

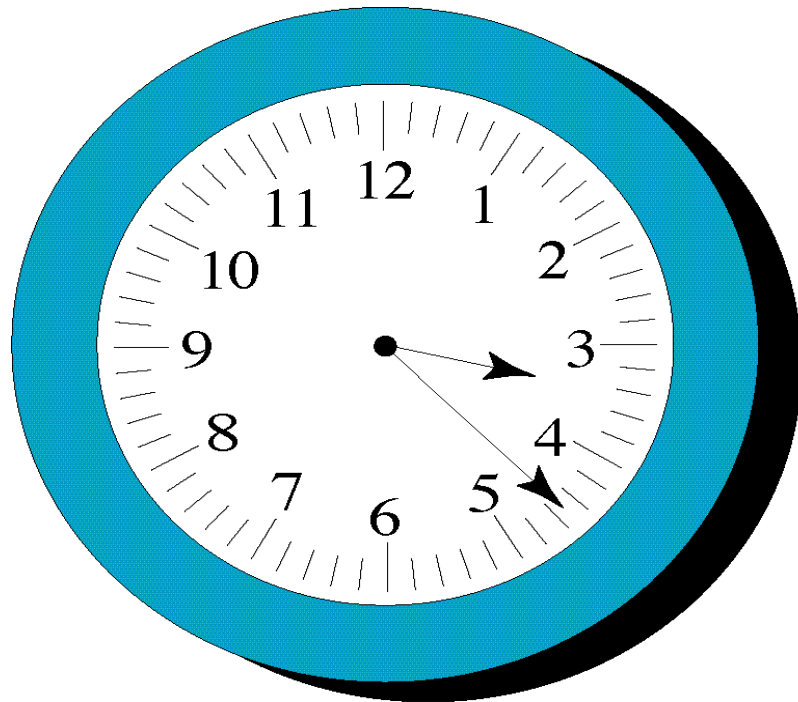
# TOPIC 3 – Analog and Digital Signals

## 3.1 Analog vs. Digital

- Signaling is the way data is communicated.
- This type of signal used can be either analog or digital

# TOPIC 3 – Analog and Digital Signals

## 3.1 Analog vs. Digital



**a. Analog**



**b. Digital**

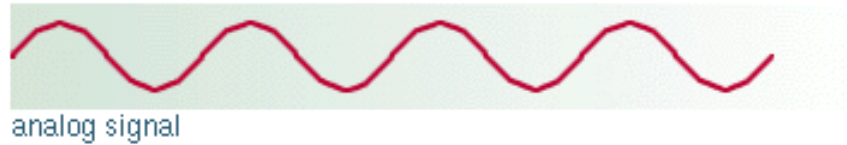
# TOPIC 3 – Analog and Digital Signals

## 3.1 Analog vs. Digital

- **ANALOG SIGNAL** - **continuous** change between high and low physical property (such as voltage or current) over time
- **DIGITAL SIGNAL** - **discrete** change between high and low physical property (such as voltage or current) over time

# TOPIC 3 – Analog and Digital Signals

## 3.1 Analog vs. Digital

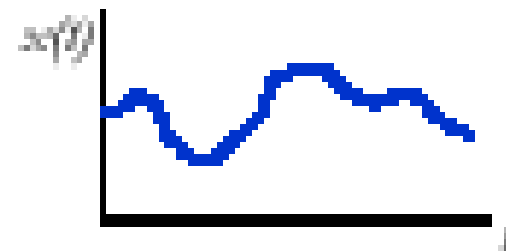


# TOPIC 3 – Analog and Digital Signals

## 3.1 Analog vs. Digital

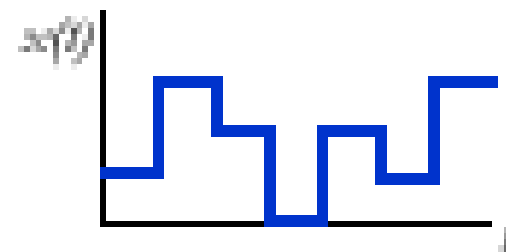
- **Analog signals**

- Value varies continuously



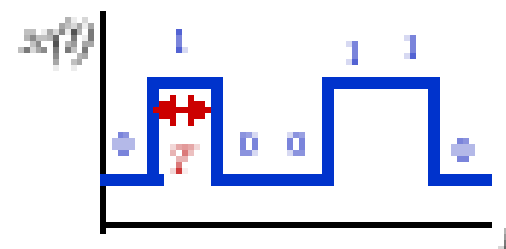
- **Digital signals**

- Value limited to a finite set



- **Binary signals**

- Has at most 2 values
- Used to represent bit values
- Bit time  $T$  needed to send 1 bit
- Data rate  $R=1/T$  bits per second



# TOPIC 3 – Analog and Digital Signals

## 3.1 Analog vs. Digital

In the natural world communication signals are generally analog for example:

–Hearing with sound waves



–Sight with light waves

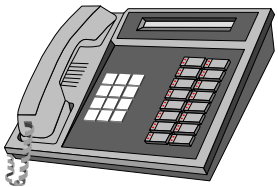


# TOPIC 3 – Analog and Digital Signals

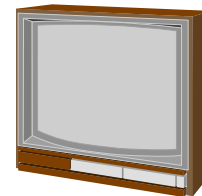
## 3.1 Analog vs. Digital

In the manmade world communication signals are generally digital for example:

– Sound: telephone, radio, CD



– Light: television, computer monitor



# TOPIC 3 – Analog and Digital Signals

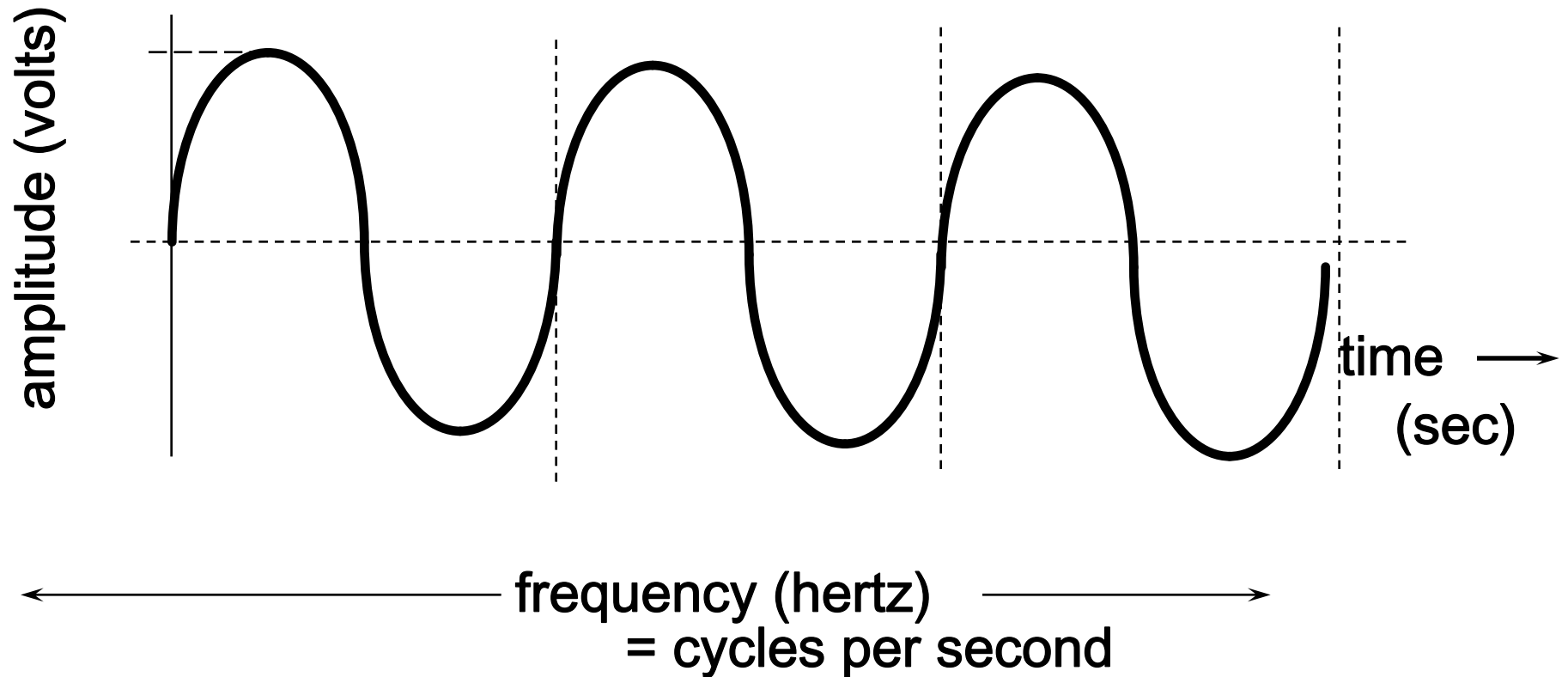
## 3.1 Analog vs. Digital

Any information can be represented  
can be recorded as an analog or a  
digital signal.

# TOPIC 3 – Analog and Digital Signals

## 3.1 Analog vs. Digital

An Analog Signal



# TOPIC 3 – Analog and Digital Signals

## 3.1 Analog vs. Digital

A Digital Signal

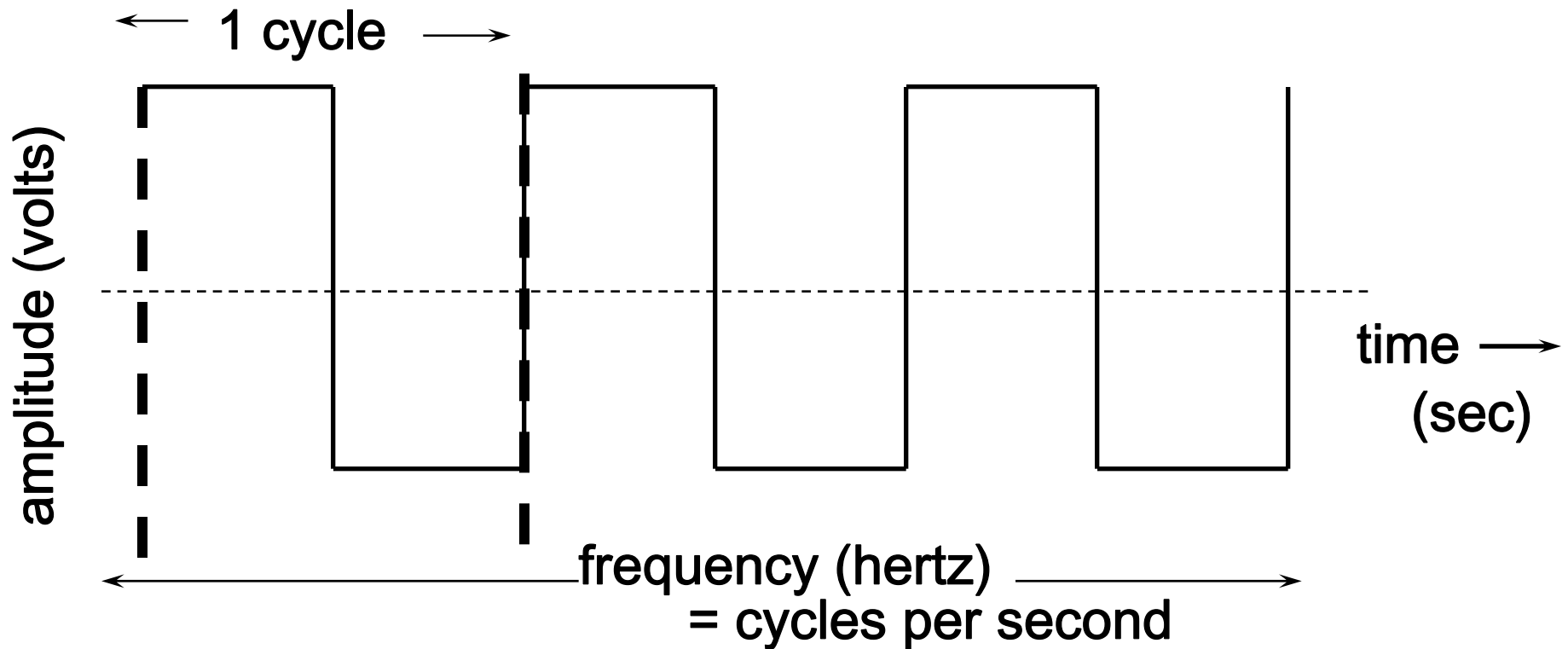
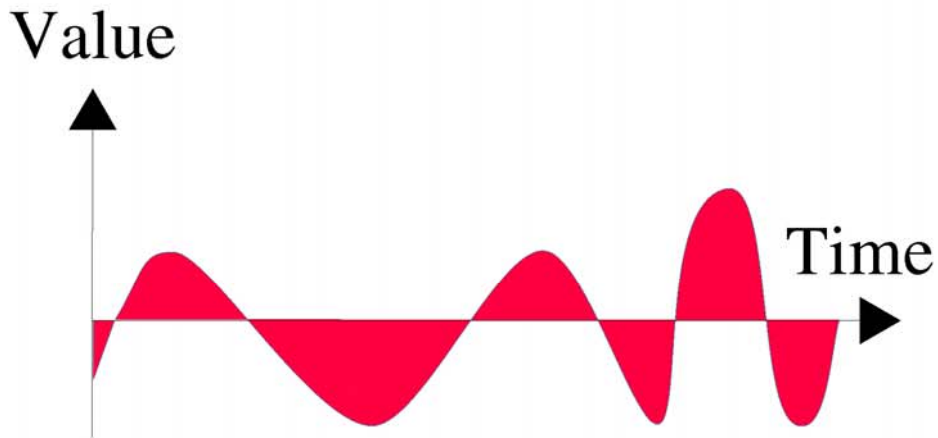


