

Data Acquisition System

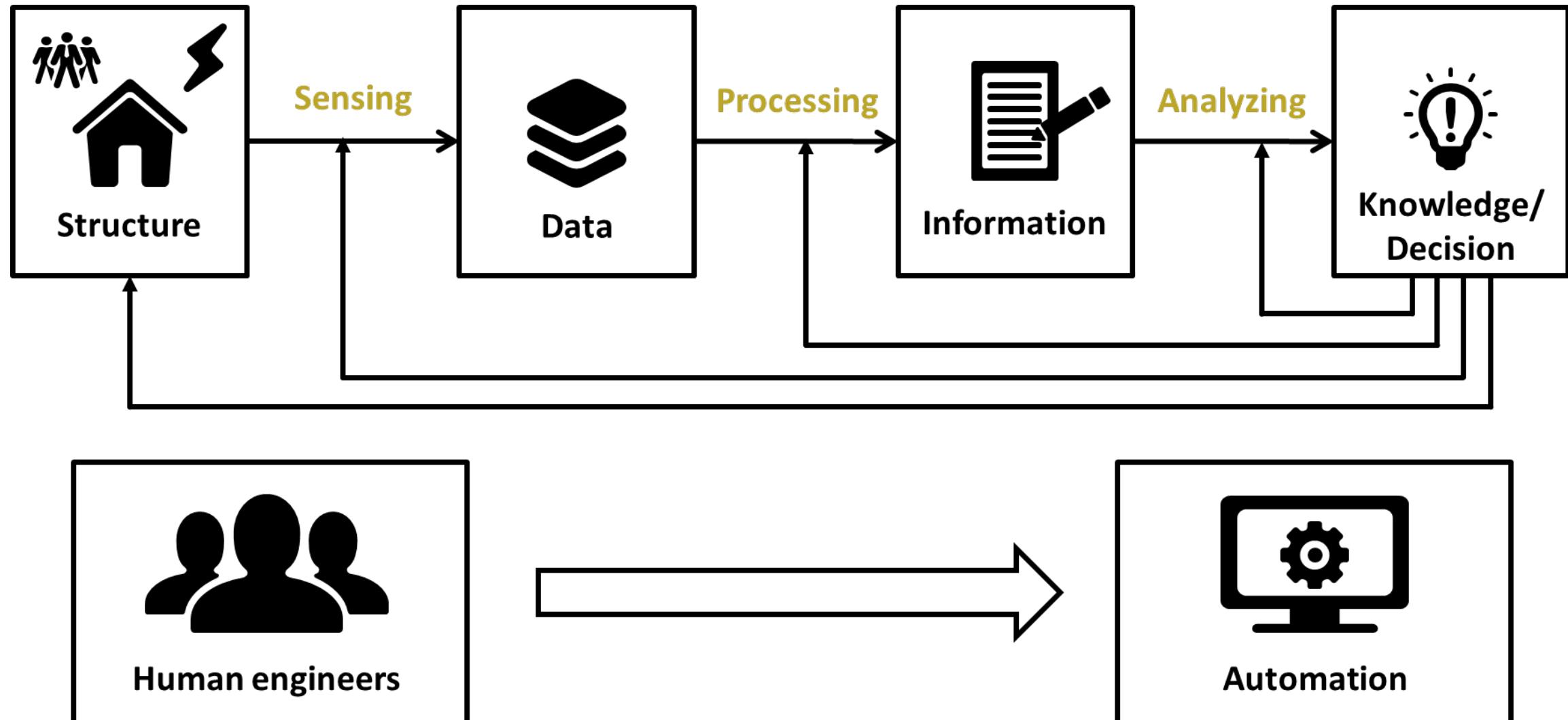
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University of Waterloo, Canada

CIVE 497 – CIVE 700: Smart Structure Technology
Last updated: 2021-01-09



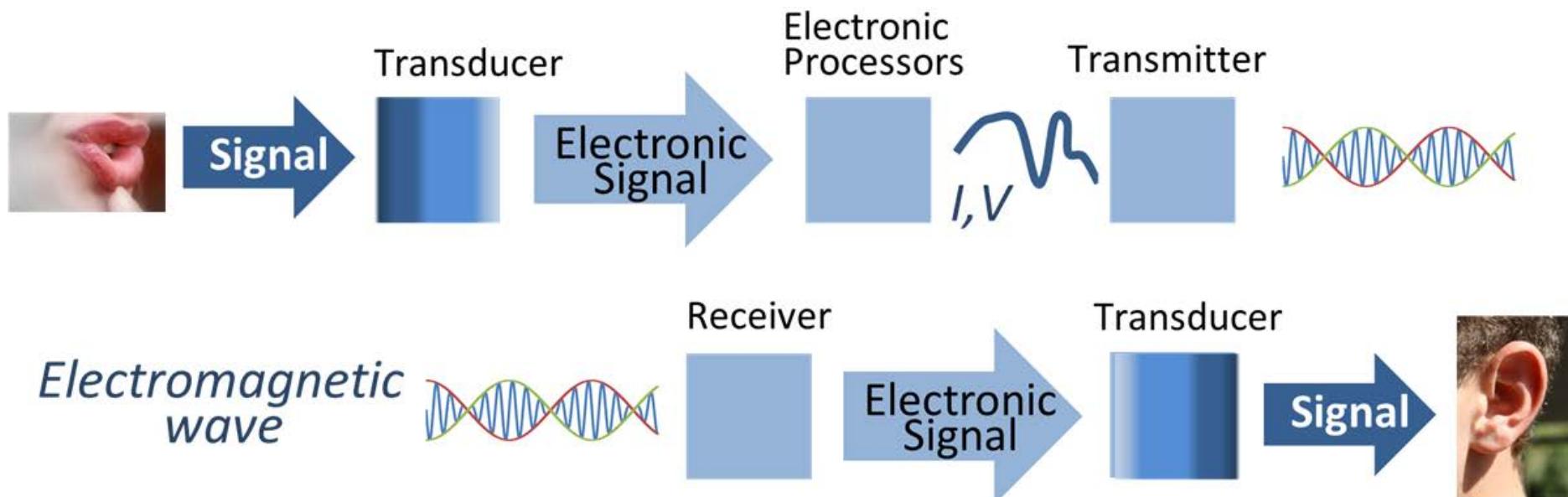
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Smart Infrastructure



What is Signal Processing?

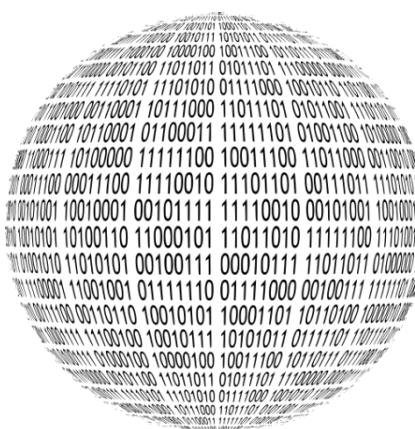
- Signal processing is procedures to reveal the information about the behavior or attributes of some phenomenon contained in the measurements, such as sound, image, or acceleration.
- These procedures rely on various transformation that are mathematically based and implemented using digital techniques.



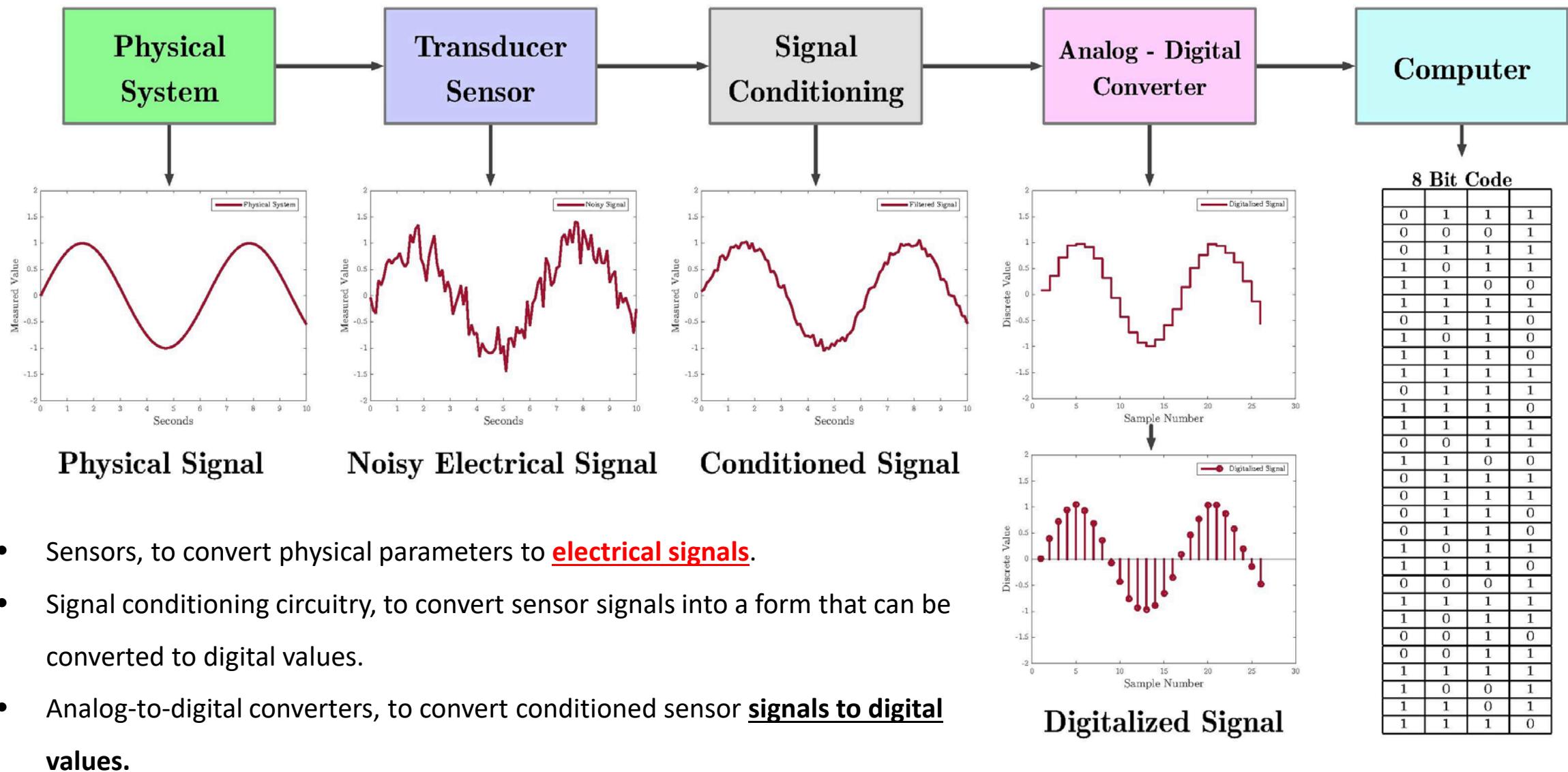
Data Acquisition

- Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into **finite digital numerical values** that can be manipulated by a computer.
- Data acquisition systems are used by most engineers and scientists for laboratory research, industrial control, test, and measurement to input and output data to and from a computer.

