ELC 4351: Digital Signal Processing

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Quantization Errors

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- Quantization errors:
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- Arithmetic errors:
  Roundoff or truncation
  Overflow

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- First, $x(t)$ is sampled and becomes a discrete-time signal $x(nT)$.
- Then, $x(nT)$ is encoded using B bits and becomes a digital signal $x[n]$.

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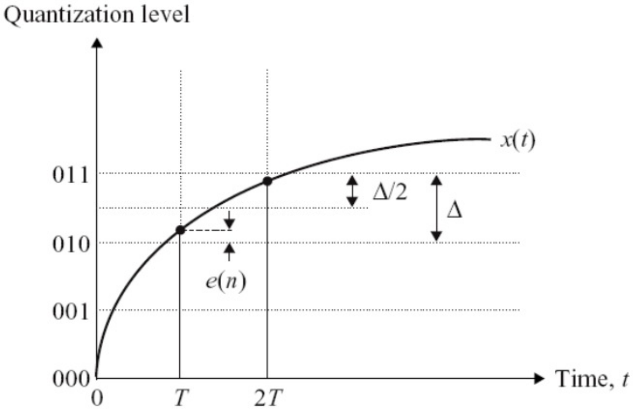
- B bits represent a sample, the number of quantization levels is 2^B.
- The quantization step (resolution): $\Delta = \frac{2}{2^B} = 2^{-B+1}$.

Rounding for Quantization

A 3-bit ADC:



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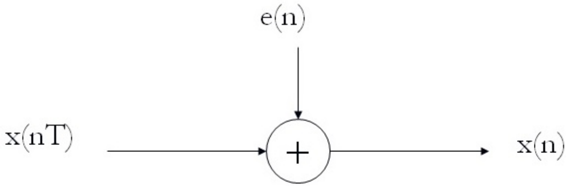
- The quantization noise depends on the quantization step.
- More bits $\Rightarrow$ smaller quantization step $\Rightarrow$ lower quantization noise.

Linear Model

- The nonlinear operation of quantizer: $x(n) = Q[x(nT)]$
- Linear operation: $x(n) = Q[x(nT)] = x(nT) + e(n)$



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- Assume $e(n)$ is a random variable uniformly distributed in the interval $[-\Delta/2, \Delta/2]$.
- Therefore, $E[e(n)] = (-\Delta/2 + \Delta/2)/2 = 0$;

$$\text{and variance: } \sigma_e^2 = \frac{\Delta^2}{12} = \frac{2^{-2B}}{3}.$$

Large wordlength B leads to small quantization error σ_e^2.

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- For each additional bit, the ADC provides about 6-dB gain.
- SNR is proportional to σ_x^2. Keep signal power as large as possible.

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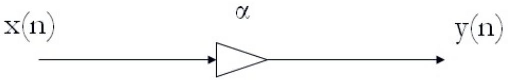
- Coefficient quantization can cause serious problems if the poles of designed IIR filters are too close to the unit circle.
- This is because those poles may move outside the unit circle due to coefficient quantization, resulting in an unstable implementation.

Roundoff Noise



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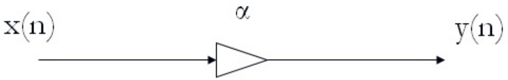

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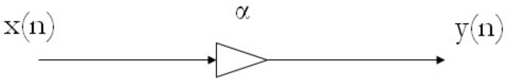

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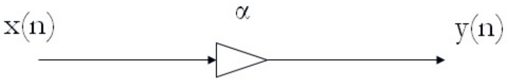

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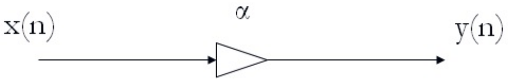

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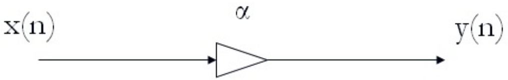

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- Truncation or rounding brings the roundoff noise.
- $y(n) = Q[\alpha x(n)] = \alpha x(n) + e(n)$
- Is this noise larger?

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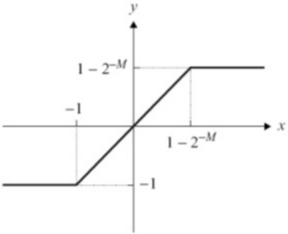
- This overflow results in severe distortion of the signal output.
- We need saturation algorithm or proper scaling.

Saturation Algorithm

- Saturation arithmetic prevents overflow by keeping the result at a maximum value.

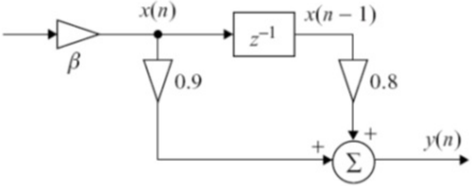
- Saturation algorithm is a nonlinear operation that clips the desired waveform.



$$y = \begin{cases} 1-2^{-M}, & x \geq 1-2^{-M} \\ x, & -1 \leq x < 1 \\ -1, & x < -1 \end{cases}$$

Scaling of Signals

- An effective technique in preventing overflow is by scaling down the signal.



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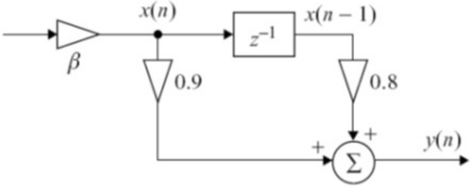

- If the signal $x(n)$ is scaled by β, the corresponding signal variance changes to $\beta^2\sigma_x^2$.

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- This is equivalent to losing 1 bit in representing the signal. Why?