis concepts)

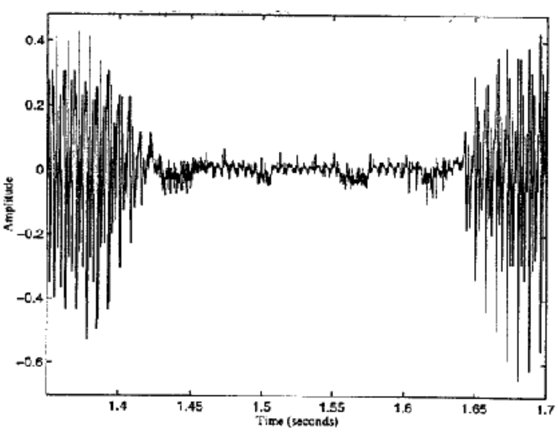
✶ Goal: to improve quality of signal to be quantized

✶ Example

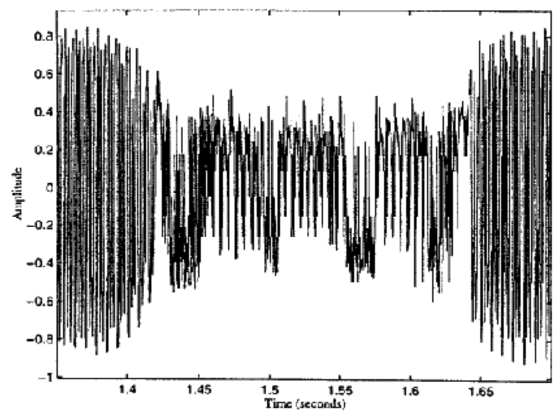


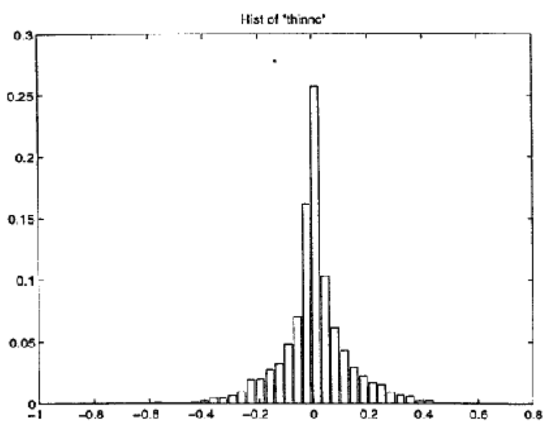
✶ Example: speech signal

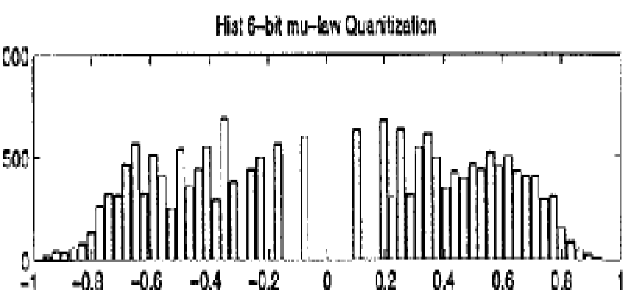
Before applying mu-law



After applying mu-law

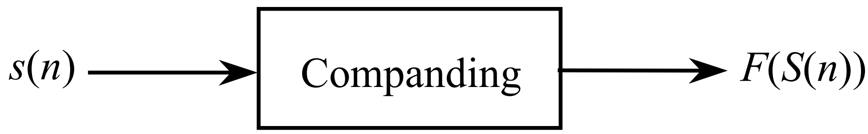






Comments ?