Welcome to Digital World !!!!



Data Acquisition Diagram



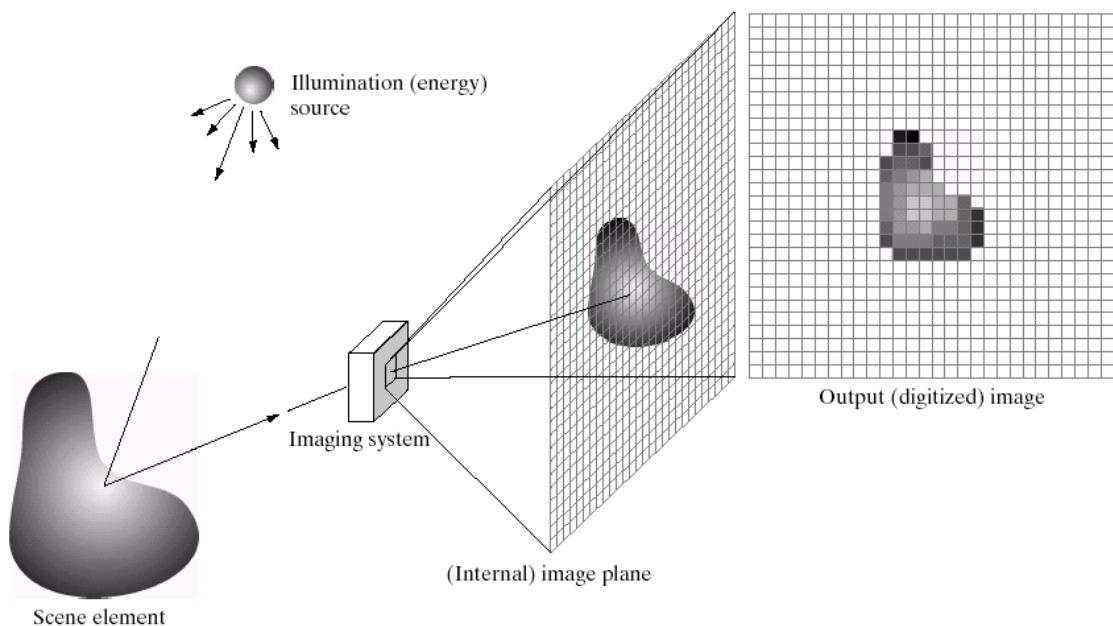
Analog vs Digital Signal

A digital signal refers to an electrical signal that is converted into a pattern of bits. Unlike an analog signal, which is a continuous signal that contains time-varying quantities, a digital signal has a discrete value at each sampling point. Several issues need to be solved to minimize distortion of the original signal (sampling, quantization, aliasing, and leakage).

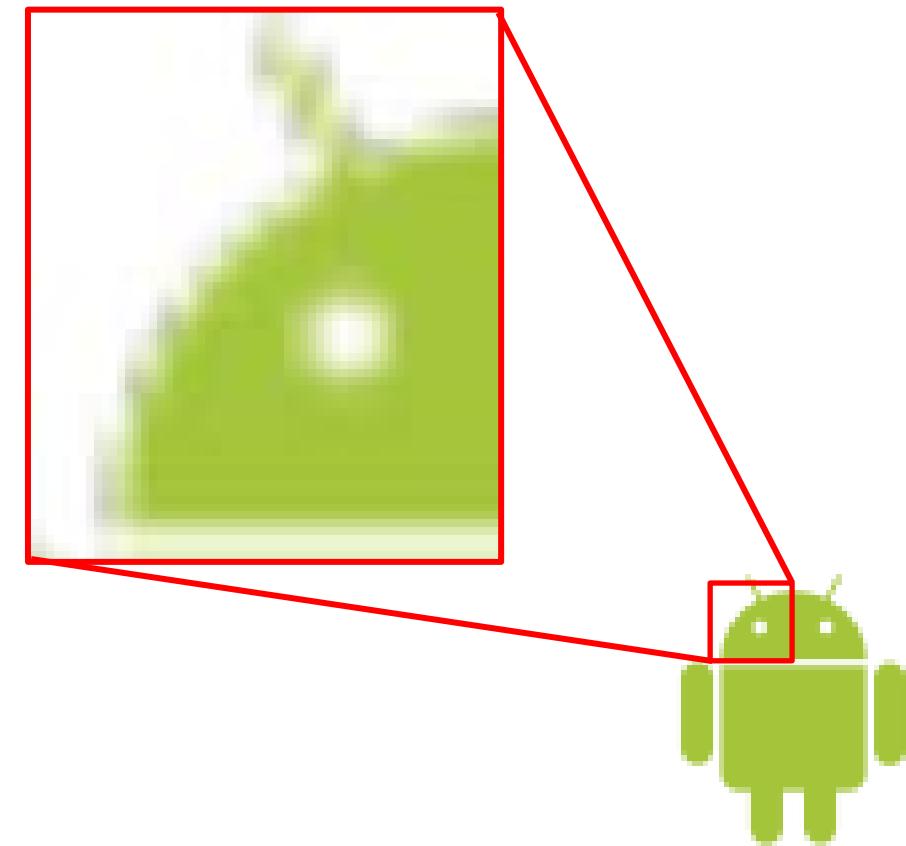
- Continuous-time vs Discrete-time signal
- Continuous-valued vs Discrete-valued signal
- Output range

Note that in certain physical situations, 'time' may not be a sole variable, for example, a plot of road roughness as a function of spatial position. Similarly, the images are considered as signals (functions) with respect to x and y pixels values.

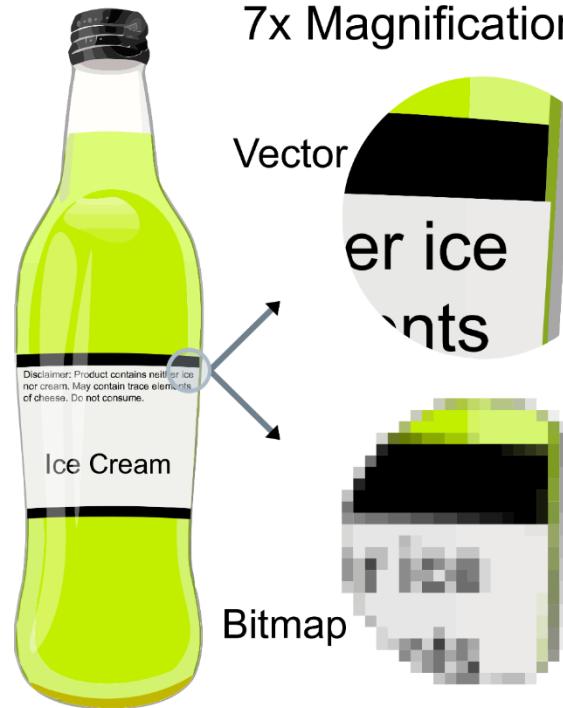
Example: Imaging System



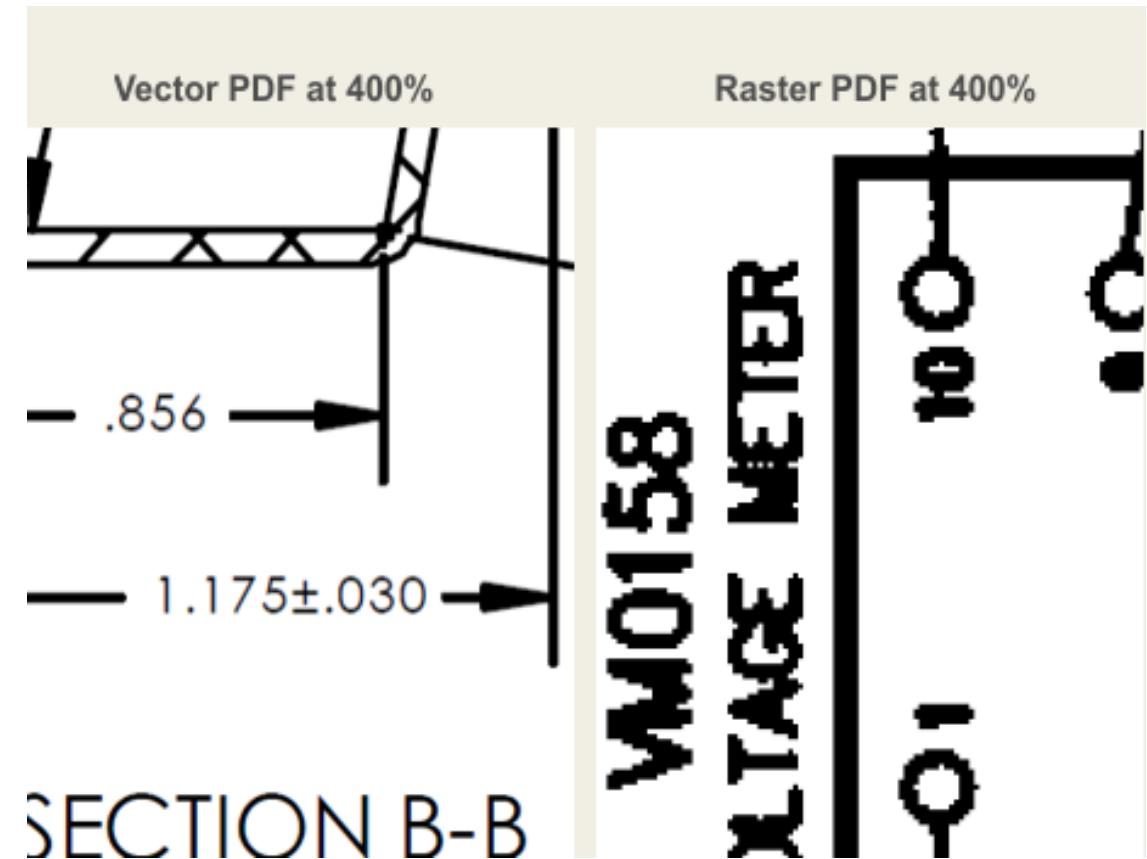
Digital Image Acquisition



Pixel



Vector graphics is the creation of digital images through a sequence of commands or mathematical statements that place lines and shapes in a given two-dimensional or three-dimensional space. In physics, a vector is a representation of both a quantity and a direction at the same time.

