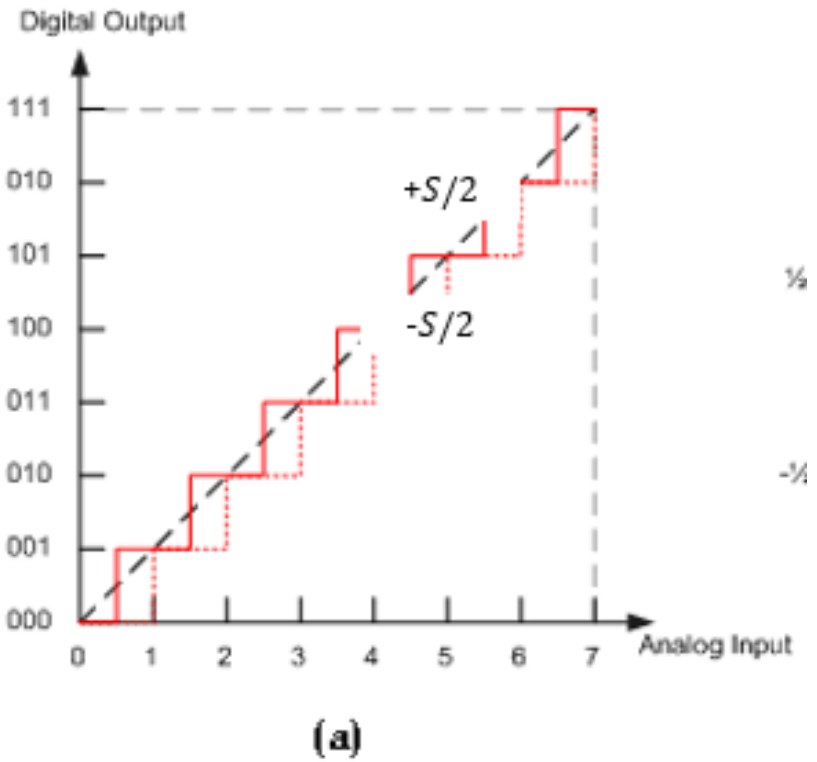
QUANTIZATION ERROR & QUANTIZATION NOISE

EEEN 464 – DIGITAL COMMUNICATION

Tuesday, June 3, 2025

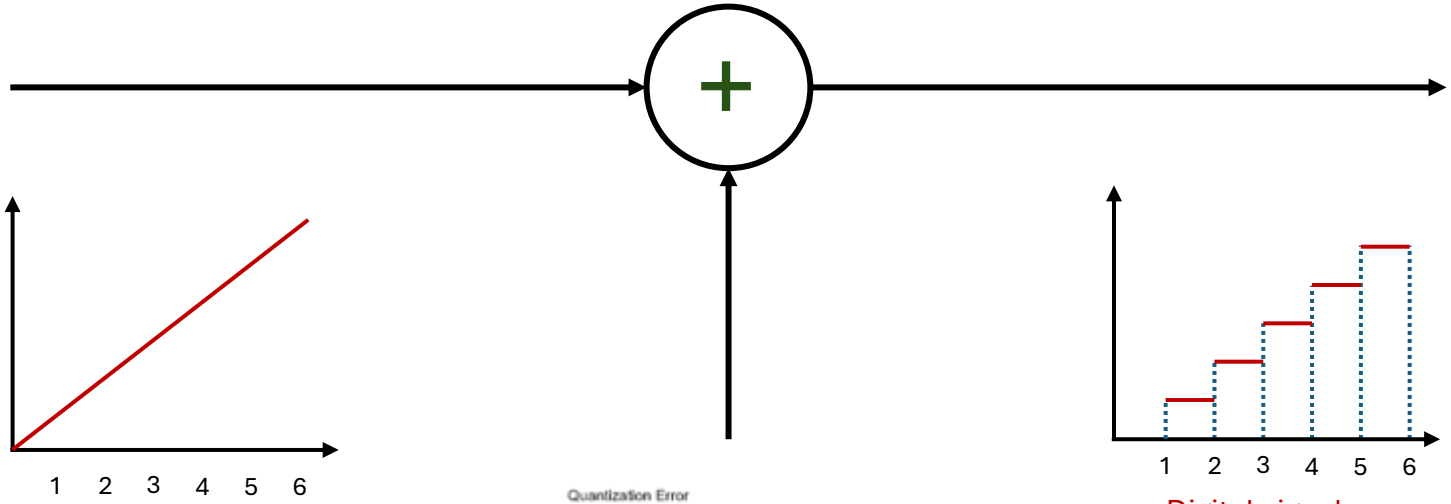
WHAT IS QUANTIZATION ERROR?