Figure 4-3

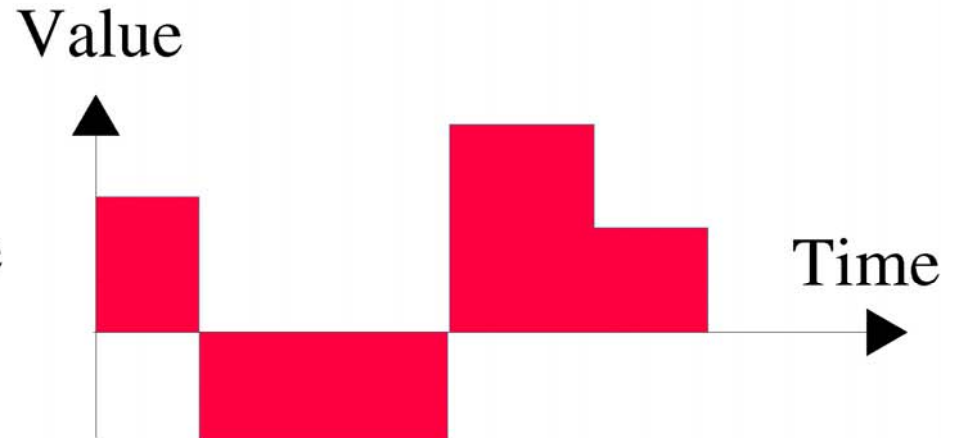
## TOPIC 3 – Analog and Digital Signals

### 3.1 Analog vs. Digital

### General Signal



a. Analog signal

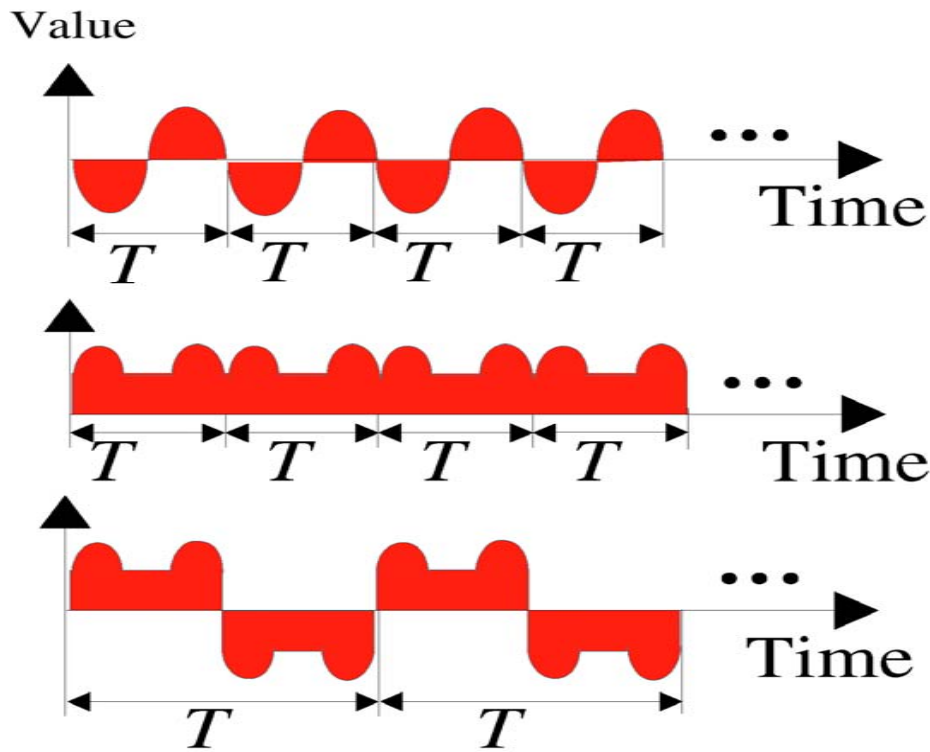


b. Digital signal

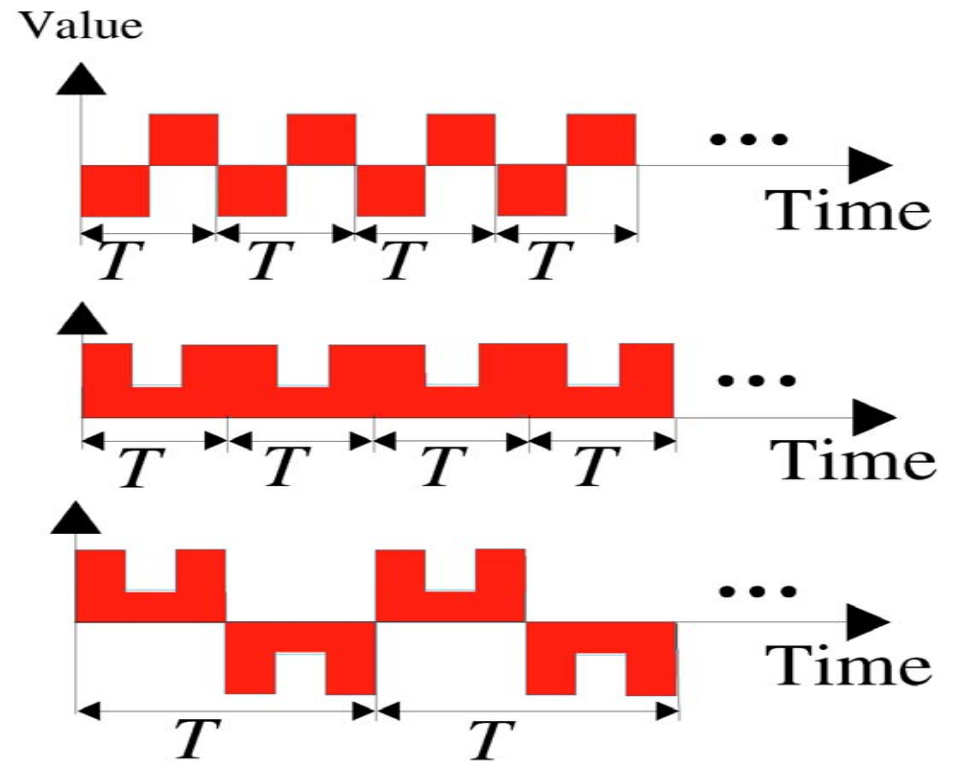
# TOPIC 3 – Analog and Digital Signals

## 3.1 Analog vs. Digital

### Periodic Signals



a. Analog

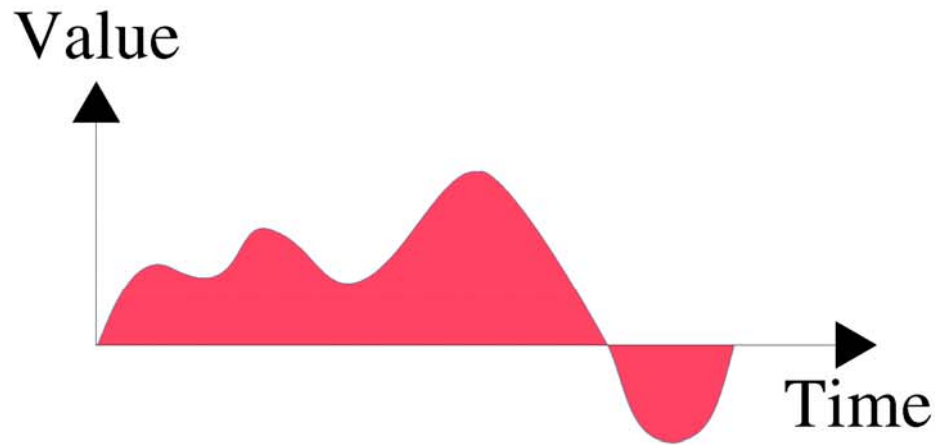


b. Digital

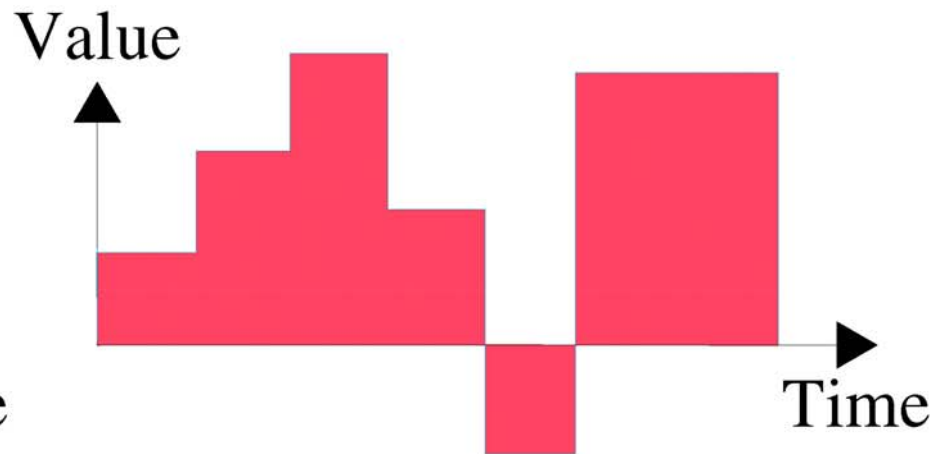
# TOPIC 3 – Analog and Digital Signals

## 3.1 Analog vs. Digital

### Aperiodic Signals



a. Analog



b. Digital

# **TOPIC 3 – Analog and Digital Signals**

## **3.2 Analog Sampling Basics/ Analog to Digital Conversion**

- **Analog signals are those which are naturally occurring.**
- **Any analog signal can be converted to a digital signal.**

