

Design IV

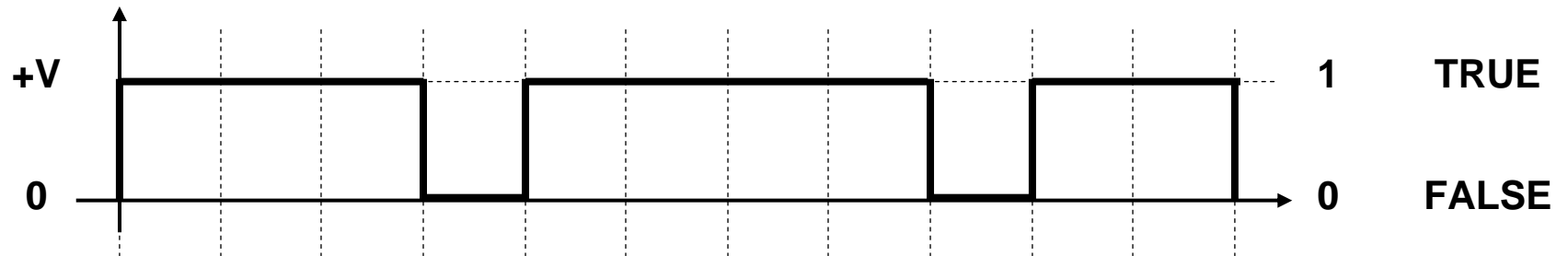
E232 Fall 07

Class 8

Bruce McNair
bmcnair@stevens.edu

Computerized Data Acquisition

- Signal representation



**All information is represented by a series of 1's and 0's
using Base-2 arithmetic**

Computerized Data Acquisition

- Signal representation

In Base-10 arithmetic:

$$849_{10} = (8 \times 10^2) + (4 \times 10^1) + (9 \times 10^0)$$

In Base-2 arithmetic:

$$\begin{aligned} 849_{10} &= 1101010001_2 = \\ & (1 \times 2^9) + (1 \times 2^8) + (0 \times 2^7) + (1 \times 2^6) + (0 \times 2^5) + \\ & (1 \times 2^4) + (0 \times 2^3) + (0 \times 2^2) + (0 \times 2^1) + (1 \times 2^0) = \\ & 512 + 256 + 64 + 16 + 1 \end{aligned}$$

Computerized Data Acquisition

- Converting Base-10 to Base-2:
 - Successive integer division by 2, noting remainder

Remainder:

2)849		
2)424	-> 1	
2)212	-> 0	
2)106	-> 0	
2)53	-> 0	
2)26	-> 1	
2)13	-> 0	
2)6	-> 1	
2)3	-> 0	
2)1	-> 1	
0	-> 1	-> 1101010001

Computerized Data Acquisition

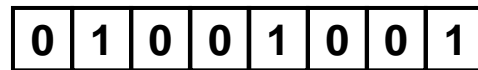
- Converting Base-2 to Base-10:
 - Successive doubling with addition of bits

$$\begin{aligned} & 1001001_2 = \\ & 2^6 + 2^3 + 2^0 = \\ & (((1 \times 2) + 0) \times 2) + 0) \times 2) + 1) \times 2) + 0) \times 2) + 0) \times 2) + 1 = 73_{10} \end{aligned}$$

Computerized Data Acquisition

- Representing binary numbers

73_{10} :



MSB

LSB

- Representing negative numbers – 2's complement:

-73_{10} :



MSB

LSB

Computerized Data Acquisition

- Representing binary numbers

73_{10} :

0	1	0	0	1	0	0	1
---	---	---	---	---	---	---	---

MSB

LSB

- Representing negative numbers – 2's complement:

-73_{10} :

Sign

1	0	1	1	0	1	1	1
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MSB

LSB

	01001001
Invert bits	10110110
Add 1	00000001
	10110111

Computerized Data Acquisition

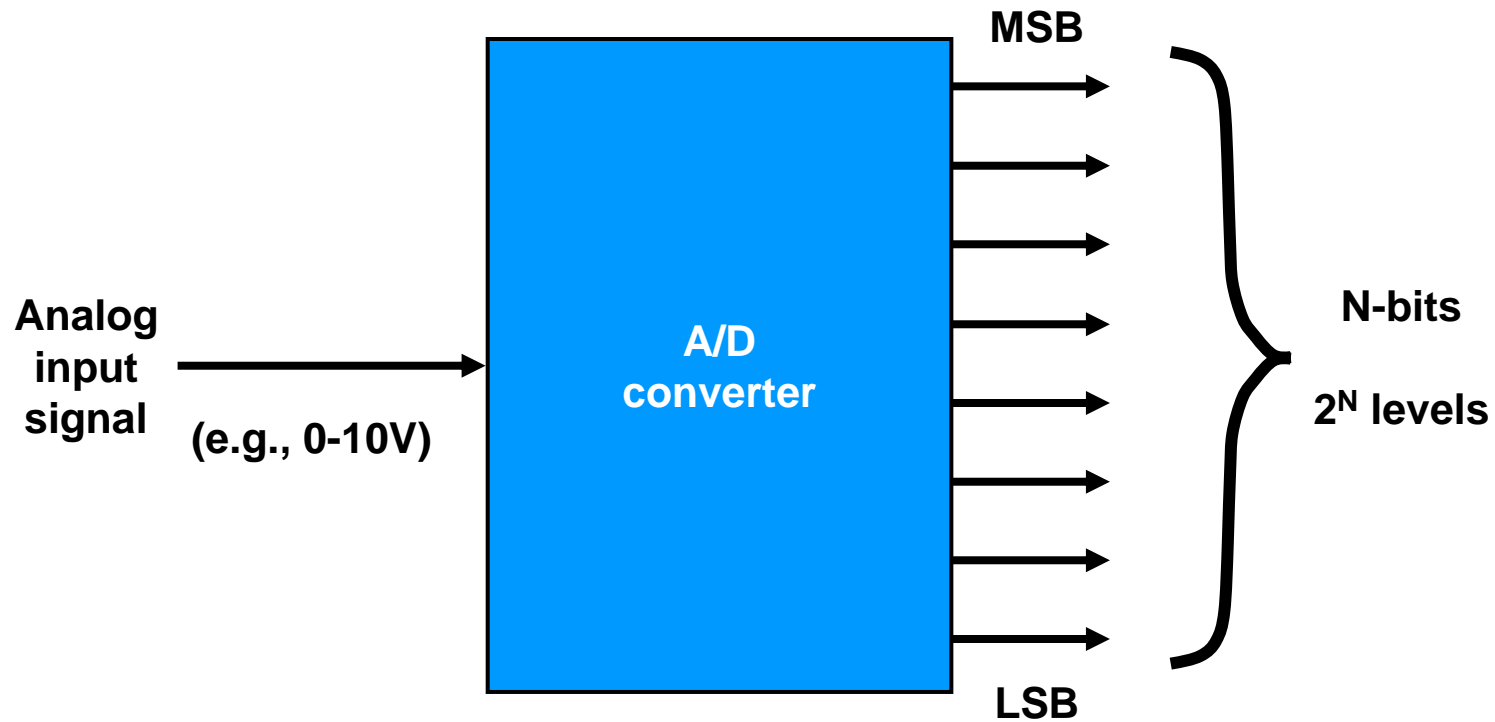
- Arithmetic with 2's complement

10_{10}	00001010
$+23_{10}$	00010111
-----	-----
33_{10}	00100001
-17_{10}	11101111
-----	-----
16_{10}	X00010000

2's complement numbers can be added (subtraction by adding negative numbers) continually, as long as final result can fit in word size.