1. **Quantization error** is the difference between an analog signal and the closest digital value used to represent it.
2. **Quantization error** is a type of systematic error that occurs when converting analog signals to digital signals.
3. **Quantization error** can be regarded as a **distortion or noise** which is added to the original analogue signal during A/D conversion.
4. **Quantization error** is similar to round-off and truncation errors.

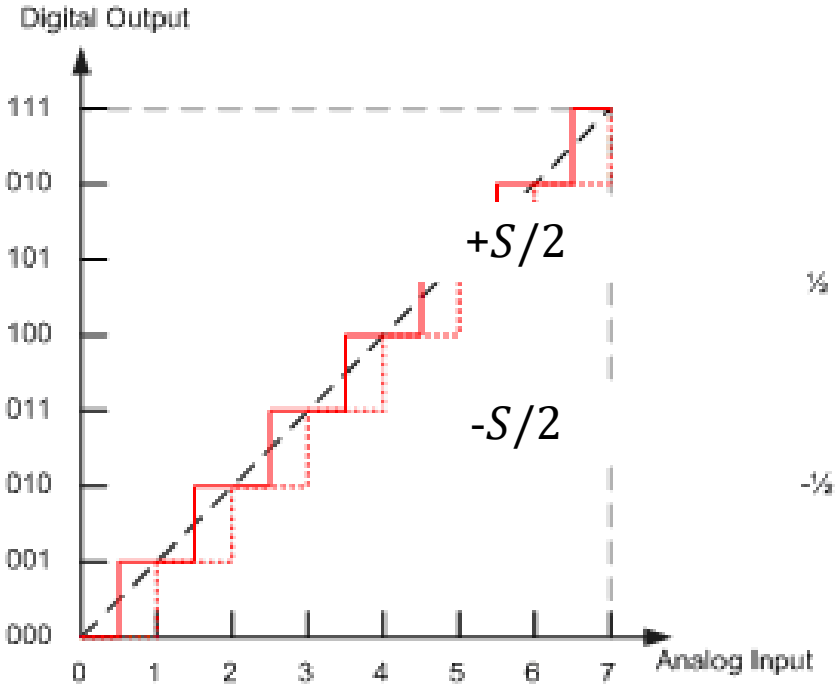


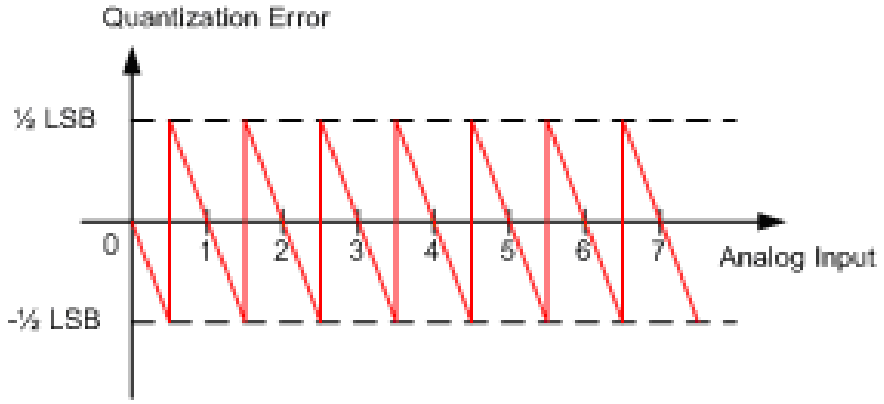
MODELING QUANTIZATION ERROR AS ADDITIVE NOISE

- Quantization error can be modelled as additive noise as shown below.



