

# Design IV

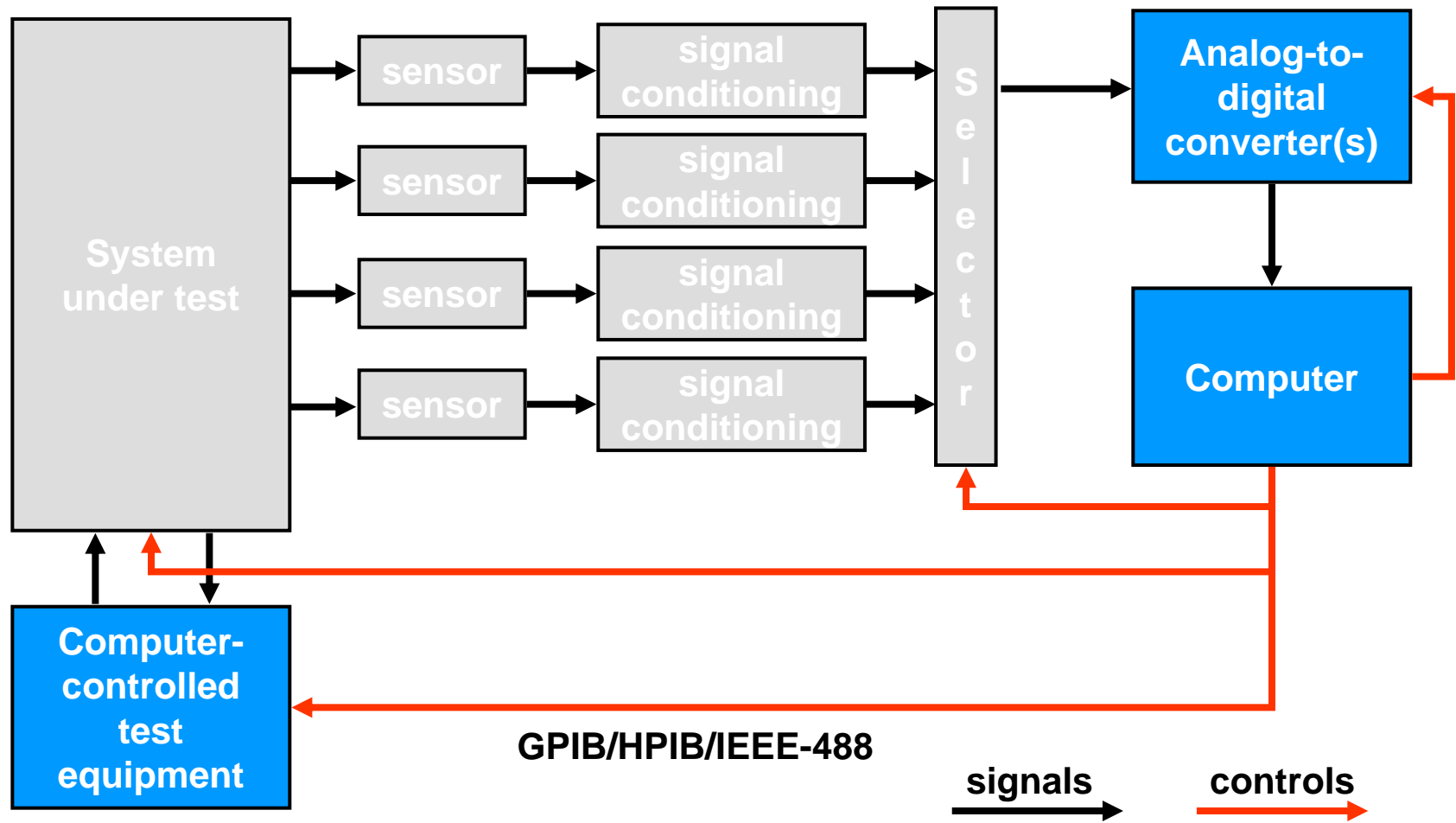
## E232 Spring 07

Class 8

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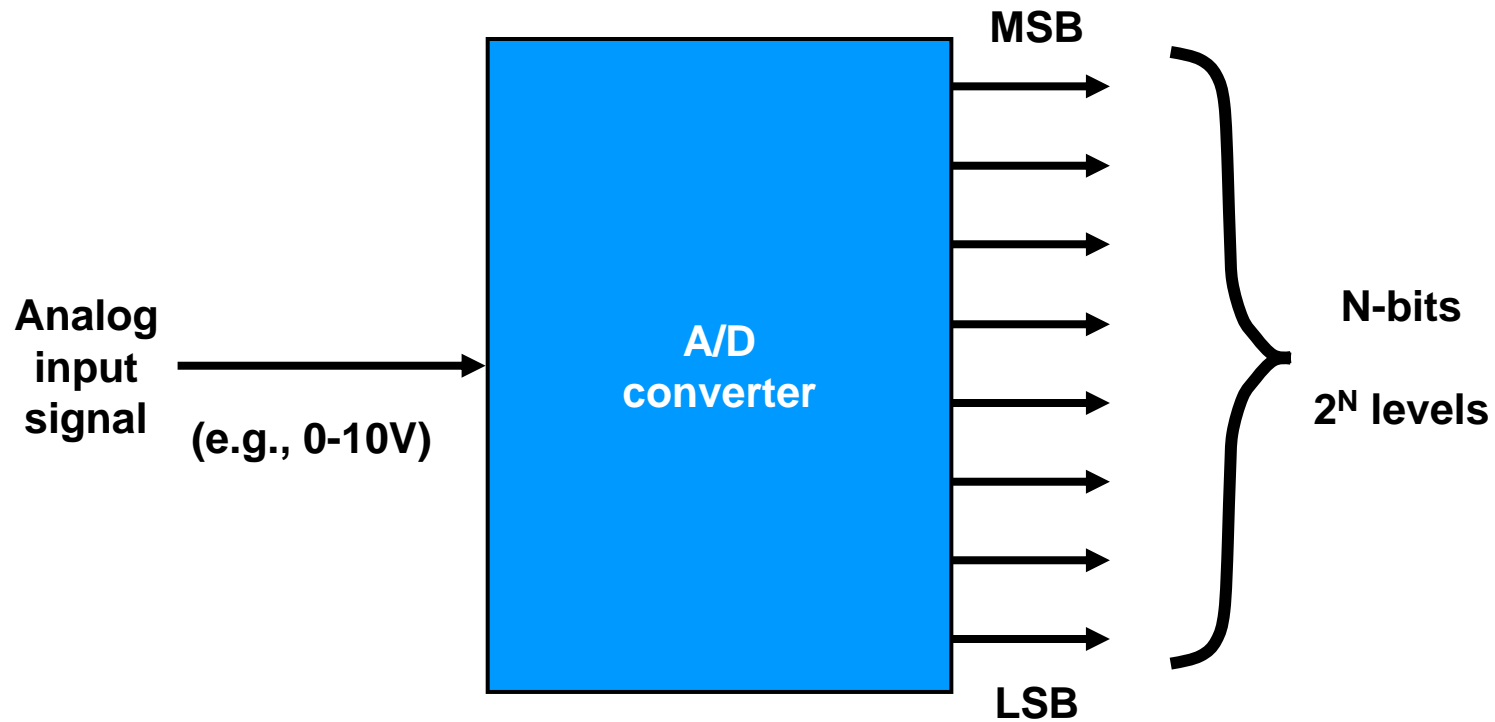
# Computerized Data Acquisition