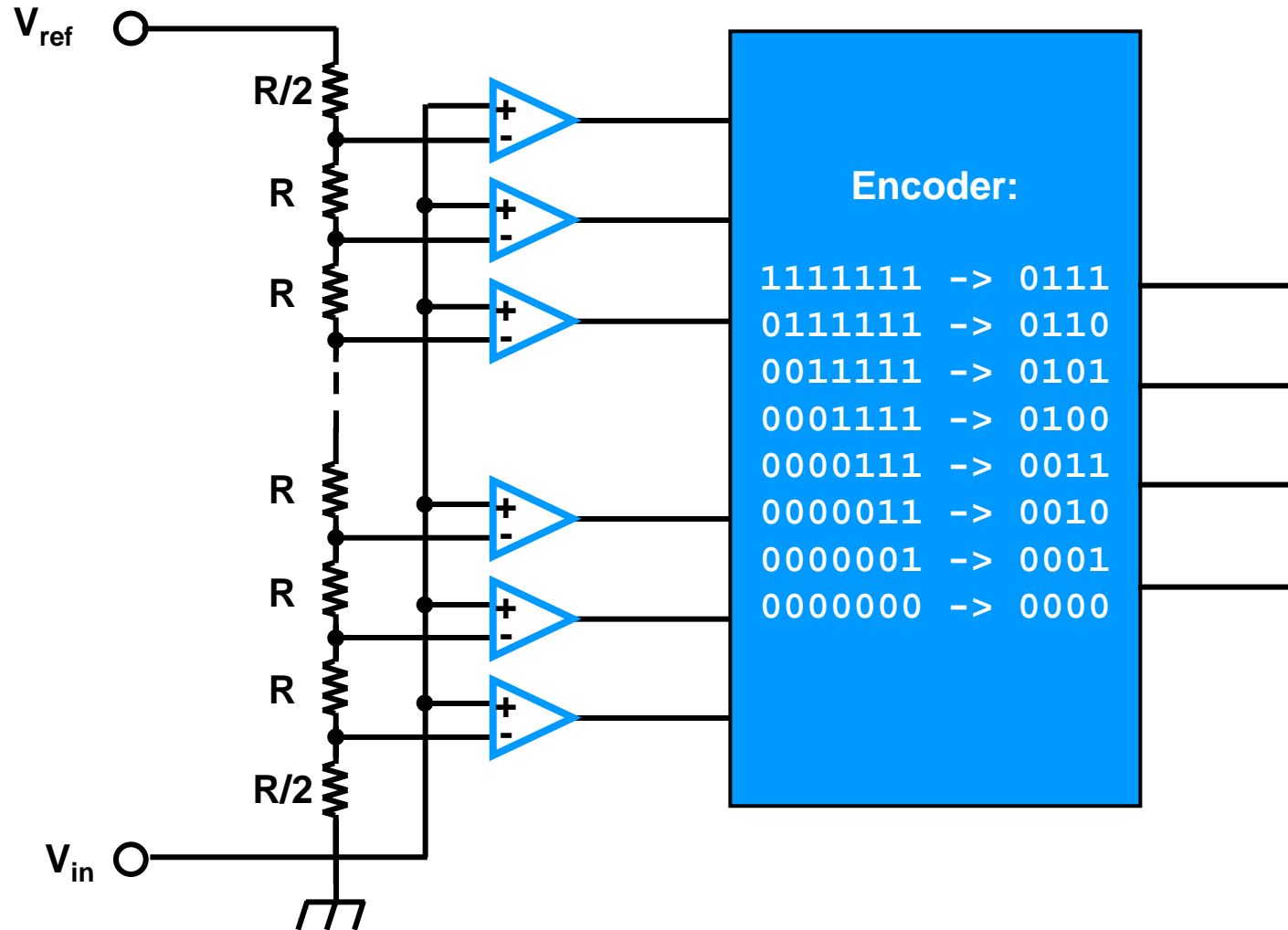
Computerized Data Acquisition

- Analog-to-digital converters



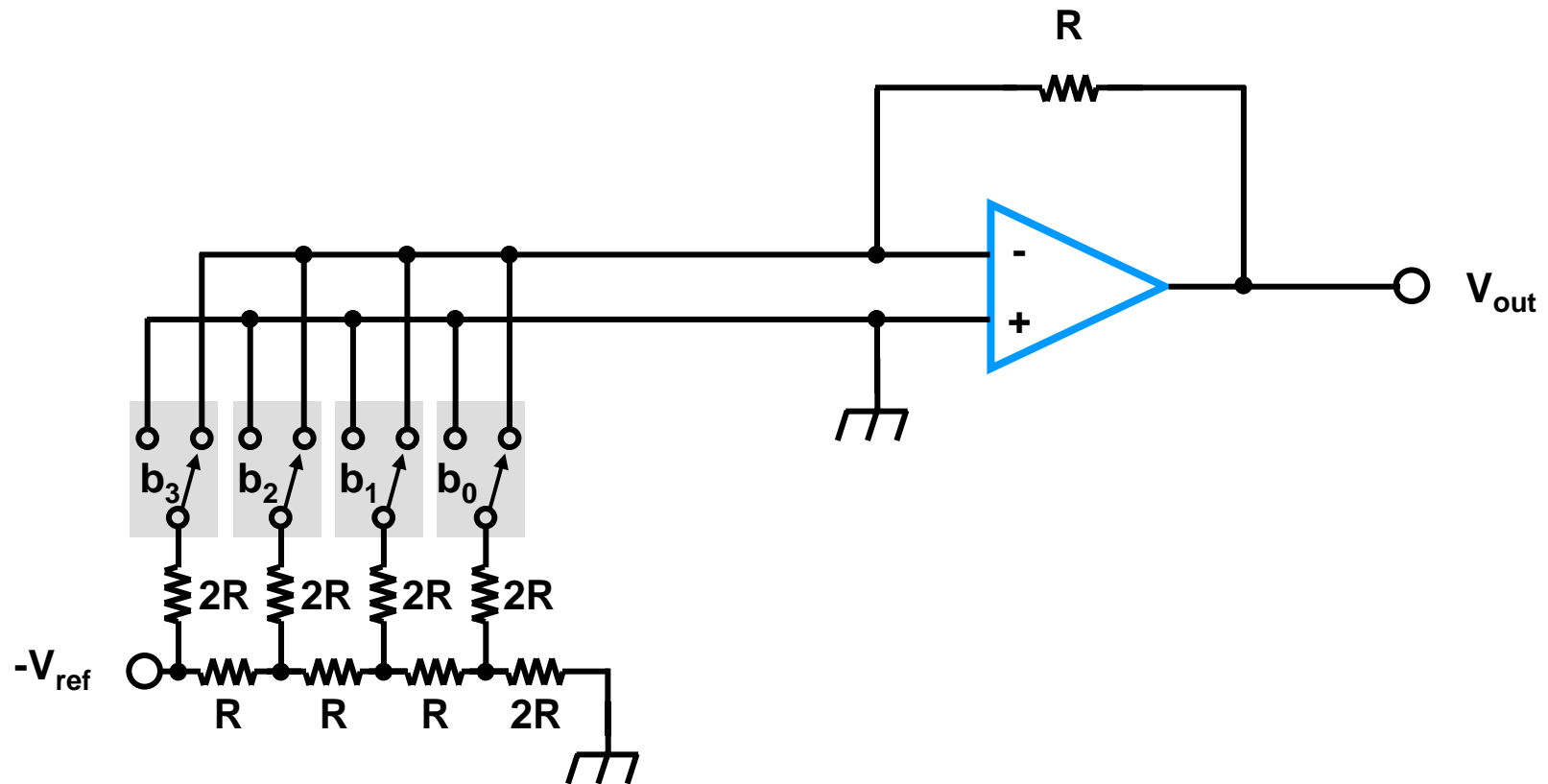
Computerized Data Acquisition

- Analog-to-digital converters – Parallel/Flash A/D



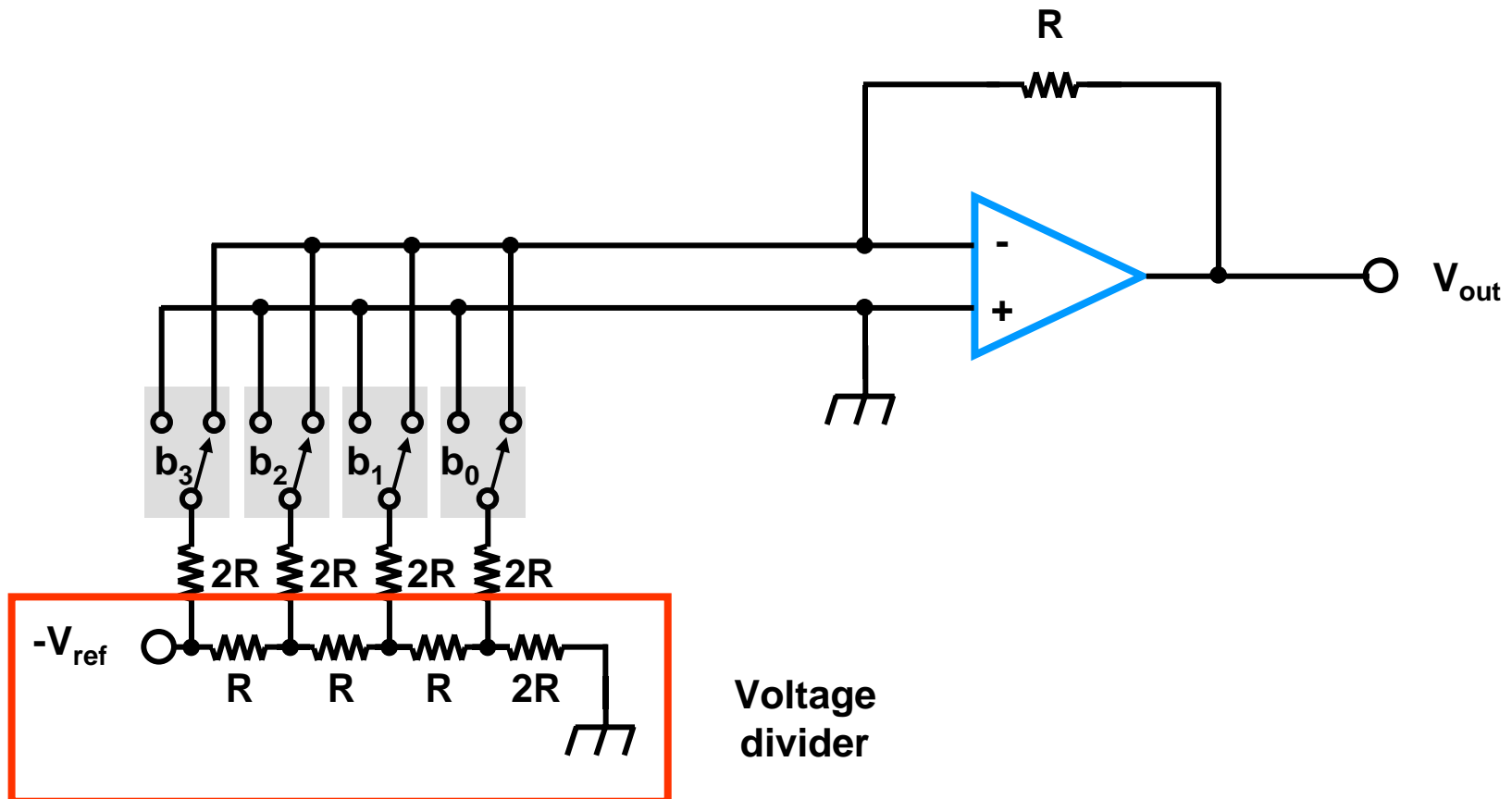
Computerized Data Acquisition

- Digital-to-analog converters



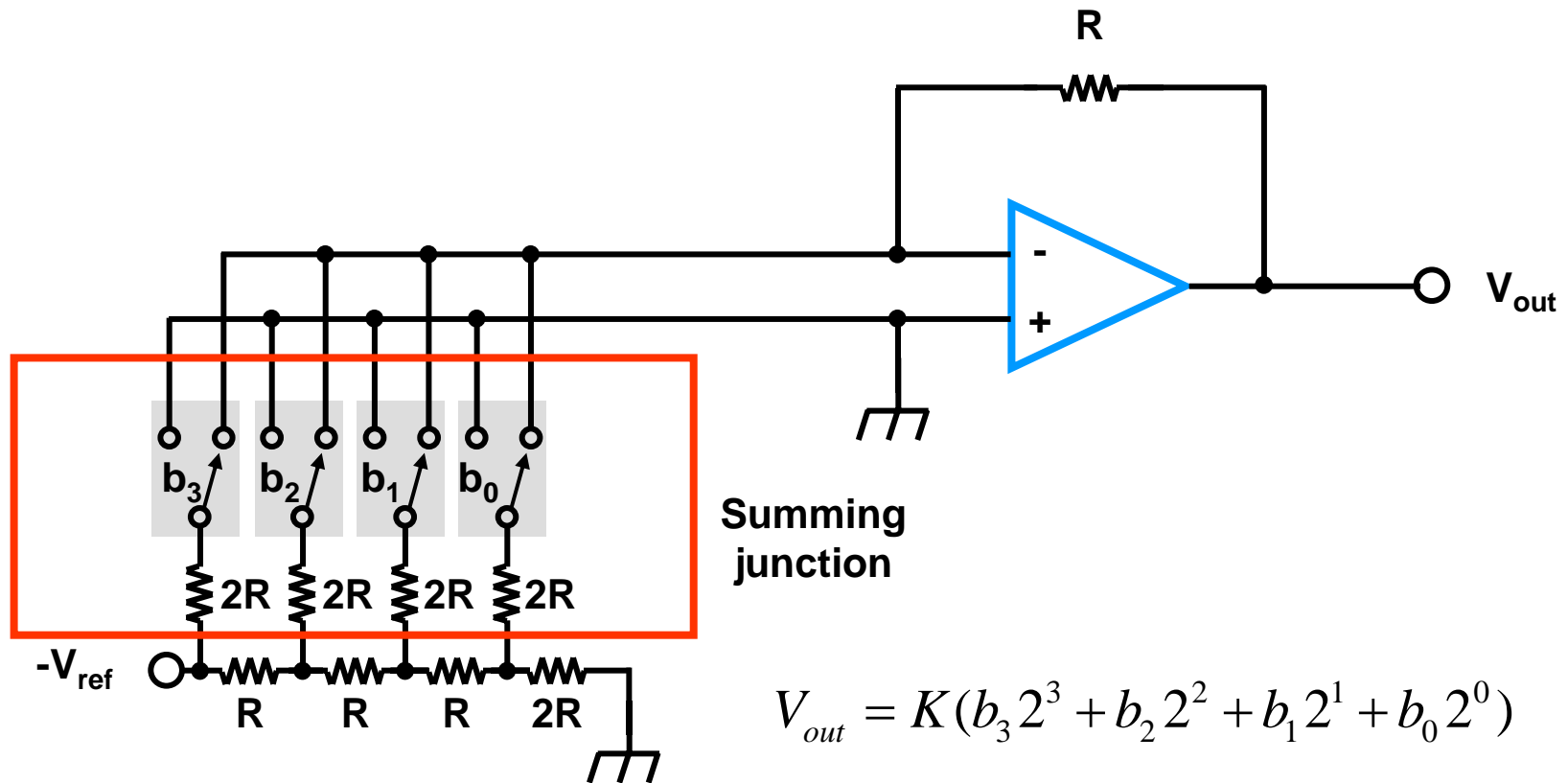
Computerized Data Acquisition