QUANTIZATION ERROR AS A FUNCTION OF AMPLITUDE





Quantization Error is $\varepsilon = V - V_q$

$$-\frac{S}{2} \leq \varepsilon \leq \frac{S}{2}$$

AVERAGE QUANTIZATION NOISE POWER

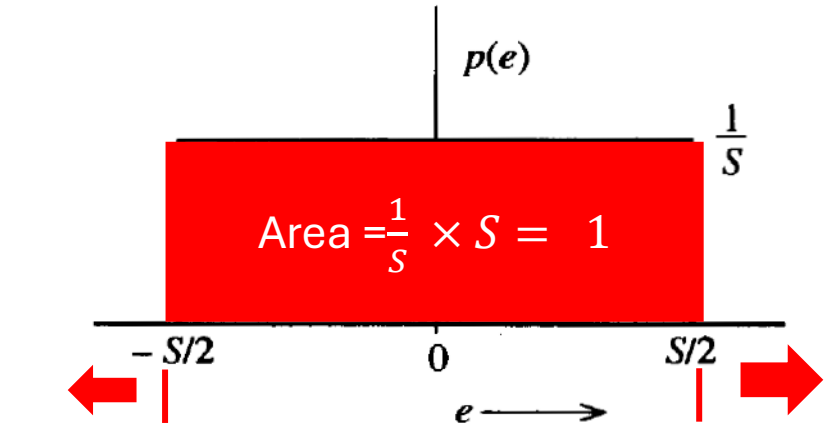
1. Assume that the probability distribution of error is constant within the range ±S/2.

2. **Average quantization noise power** is:

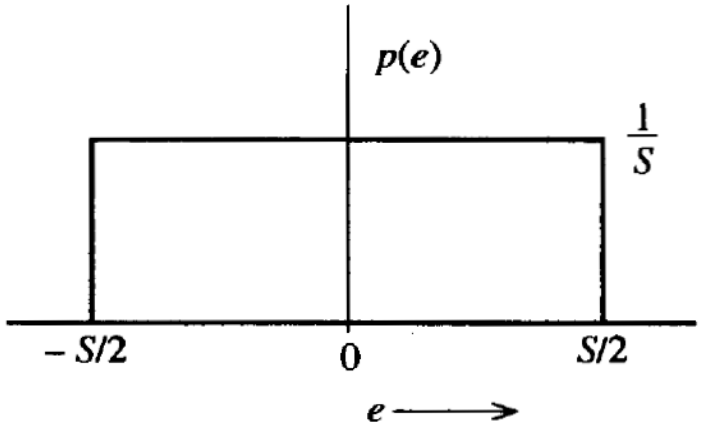
$$\sigma^2 = \int_{-\infty}^{\infty} (e-\mu)^2 p(e)\, de$$

where μ = mean

3. The range of the quantization error, i.e $\pm\frac{S}{2}$ forms the limits of integration.



AVERAGE QUANTIZATION NOISE POWER



$$\sigma^2 = \int_{-\infty}^{\infty} (e-\mu)^2 p(e)\, de$$

$$\sigma^2 = \int_{-S/2}^{S/2} (e-0)^2 \frac{1}{S}\, de$$

$$= \frac{1}{S} \int_{-S/2}^{S/2} e^2\, de$$

$$= \frac{1}{S}\left(\frac{e^3}{3}\right)_{-S/2}^{S/2} = \frac{S^2}{12}$$

HOW TO REDUCE QUANTIZATION NOISE

Quantization noise is reduced by:

1. **Oversampling:** By sampling a signal at a rate higher than the Nyquist rate.

   As a result, quantization noise is spread across a wider frequency range, effectively lowering its power density within the signal bandwidth, resulting in a cleaner signal with less noticeable noise. **Studio music is oversampled at 44.1 kHz, 48 kHz, 88.2 kHz, or 96 kHz.**

2. **Using a quantizer with a higher resolution:** A higher resolution means more quantization levels, allowing for a more precise representation of the original signal and therefore less distortion from the quantization process.

   Common voice and music production quantization levels include 8-bit, 16-bit, and 24-bit.

SIGNAL TO QUANTISATION NOISE RATIO (SQNR) IN PCM

- **Signal to quantization noise ratio (SQNR) in PCM** refers to the ratio between the power of the original signal and the power of the quantization noise introduced during the analog-to-digital conversion process.
- **SQRN** is used to measure how well the signal is represented without distortion from quantization errors.
- **SQNR** is calculated using the formula:

SQRN = Signal Power / Quantization Noise Power.

SIGNAL TO QUANTISATION NOISE RATIO (SQR)

Signal to Quantization Ratio (SQR) is a measure of the performance of a PCM system.

$$SQR = \frac{E\{x^2(t)\}}{E\{[y(t) - x(t)]^2\}}$$

- Where
  - E{..} is the expectation or average
  - x(t) is the analog input signal
  - y(t) is decoded output signal

Assumptions

1. Error y(t) – x(t) is limited in amplitude to S/2 where S is the height of the quantisation interval.
2. Sample value is equally likely to fall anywhere in the quantisation interval.
3. Signal amplitude is confined to the maximum range of the coder.