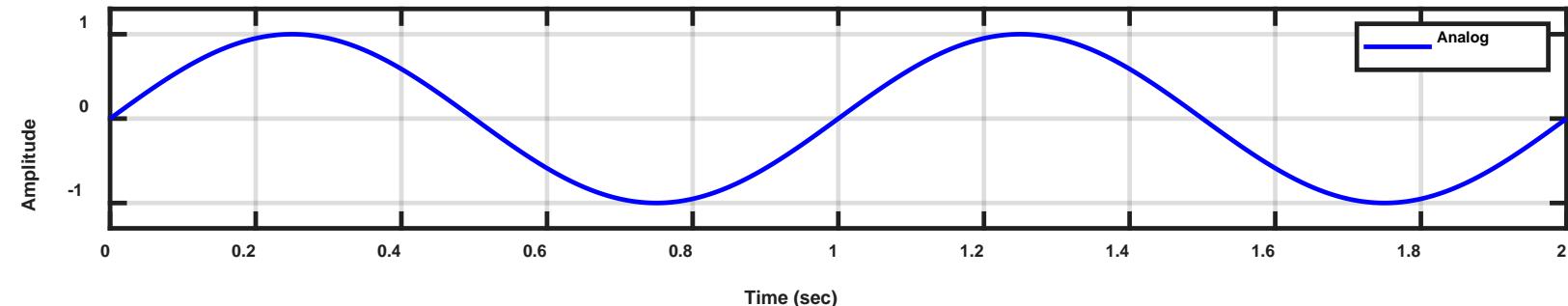


Digitization of Analog Signals

Sampling: How often the data is sampled in the time axis.

$$y = \sin(2\pi ft)$$

Frequency (f): 1Hz

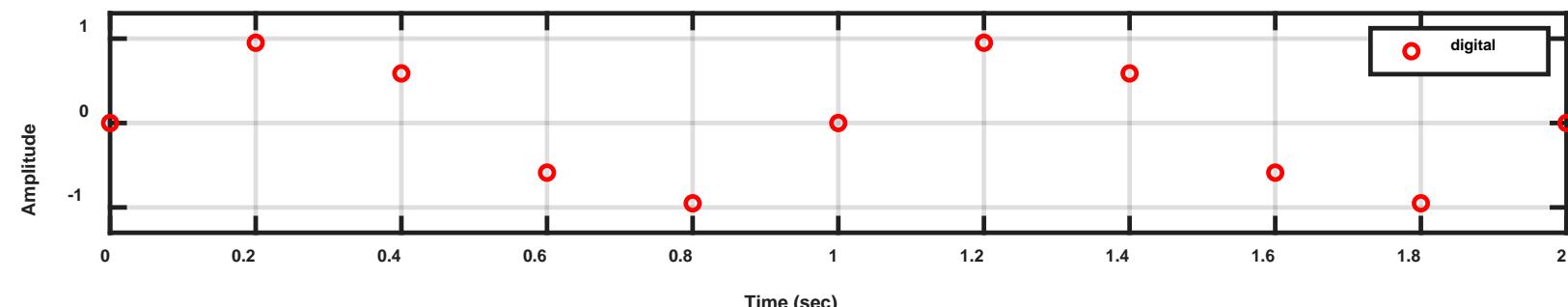
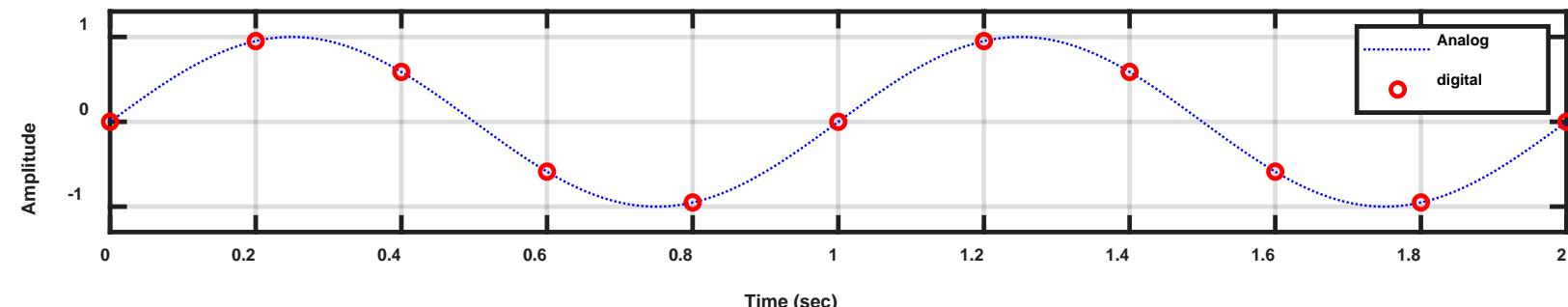


Sampling frequency

$$f_s = 5 \text{ Hz}$$

Sampling interval

$$\Delta t = 0.2 \text{ sec}$$



Determination of a Sampling Frequency (Rate)

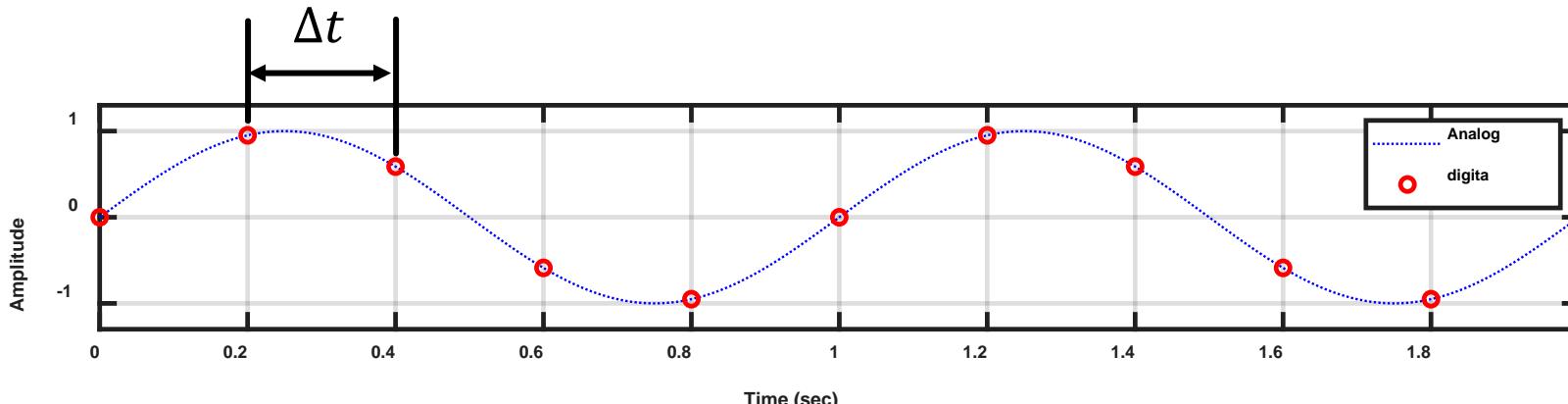
- Sampling frequency (Hz) is the inverse of the sampling interval

$$f_s = 1/\Delta t \text{ (Hz)}$$

- Make sure the sampling frequency is at least twice the desired frequency to be measured.** (When the signal is analyzed in the frequency domain)

$$f_h < \frac{f_s}{2} = 1/(2\Delta t)$$

- As a rule of thumb, 10 samples or more digital points during the signal period of interest (when the signal is analyzed in the time domain).



Continuous Time Signals in a Frequency Domain

$$y_1 = \sin(2\pi f_1 t)$$

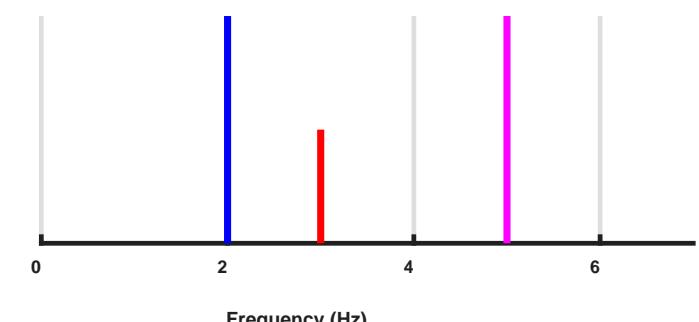
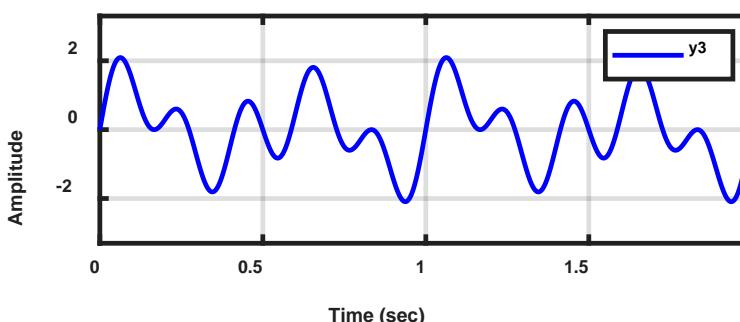
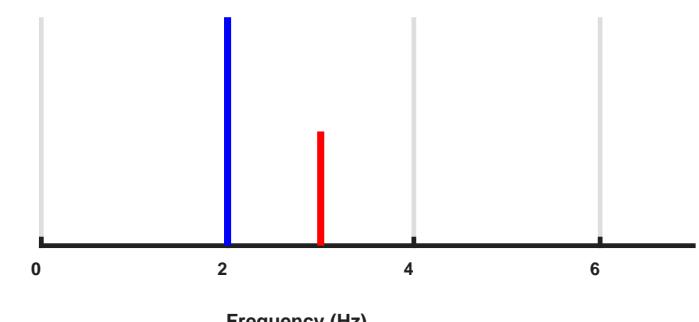
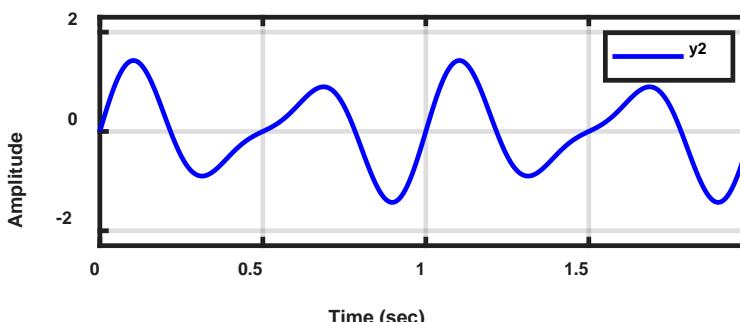
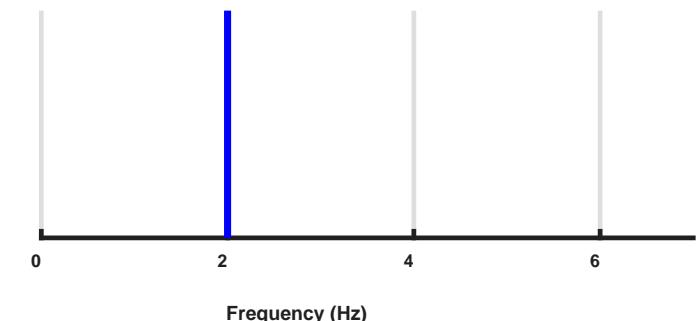
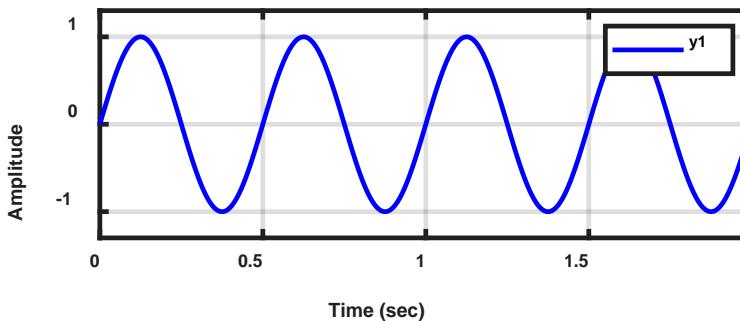
$$f_1: 2\text{Hz}$$