- Measurement system architecture



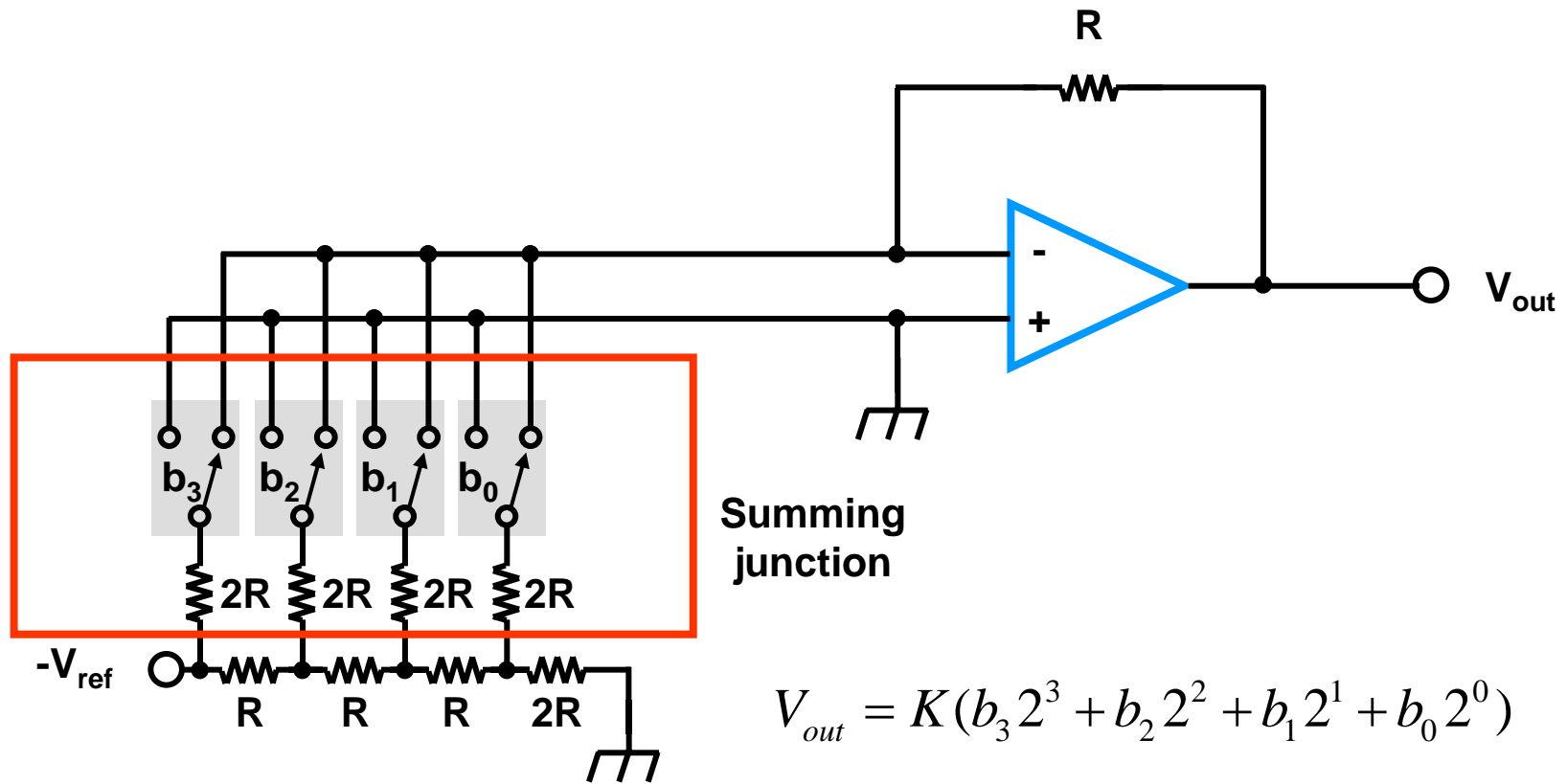
# Computerized Data Acquisition

- Analog-to-digital converters



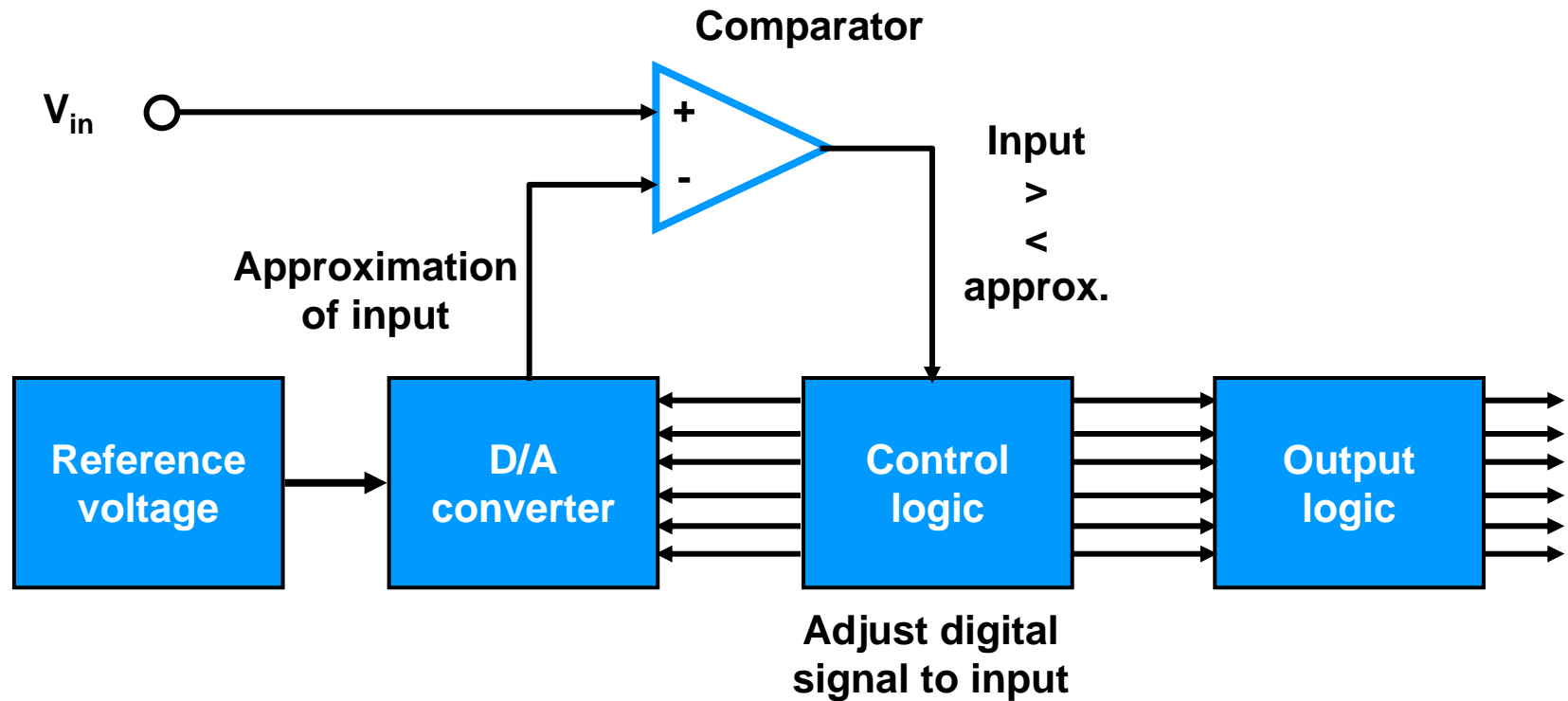
# Computerized Data Acquisition

- Digital-to-analog converters



# Computerized Data Acquisition

- Successive approximation A/D converter

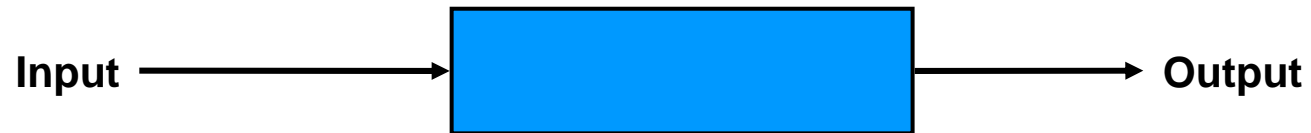


# Today's topics

- Computerized Data Acquisition
  - Quantization effects
  - Sampling
    - Anti-alias filtering
    - Reconstruction filtering

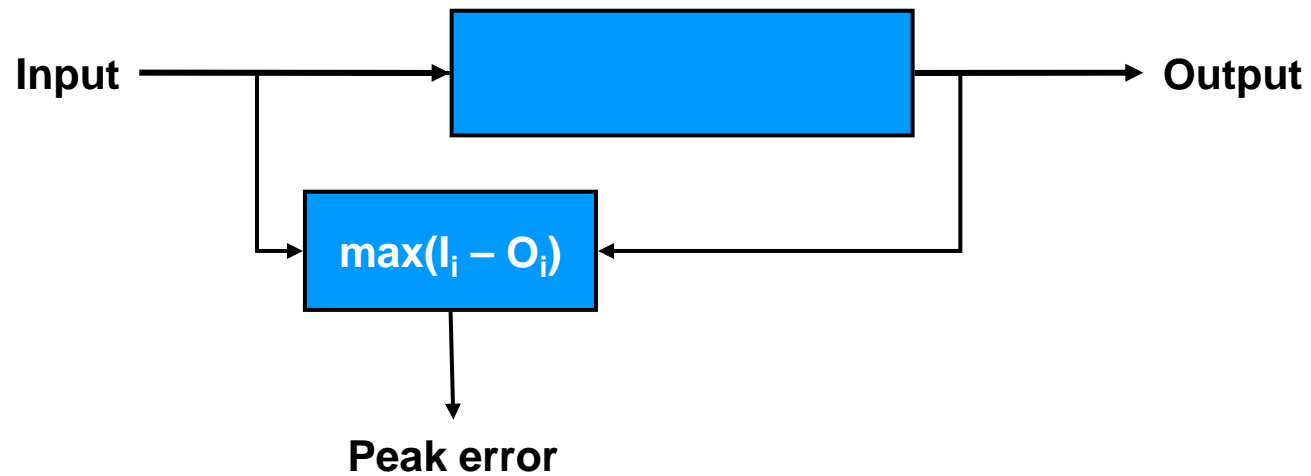
# Quantifying Error

- How well does output represent input signal?