- <u>Mu-Law / A-Law quantization</u> for voice transmission



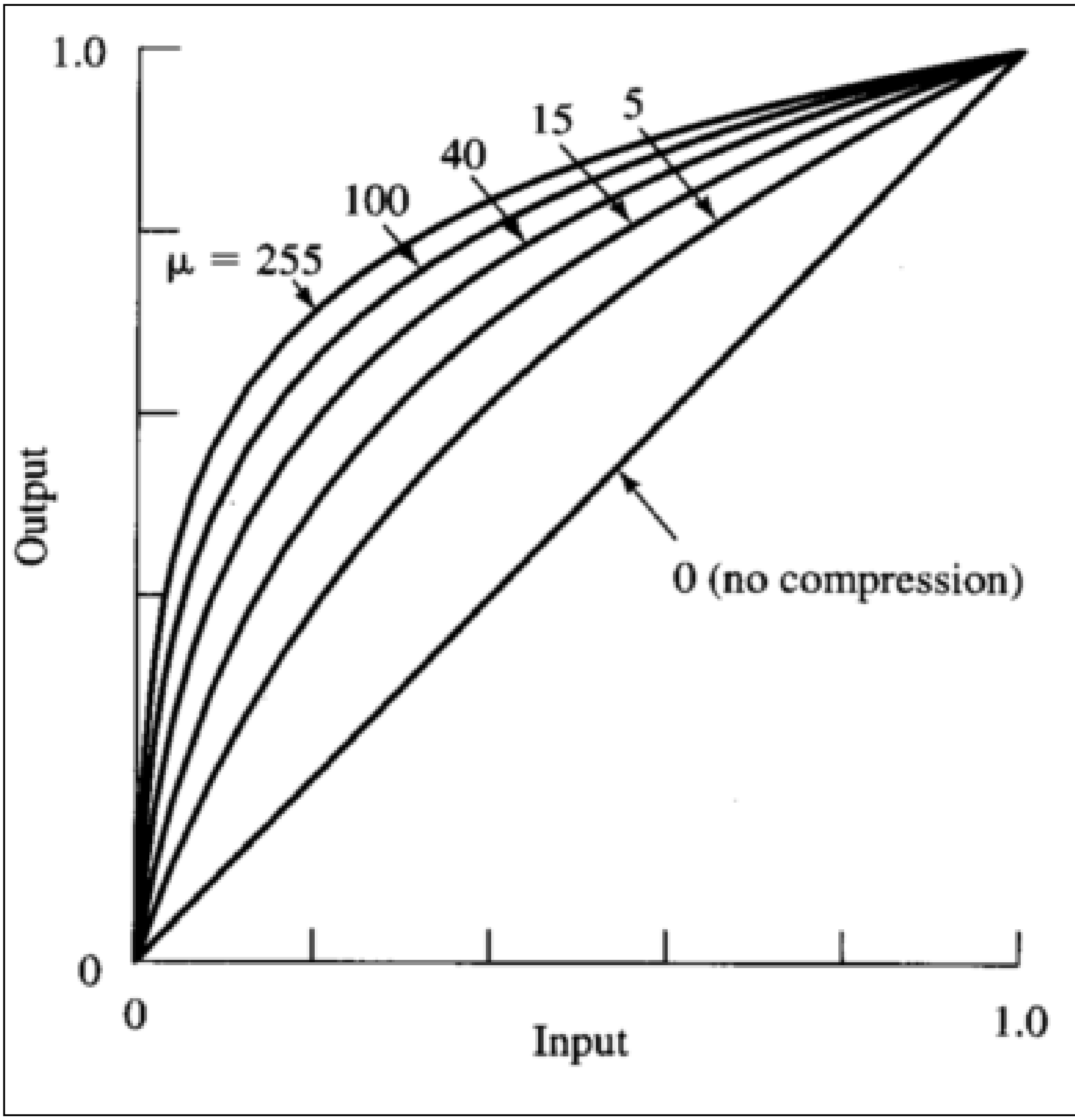
- Mu-Law (USA-Japan); $\mu = 255$

$$F(s) = \operatorname{sgn}(s)\frac{In\left(1+\mu|s|\right)}{In\left(1+\mu\right)}$$

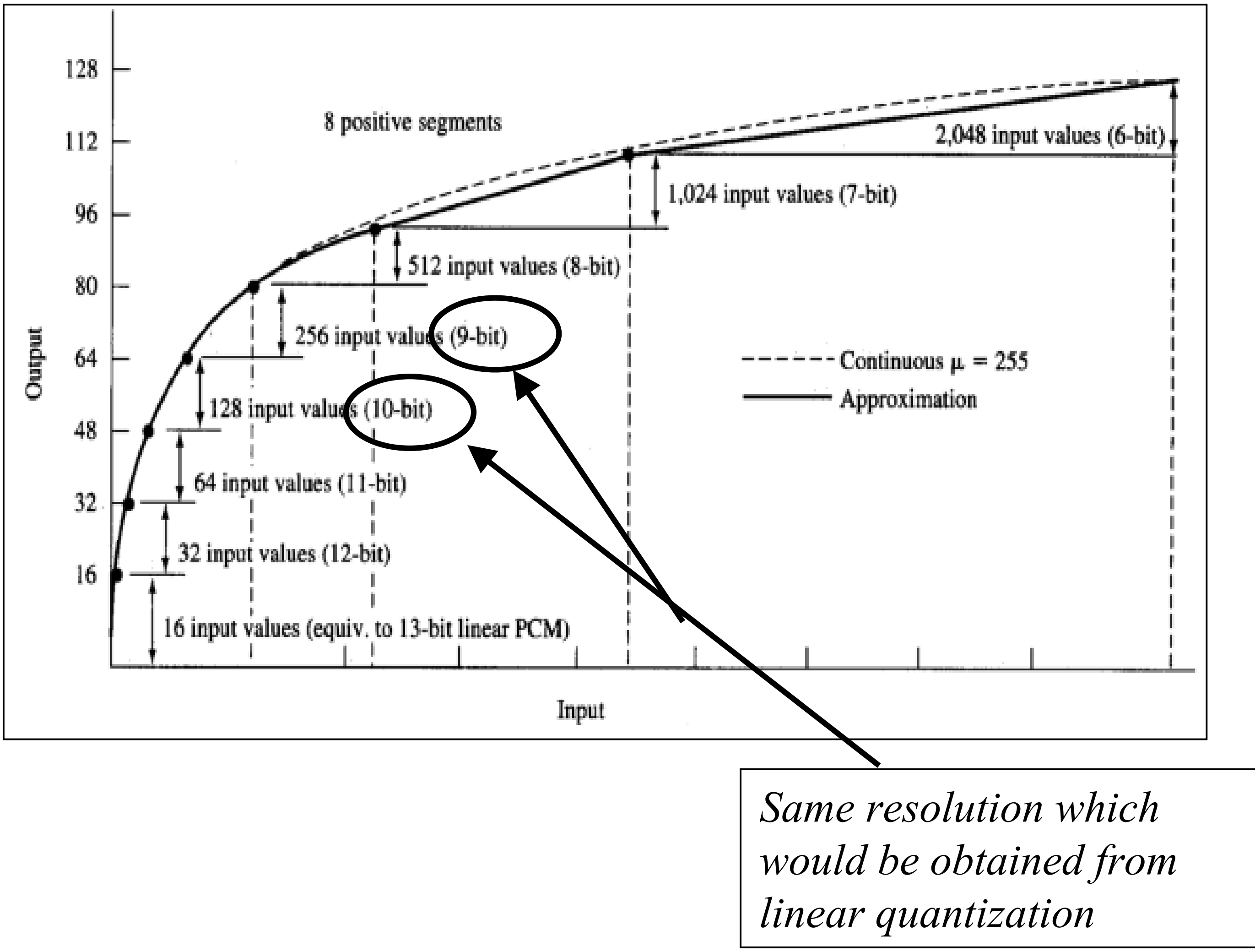
- Mu-Law (Europe-South America); $A = 87.56$