$$y_2 = \sin(2\pi f_1 t) + 0.5\sin(2\pi f_2 t)$$

$$f_1: 2\text{Hz}, f_2: 3\text{Hz}$$

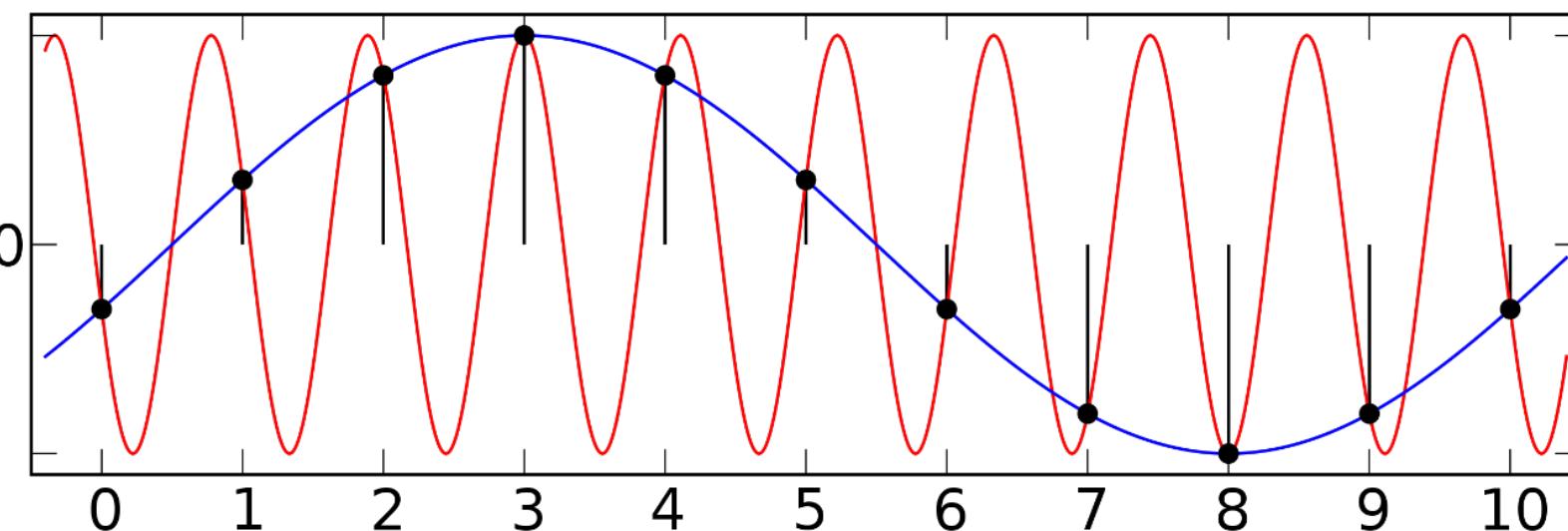
$$y_3 = \sin(2\pi f_1 t) + 0.5\sin(2\pi f_2 t) + \sin(2\pi f_3 t)$$

$$f_1: 2\text{Hz}, f_2: 3\text{Hz}, f_3: 5\text{Hz}$$



Aliasing

- Aliasing refers to the distortion or artifact that results when the signal reconstructed from samples is different from the original continuous signal.
- A higher frequency component is disguised as a lower frequency component because of inadequate sampling.



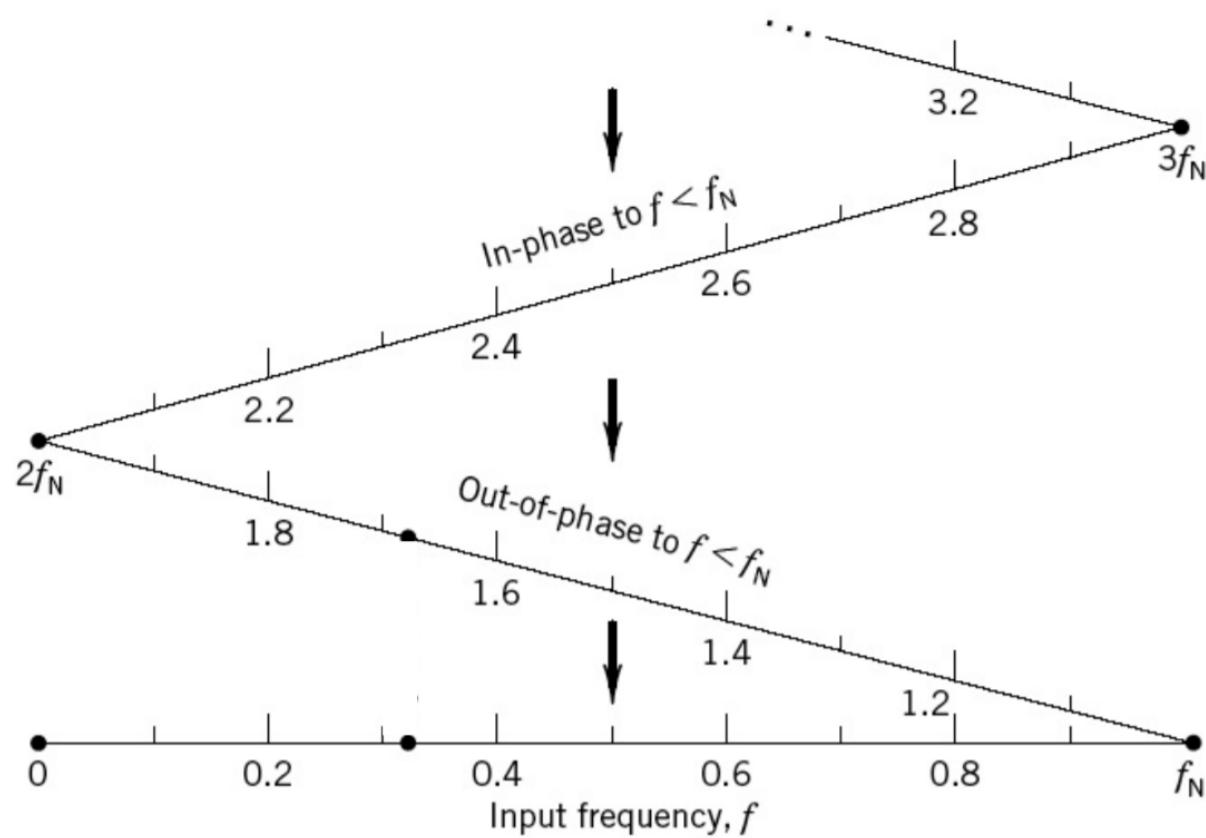
Sample from a sine wave

- Original signal
- Sampled points

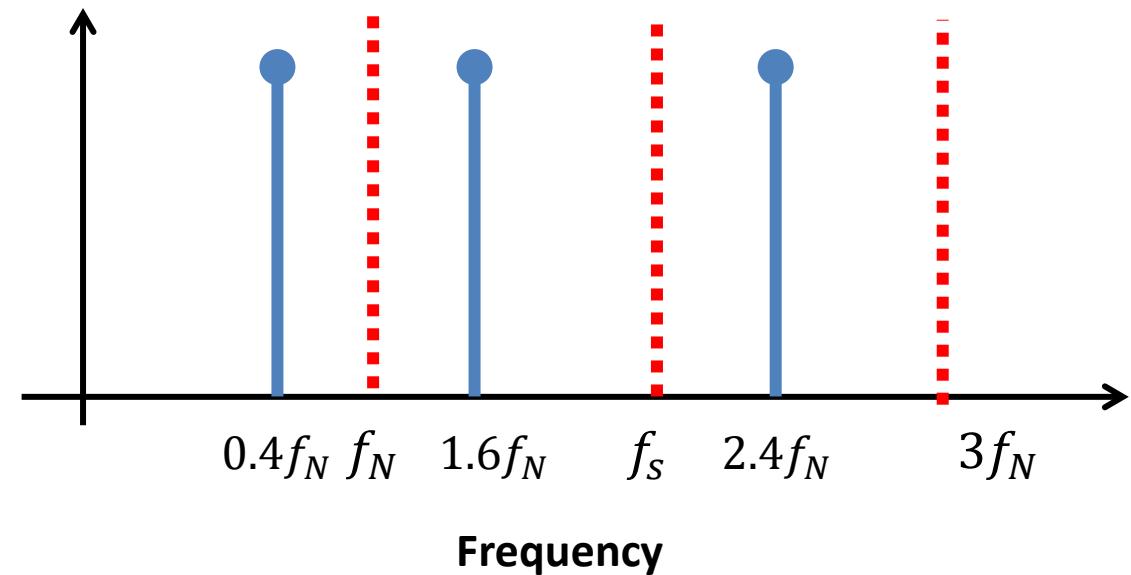
Q: What do you learn from this graph?