- Digital-to-analog converters



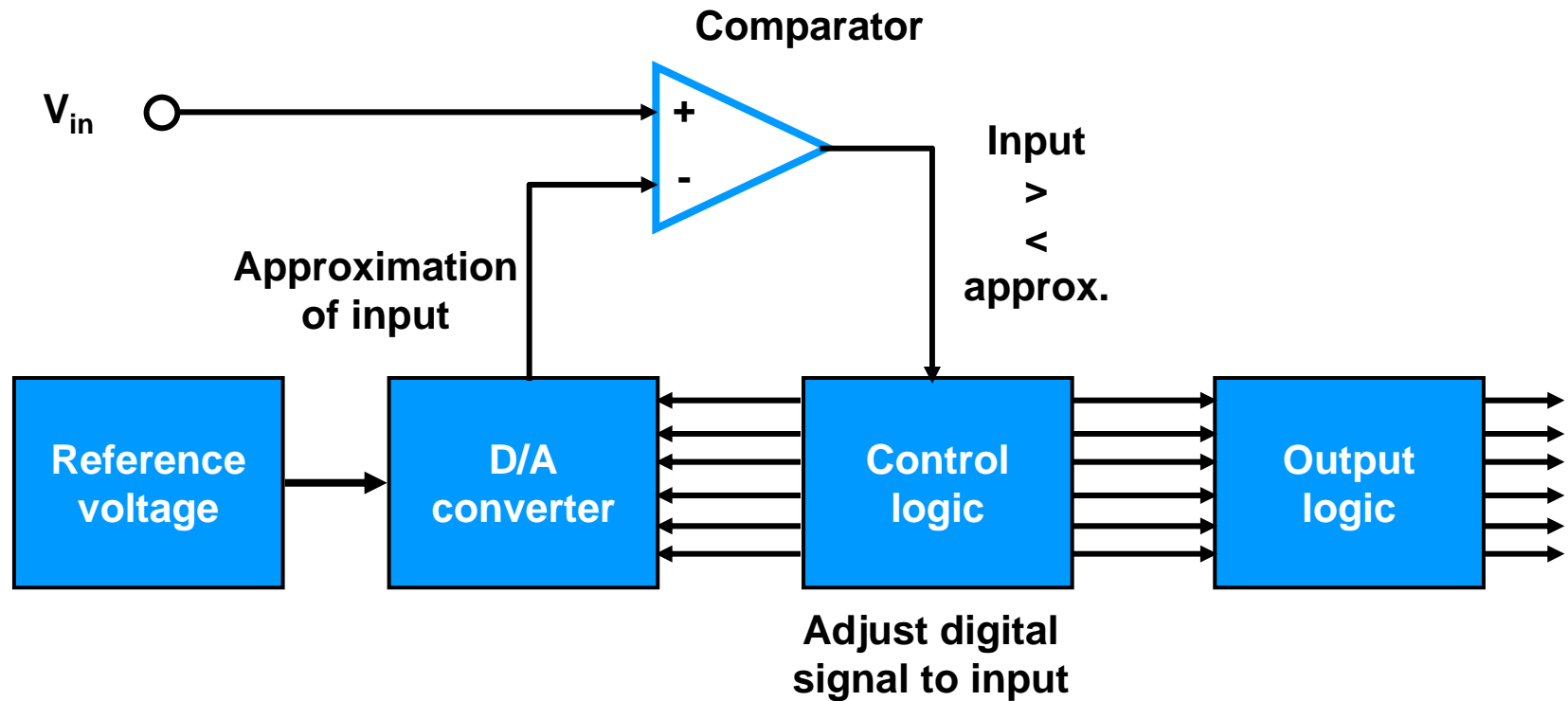
Computerized Data Acquisition

- Digital-to-analog converters



Computerized Data Acquisition

- Successive approximation A/D converter

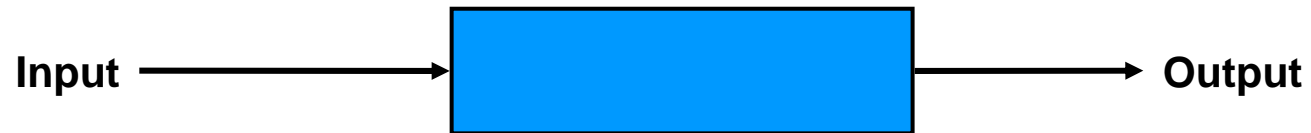


Next topics

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

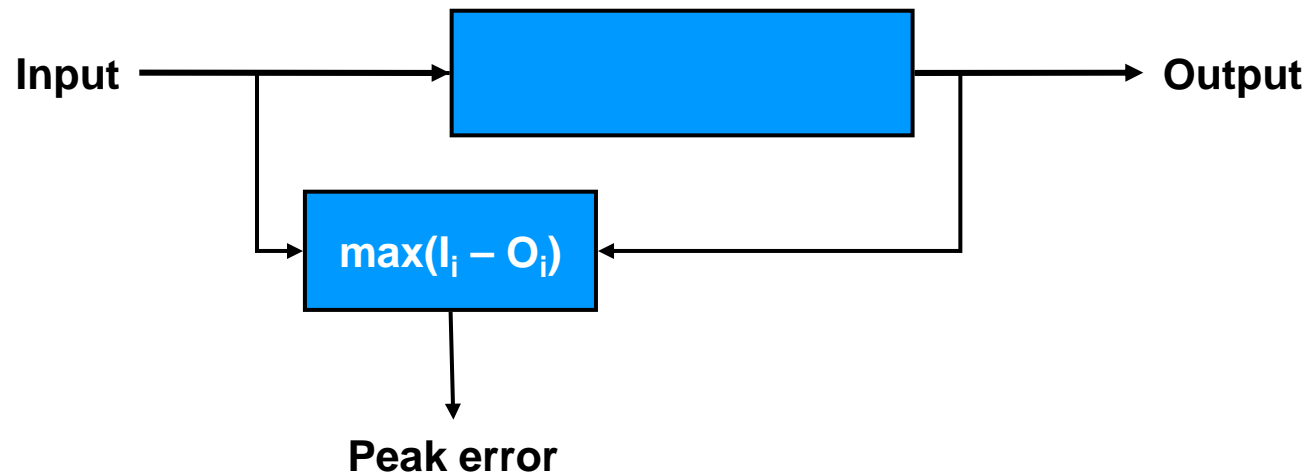
Quantifying Error

- How well does output represent input signal?