# **TOPIC 3 – Analog and Digital Signals**

## **3.2 Analog Sampling Basics/ Analog to Digital Conversion**

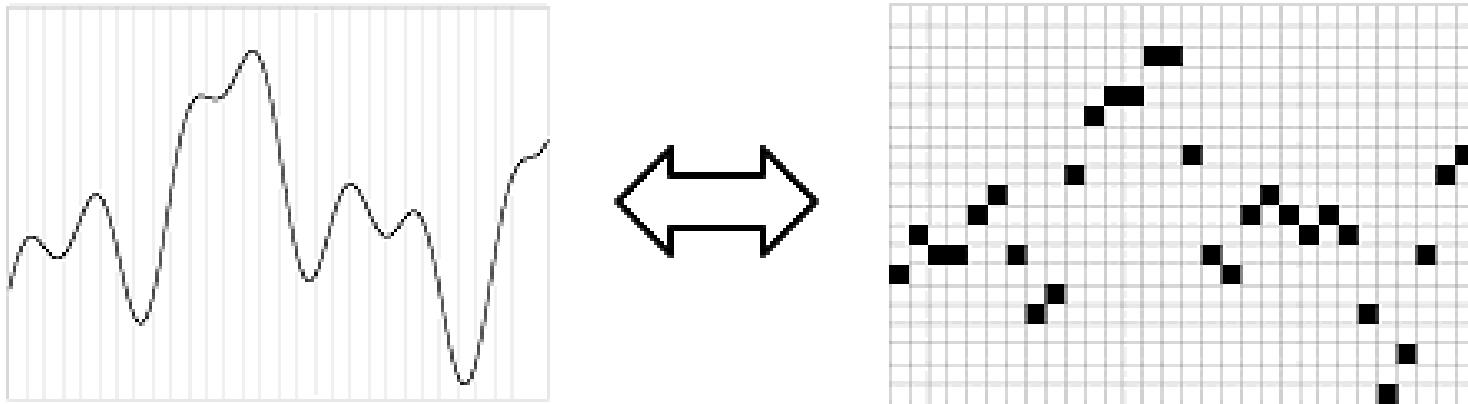
- Quantization
- Sampling Rate
  - Nyquist Theorem and Nyquist Frequency
- Aliasing
- Dithering

# TOPIC 3 – Analog and Digital Signals

## 3.2 Analog Sampling Basics/ Analog to Digital Conversion

### Quantization

- Quantization is defined as the process of converting an analog signal to a digital representation. Quantization is performed by an analog-to-digital converter (A/D converter or ADC)



# TOPIC 3 – Analog and Digital Signals

## 3.2 Analog Sampling Basics/ Analog to Digital Conversion

More about Quantization:

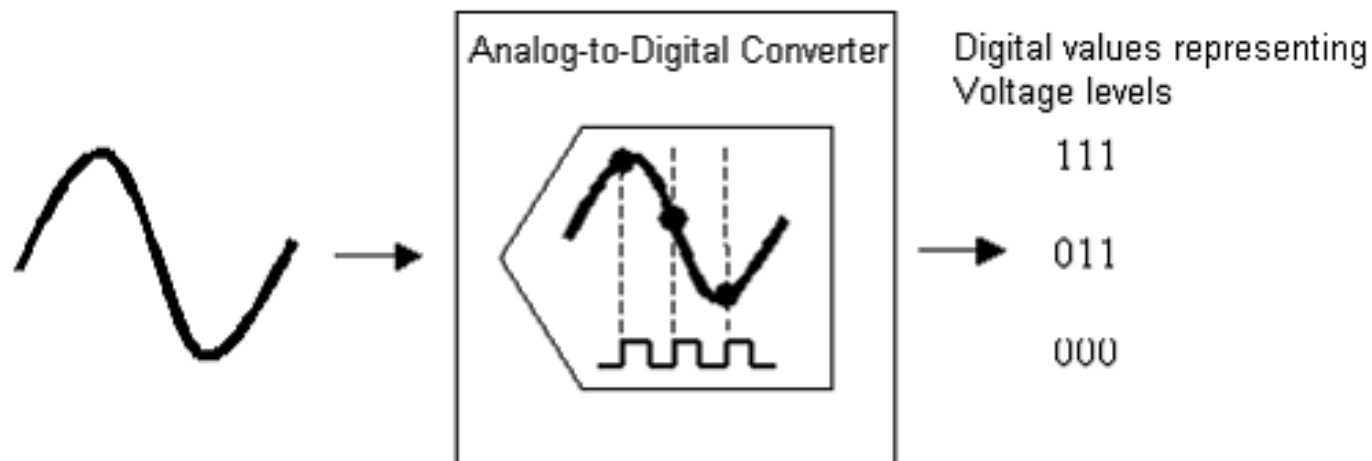
- The process by which measurements of analog signals are rounded to discrete values.
- These discrete values are referred to as “bits”.
- Typically, each bit has only two possible states, 0 or 1.
- This is called the binary system.
- The number of bits available to describe these values determines the resolution or accuracy.

# TOPIC 3 – Analog and Digital Signals

## 3.2 Analog Sampling Basics/ Analog to Digital Conversion

### Sampling Rate

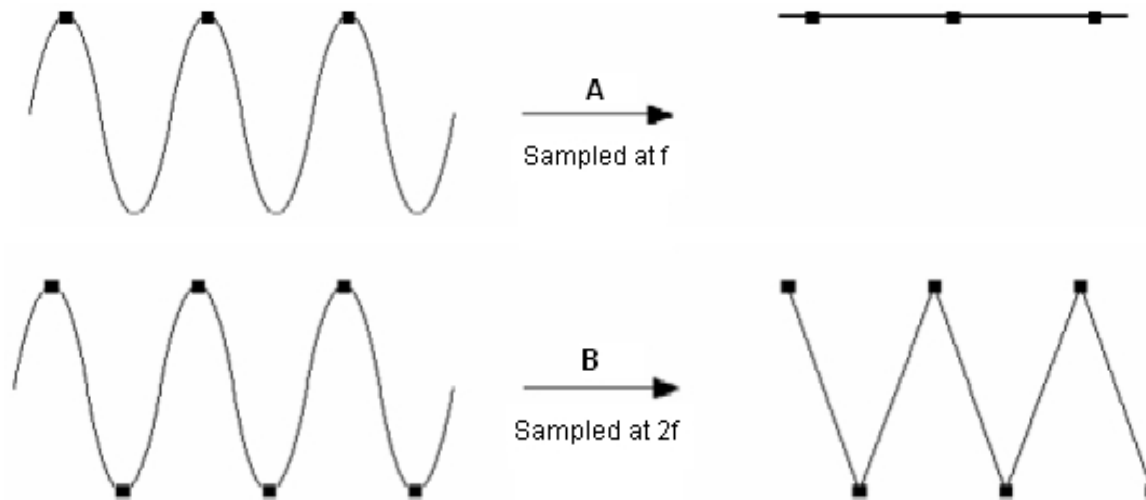
- Sampling rate is the speed at which the digitizer's ADC converts the input signal, after the signal has passed through the analog input path, to digital values