Aliasing (Continue)

Folding Diagram

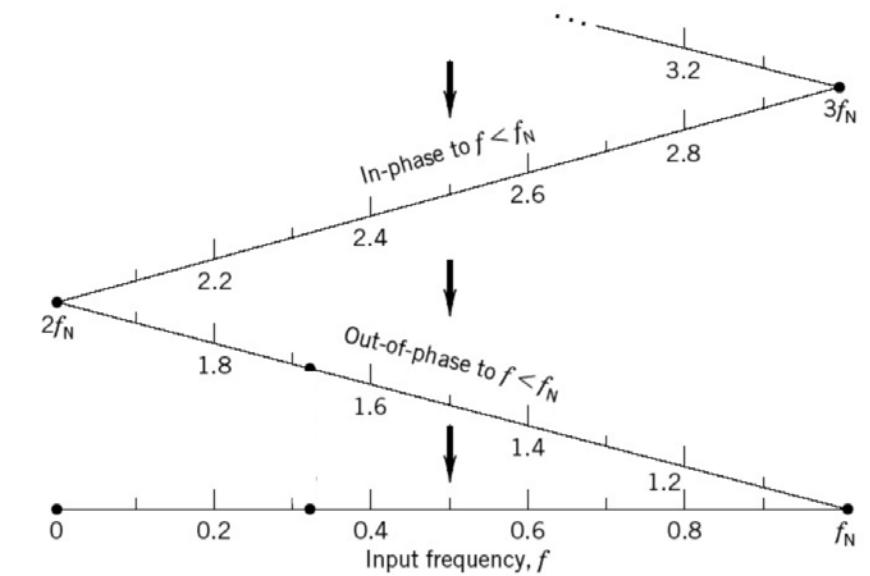


f_N : Nyquist frequency

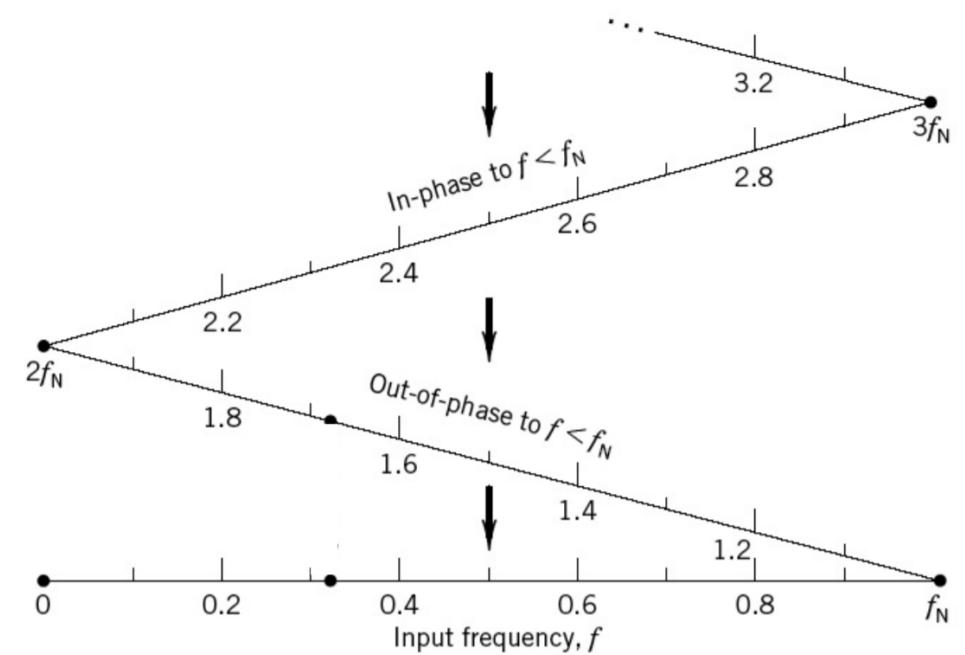


- Signal frequency: 160 Hz (or 240 Hz)
- Sample rate: 200 Hz
- Nyquist frequency: 100 Hz
- Alias frequency: 40 Hz

Example: Spinner



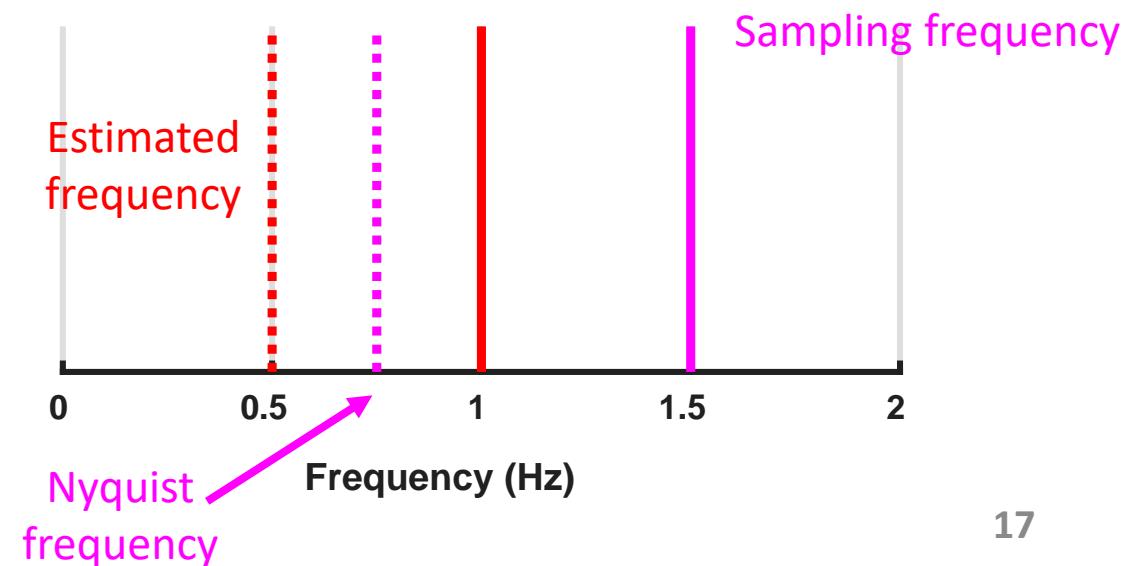
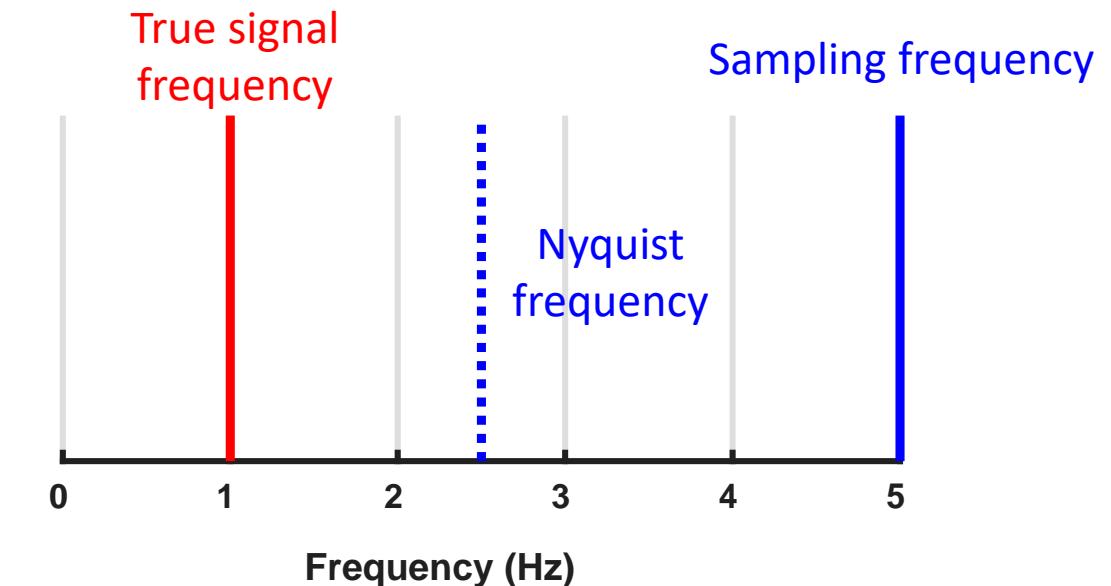
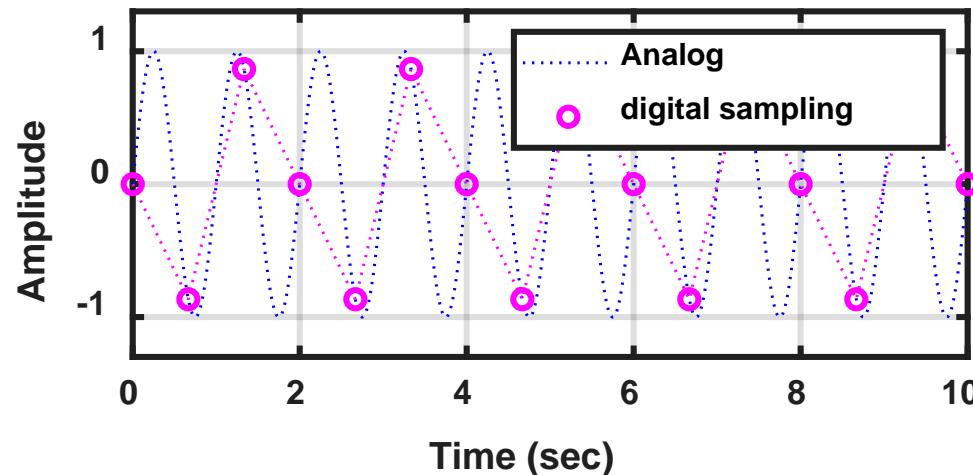
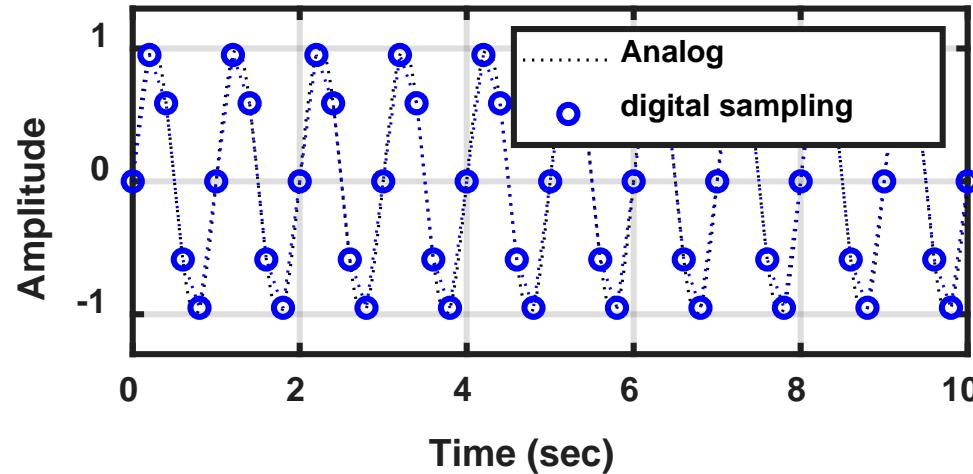
Example: Helicopter Like Spaceship 1