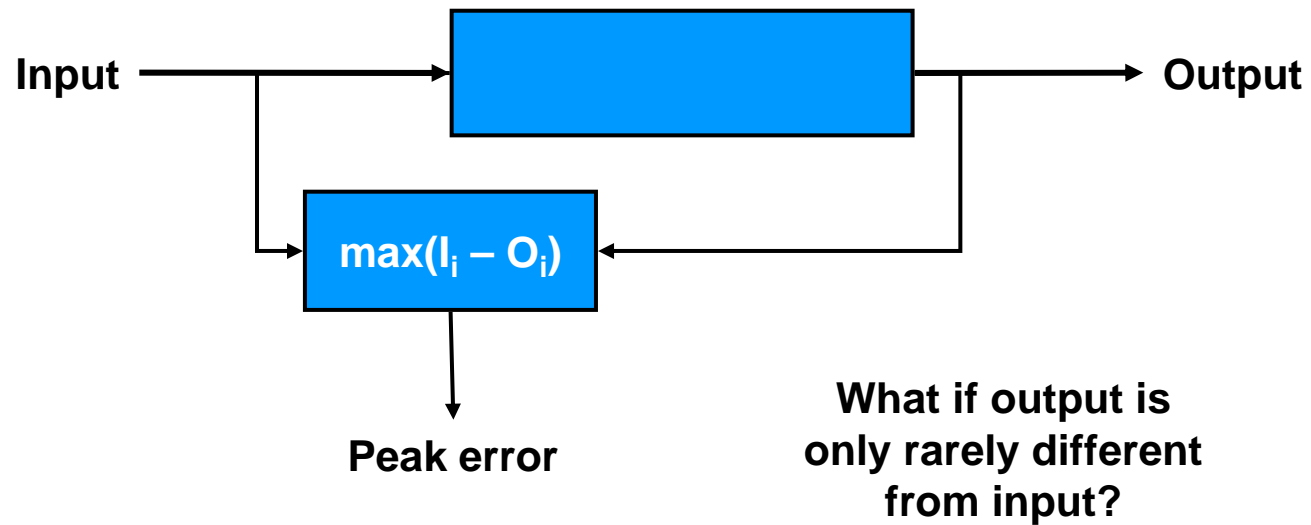
# Quantifying Error

- Peak error



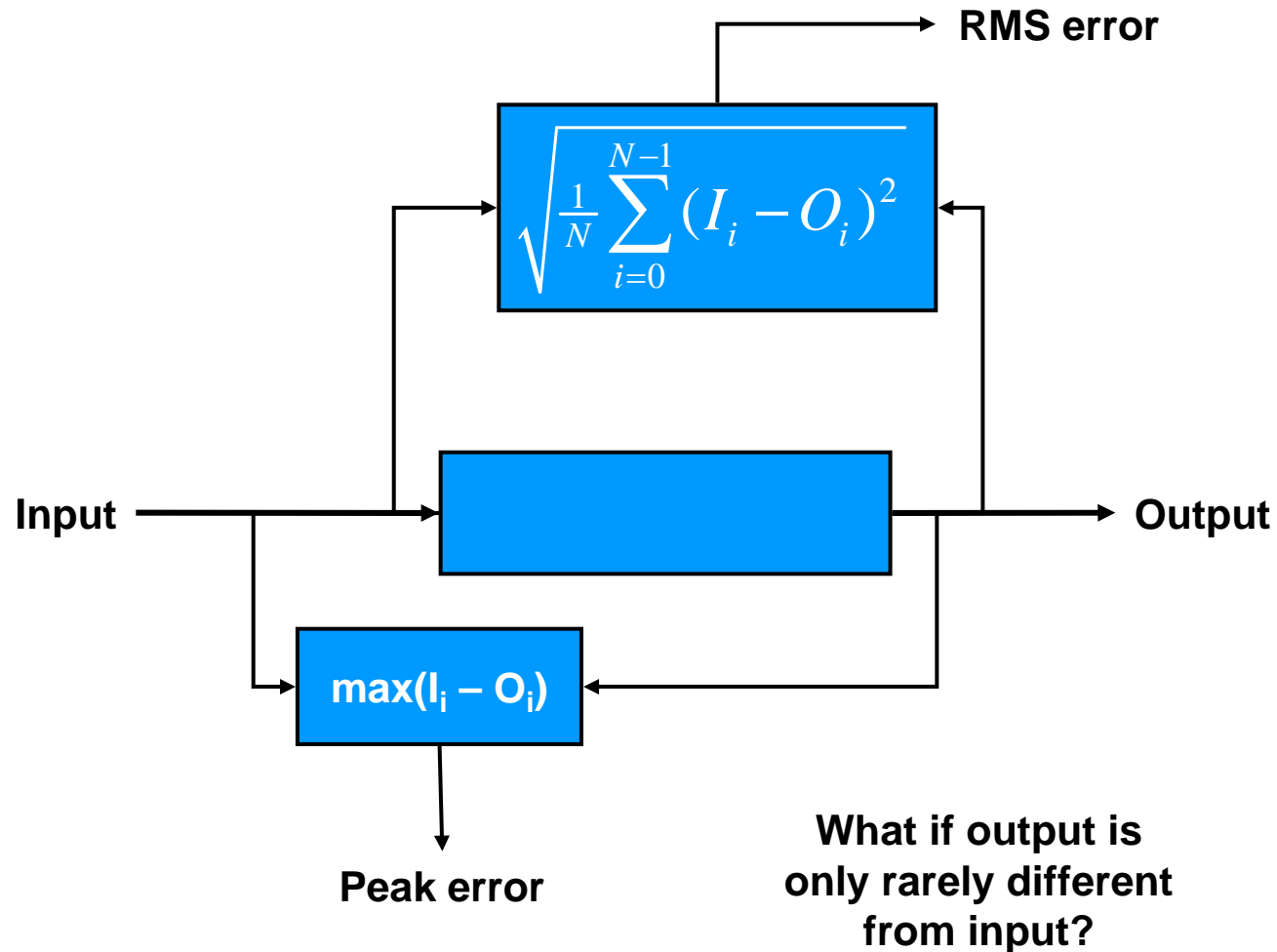
# Quantifying Error

- Peak error



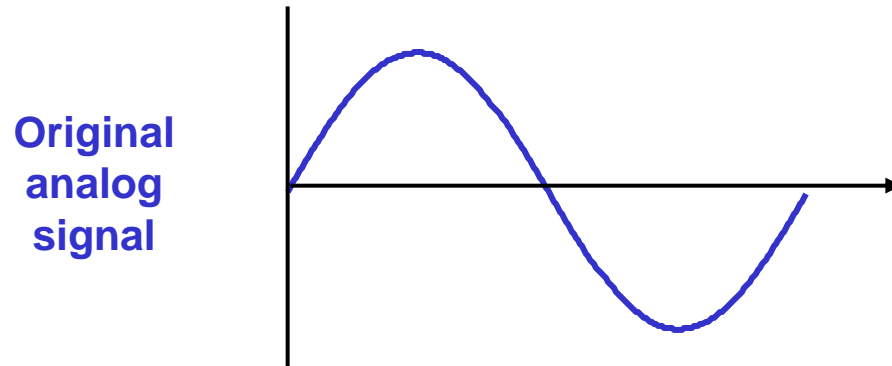
# Quantifying Error

- Root-Mean-Square (RMS) error



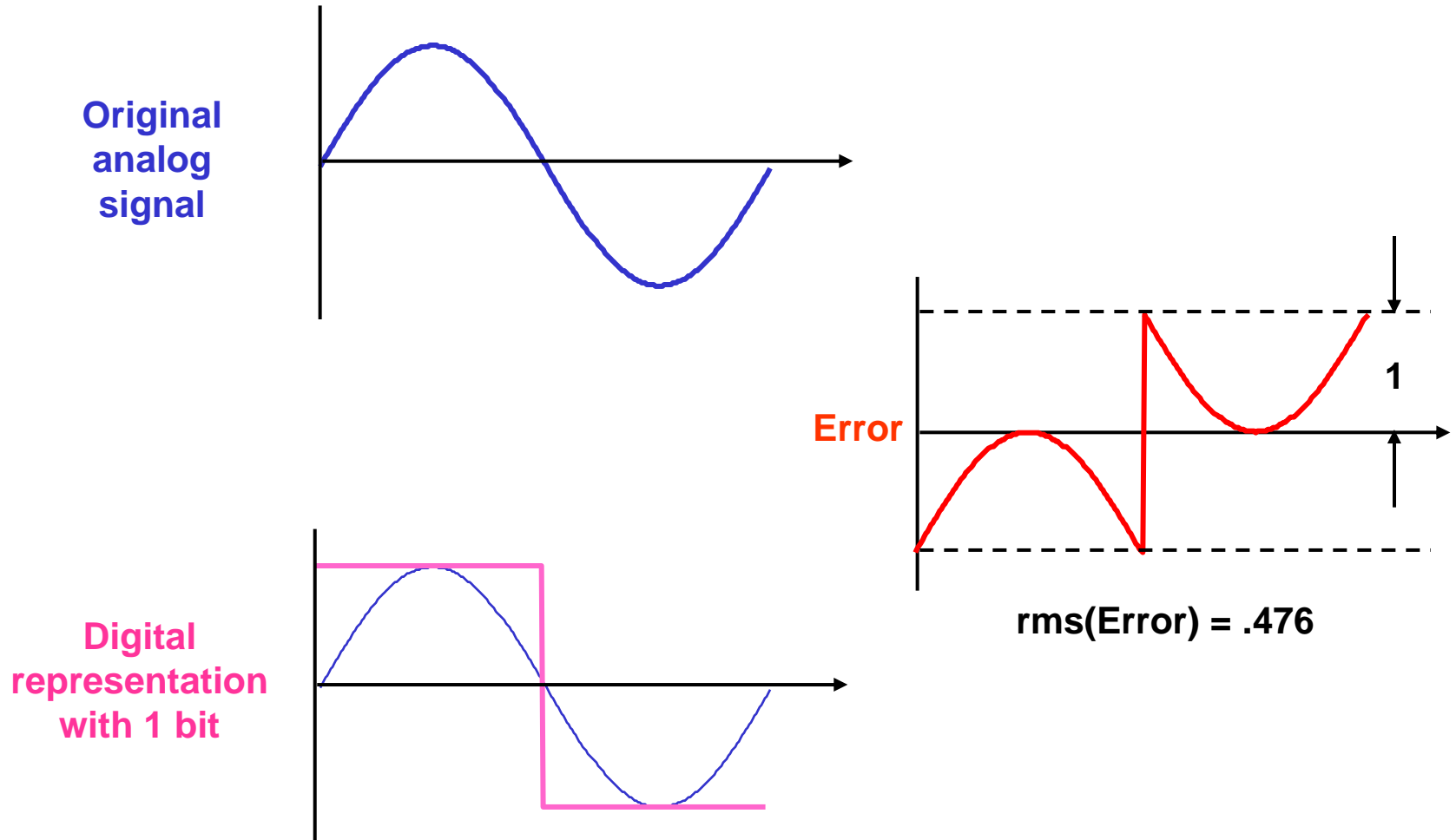
# Computerized Data Acquisition Systems

- Quantization effects



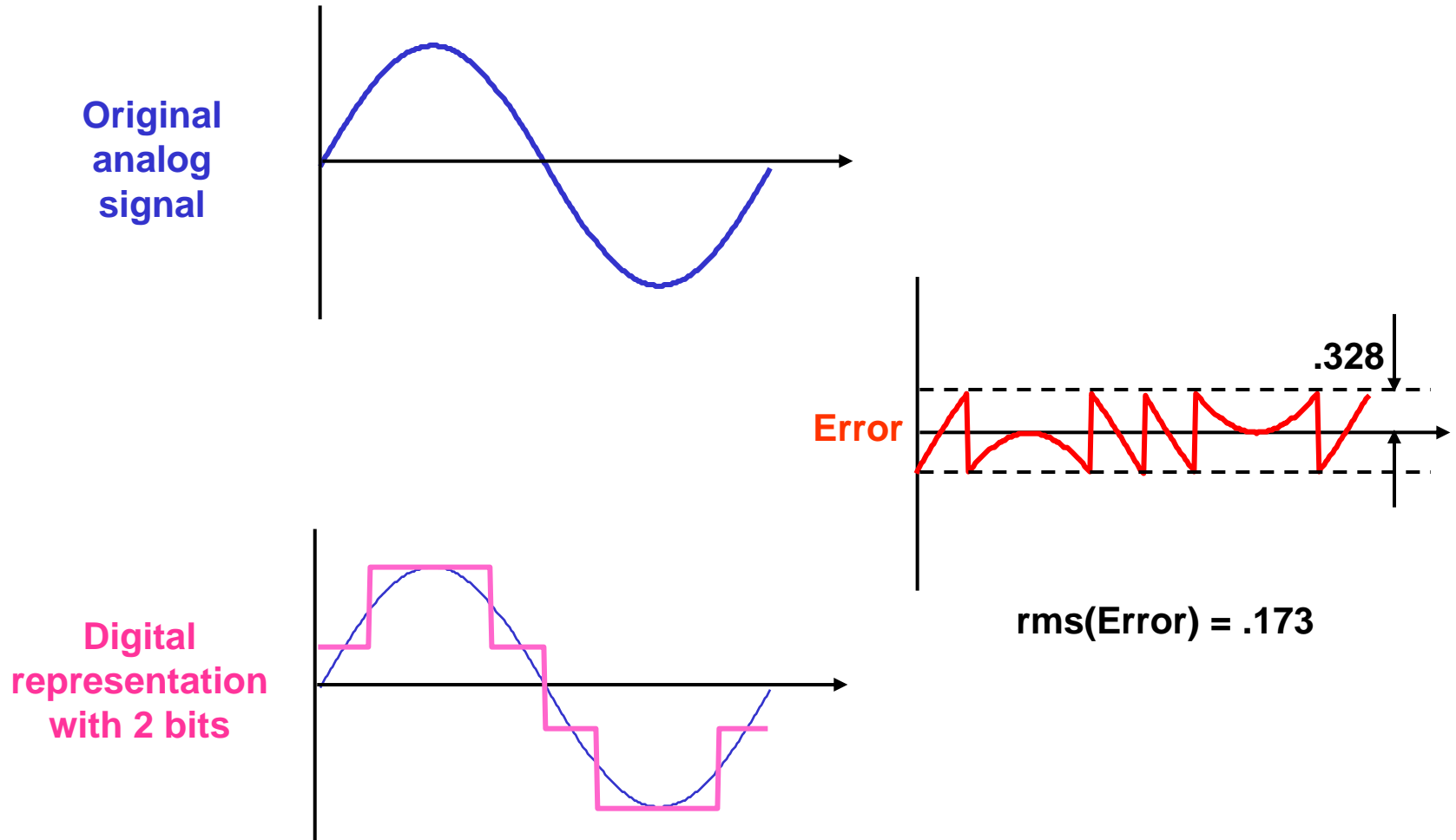
# Computerized Data Acquisition Systems

- Quantization effects