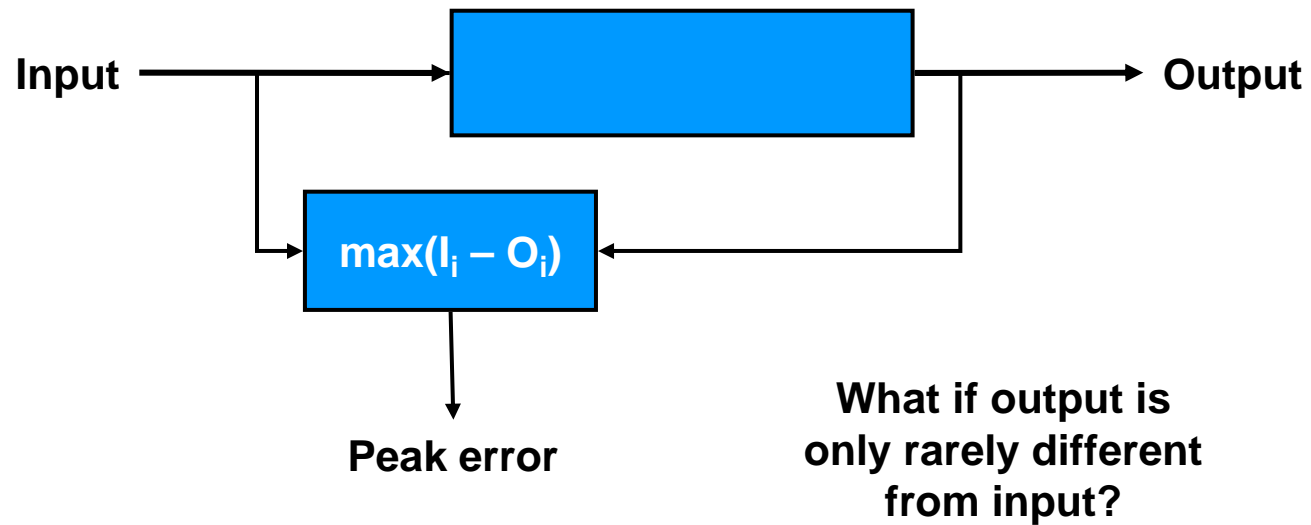
Quantifying Error

- Peak error



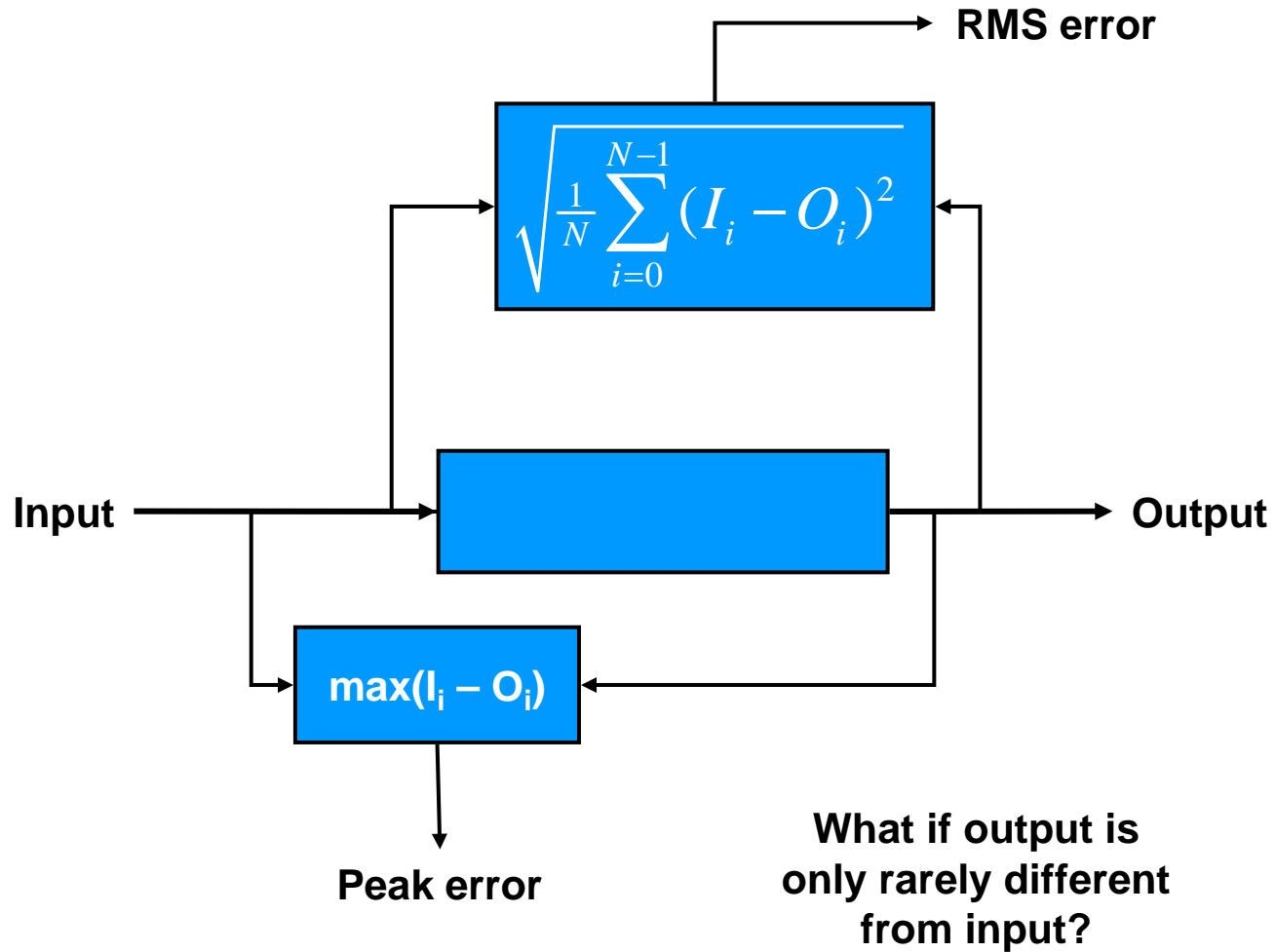
Quantifying Error

- Peak error



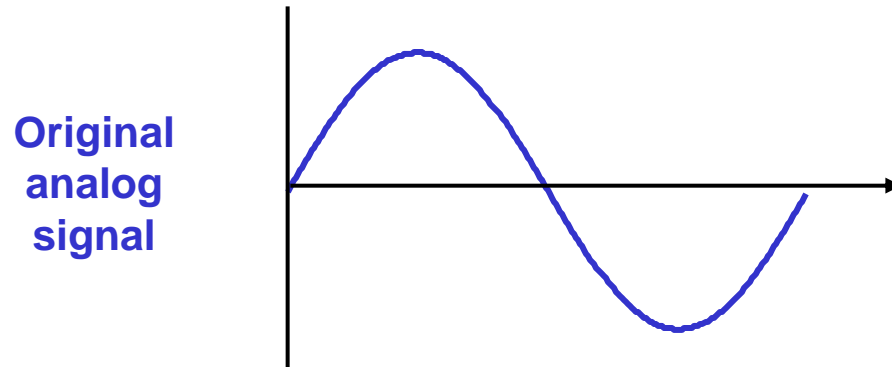
Quantifying Error

- Root-Mean-Square (RMS) error



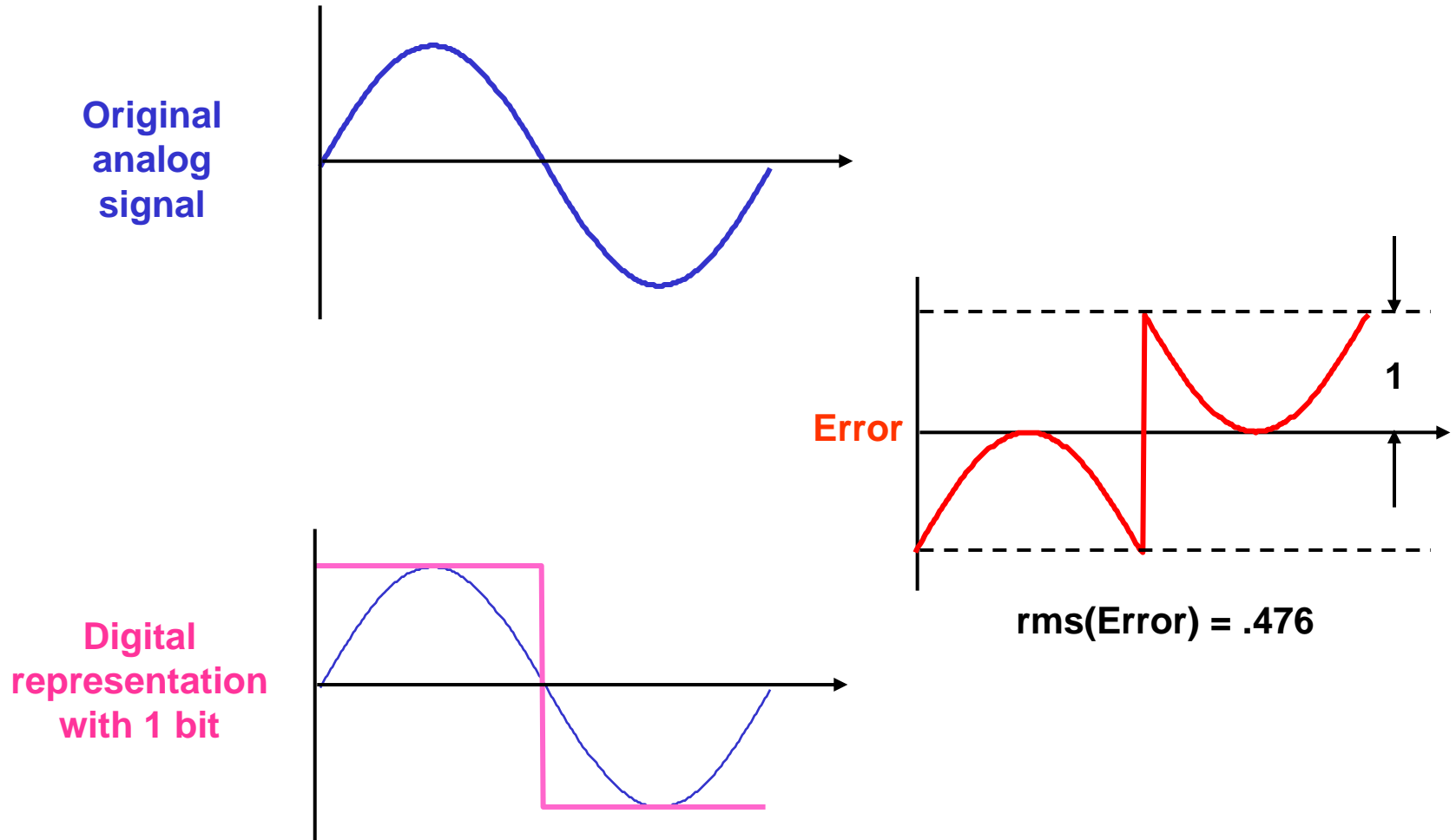
Computerized Data Acquisition Systems

- Quantization effects



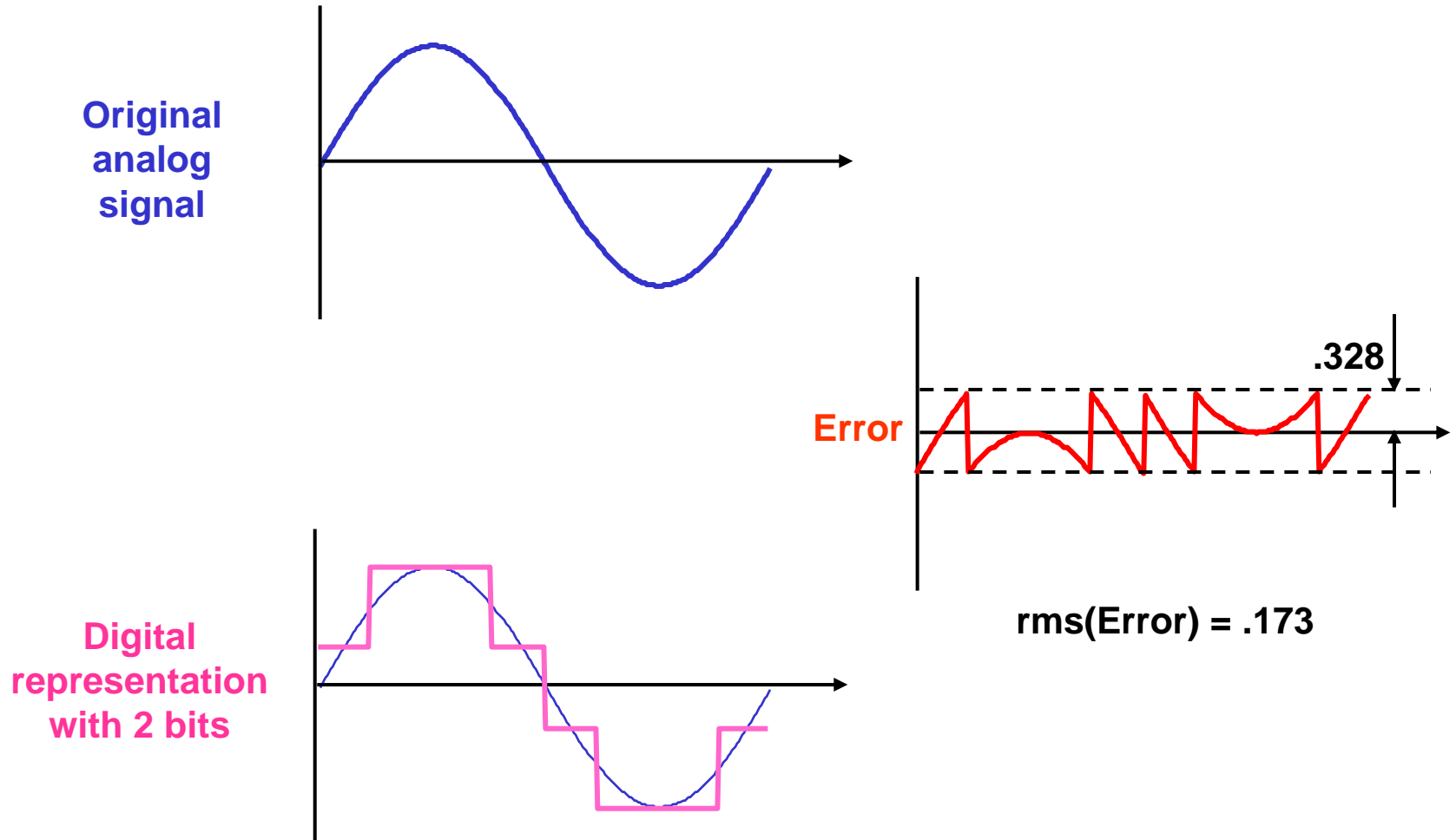
Computerized Data Acquisition Systems