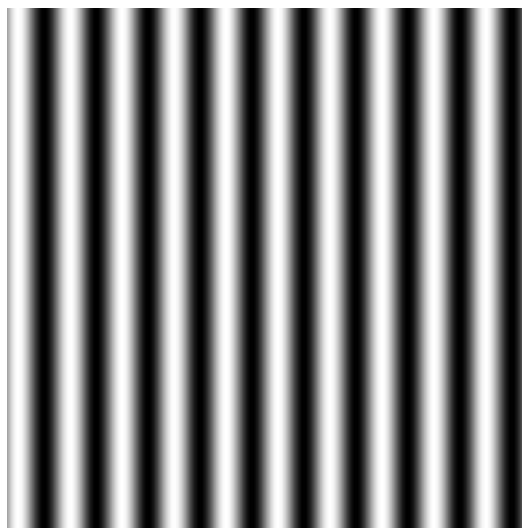
Example: Helicopter Like Spaceship 2



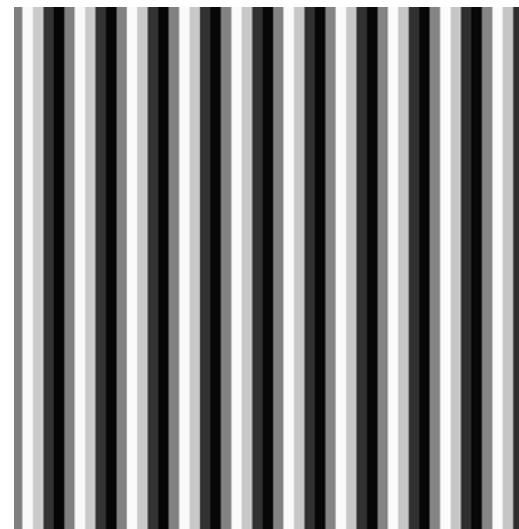
Example: Effect of Aliasing



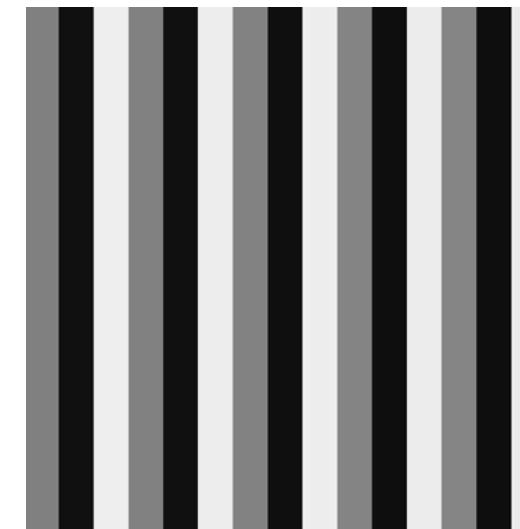
Example: Spatial Aliasing



Original image (1200 x 1200)



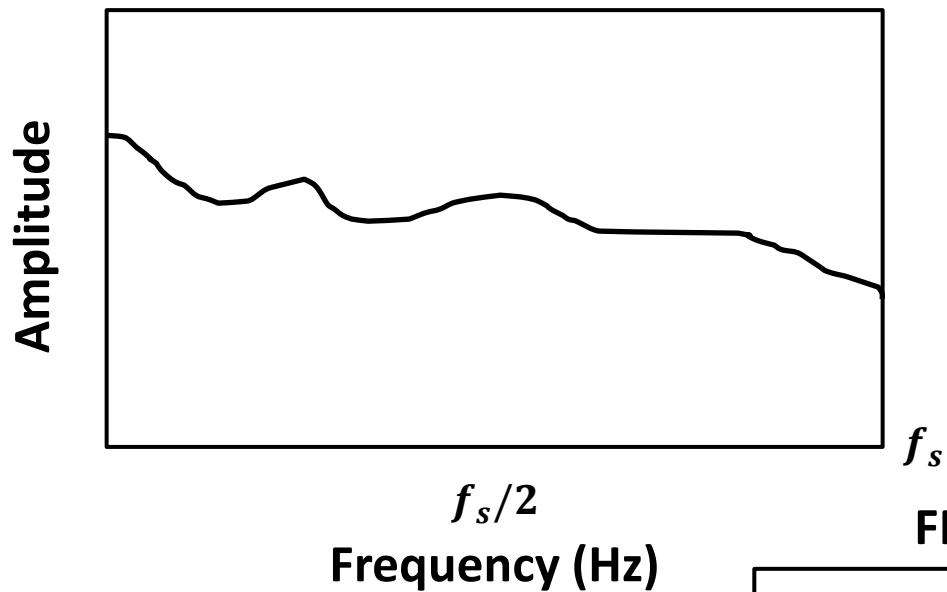
Resampling (50 X 50)



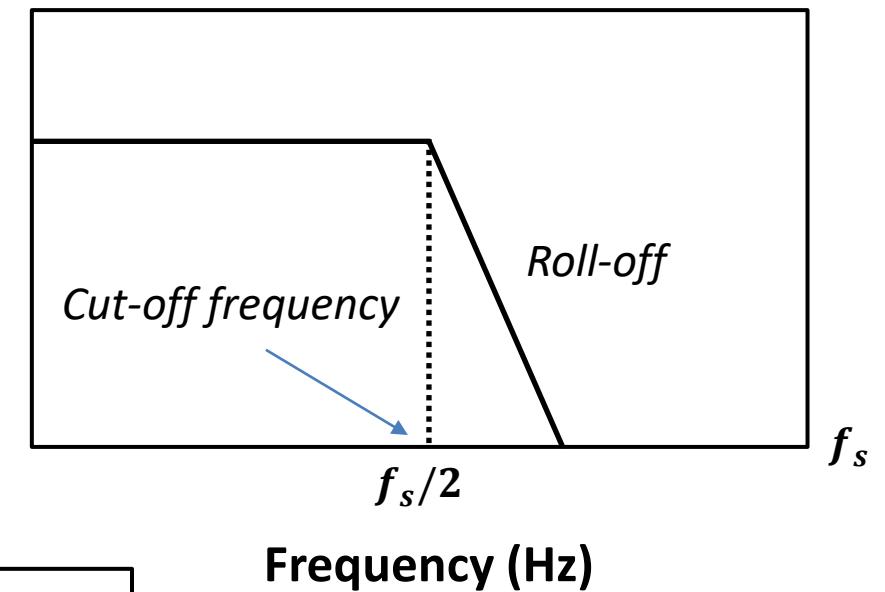
Resampling (15 X 15)

Anti-Aliasing Analog Filter

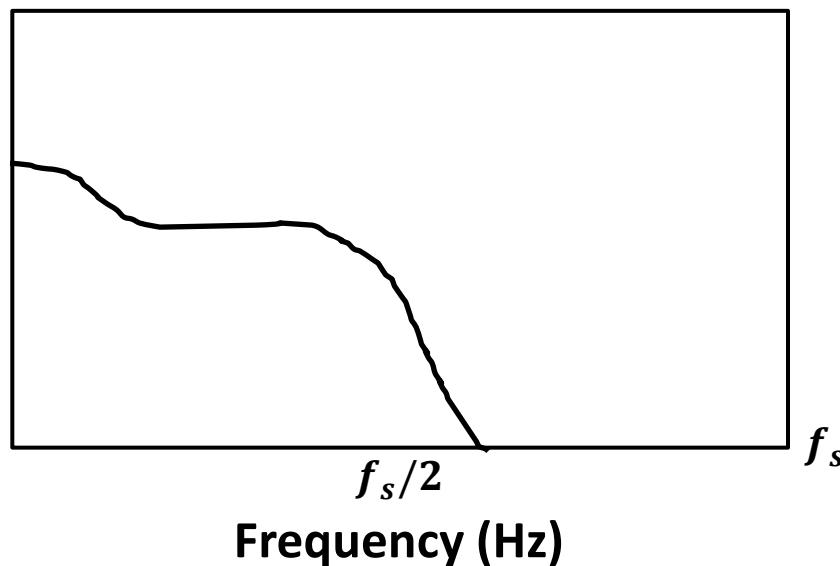
FFT of Analog Signal



FFT of Analog Filter



FFT of Filtered Signal

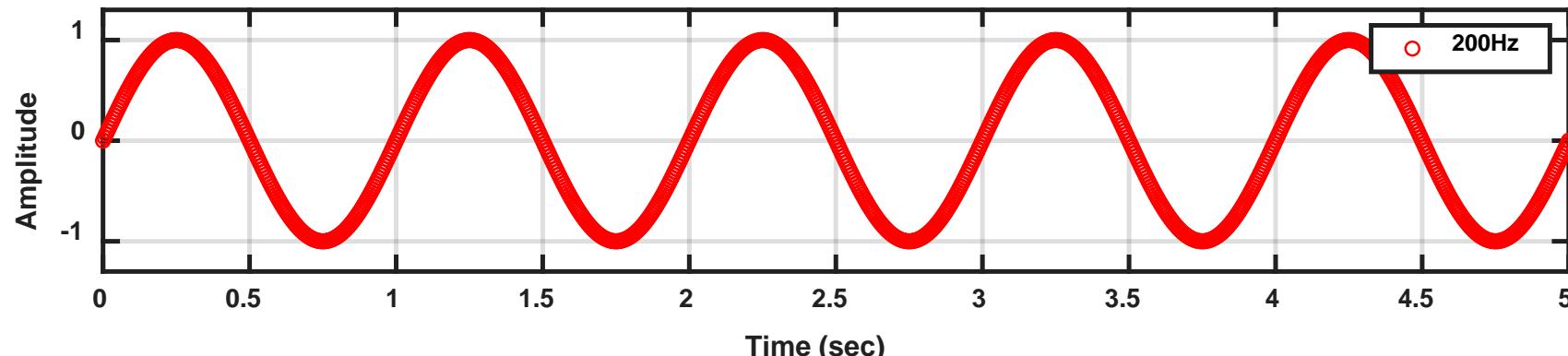
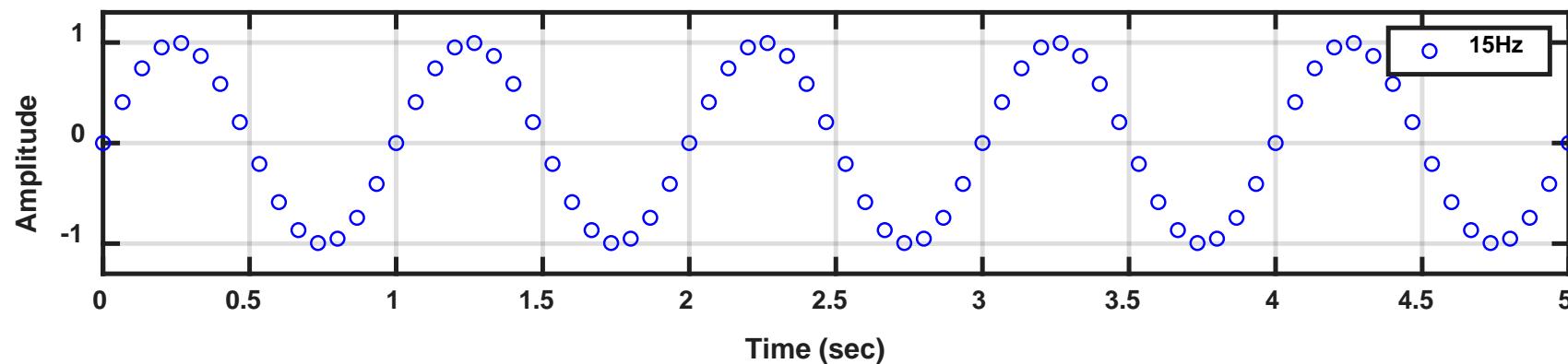


Anti-Aliasing is done before
sampling.

Oversampling

Oversampling will provide a true picture of the time course of the event being studied but too much oversampling will result in very large data files.

Example: Drawing a graph



Do we really
need 200Hz?