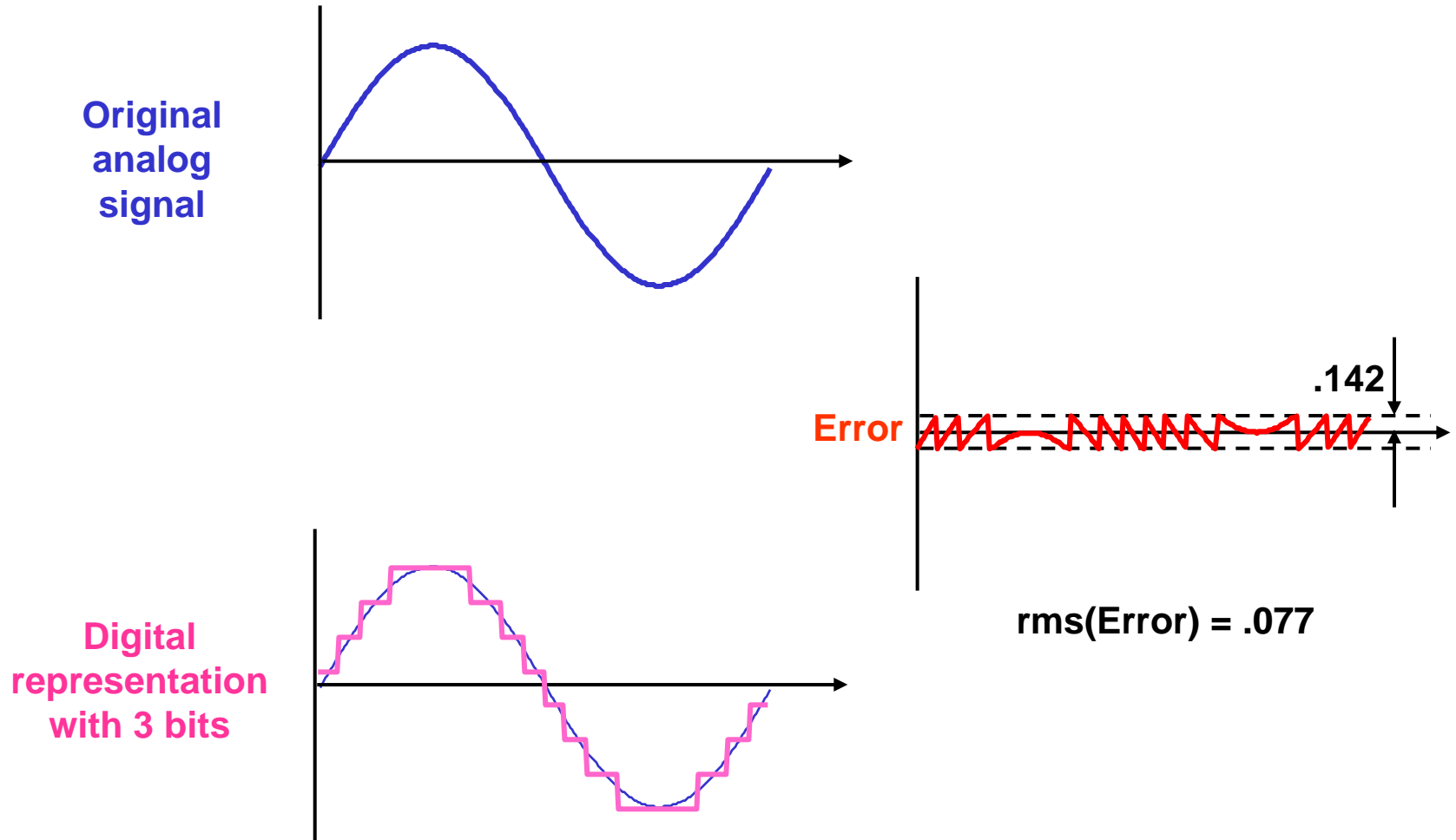
# Computerized Data Acquisition Systems

- Quantization effects



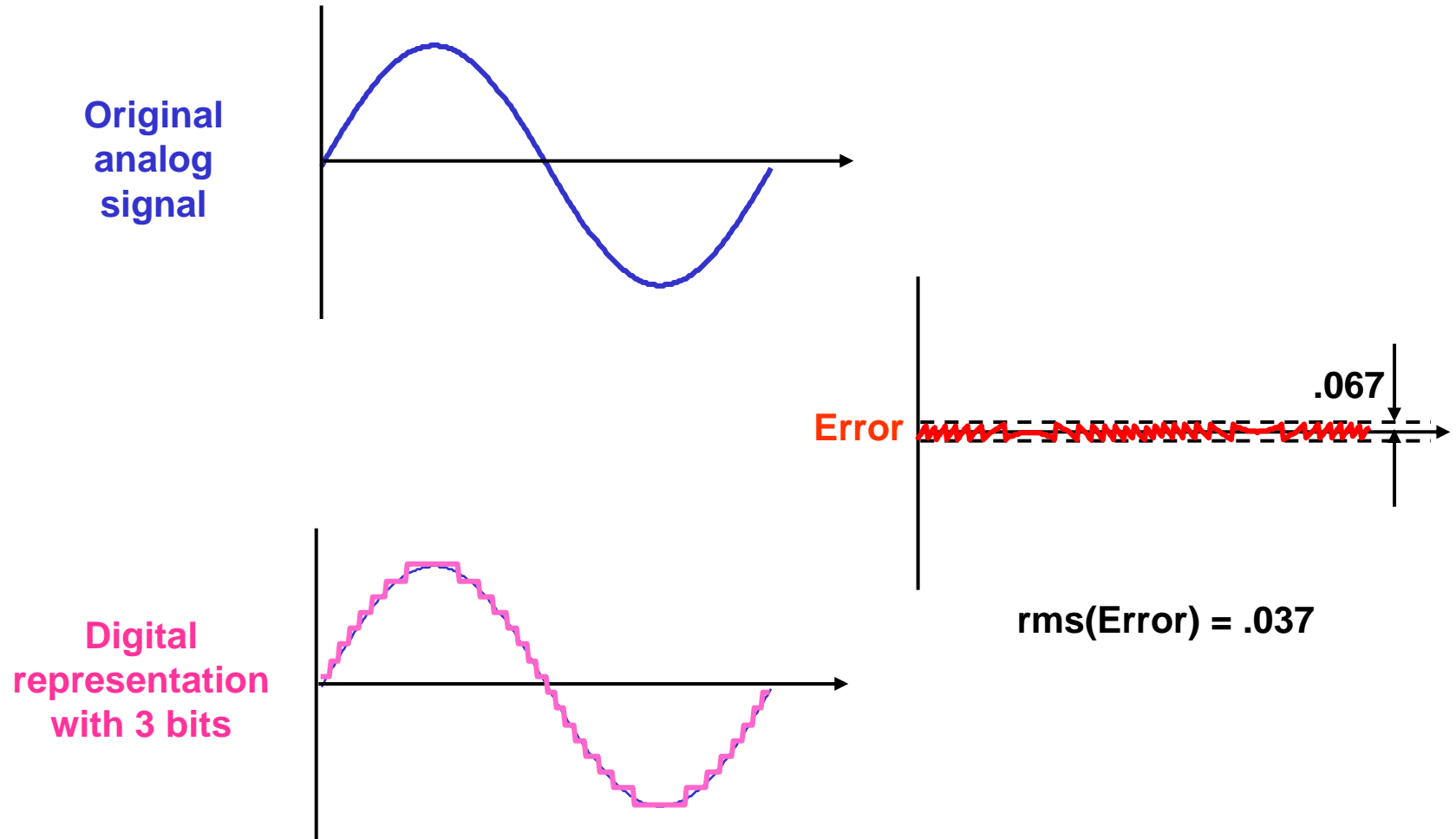
# Computerized Data Acquisition Systems

- Quantization effects

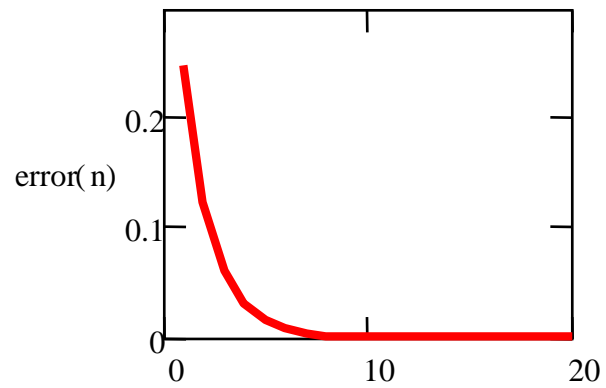


# Computerized Data Acquisition Systems

- Quantization effects

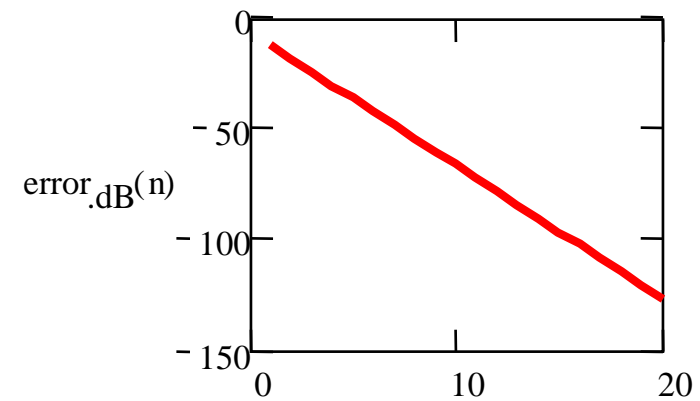
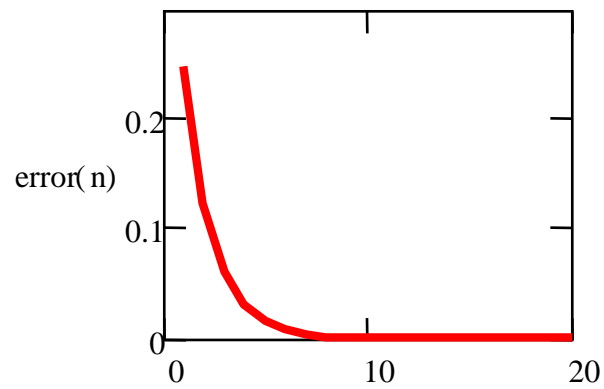