# TOPIC 3 – Analog and Digital Signals

## 3.2 Analog Sampling Basics/ Analog to Digital Conversion

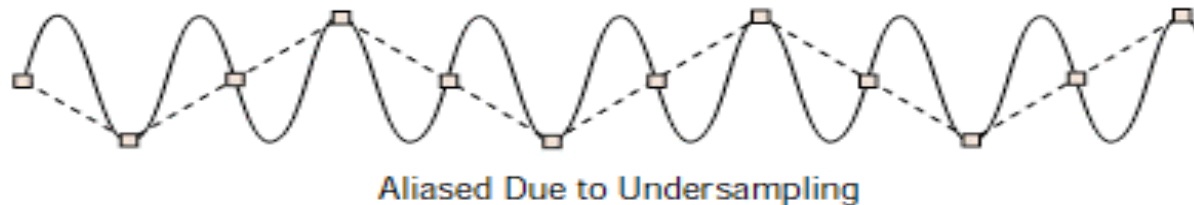
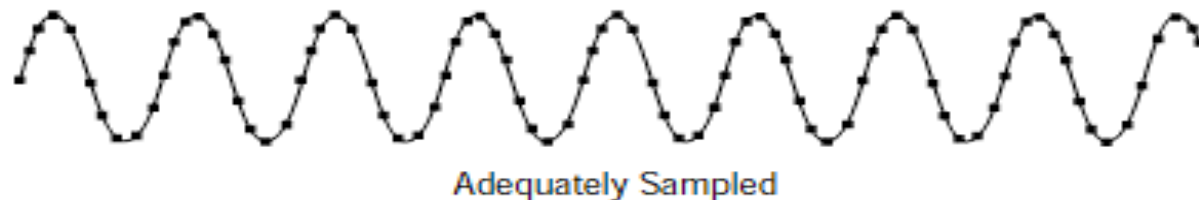
- Effects of various Sampling Rates when sampling a sine wave of frequency  $f$



# TOPIC 3 – Analog and Digital Signals

## 3.2 Analog Sampling Basics/ Analog to Digital Conversion

- Sampling rate and Nyquist:
  - Minimum rate defined by the Nyquist Theorem
    - Sample at a minimum of double the highest frequency component.
    - Nyquist frequency is defined as  $1/2$  the sample rate.
    - Frequencies above the Nyquist frequency will alias to appear between DC and the Nyquist frequency.



# TOPIC 3 – Analog and Digital Signals

## 3.2 Analog Sampling Basics/ Analog to Digital Conversion

### Nyquist Example

Spectrum of audible speech: 300 to 4000 Hz (Cycles per second)

Spectrum of hearing: 0 to 30 KHz

According to Nyquist, sampling speech, in this case, must be done at two times the highest frequency (ie. 4000 Hz). So our sampling rate would be 8000 Hz.

If we are working with an 8-bit ADC, then we would need to process  
 $8 \text{ bits} \times 8000 \text{ Hz} = 64000 \text{ bits per second (64Kbps)}$ .

In telecommunications, a data rate of 64Kbps is called the DS-0 rate.

# TOPIC 3 – Analog and Digital Signals

## 3.2 Analog Sampling Basics/ Analog to Digital Conversion

### Nyquist Example, continued

So an 3 bit ADC provides 8 states (also called **resolution** or levels of sensitivity).

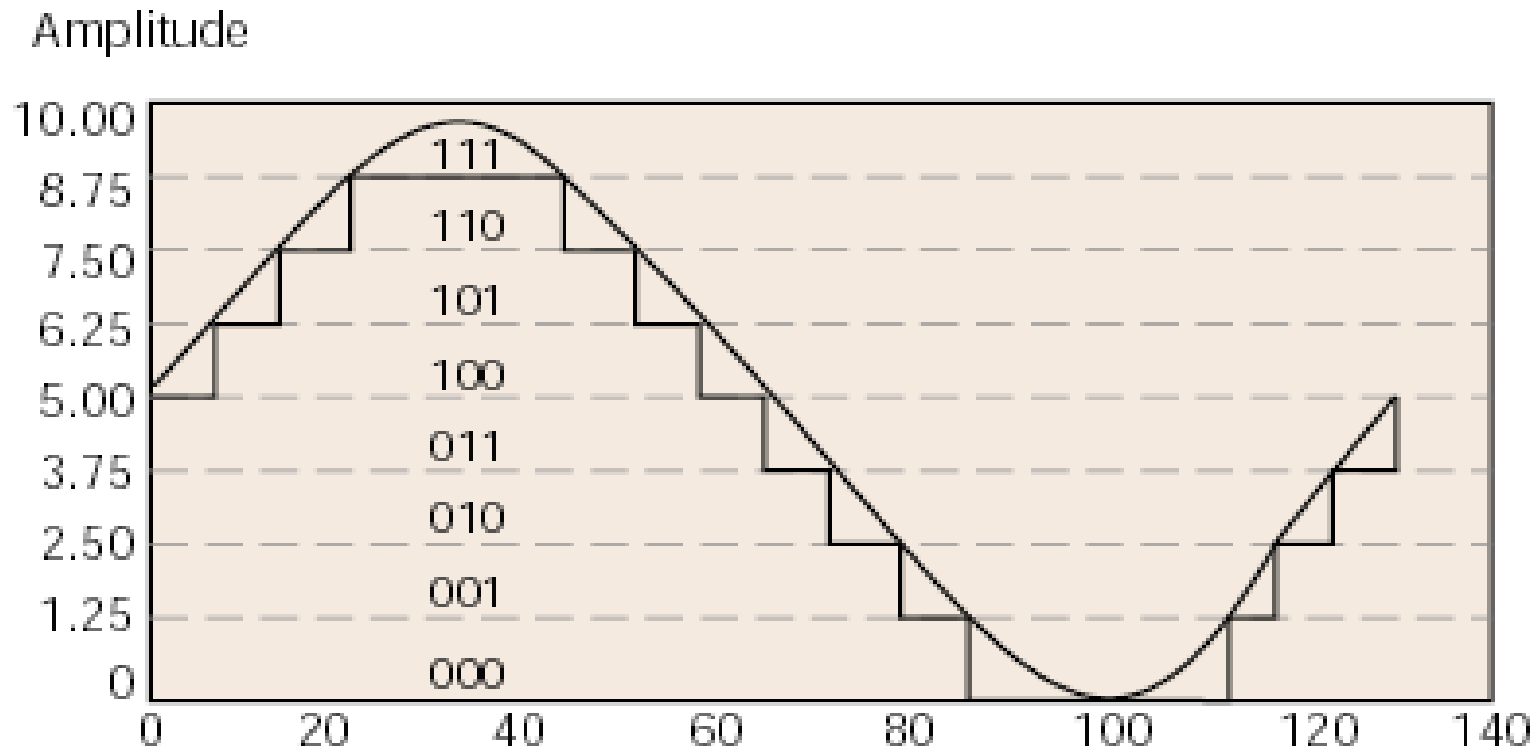
So if the full output range of our 3-bit ADC is 10 VDC, then each level represents  $10 \text{ VDC} / 8 = 1.25 \text{ VDC}$

Similarly, a 16-bit ADC has 65536 levels for a resolution of .152 mVDC.