Example: Image Oversampling



maxresdefault.jpg

JPG File



Date taken: [Specify date taken](#)
Tags: [Add a tag](#)
Rating: 
Dimensions: 150 x 84
Size: 5.77 KB
Title: [Add a title](#)
Authors: [Add an author](#)
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Camera maker: [Add text](#)
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Subject: [Specify the subject](#)
Date created: 12/26/2018 1:56 PM
Date modified: 12/26/2018 1:58 PM

maxresdefault_high.jpg

JPG File



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Dimensions: 1500 x 840
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Quantization of Analog Signals

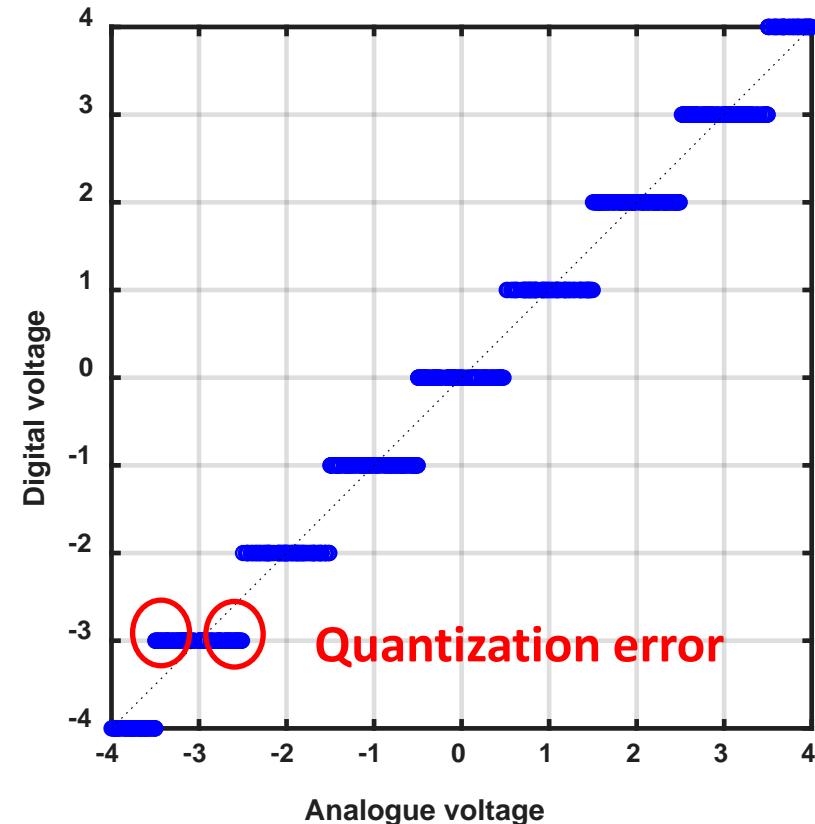
- **Quantization** is the process of constraining an input from a continuous or otherwise large set of values (such as the real numbers) to a discrete set (such as the integers).
- An analog signal from a sensor is sampled in time (sampling frequency) and in amplitude (Quantization).

Example)

3 bit Analog-digital converter produces

$2^3 = 8$ bins for a voltage range of $-4 \sim 4$ v.

Q: example graph



Example for Resolution Calculation

- **Given parameters**

- Sensor sensitivity: 100mV/g
- Voltage output range: -2V to +2V
- # of ADC bits: 16 bits

- **Calculation**

- 16 bit ADC divides the full scale voltage into $2^{16} = 65536$ bins
- Resolution in terms of voltage: $4V/65536 = 6.1035e-005V$
- Resolution in terms of acceleration:

$$6.1035 \times 10^{-5} V \times \frac{1}{100mV/g} = 6.1035 \times 10^{-4}g$$

$$\text{Resolution (g)} = \frac{\text{Output voltage range (V)}}{2^{\# \text{ of ADC bits}}} \times \frac{1}{\text{Sensor Sensitivity (V/g)}}$$

Other Considerations for Resolution

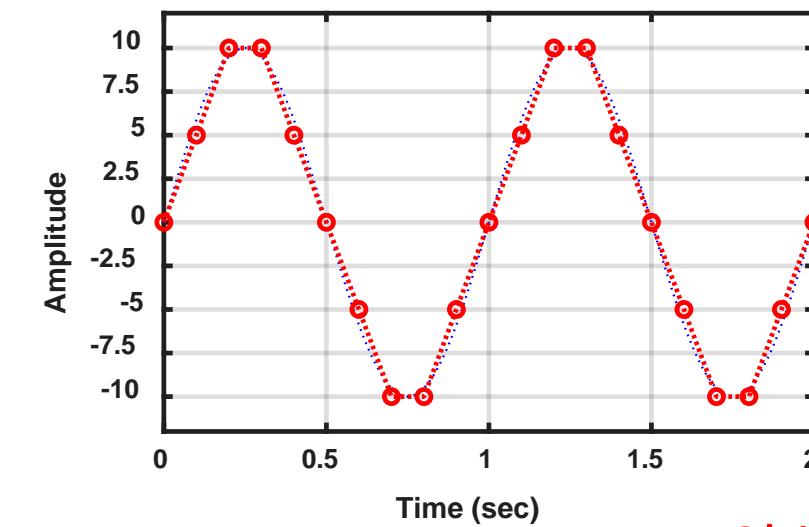
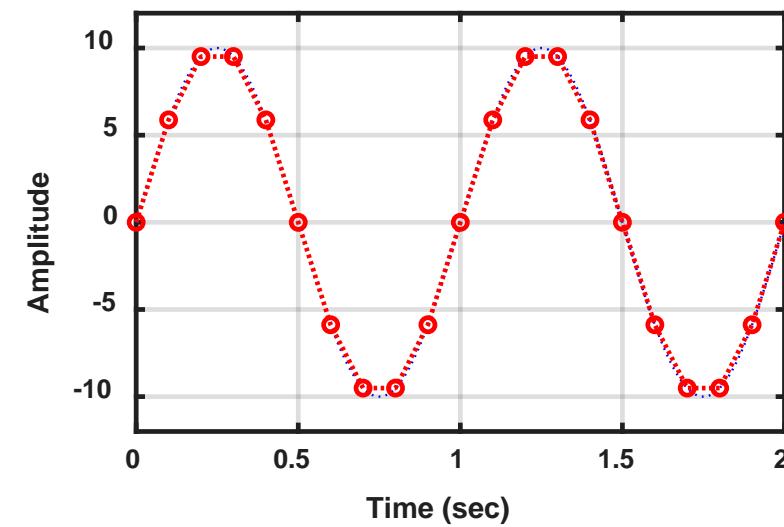
Supplement

$$y = 10 * \sin(2\pi ft)$$

Frequency (f): 1

Sampling frequency

$$f_s = 1/10 \text{ Hz}$$



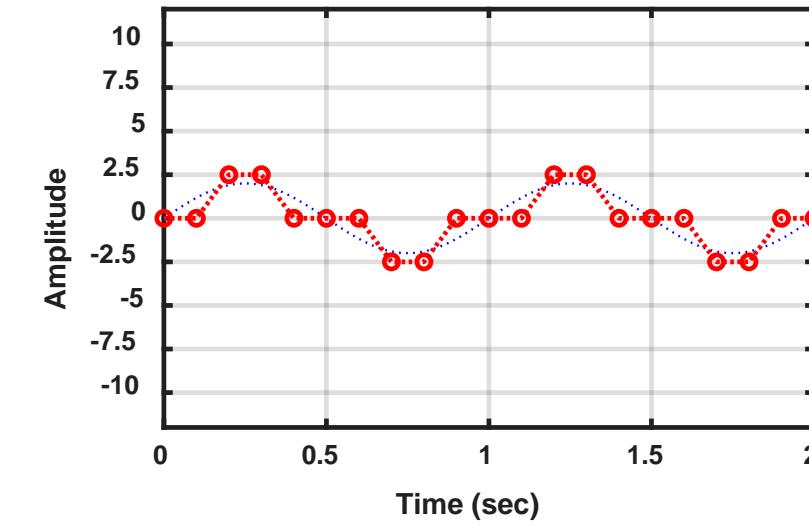
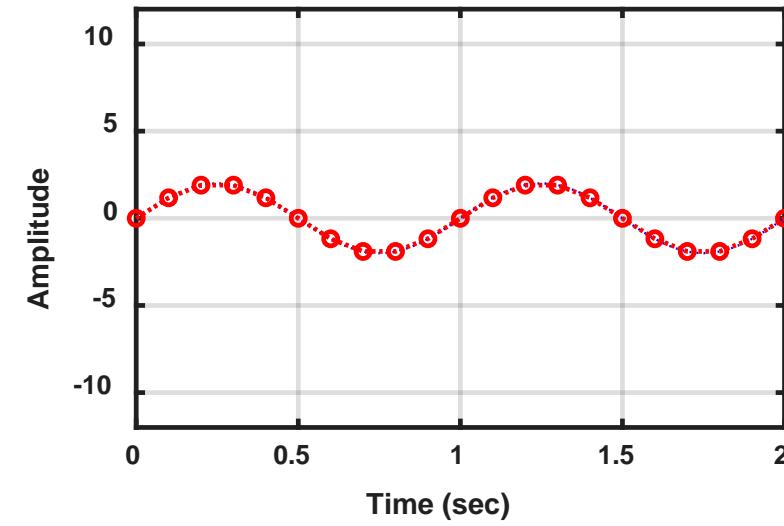
3bit ADC

$$y = 2 * \sin(2\pi ft)$$

Frequency (f): 1

Sampling frequency

$$f_s = 1/10 \text{ Hz}$$



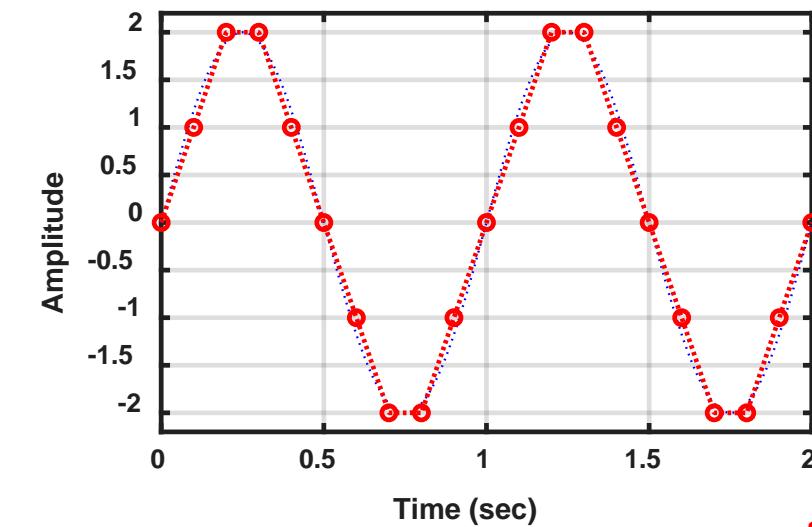
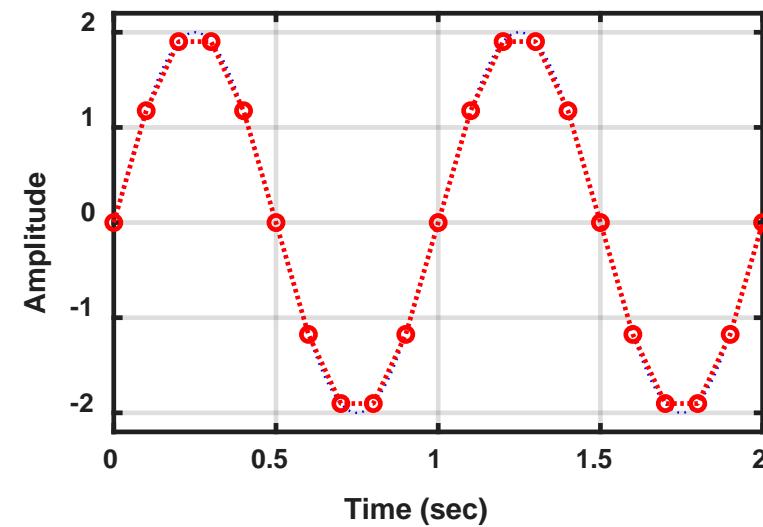
Clipping