# Quantization Error



$$Q.E.(n) = \frac{.5}{2^n}$$

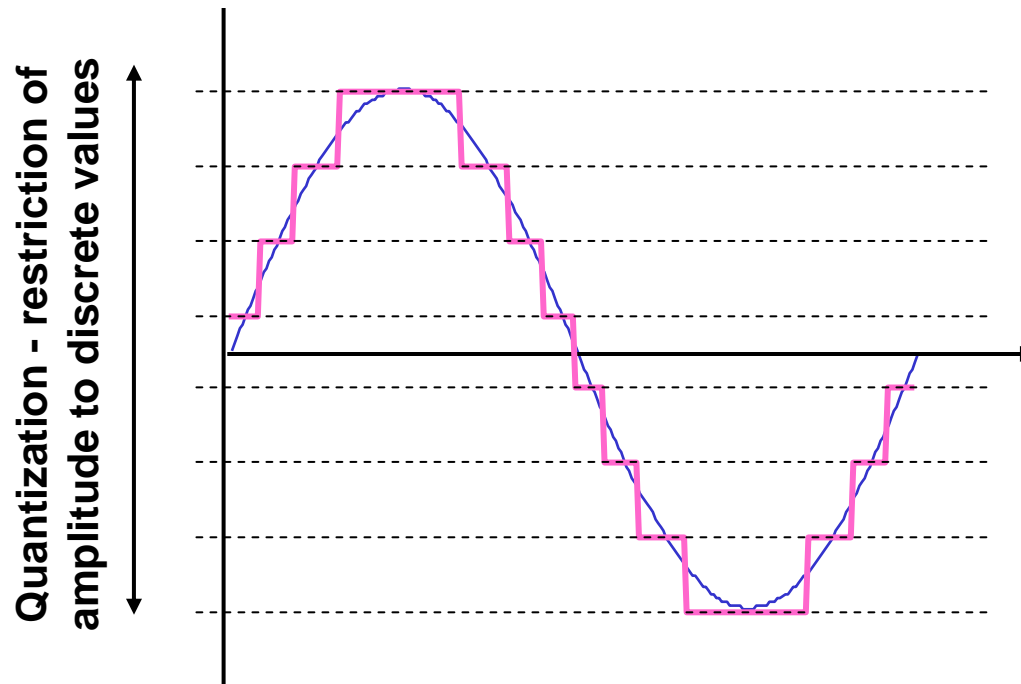
# Quantization Error



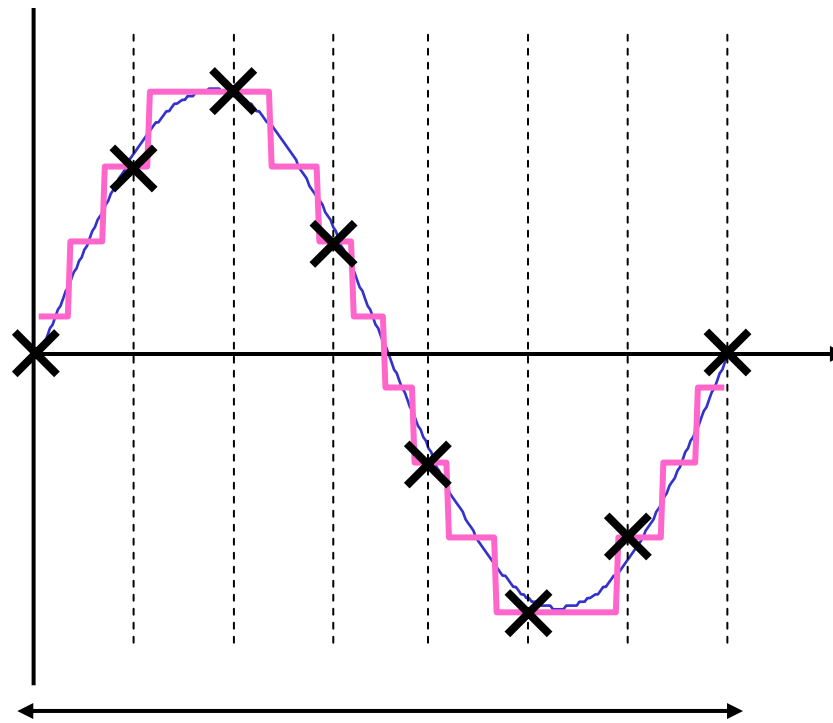
$$Q.E.(n) = \frac{.5}{2^n}$$

$$Q.E._{dB}(n) \approx -n \cdot 6$$

# Sampling Time-varying Signals

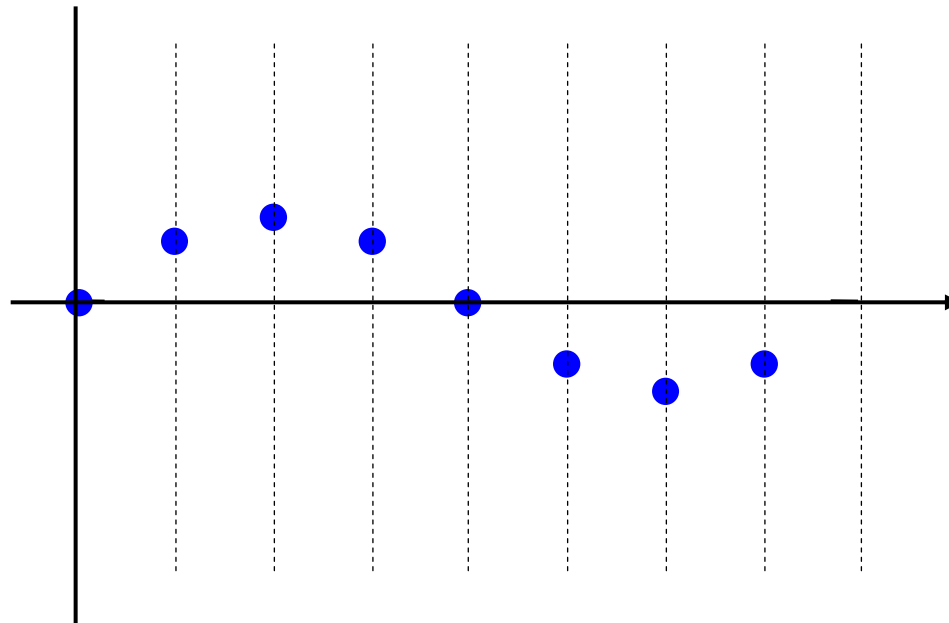


# Sampling Time-varying Signals



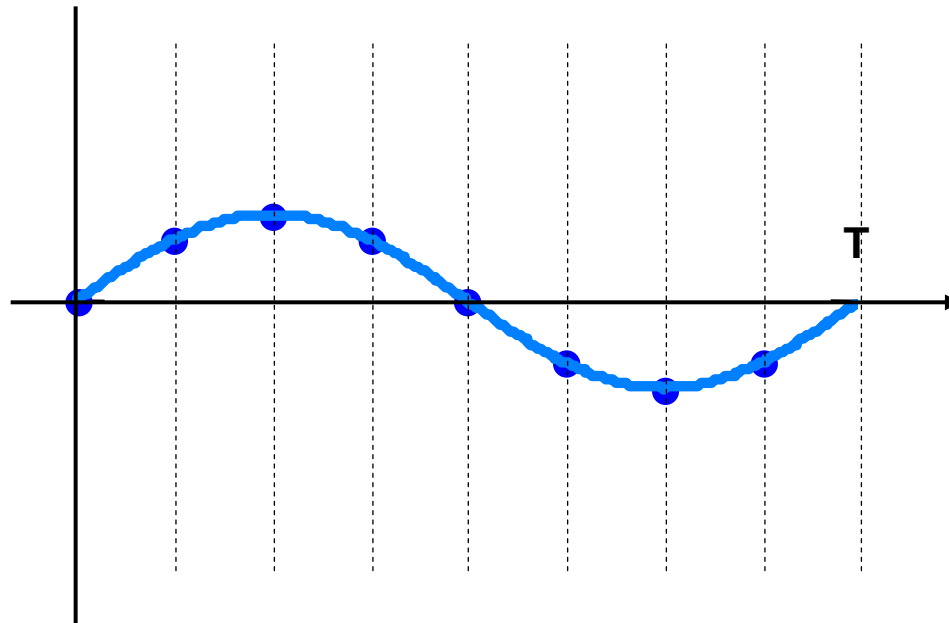
**Sampling at discrete points in time**

# Sampling Time-varying Signals



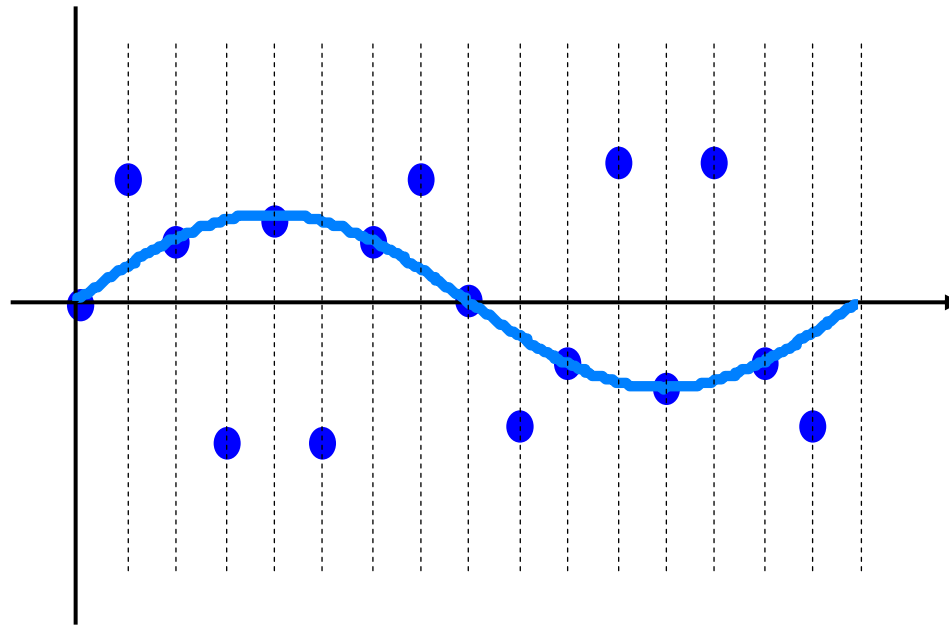
**These are samples of an analog signal –  
what is the waveform?**

# Sampling Time-varying Signals



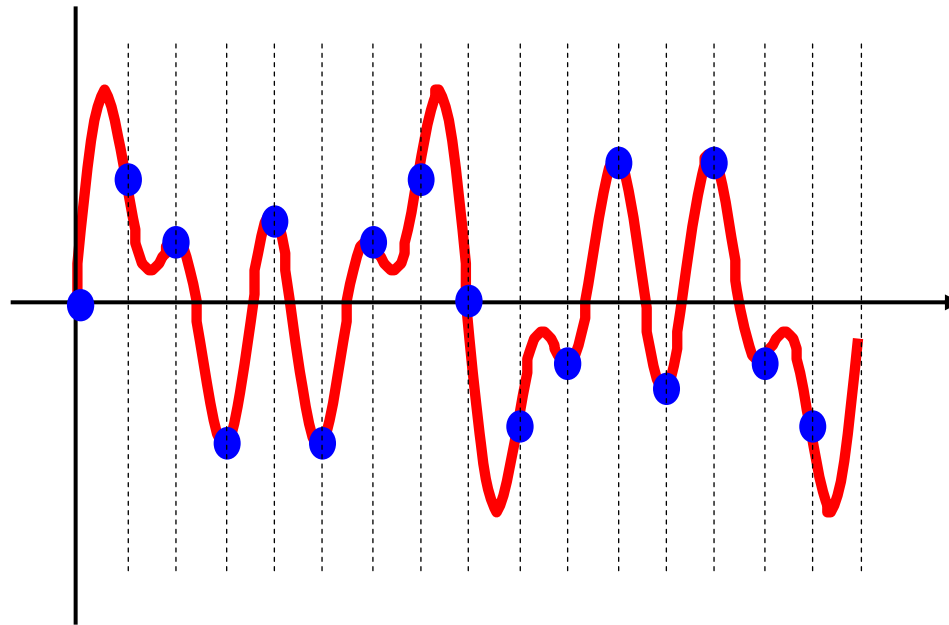
**Is it a sinusoid with a period  $T$ ?**