$$F(s) = \operatorname{sgn}(s)\frac{A|s|}{1+In(A)}; \qquad 0 \le |s| < \frac{1}{A}$$

$$\operatorname{sgn}(s)\frac{1+In\left(A|s|\right)}{1+In(A)}; \qquad \frac{1}{A} \le |s| \le 1$$



Input-output characteristic for μ-law companding μ-255 Piecewise linear approximation



Approximate the μ-255 curve by a piecewise linear curve
Divide output region into 8 unequal segments (for positive side)

Within each segment, uniformly quantize using 4 bits (i.e., 16 regions)

1 bit for polarity (1 for x>=0, 0 for x<0)
3 bits for identifying the segment
4 bits to identify quantization level within each segment

- TDM for digital signals

Example: TDM in $T-1$ system

✶ designed for short distances (15 to 65 km)

✶ 1.544 megabits/s pulse signal developed for transmission

✶ signal developed by 24 channel TDM

✶ each channel sampled at 8 KHz, with 8-bit μ-law companding

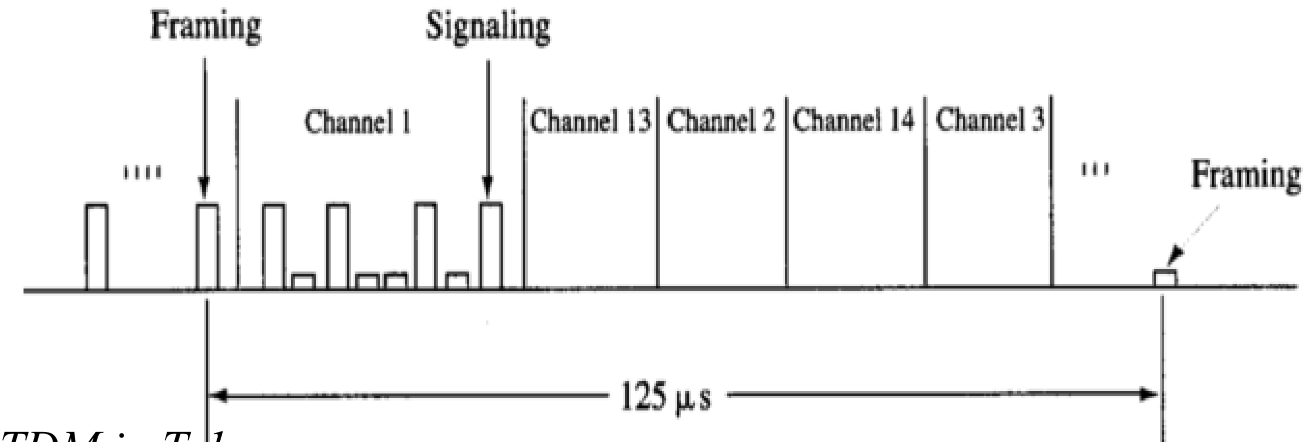
✶ each frame each 24×8 bits

192 bits used for information
1 bit used for frame synchronization

✶ transmission rate is

$$8000 \text{ frames/s} \times 193 \text{ bits/frame} =$$

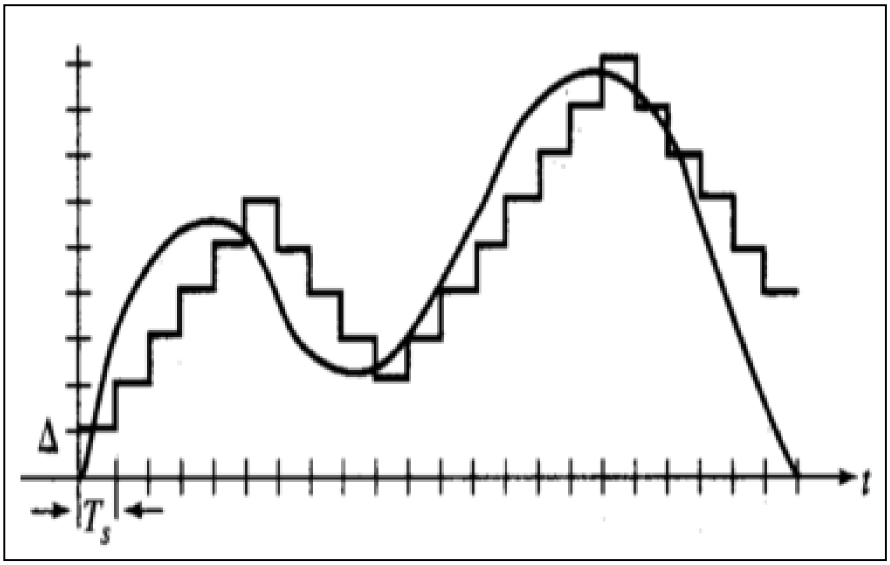
$$1.544 \text{ Mbits/sec}$$



TDM in T-1

7) Delta Modulation

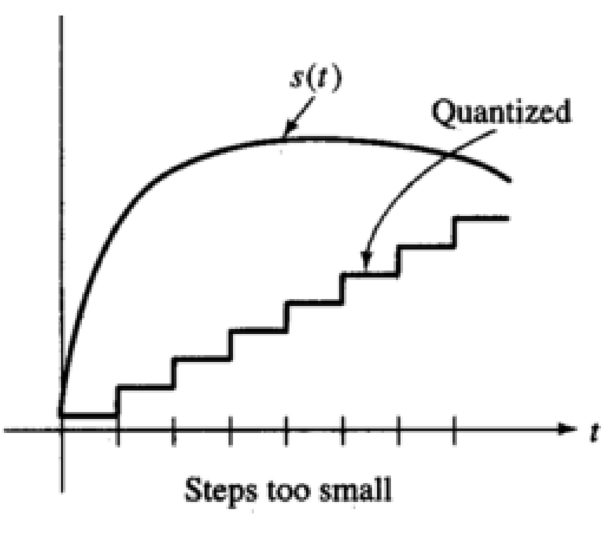
- Simplified 1-bit PCM

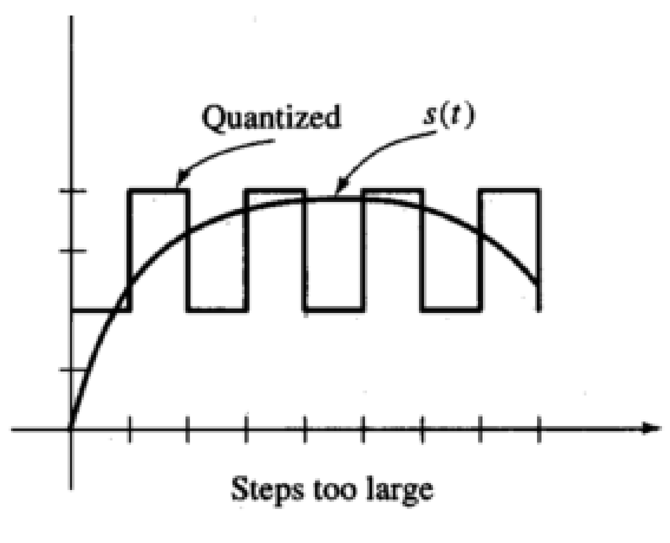


- Quantization issues

slope overload

granular noise

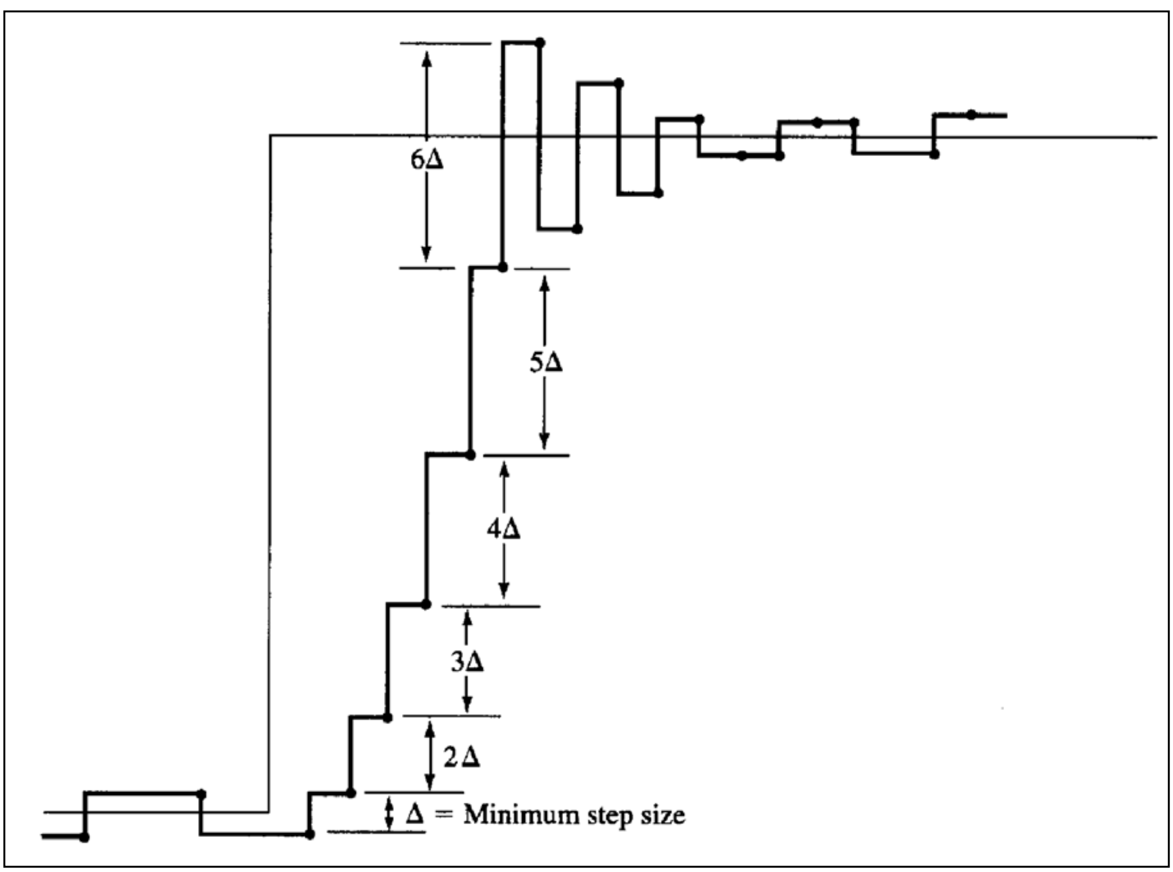




- <u>Adaptive delta modulation</u>
  - designed to overcome slope overload and granular noise issues
  - Song algorithm: compares transmitted bit with previous bit.

