

1 Lecture Outline

Reading: Chapter 2 Quantization

- Quantization process
- Demonstrations

2 Quantization Process (2.1)

Sampling and quantization are necessary prerequisites for DSP. Each measured sample $x(nT)$ is held for at most T seconds during which time the A/D converts it to a quantized sample, $x_Q(nT)$ which is represented by B (finite) bits.

Figure 1: Orfanidis p. 61, Fig. 2.1.1. Analog-to-Digital Conversion.

Figure 2: Orfanidis p. 62, Fig. 2.1.2. Analog-to-Digital Conversion.

The quantized sample being represented by B bits can take on only one of 2^B possible values. The ADC is characterized by a full-scale range R , which is divided equally into 2^B quantization levels. The spacing between levels, called the quantization width or quantization resolution is given by

$$Q = \frac{R}{2^B} \quad (1)$$

Example: (Crystal Semiconductors' CS4215 used in many sound cards). A typical ADC for digital audio might have the following parameters: $R = 2.8$ V, $B = 16$ bits. Therefore the quantization resolution is

$$\begin{aligned} Q &= \frac{R}{2^B} \\ &= \frac{2.8}{65536} \\ &= 42.7\mu\text{V} \end{aligned} \quad (2)$$

Typical ADCs are bipolar

$$-\frac{R}{2} \leq x_Q(nT) \leq \frac{R}{2} \quad (3)$$

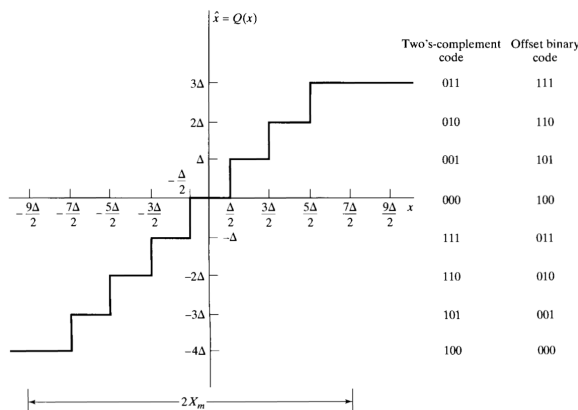


Figure 4.48 Typical quantizer for A/D conversion.

(a)

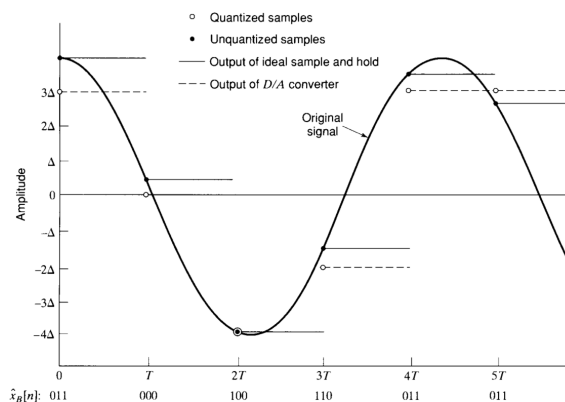


Figure 4.49 Sampling, quantization, coding, and D/A conversion with a 3-bit quantizer.

(b)

Figure 3: Oppenheim and Schaffer Fig. 4.48 and 4.49.

and round (or truncate) $x(nT)$ to the nearest $x_Q(nT)$. The quantization error is given by

$$e(n) = x(n) - x_Q(n) \quad (4)$$

$$-Q/2 \leq e(n) < Q/2. \quad (5)$$

We usually assume that the distribution of quantization errors is uniform.

Figure 4: Uniform distribution of quantization errors.

If we think of R and Q as the range of the signal and range of the quantization noise, then the signal-to-noise ratio (SNR) is R/Q . Expressed in dB we have:

$$\begin{aligned} \text{SNR (dB)} &= 20 \log_{10} \left(\frac{R}{Q} \right); \quad Q = R/2^B \\ &= 20 \log_{10} (2^B) \\ &= 20B \log_{10} (2) \\ &= 6B \end{aligned} \quad (6)$$

Thus for each bit in our sample word length, we increase the SNR or dynamic range of the quantizer by 6dB, i.e. 6dB per bit rule.

Example: 8 bit audio, 16 bit audio demos.

Example: The CD standard specifies 16 bit samples. Therefore, the dynamic range or SNR of the CD standard is $6 \times 16 = 96$ dB. Since the human ear has a dynamic range of about 91dB the quantization noise is barely at the threshold of hearing. This is the reason why “CD quality” digital audio requires at least 16-bit quantization.