# TOPIC 3 – Analog and Digital Signals

## 3.2 Analog Sampling Basics/ Analog to Digital Conversion

So for a 3-bit analog to digital conversion for an analog signal with an arbitrary maximum amplitude of 10:



# TOPIC 3 – Analog and Digital Signals

## 3.2 Analog Sampling Basics/ Analog to Digital Conversion

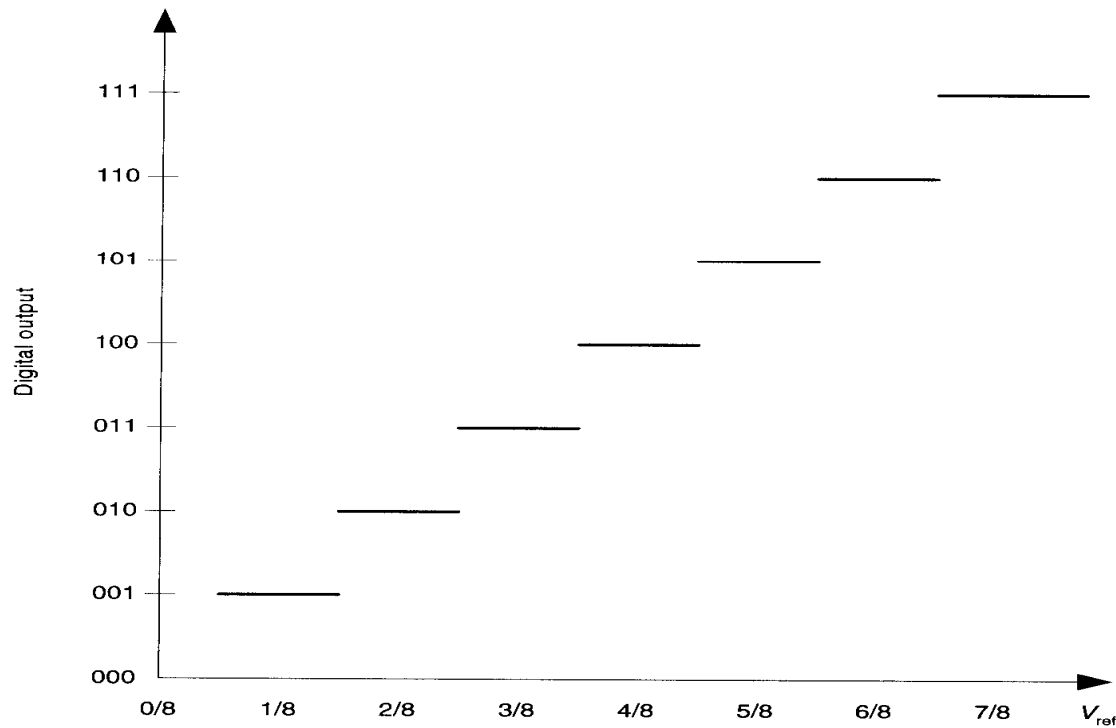


Figure 2.44 Converting characteristic of 3-bit ADC.

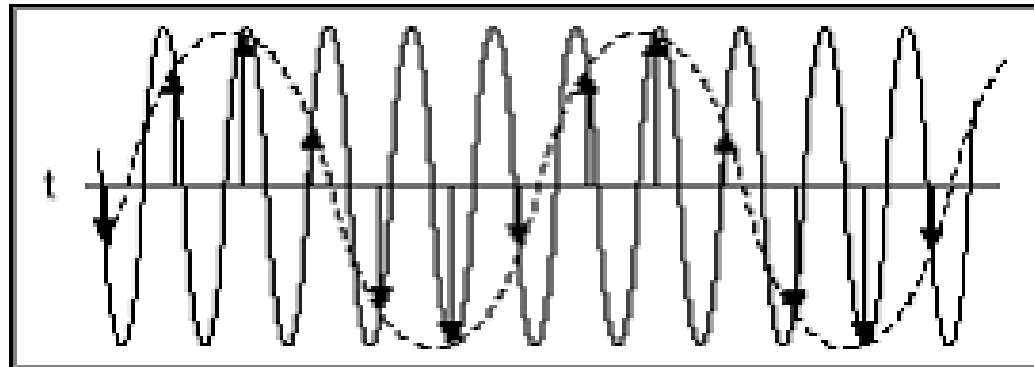
# TOPIC 3 – Analog and Digital Signals

## 3.2 Analog Sampling Basics/ Analog to Digital Conversion

### Aliasing

- If a signal is sampled at a sampling rate smaller than *twice the Nyquist frequency*, false lower frequency component(s) appears in the sampled data. This phenomenon is called Aliasing