If same $\quad \Delta' = K\Delta \; ; \quad K > 1$

If different $\quad \Delta' = K\Delta \; ; \quad K < 1$

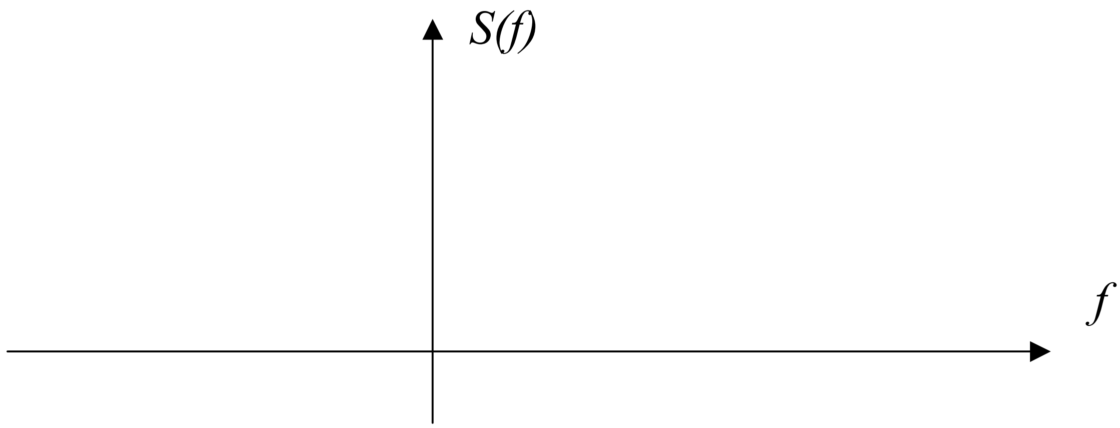


Song Algorithm

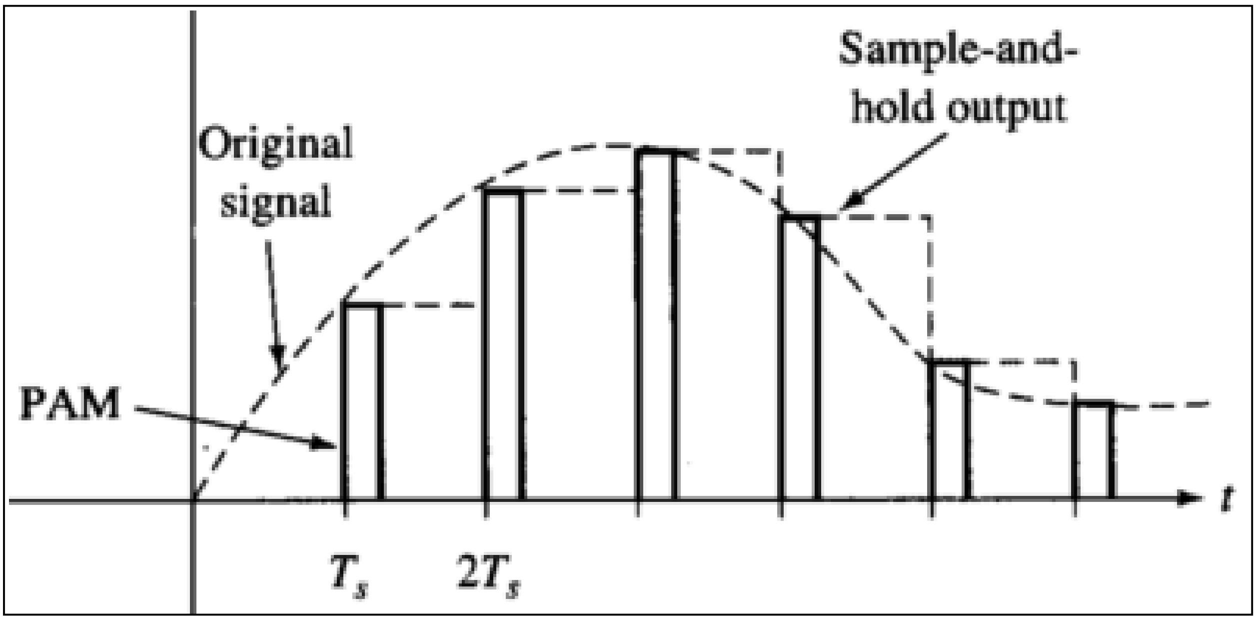
8) PAM, PPM & PWM Receivers

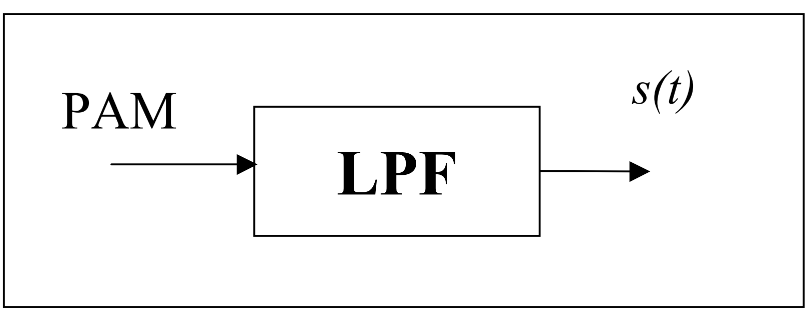
- <u>PAM receiver (Instantaneous-Sampled PAM)</u>