- Quantization effects



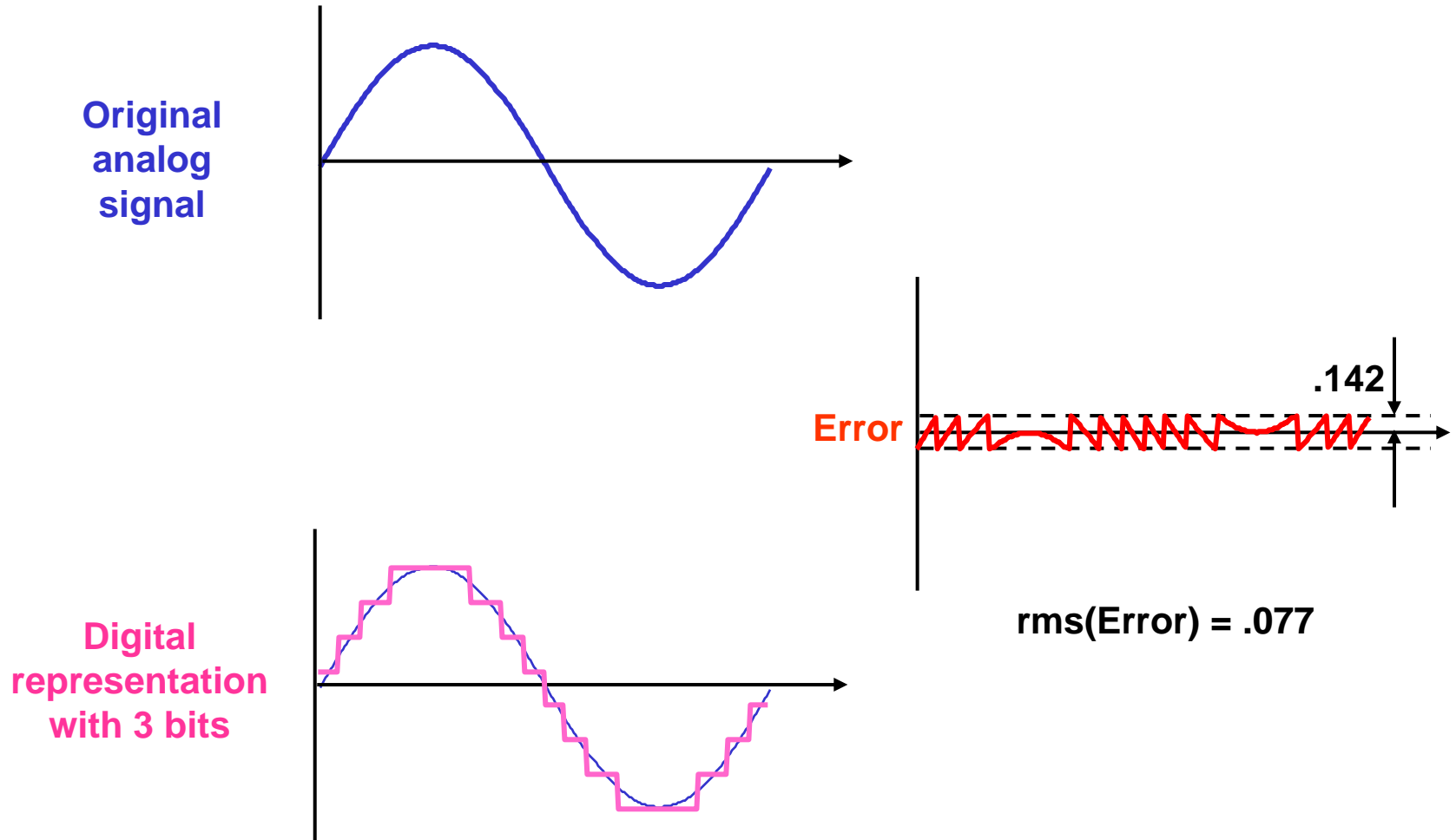
Computerized Data Acquisition Systems

- Quantization effects



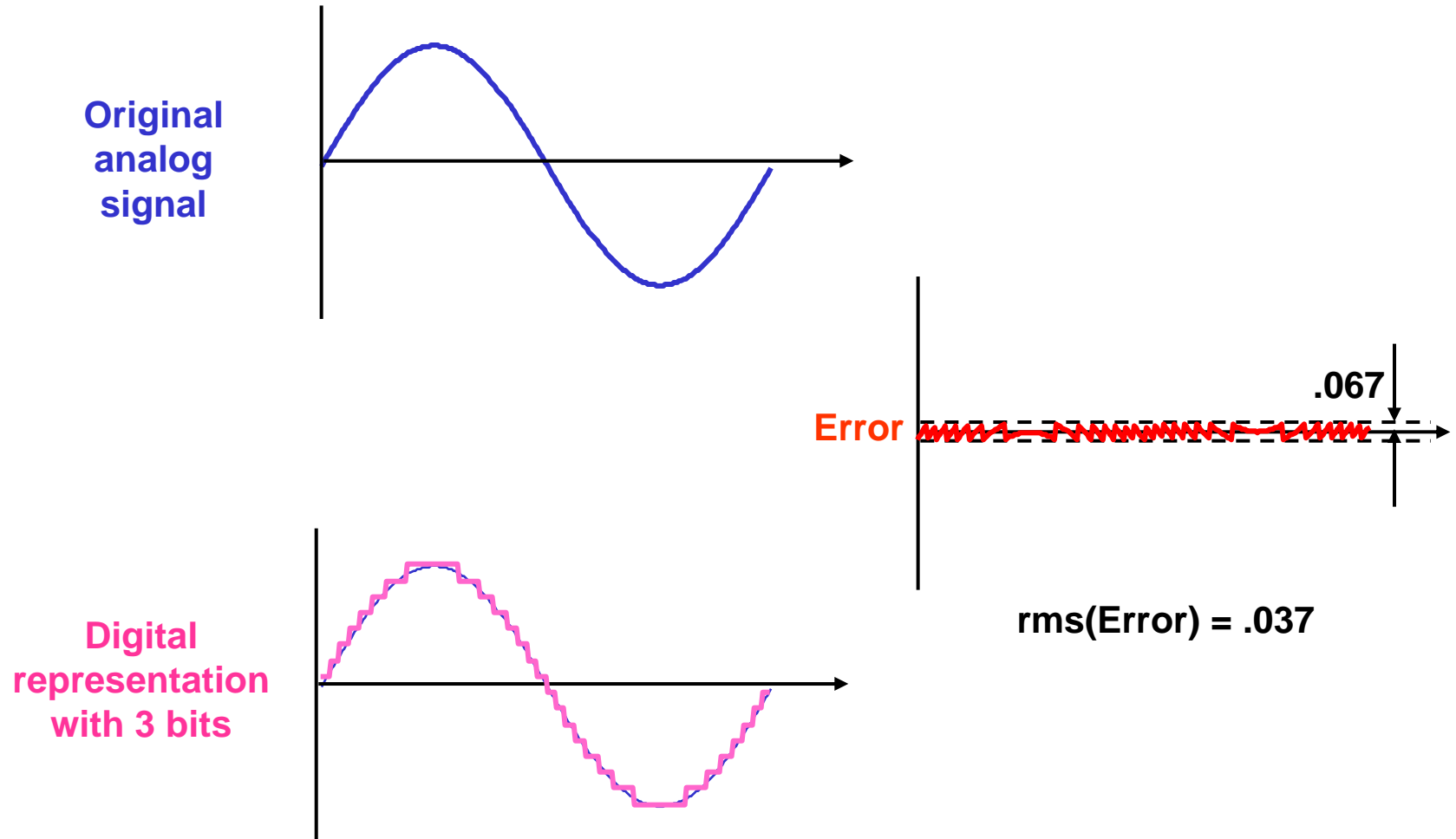
Computerized Data Acquisition Systems

- Quantization effects

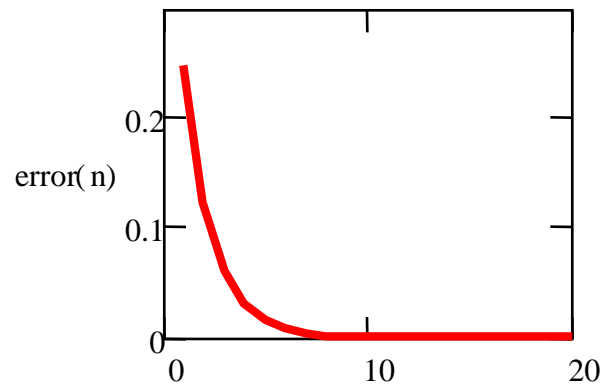


Computerized Data Acquisition Systems

- Quantization effects

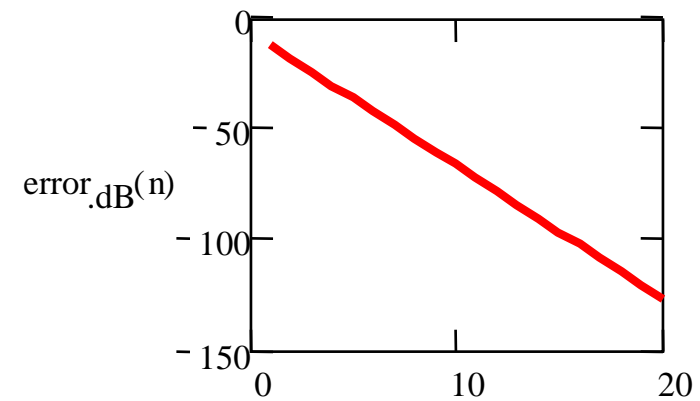
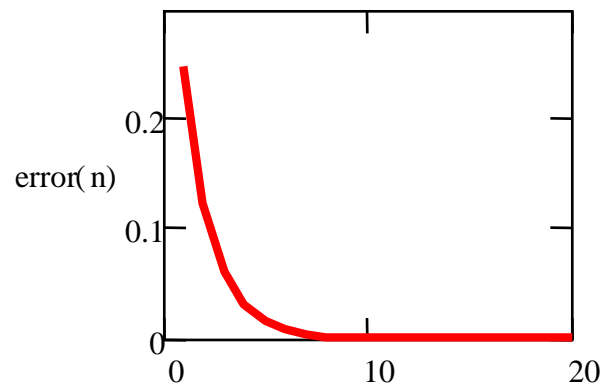