# Sampling Time-varying Signals



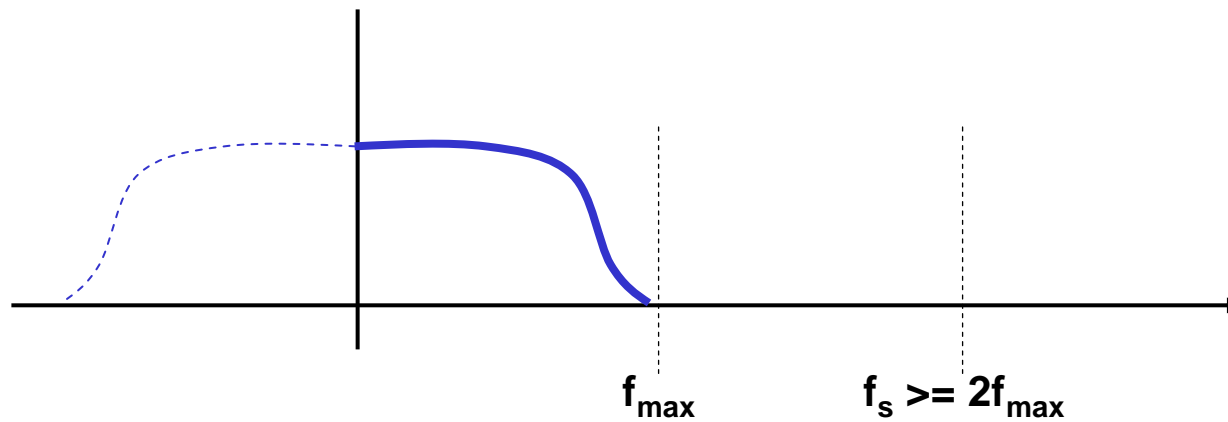
**What if we provide more samples?**

# Sampling Time-varying Signals



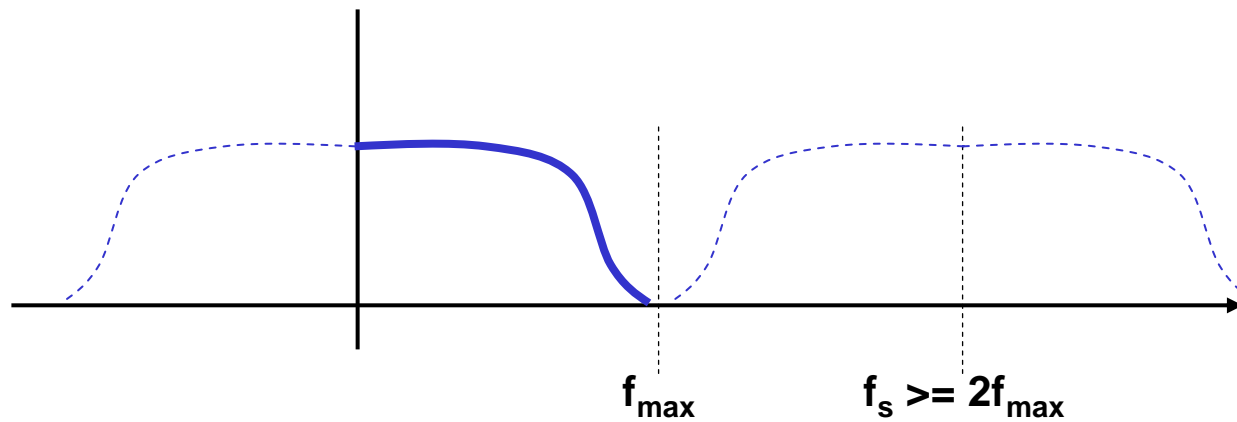
**This is what the actual signal looked like:  
The first set of samples was at too low a frequency**

# Nyquist Sampling Theorem



**A signal that has energy to  $f_{\max}$  must be sampled at a rate ( $2 \times f_{\max}$ ) or greater**

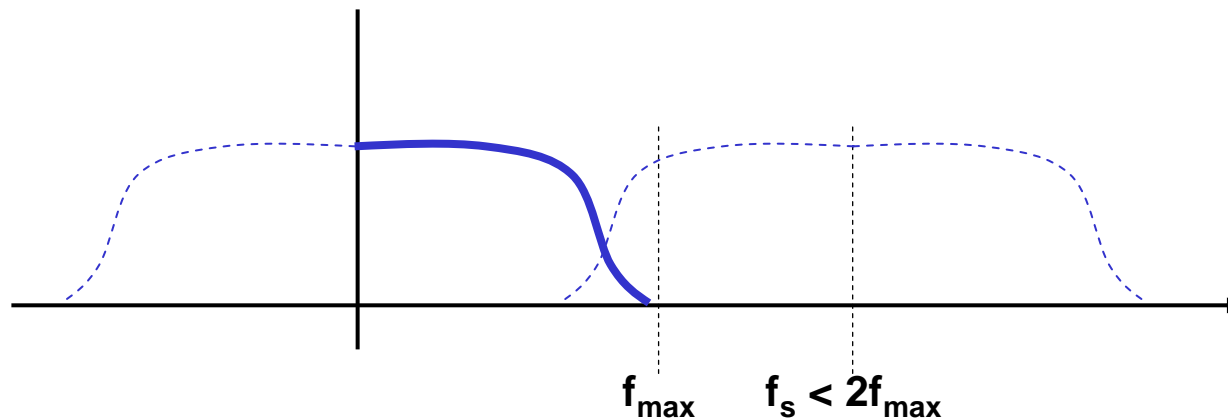
# Nyquist Sampling Theorem



**A signal that has energy to  $f_{\max}$  must be sampled at a rate ( $2 \times f_{\max}$ ) or greater**

**Sampling creates an “alias” copy of a signal**

# Nyquist Sampling Theorem

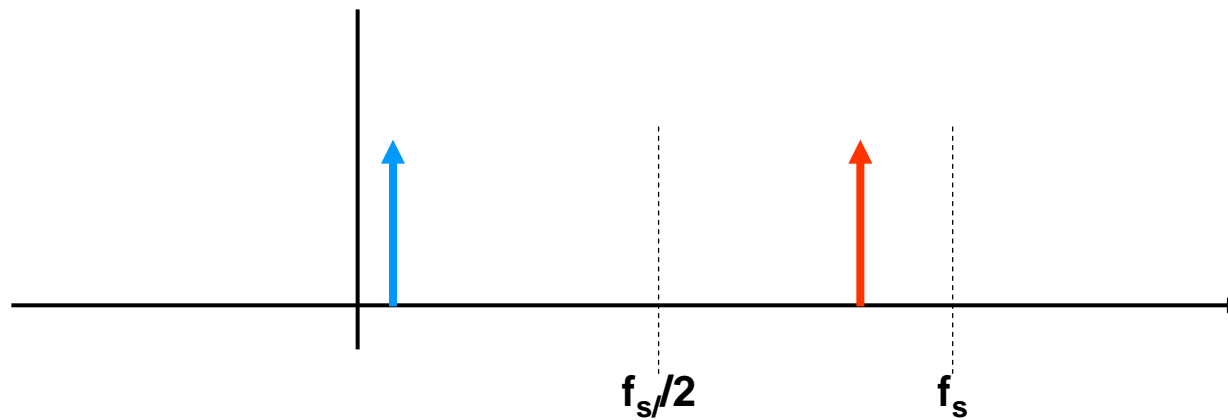


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**Sampling creates an “alias” copy of a signal**

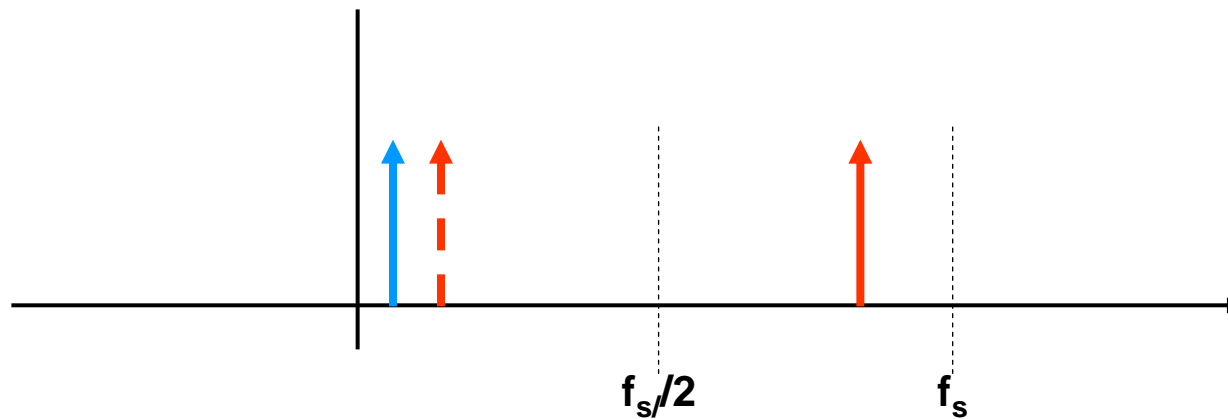
**If the sampling rate is less than twice the highest frequency, the alias overlaps the original, creating distortion**

# Nyquist Sampling Theorem



Consider  $f_s = 1000$  Hz with two signals,  $f_1 = 5$  Hz,  $f_2 = 990$  Hz.

# Nyquist Sampling Theorem



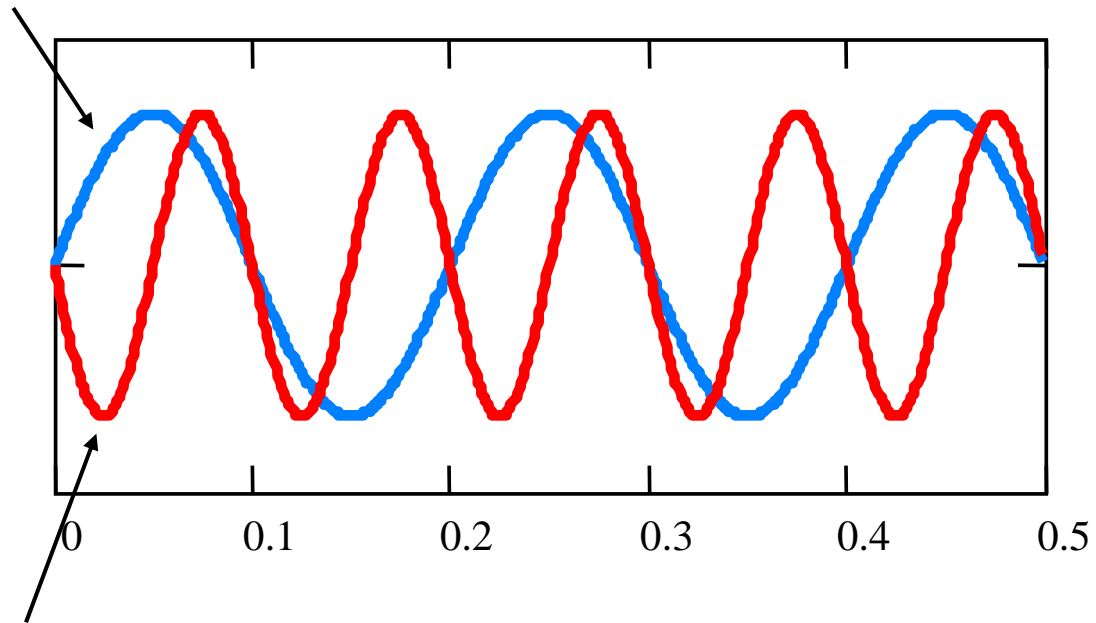
Consider  $f_s = 1000$  Hz with two signals,  $f_1 = 5$  Hz,  $f_2 = 990$  Hz.