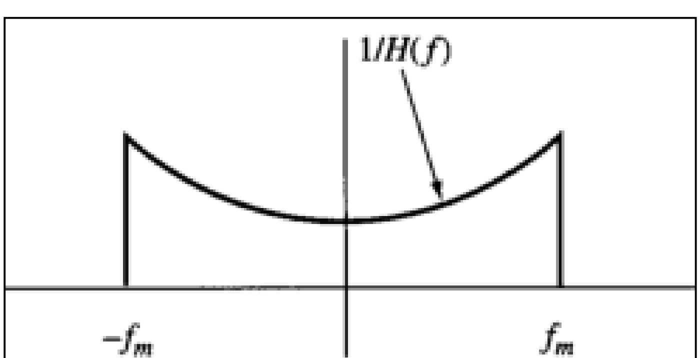
  • Recall frequency transform for for natural-Sampled PAM



- Sample-and-Hold for PAM demodulation

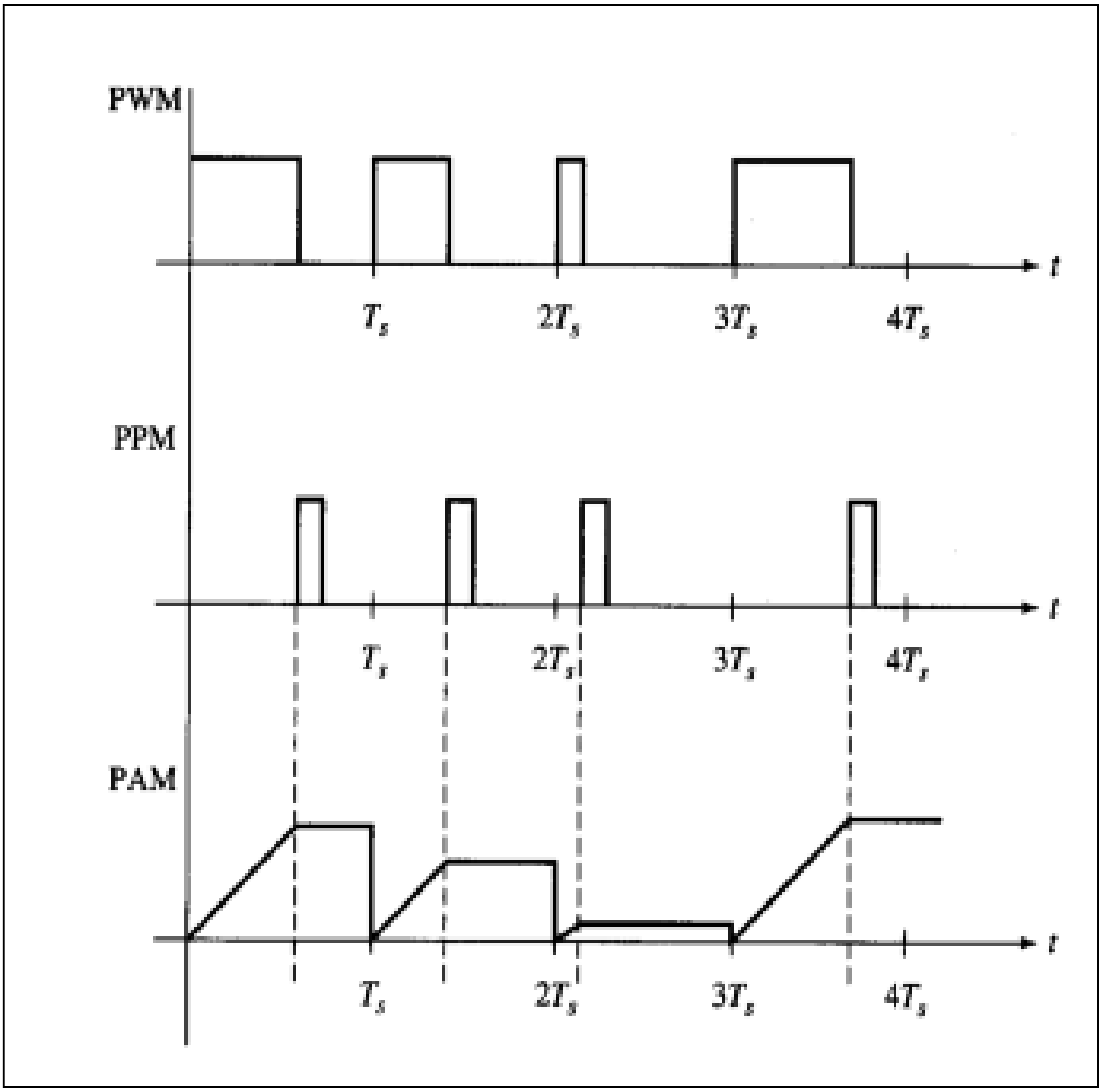






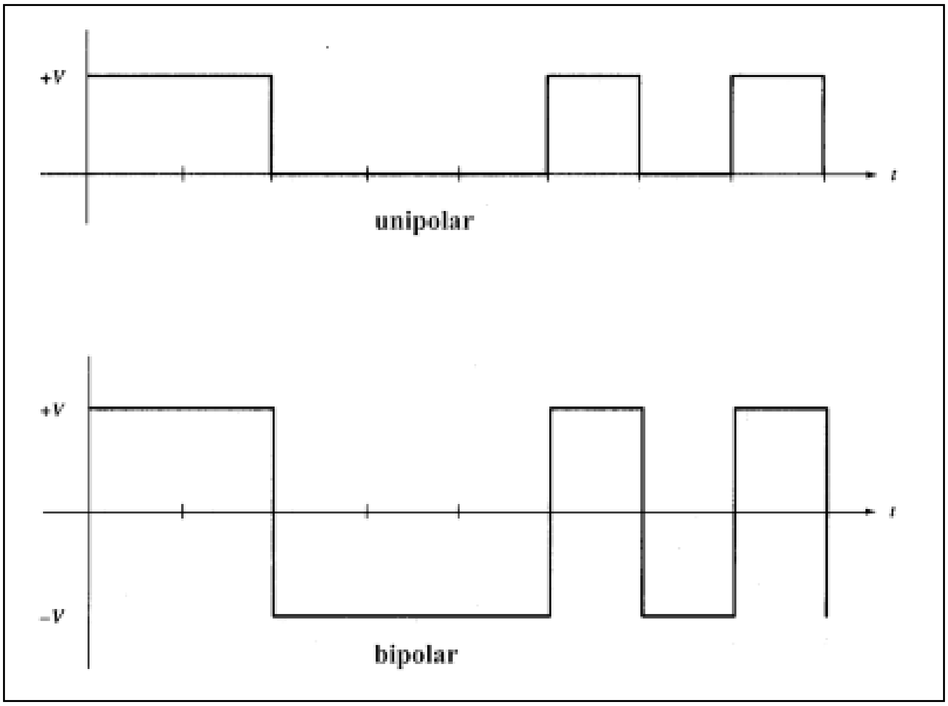
- PWM & PPM receivers

2-step process

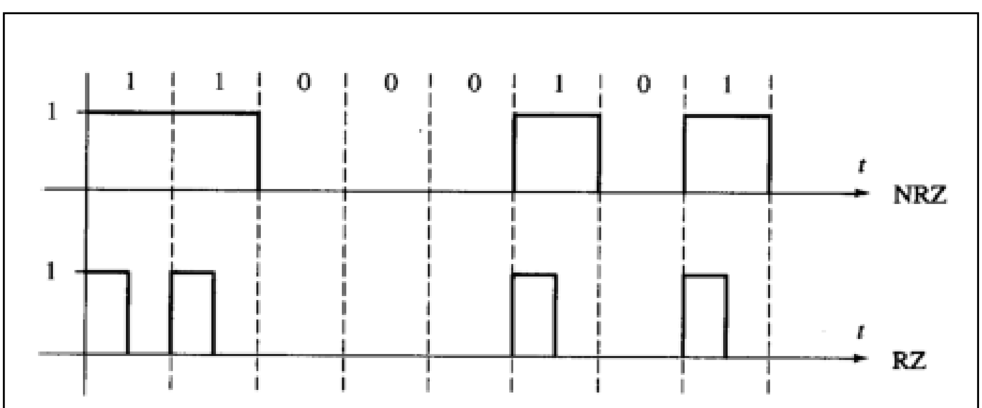


9) Digital Baseband

- Signal Format

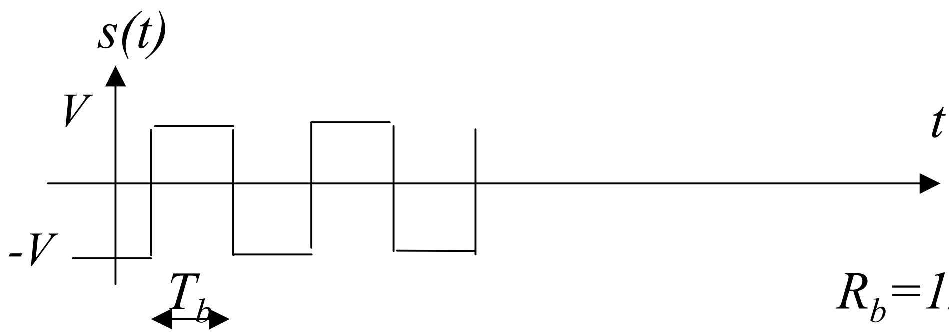


Unipolar/Bipolar waveforms



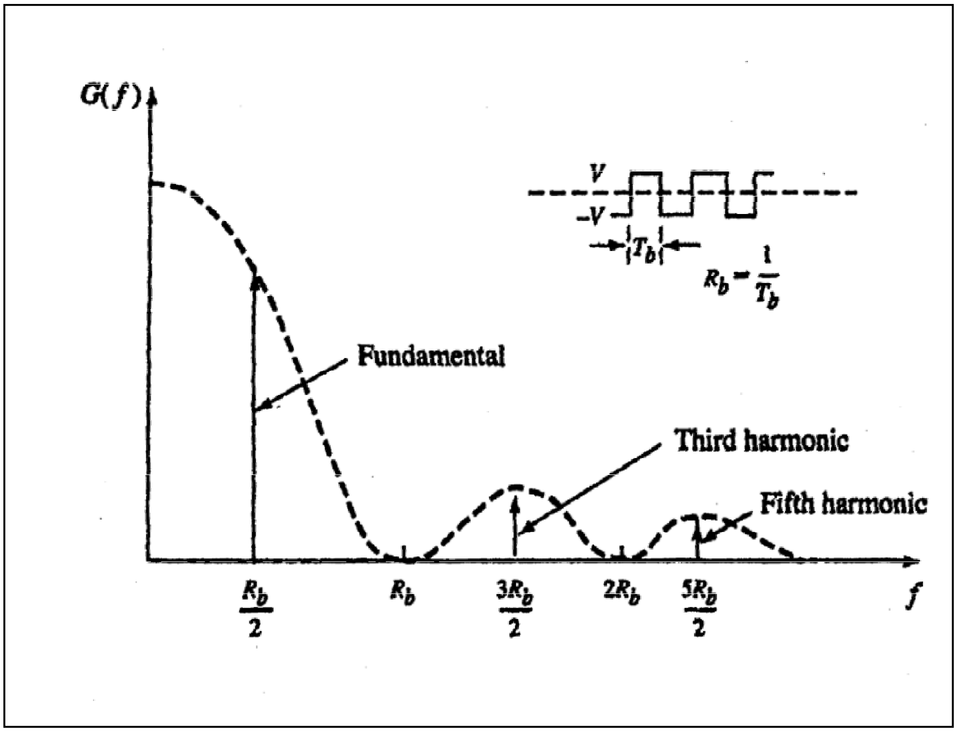
RZ & NRZ waveforms

- Power Spectrum (Ex: Periodic NRZ)



$R_b = 1/T_b$
$T_b = T/2$

a) Power Spectrum of *s(t) (periodic case: 0 1 0 1 0 ...)*



