2.0 Digitization of Speech, Audio and Video Signals

Relatives of PCM

- improved performance by computation, memory and better technologies
- performance considerations:
  1. bit rates
  2. quality (perceptual acceptability, etc.)
  3. practical feasibility (computation requirements, etc.)

     tradeoffs among these considerations

2.1 Non-uniform Quantization ––– Companding

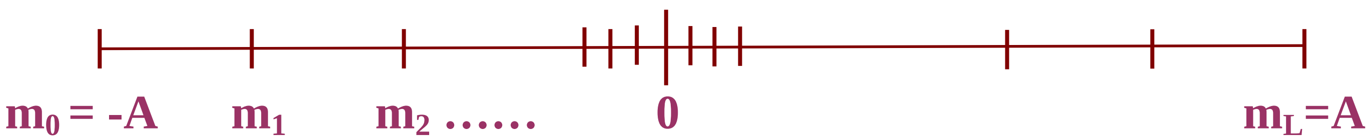
- **Uniformly Quantized PCM**

  $$SNR_Q = \left(\frac{3\sigma_x^2}{A^2}\right)2^{2R} \quad \alpha \;\; \sigma_x^2$$

  poor quality for small σ_x^2

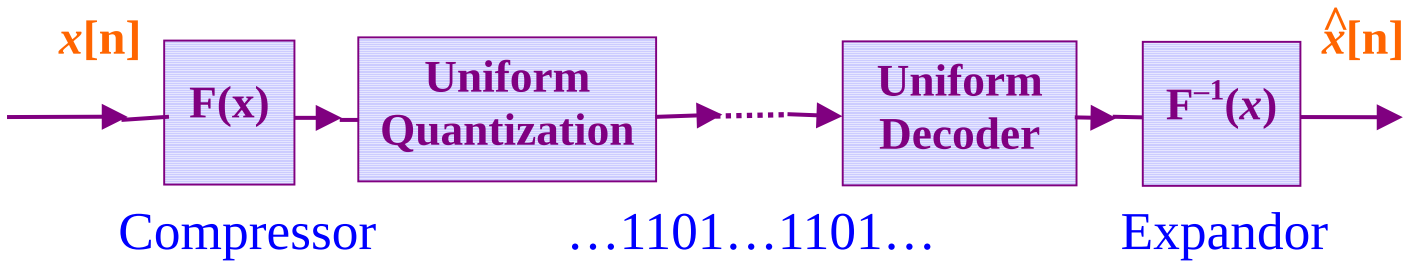
  Too high bit rates required if good quality for small σ_x^2 maintained

- Concept : small quantization levels for small *x*
  large quantization levels for large *x*



Non-uniform quantization

Companding



Compressor + Expandor → Compandor

$F(x)$ is to specify the non-uniform quantization characteristics

- **Goal: constant $\mathbf{SNR_Q}$ for all x**

$$SNR_Q = \left(\frac{\sigma_x^2}{\sigma_e^2}\right) = \frac{\int_{-A}^{A} x^2\, P_x(x)dx}{\sigma_e^2} = \text{constant}$$

$$\sigma_e^2 = \sum_{k=1}^{L} P_k \left(\frac{1}{12}\Delta_k^2\right)$$

$$P_k = \text{prob}\,[\, x[n] \in J_k \,]$$

$$\Delta_k = \text{quantization level of } J_k$$

for small Δ_k and large L

$$\Delta_k \approx \frac{2A}{L \bullet F'(\tilde{x}_k)}, \qquad \tilde{x}_k \in J_k$$

$$\sigma_e^2 = \frac{1}{3} A^2 2^{-2R} \bullet \sum_{k=1}^{L} P_k \left[\frac{1}{F'(\tilde{x}_k)}\right]^2$$

$$\sigma_e^2 \approx \frac{1}{3} A^2 2^{-2R} \bullet \int_{-A}^{A} P_x(x) \left[\frac{1}{F'(x)}\right]^2 dx$$

$$SNR_Q \approx \frac{\int_{-A}^{A} x^2\, P_x(x)dx}{\frac{1}{3} A^2 2^{-2R} \bullet \int_{-A}^{A} P_x(x) \left(\frac{1}{F'(x)}\right)^2 dx} = \text{constant}$$

Companding

- **Logarithmic Companding Law (A=1 for simplicity)**

$$\left| \frac{1}{F'(x)} \right| = kx$$

$$| F(x) | = 1 + \ln | x | \quad (F(\pm 1) = \pm 1)$$

Approximations to the logarithmic law

- μ-law

$$| F(x) | = \frac{\log [1+\mu | x |]}{\log (1+\mu)} , \; 0 \le | x | \le 1$$

A-law

$$| F(x) | = \begin{cases} \dfrac{A | x |}{1+ \ln A} , & 0 \le | x | \le \dfrac{1}{A} \\ \dfrac{1+ \ln [A | x |]}{1+ \ln A} , & \dfrac{1}{A} \le | x | \le 1 \end{cases}$$

Typical values in practice

$$\mu = 255 , \; A = 87.6$$

See Fig. 3.14 , p. 202 of Haykin

Companding

- Bell system 64 Kbps voice coder:

  μ-law , μ = 255 , f_s = 8KHz , R= 8 bits/sample

- Bell System T1 Carrier :

  24 voice channels each at 64 Kbps/ch
  Time-Division Multiplex(TDM)

  1 extra framing bit per 24 samples

  $r = (8 \text{ bit} \times 24 + 1) \times 8 \text{ KHz} = 1.544 \text{ Mbps}$

- Bell System T2 Carrier :

  4 of T1 Carriers TDMed (by M12)

  r = 6.312 Mbps

- Bell System T3 Carrier :

  7 of T2 Carriers TDMed (by M23)

  or

  28 of T1 Carriers TDMed (by M13)

  r = 44.736 Mbps

- Bell System Digital Hierarchy