Sampling creates a reflected signal (alias) around the sampling frequency.

Aliased signal at  $f_s - f_2 = 10$  Hz cannot be distinguished from a real signal at 10 Hz.

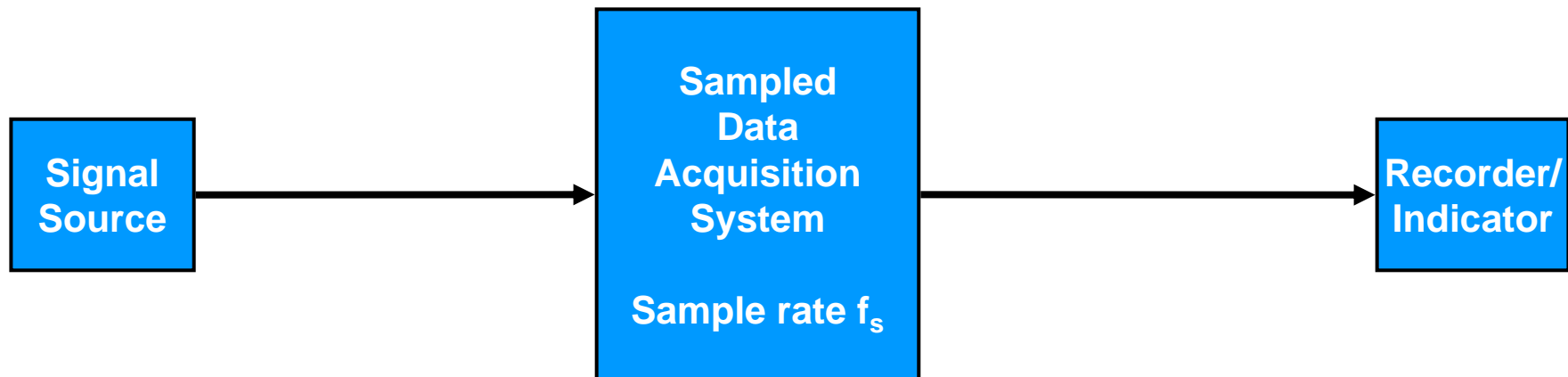
# Nyquist Sampling Theorem

Actual 5 Hz signal

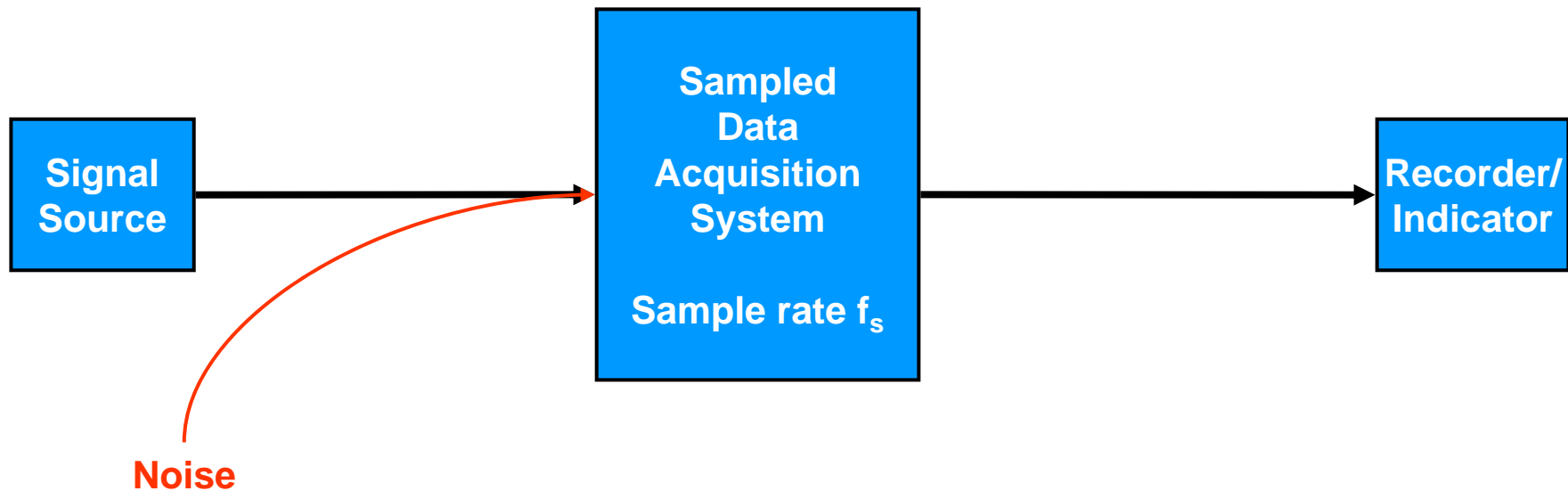


Alias of 990 Hz signal

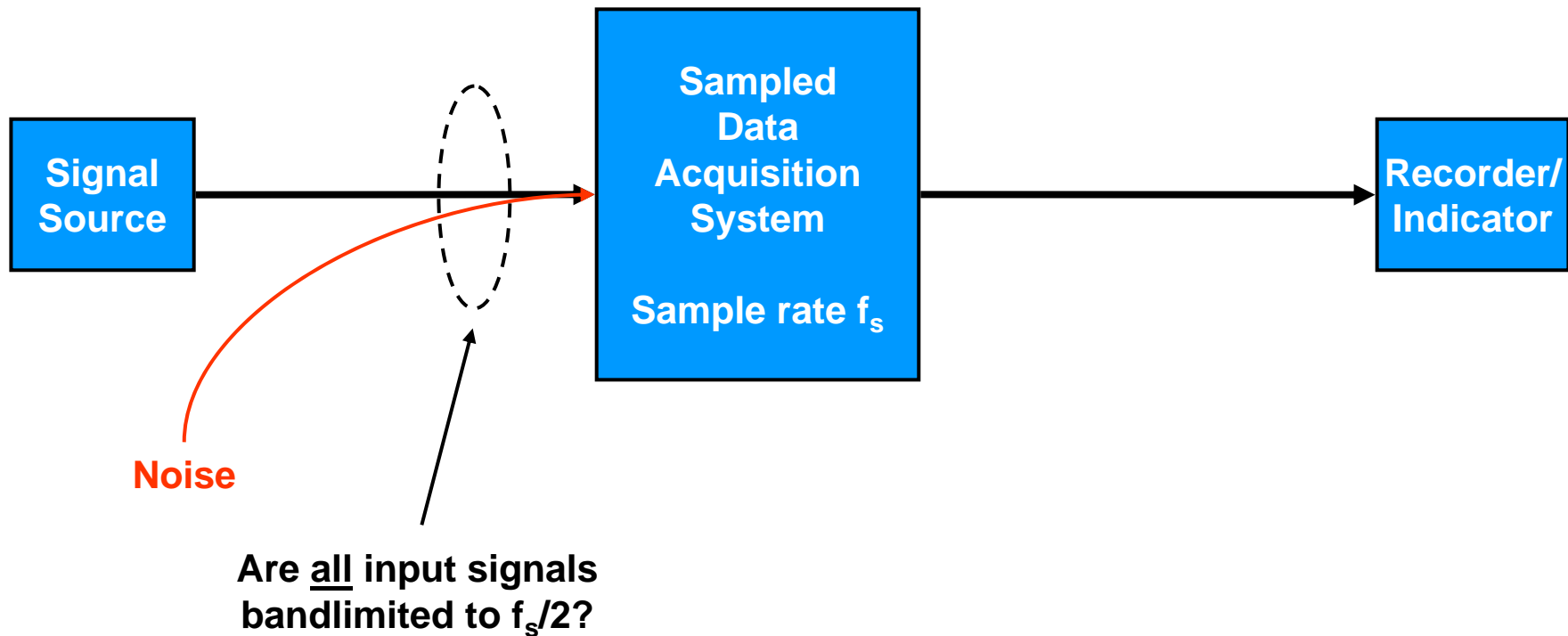
# Practical Sampling Considerations



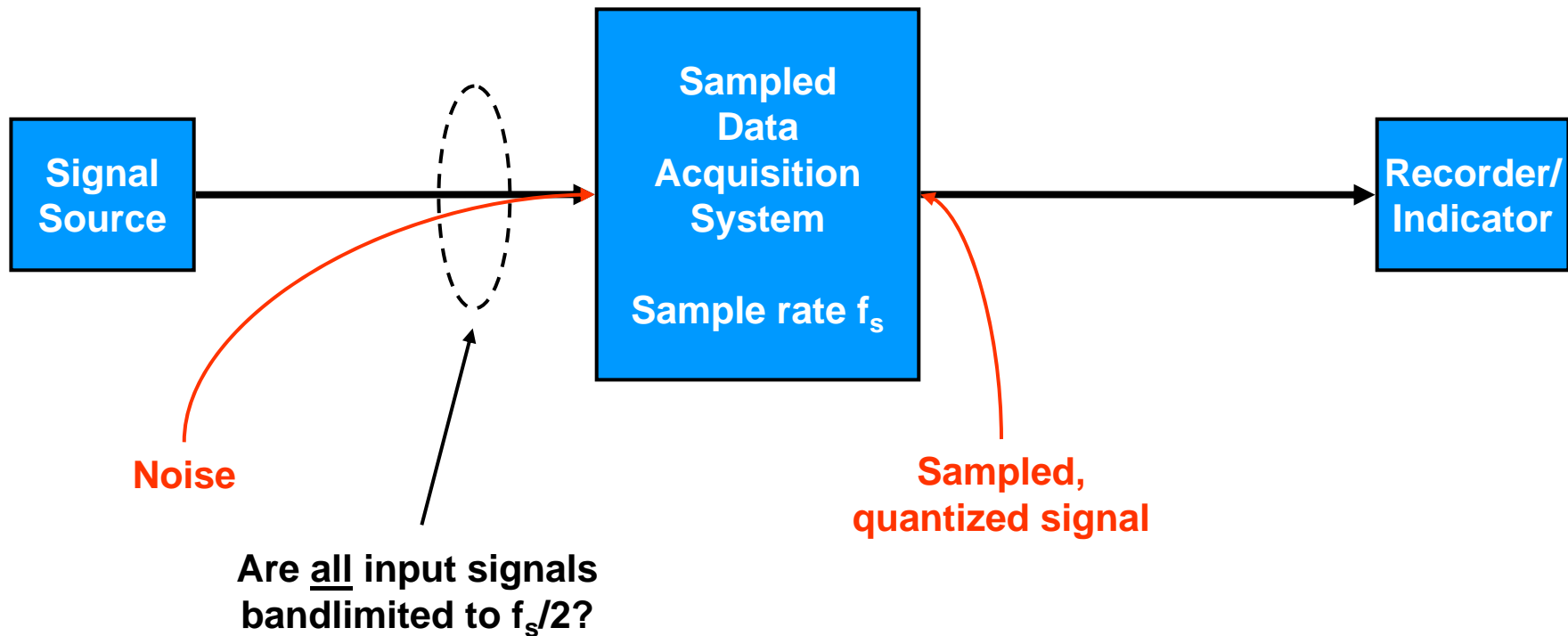