G(f)
V
-V
T_b
$R_b = \frac{1}{T_b}$
Fundamental
Third harmonic
Fifth harmonic
$\frac{R_b}{2}$
R_b
$\frac{3R_b}{2}$
$2R_b$
$\frac{5R_b}{2}$
f

b) Power Spectrum of random NRZ (Extension to non periodic s(t) case)

-Use concept of power spectral density (PSD)

Def: The PSD for a non periodic signal s(t) is defined as:

$$G(f) = \lim_{\Delta T \to \infty} \left(\frac{1}{\Delta T} \left| \int_{-\Delta T/2}^{\Delta T/2} s(t) e^{-j2\pi ft} dt \right|^2 \right)$$

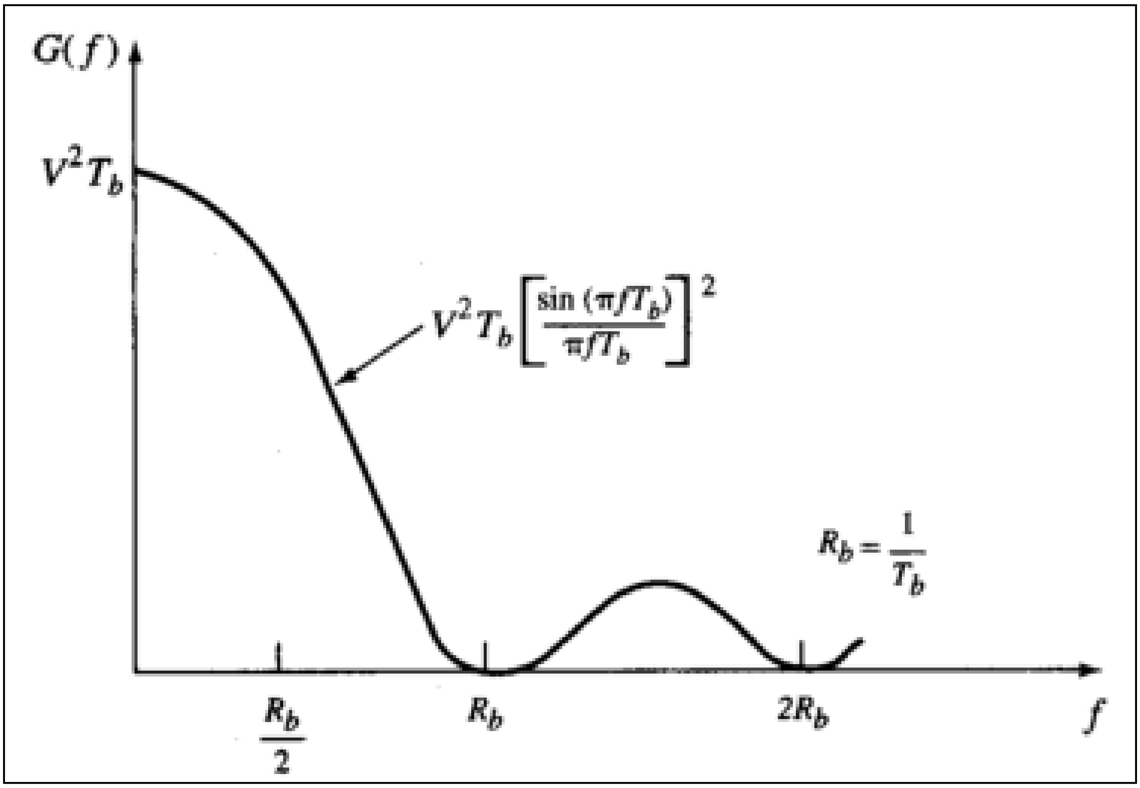
- Assume that ΔT increases in multiples of the bit length (T_b)

=> same contribution is added in each period

=> restrict integration over one period only

$$G(f) = \frac{1}{T_b} \left| \int_{-T_b/2}^{T_b/2} V e^{-j2\pi ft} dt \right|^2$$

$$= V^2 T_b \left(\frac{\sin(\pi f T_b)}{\pi f T_b} \right)^2$$



Def: Nominal signal bandwidth: Signal bandwidth up to the 1st zero of signal spectral lobe

What is the above signal nominal bandwidth ?

• <u>Potential problems with NRZ transmissions</u>

- No transition between one bit to the next
- Potential data inversion problems

- Differential coding option:
data is represented as changes in levels rather than by the actual signal level