Quantization Error



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

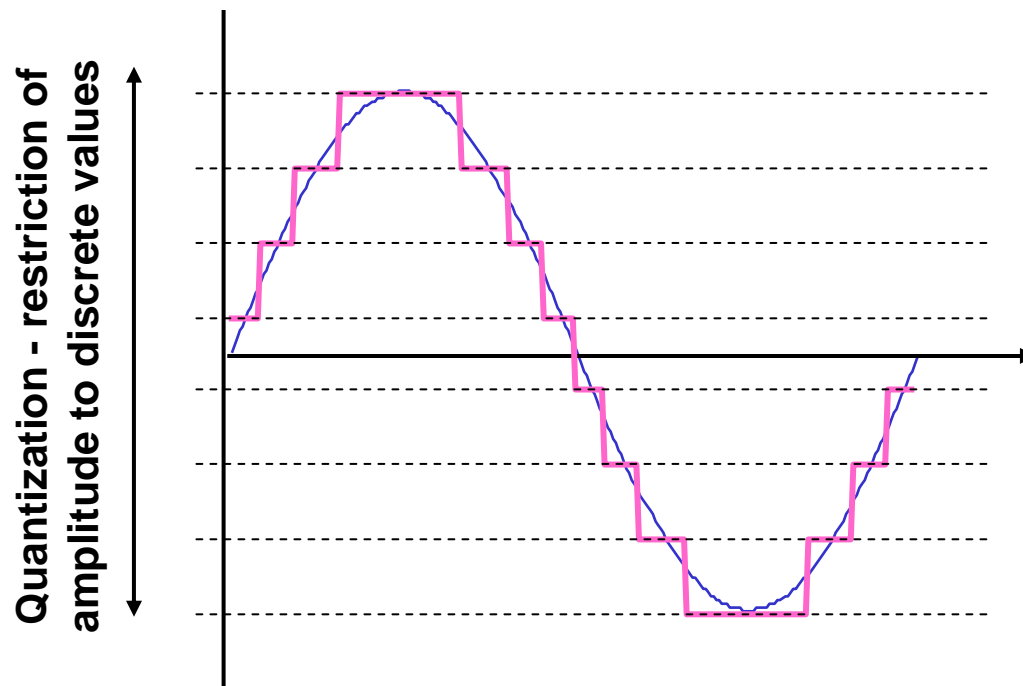
Quantization Error



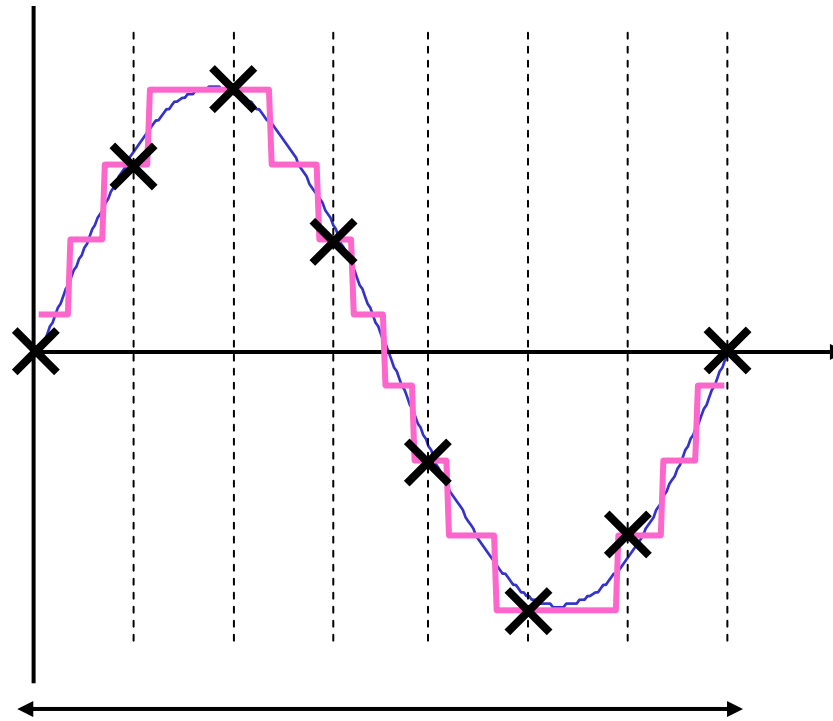
$$Q.E.(n) = \frac{.5}{2^n}$$

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

Sampling Time-varying Signals

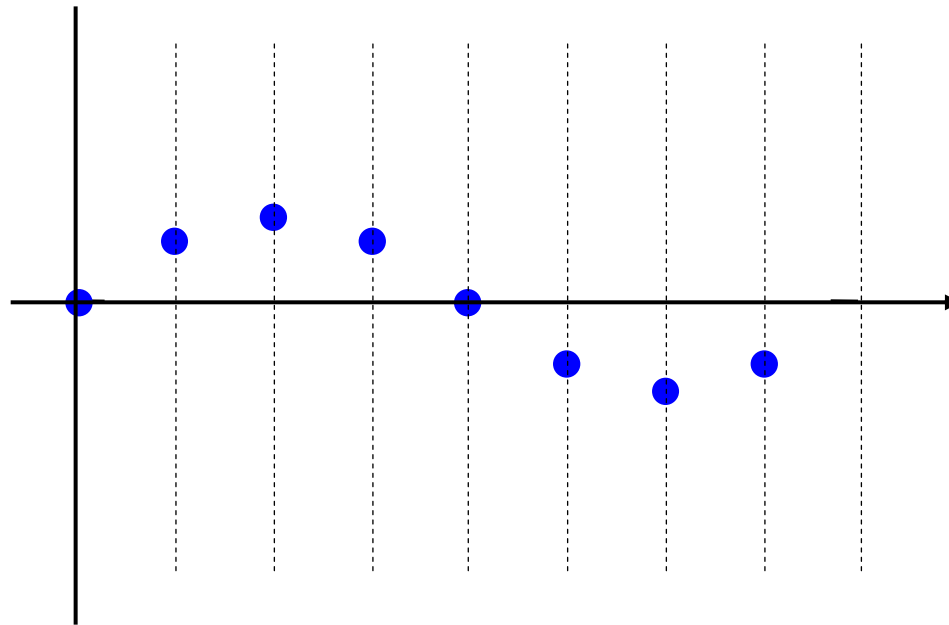


Sampling Time-varying Signals



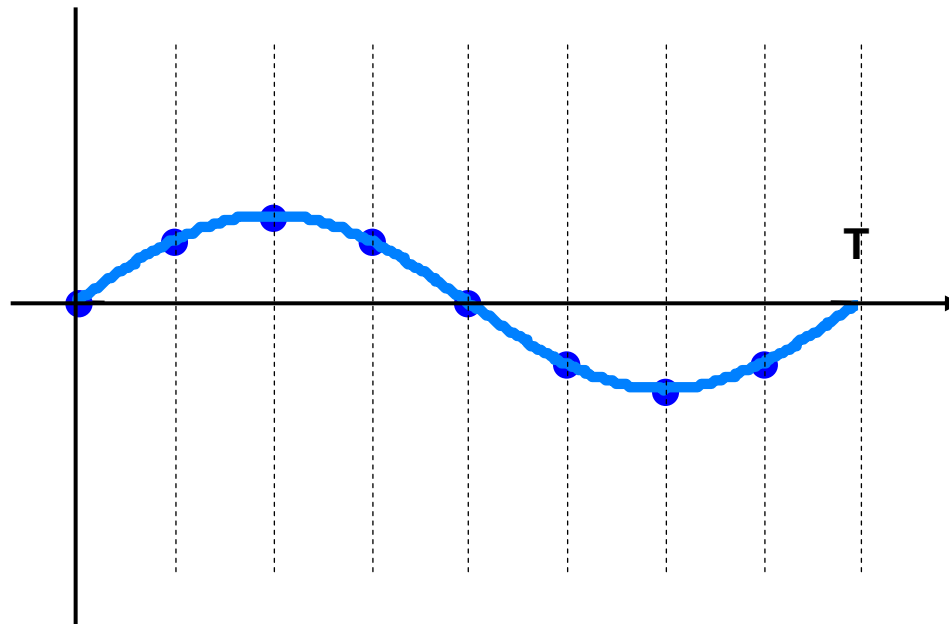
Sampling at discrete points in time

Sampling Time-varying Signals



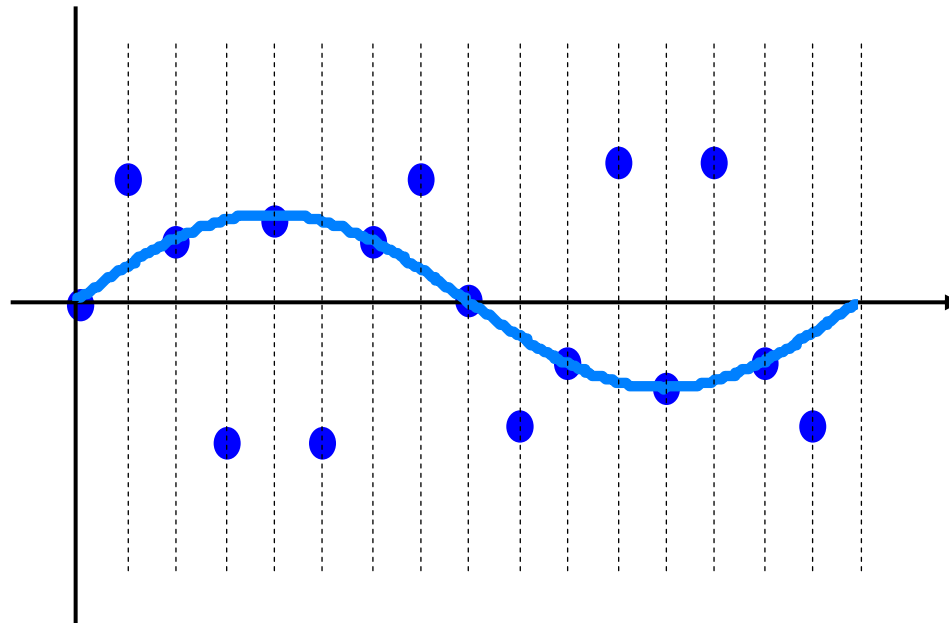
**These are samples of an analog signal –
what is the waveform?**

Sampling Time-varying Signals



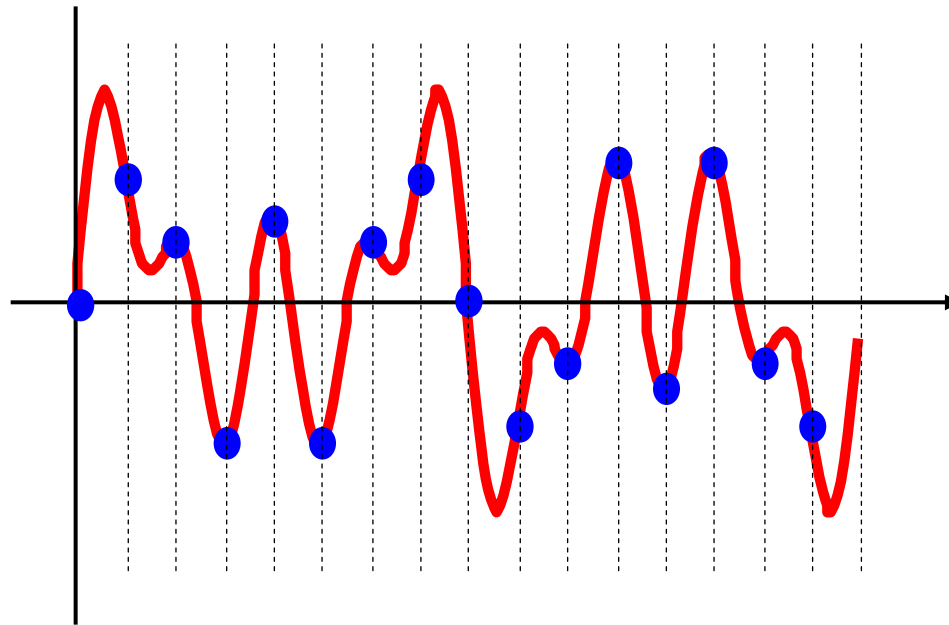
Is it a sinusoid with a period T ?

Sampling Time-varying Signals



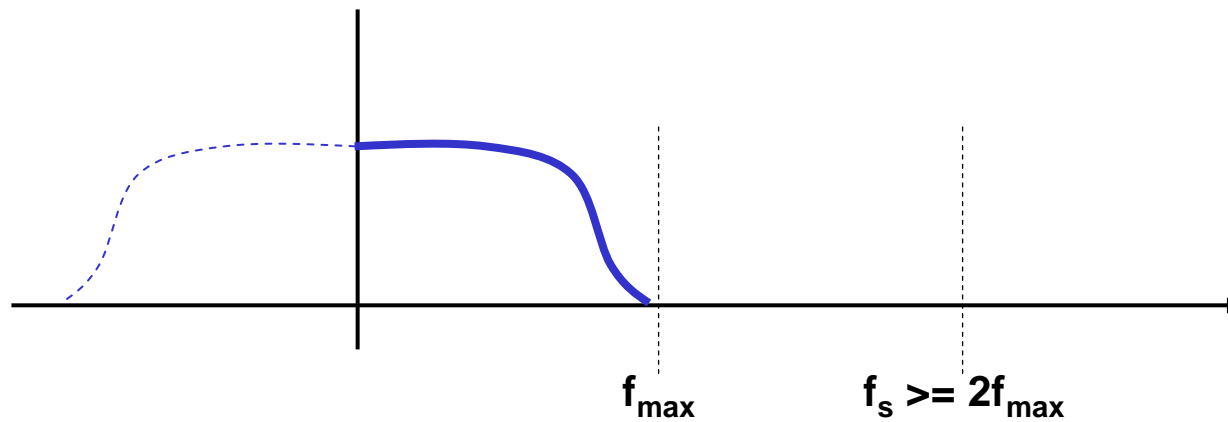
What if we provide more samples?

Sampling Time-varying Signals



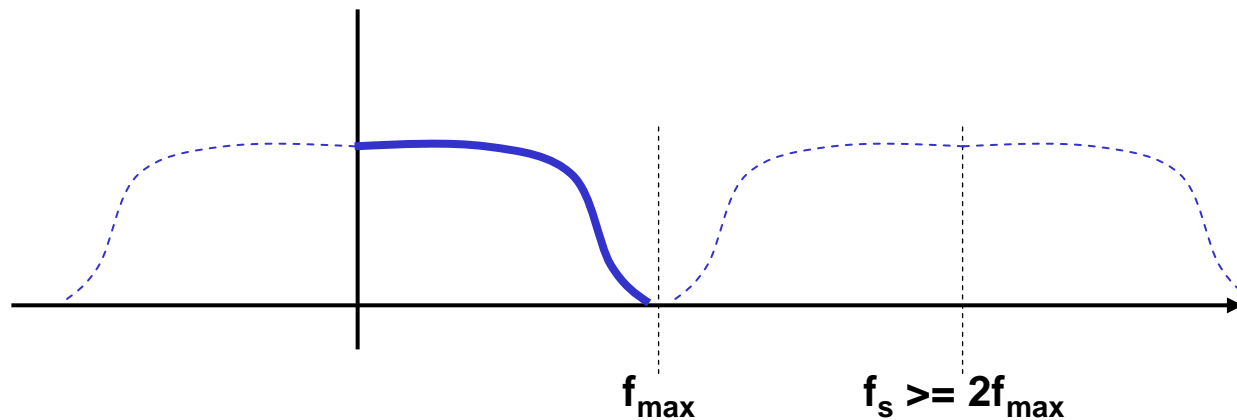
**This is what the actual signal looked like:
The first set of samples was at too low a frequency**

Nyquist Sampling Theorem



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

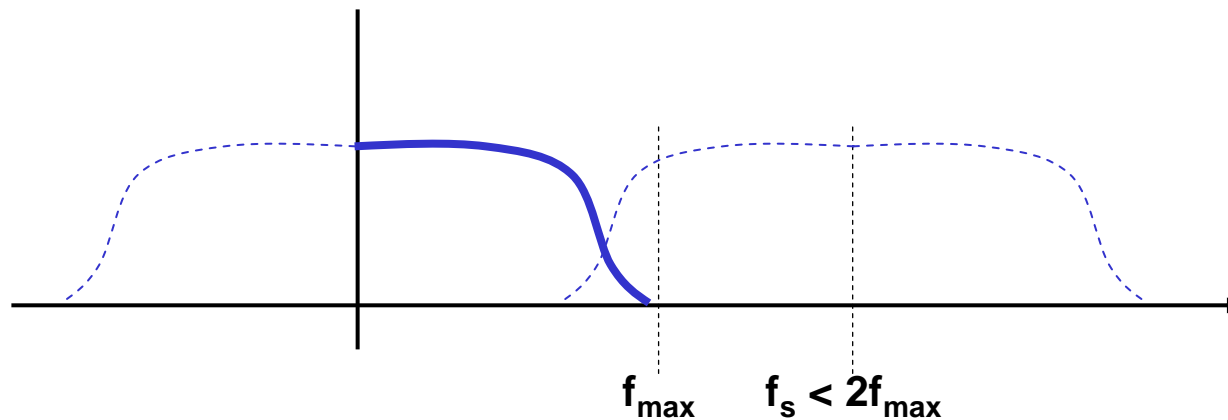
Nyquist Sampling Theorem



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

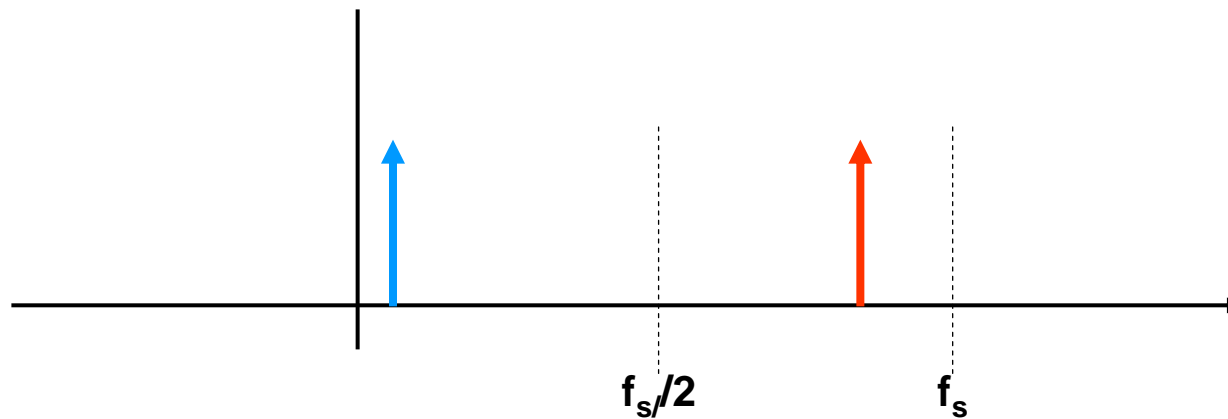


A signal that has energy to f_{\max} must be sampled at a rate ($2 \times f_{\max}$) or greater