Aliasing in the time domain-



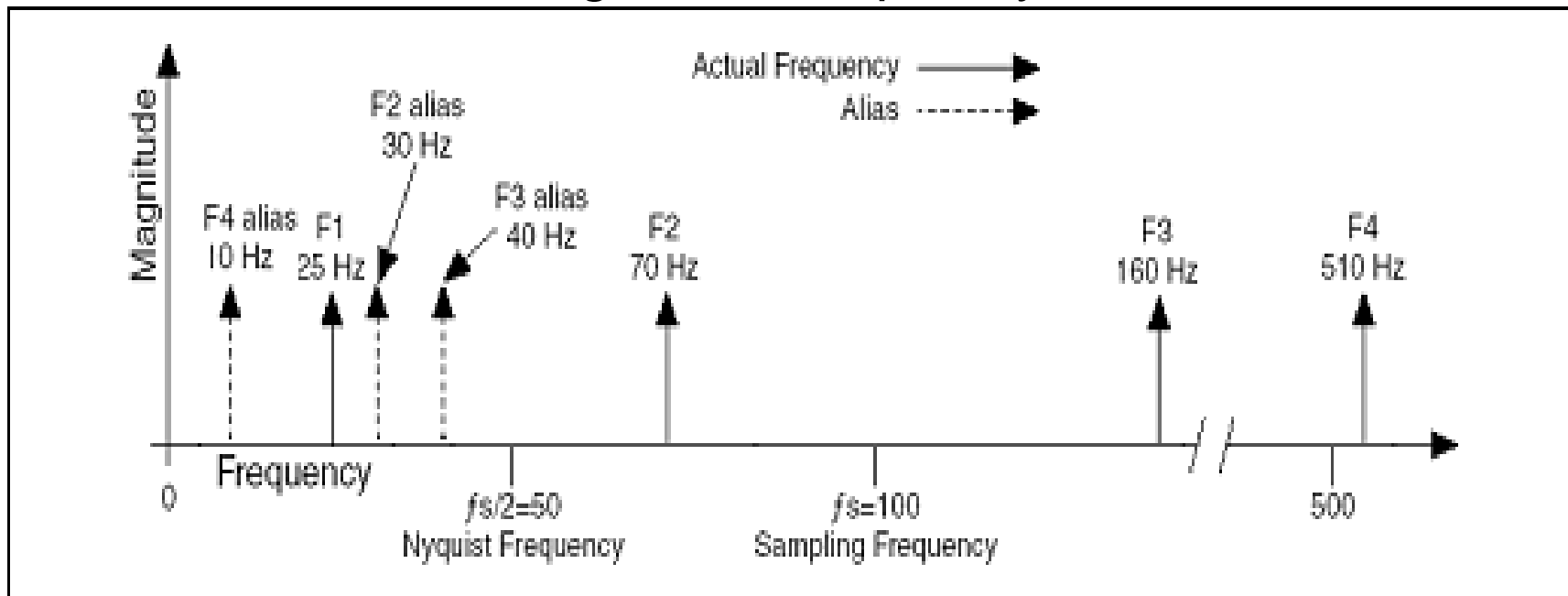
# TOPIC 3 – Analog and Digital Signals

## 3.2 Analog Sampling Basics/ Analog to Digital Conversion

### Alias Frequency

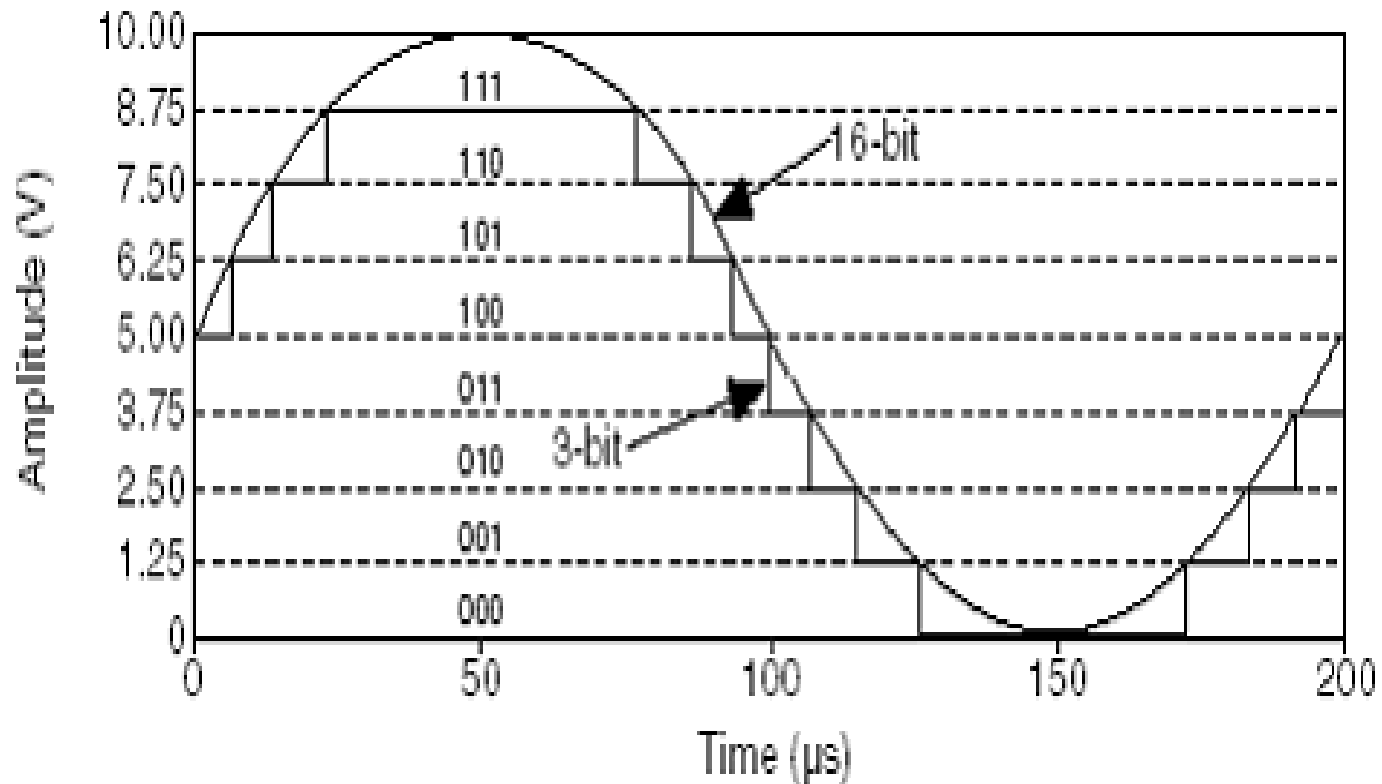
- Alias Freq. = ABS (Closest Integer Multiple of Sampling Freq. – Input Freq. where ABS means the absolute value.

Aliasing in the frequency domain



# Quantization Error

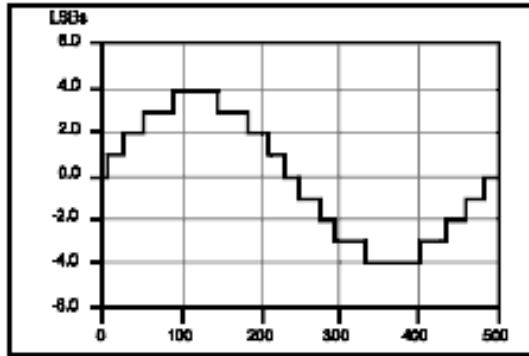
## 3.2 Analog Sampling Basics/ Analog to Digital Conversion



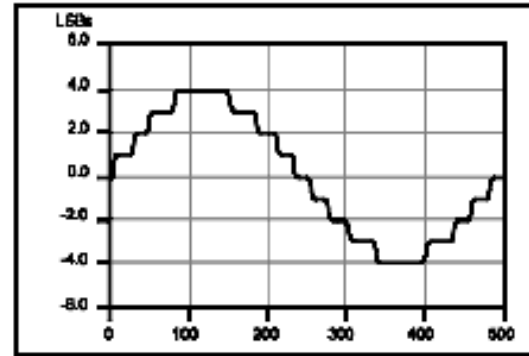
# Dithering

## 3.2 Analog Sampling Basics/ Analog to Digital Conversion

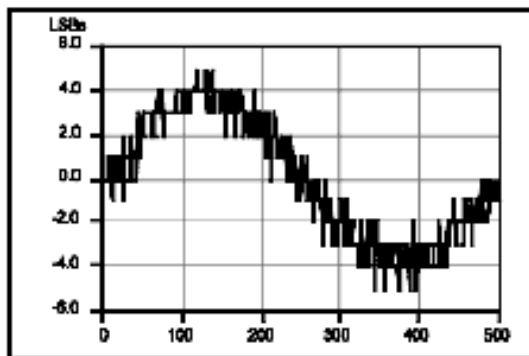
- Dithering involves the deliberate addition of noise to our input signal. It helps by smearing out the little differences in amplitude resolution