# Practical Sampling Considerations



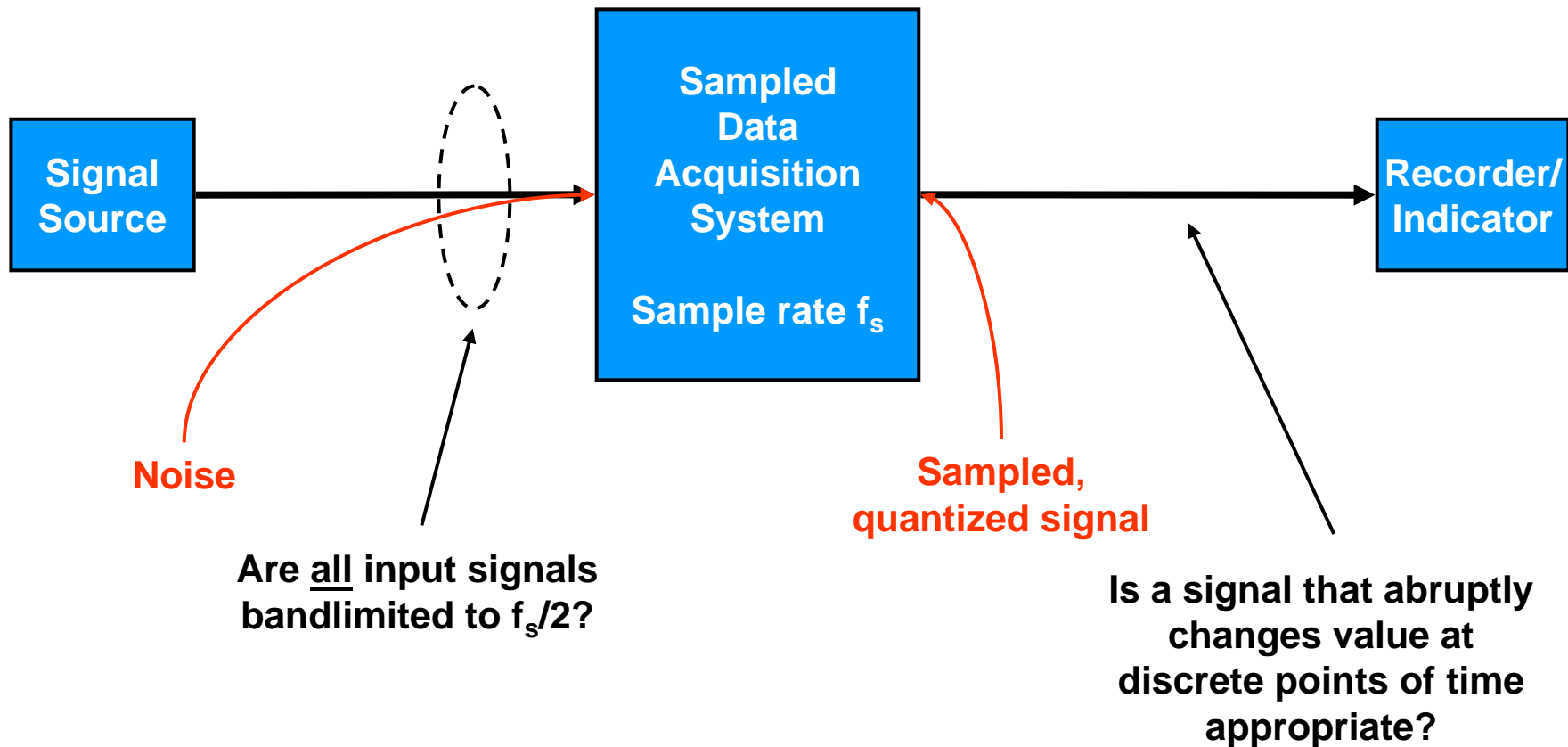
# Practical Sampling Considerations



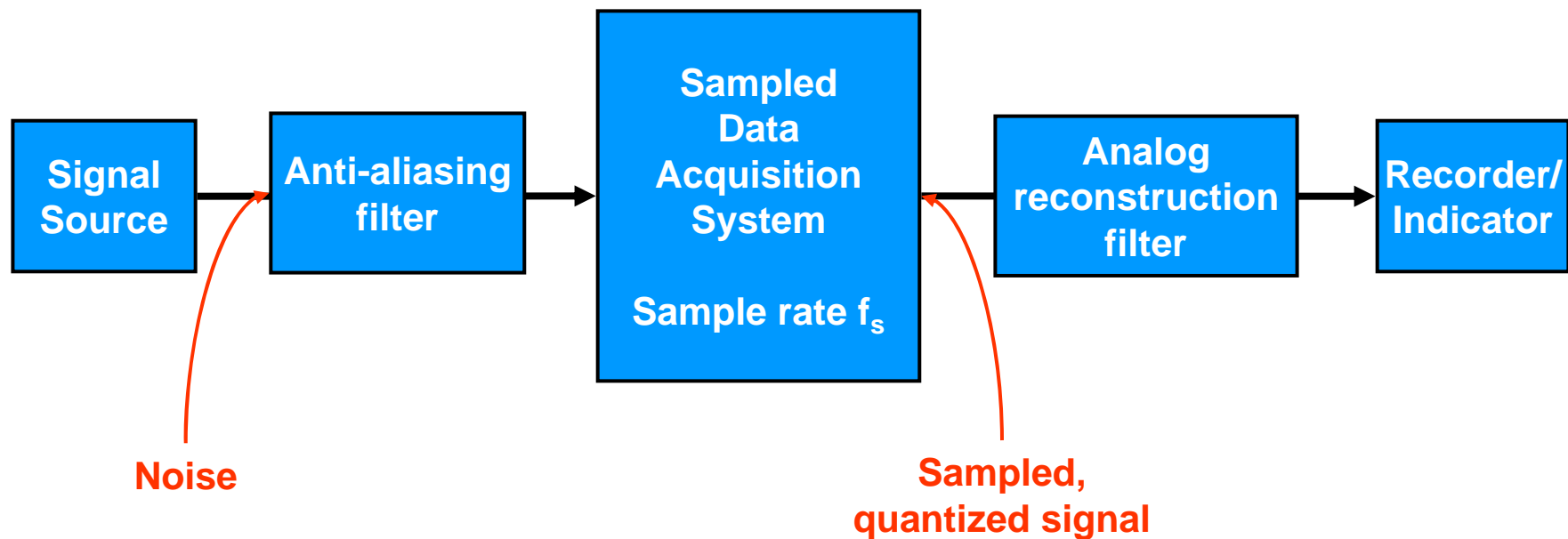
# Practical Sampling Considerations



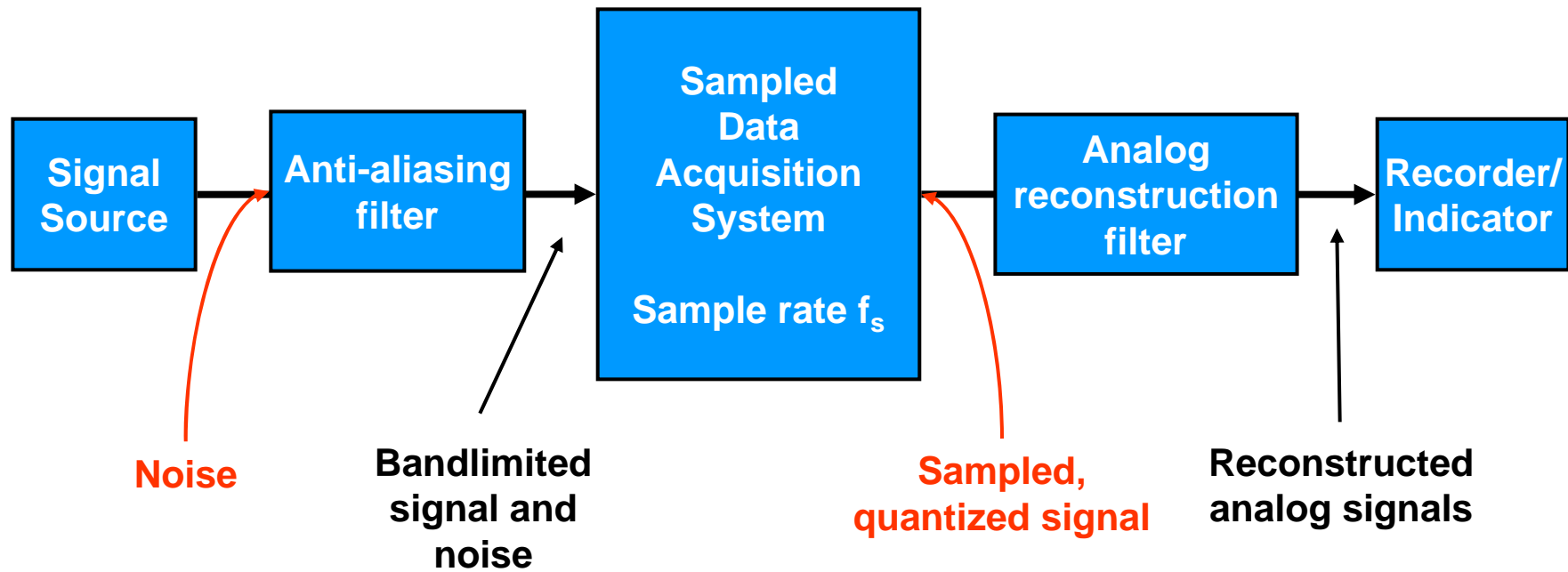
# Practical Sampling Considerations



# Practical Sampling Considerations



# Practical Sampling Considerations



# Next time

- Computerized Data Acquisition
  - Fourier Transform and frequency domain analysis

# Homework 4

- Read Chapter 5
- Problems 4.2, 4.5, 4.10, 5.14, 5.17