Sampling creates an “alias” copy of a signal

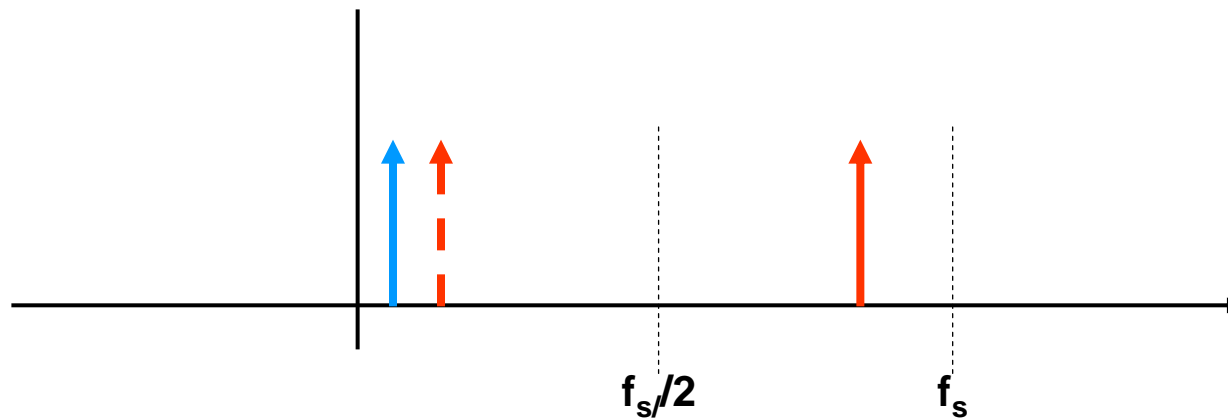
If the sampling rate is less than twice the highest frequency, the alias overlaps the original, creating distortion

Nyquist Sampling Theorem



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

Nyquist Sampling Theorem



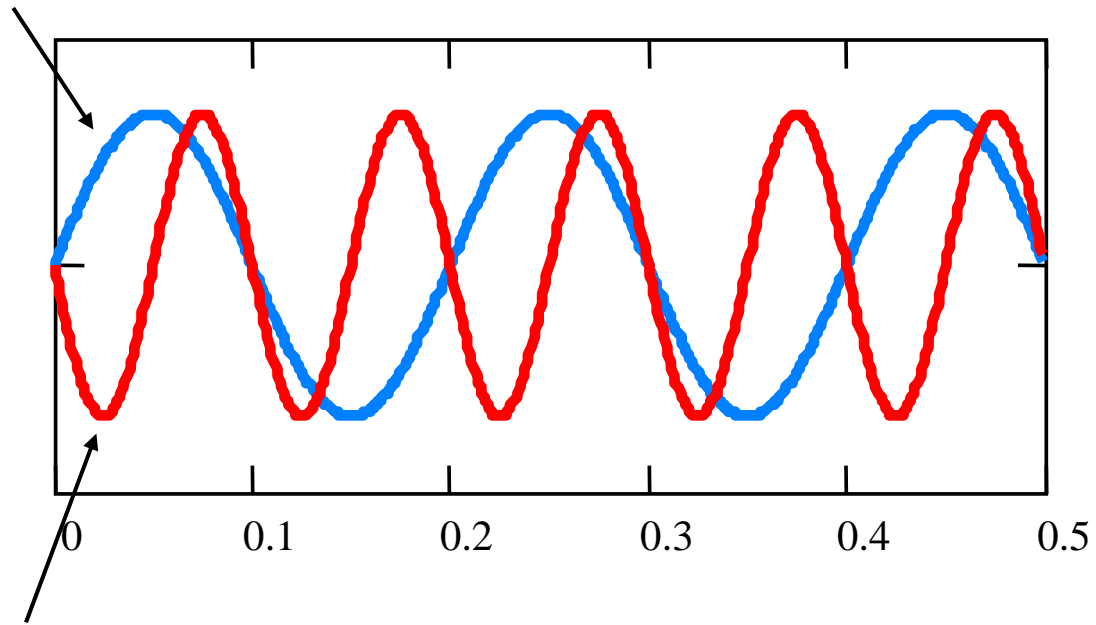
Consider $f_s = 1000$ Hz with two signals, $f_1 = 5$ Hz, $f_2 = 990$ Hz.

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.