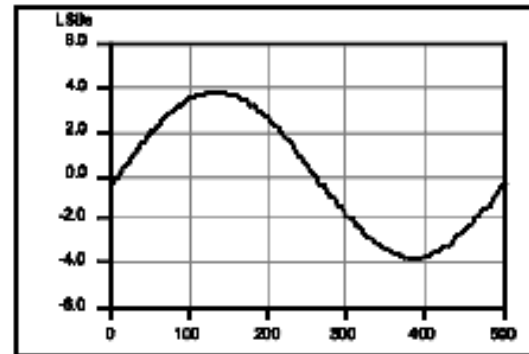
a. Dither disabled; no averaging



b. Dither disabled; average of 50 acquisitions



c. Dither enabled; no averaging



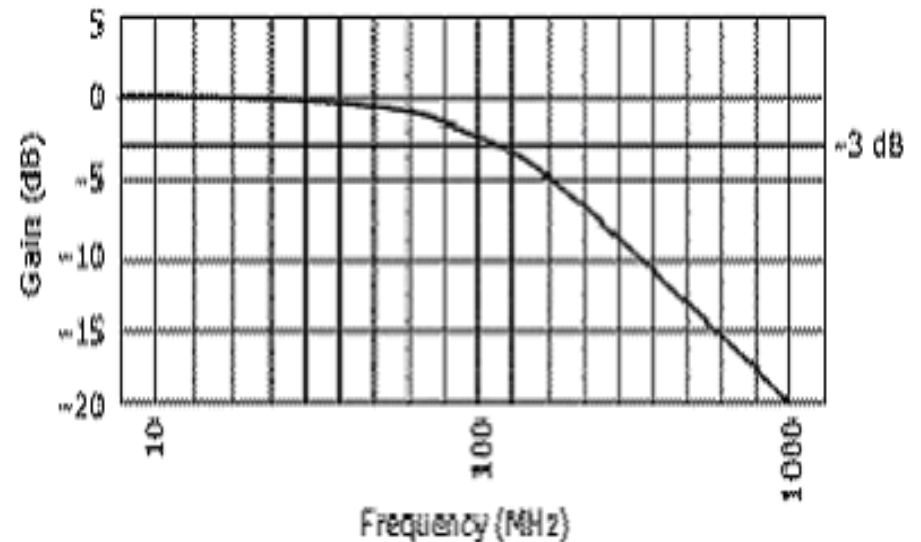
d. Dither enabled; average of 50 acquisitions

# TOPIC 3 – Analog and Digital Signals

## 3.2 Analog Sampling Basics

### Bandwidth

- Bandwidth is measured between the lower and upper frequency points where the signal amplitude falls to -3 dB below the pass-band frequency
- For example this is a typical Input response of a 100 MHz high-speed digitizer



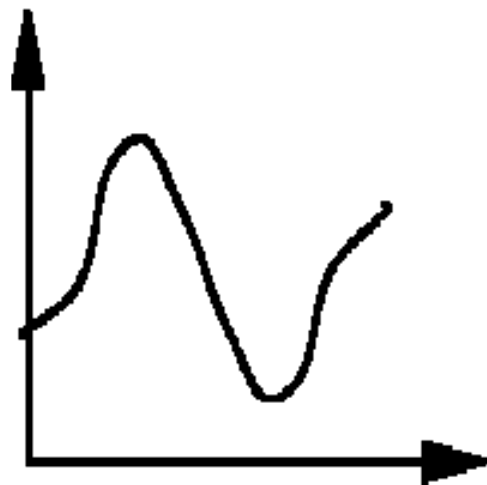
# TOPIC 3 – Analog and Digital Signals

## 3.3 Analog to Digital Conversion (ADC)

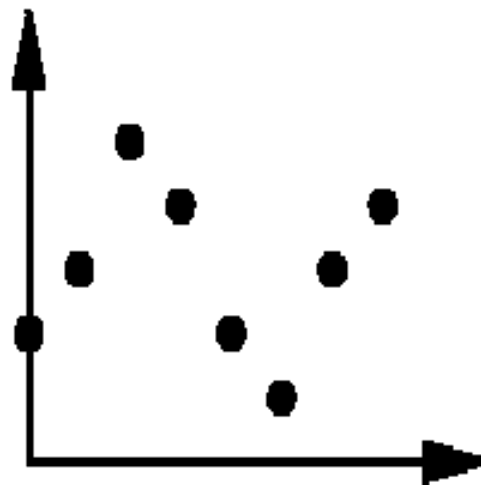
- If you have 3-bit analog to digital converters, the varying analog signal must be quantized to 1 of 8 discrete values.
- For example, with 2 states and 3 bit conversion there are  $2^3 = 8$  possible discrete values.

# TOPIC 3 – Analog and Digital Signals

## 3.3 Analog to Digital Conversion (ADC)



**analog signal**



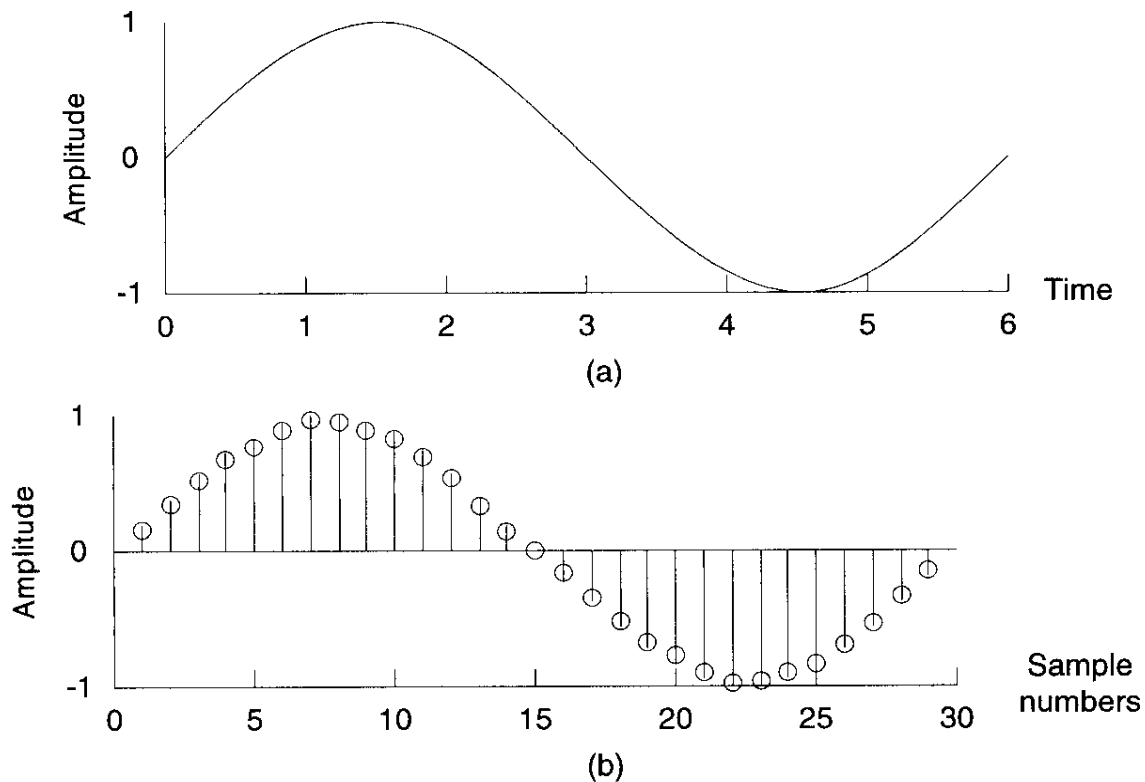
**sampled signal**

**100101010000110101**

**digital information**

# TOPIC 3 – Analog and Digital Signals

## 3.2 Analog to Digital Conversion (ADC)



**Figure 2.47** (a) Continuous signal. (b) Sampled sequence of the signal in (a) with a sampling period of 0.2 s.

# TOPIC 3 – Analog and Digital Signals

## 3.2 Analog Sampling Basics

### Nyquist Theorem and Nyquist Frequency

- Nyquist Theorem: Sampling rate must be greater than 2 times the highest frequency component (of interest) in the measured signal
- *Nyquist Frequency* is the highest frequency component allowed to avoid Aliasing for a given sampling frequency

# TOPIC 3 – Analog and Digital Signals

## 3.3 Analog to Digital Conversion (ADC)

- Resolution:
  - Defined in terms of number of bits
  - $2^b$  where b: number of bits
    - e.g. 3 bit resolution yields 8 levels of resolution
    - 8 bit resolution yields 256 levels
    - 16 bit resolution yields 65536 levels