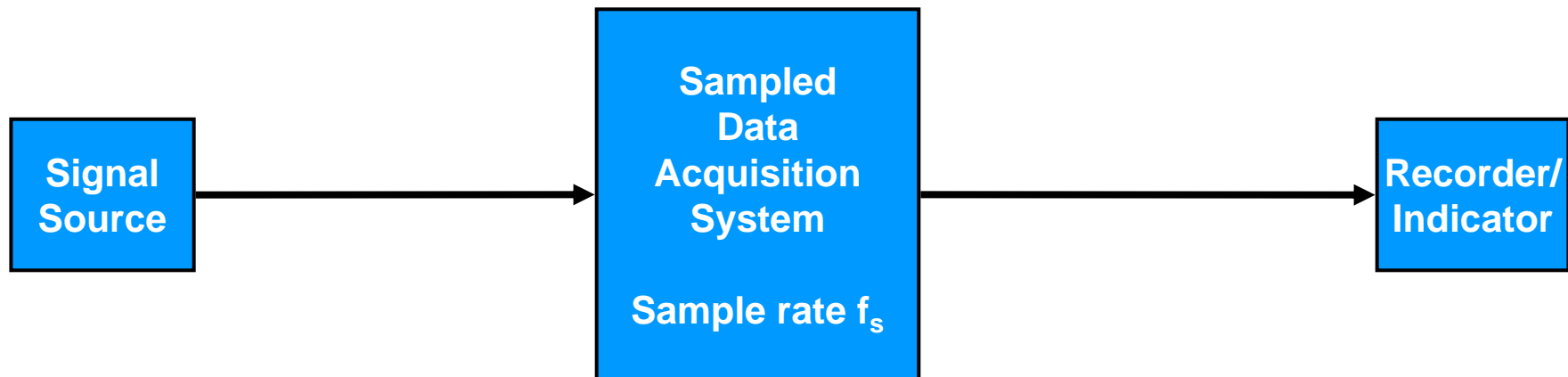
Nyquist Sampling Theorem

Actual 5 Hz signal

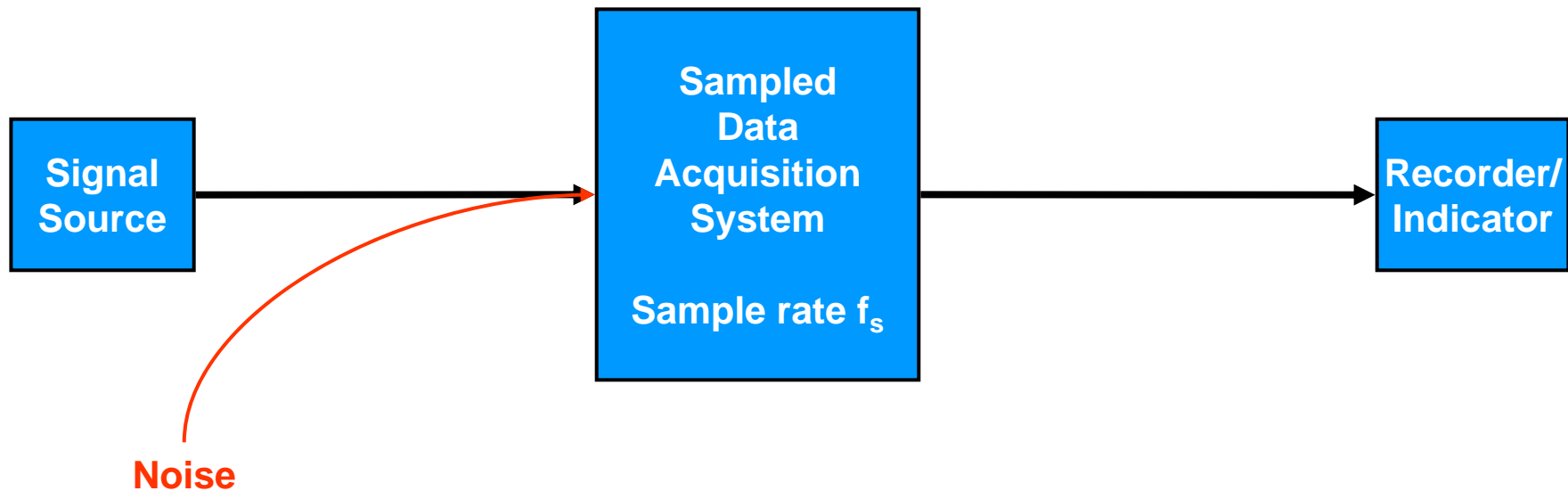


Alias of 990 Hz signal

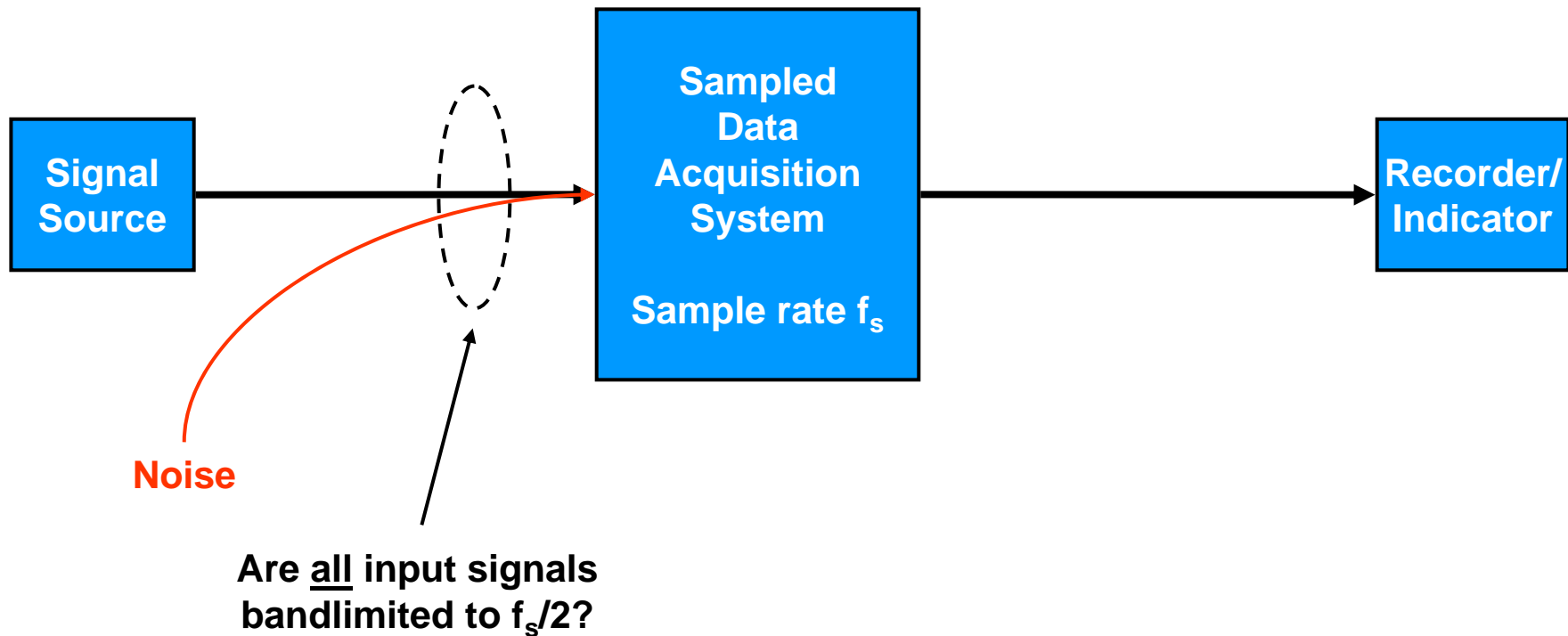
Practical Sampling Considerations



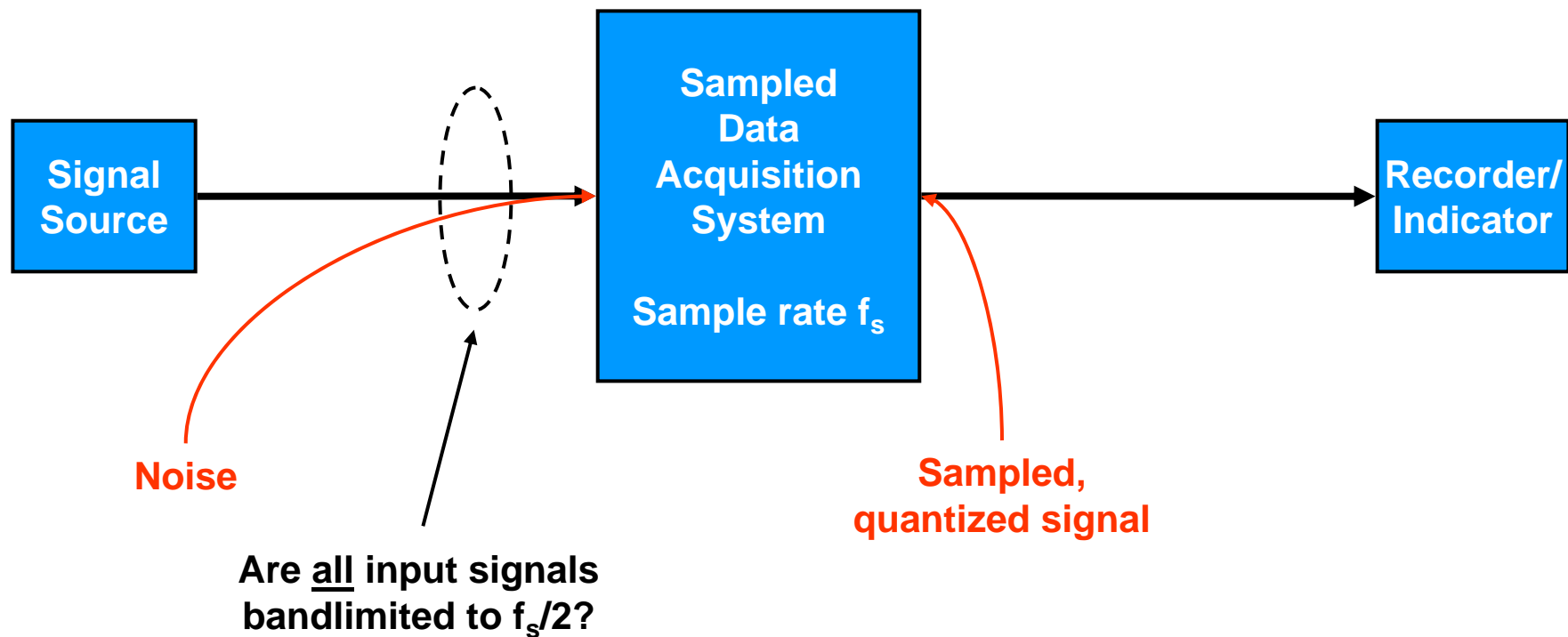
Practical Sampling Considerations



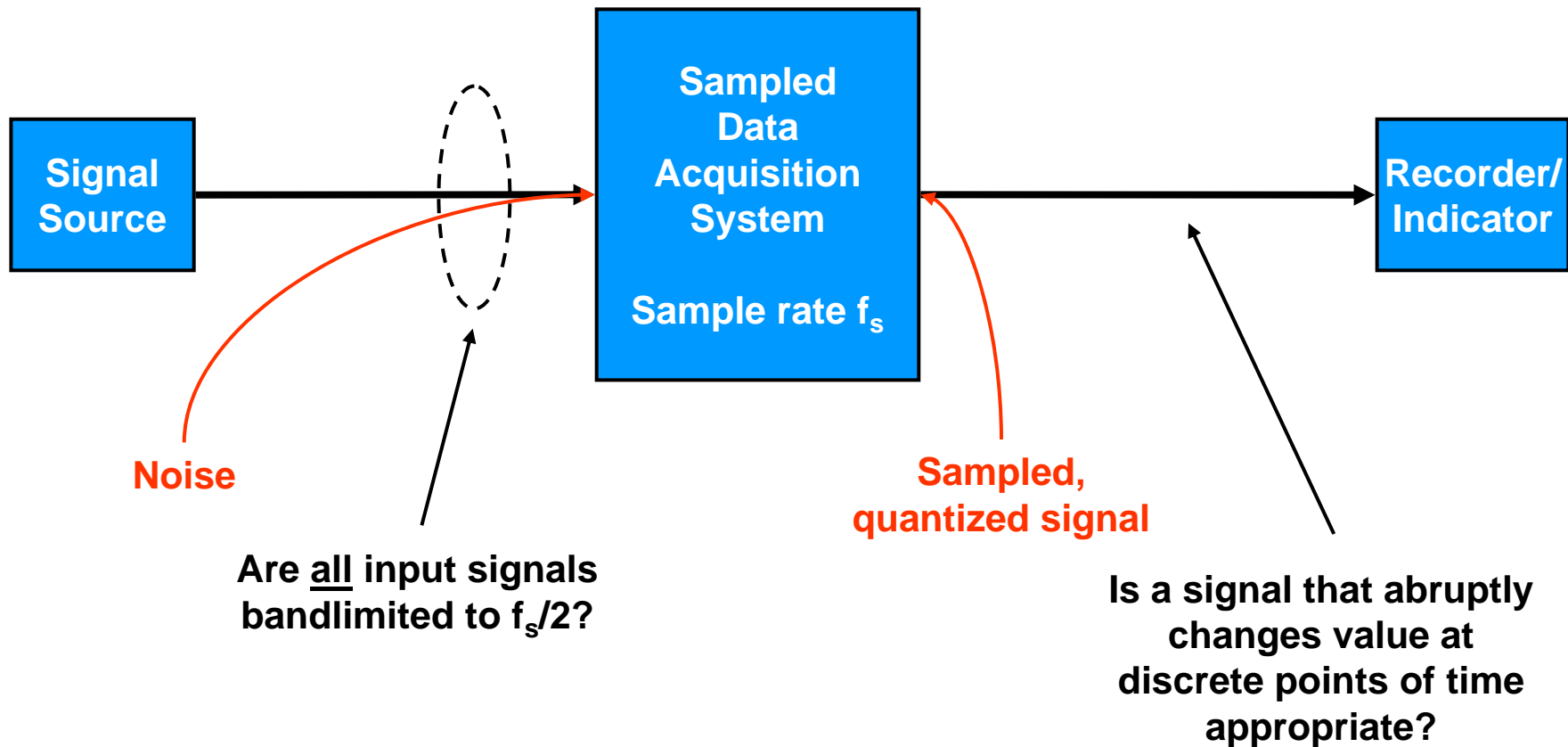
Practical Sampling Considerations



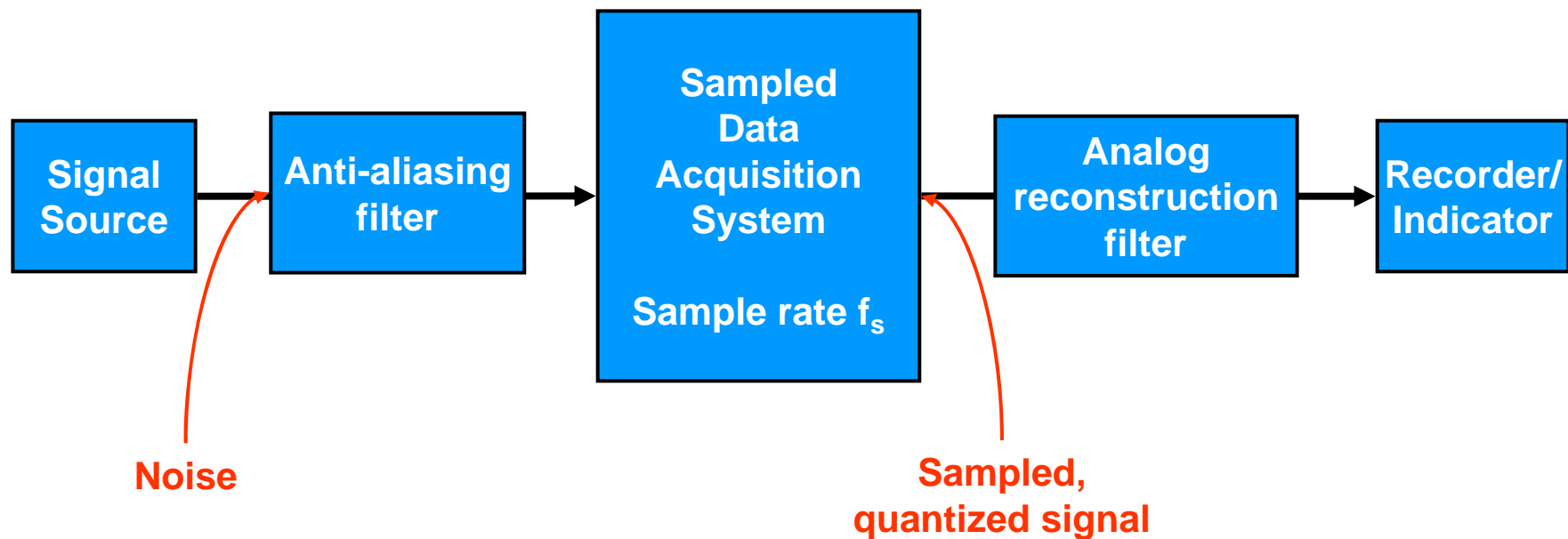
Practical Sampling Considerations



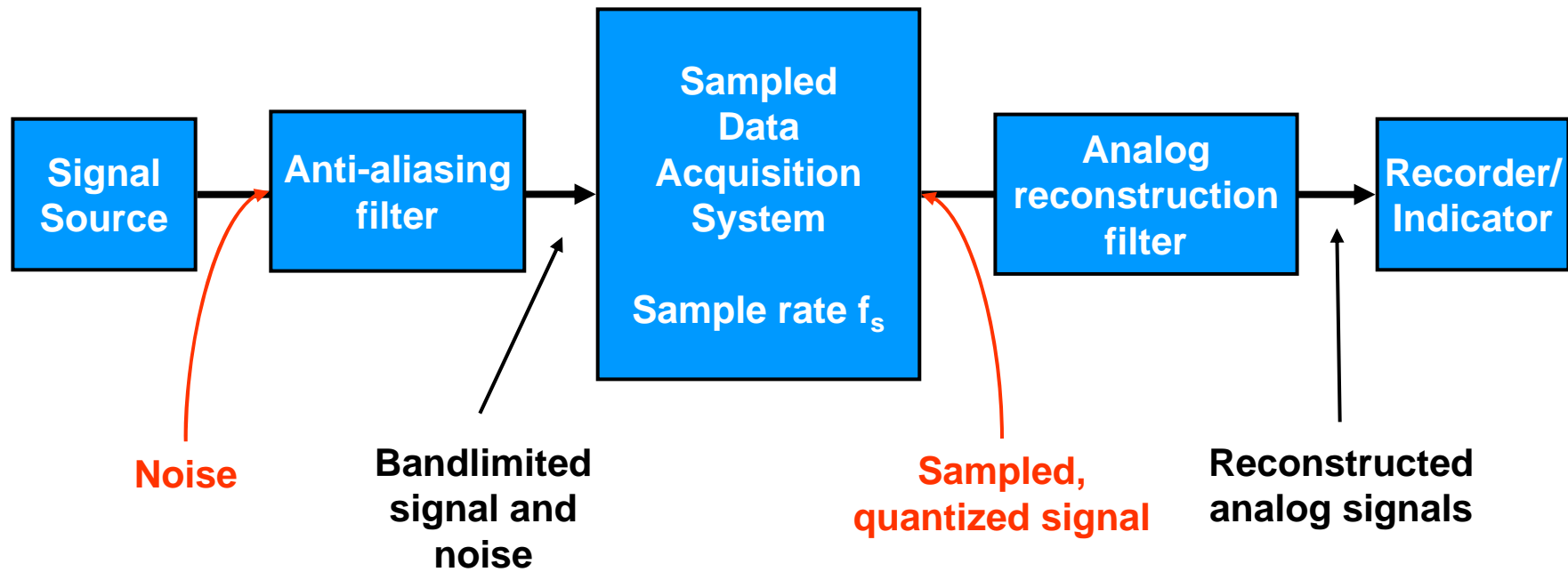
Practical Sampling Considerations



Practical Sampling Considerations



Practical Sampling Considerations



Next time

- Computerized Data Acquisition
 - Fourier Transform and frequency domain analysis

Homework 4

- Read Chapter 5
- Problems 4.1, 4.4, 4.9, 4.15