$$y = 2 * \sin(2\pi ft)$$

Frequency (f): 1

Sampling frequency

$$f_s = 1/10 \text{ Hz}$$



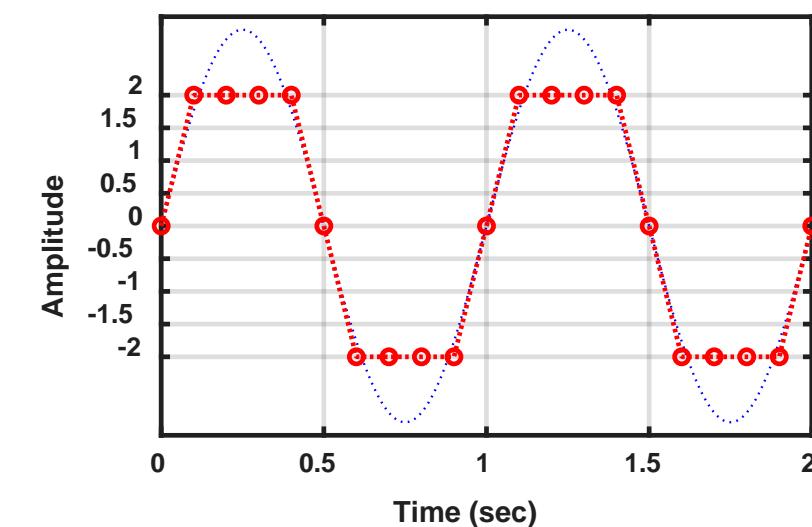
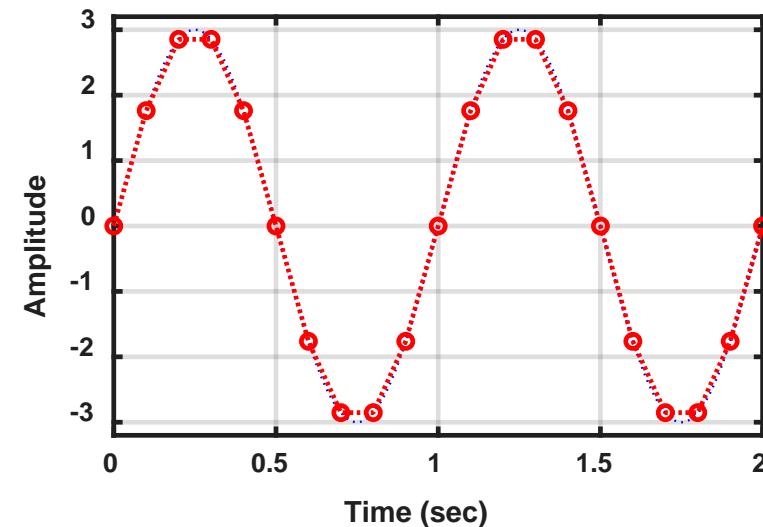
-2V - 2V

$$y = 3 * \sin(2\pi ft)$$

Frequency (f): 1

Sampling frequency

$$f_s = 1/10 \text{ Hz}$$



Example: Accelerometer in iPhone X Accelerometer

BMI 160, Bosch Sensortec

Parameter	Technical data
Digital resolution	Accelerometer (A): 16 bit Gyroscope (G): 16bit
Measurement ranges (programmable)	(A): $\pm 2 \text{ g}$, $\pm 4 \text{ g}$, $\pm 8 \text{ g}$, $\pm 16 \text{ g}$ (G): $\pm 125^\circ/\text{s}$, $\pm 250^\circ/\text{s}$, $\pm 500^\circ/\text{s}$, $\pm 1000^\circ/\text{s}$, $\pm 2000^\circ/\text{s}$
Sensitivity (calibrated)	(A): $\pm 2\text{g}$: 16384LSB/g $\pm 4\text{g}$: 8192LSB/g $\pm 8\text{g}$: 4096LSB/g $\pm 16\text{g}$: 2048LSB/g (G): $\pm 125^\circ/\text{s}$: 262.4 LSB/ $^\circ/\text{s}$ $\pm 250^\circ/\text{s}$: 131.2 LSB/ $^\circ/\text{s}$ $\pm 500^\circ/\text{s}$: 65.6 LSB/ $^\circ/\text{s}$ $\pm 1000^\circ/\text{s}$: 32.8 LSB/ $^\circ/\text{s}$ $\pm 2000^\circ/\text{s}$: 16.4 LSB/ $^\circ/\text{s}$
Zero-g offset (typ., over life-time)	(A): $\pm 40\text{mg}$ (G): $\pm 10^\circ/\text{s}$
Noise density (typ.)	(A): $180 \mu\text{g}/\sqrt{\text{Hz}}$ (G): $0.008^\circ/\text{s}/\sqrt{\text{Hz}}$
Bandwidths (programmable)	1600 Hz ... 25/32 Hz

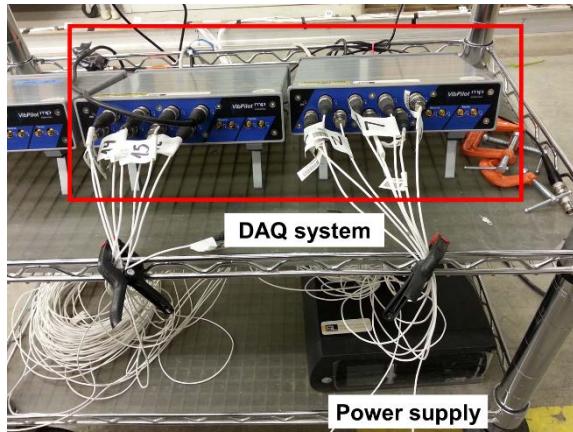
**LSB: Least Square Bit
(resolution)**

$$\text{LSB} = \frac{V_{\text{ref}}(+) - V_{\text{ref}}(-)}{2^N}$$

Digital inputs/outputs	SPI, I ² C, 4x digital interrupts
Supply voltage (VDD)	1.71 ... 3.6 V
I/O supply voltage (VDDIO)	1.2 ... 3.6 V
Temperature range	-40 ... +85°C
Current consumption - full operation - low-power mode	950 μA 3 μA
FIFO data buffer	1024 byte
LGA package	$2.5 \times 3.0 \times 0.8 \text{ mm}^3$
Shock resistance	10,000 g \times 200 μs

$$2^{16} = 65536 \text{ bins}$$

Example: Modal Testing



[Click to zoom](#)

Model: 333B30

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Analog Input	
Number of channels	4 or 8; multiple unit daisy chain
Channel type	Voltage mode: single-ended or fully differential, selectable per channel IEPE mode: single-ended or pseudo-differential, selectable per channel
Analog-to-digital converter type	Sigma-delta
Resolution	24 bits
Sampling rate per channel	40 to 204.8 kHz
Input voltage range	± 1 V and ± 10 V peak full scale, selectable per channel
Overload protection	40 V
Input impedance	$1 \text{ M}\Omega$, capacitance: 45 pF
Coupling	AC/DC, switchable per channel
AC coupling	0.3 Hz 6 dB/oct. and 10 Hz 6 dB/oct., selectable per channel
Signal-to-noise ratio	At 102.4 kHz sampling: > 100 dB in 1 V range > 105 dB in 10 V range
Amplitude accuracy	± 0.06 dB (at 1 kHz)
Amplitude flatness	± 0.015 dB (DC to 80 kHz, relative to 1 kHz)

[Product Summary](#) [Specifications](#) [Documents & Downloads](#)

	English:	SI:
PERFORMANCE		
Sensitivity ($\pm 10\%$)	100 mV/g	$10.2 \text{ mV}/(\text{m/s}^2)$
Measurement Range	± 50 g pk	$\pm 490 \text{ m/s}^2$ pk
Frequency Range ($\pm 5\%$)	0.5 to 3000 Hz	0.5 to 3000 Hz
Resonant Frequency	≥ 40 kHz	≥ 40 kHz
Phase Response ($\pm 5^\circ$) (at 70°F [21°C])	2 to 3000 Hz	2 to 3000 Hz
Broadband Resolution (1 to 10000 Hz)	0.00015 g rms	0.0015 m/s^2 rms
Non-Linearity	$\leq 1\%$	$\leq 1\%$
Transverse Sensitivity	$\leq 5\%$	$\leq 5\%$
ENVIRONMENTAL		
Overload Limit (Shock)	± 5000 g pk	$\pm 49000 \text{ m/s}^2$ pk
Temperature Range (Operating)	0 to +150 °F	-18 to +66 °C
Temperature Response	See Graph %/°F	See Graph %/°F
Base Strain Sensitivity	$0.01 \text{ g}/\mu\text{e}$	$0.1 (\text{m/s}^2)/\mu\text{e}$
ELECTRICAL		
Excitation Voltage	18 to 30 VDC	18 to 30 VDC
Constant Current Excitation	2 to 20 mA	2 to 20 mA
Output Impedance	$\leq 300 \text{ Ohm}$	$\leq 300 \text{ Ohm}$
Output Bias Voltage	7 to 12 VDC	7 to 12 VDC
Discharge Time Constant	1.0 to 3.0 sec	1.0 to 3.0 sec
Settling Time (within 10% of bias)	<12 sec	<12 sec
Spectral Noise (1 Hz)	$39 \mu\text{g}/\sqrt{\text{Hz}}$	$380 (\mu\text{m/sec}^2)/\sqrt{\text{Hz}}$
Spectral Noise (10 Hz)	$11 \mu\text{g}/\sqrt{\text{Hz}}$	$110 (\mu\text{m/sec}^2)/\sqrt{\text{Hz}}$
Spectral Noise (100 Hz)	$3.4 \mu\text{g}/\sqrt{\text{Hz}}$	$33 (\mu\text{m/sec}^2)/\sqrt{\text{Hz}}$
Spectral Noise (1 kHz)	$1.4 \mu\text{g}/\sqrt{\text{Hz}}$	$14 (\mu\text{m/sec}^2)/\sqrt{\text{Hz}}$

↑ Accelerometer

← Data acquisition system

Demo: Acceleration Measurement using a Smart Phone – Arduino Science Journal

AGES 10+

ARDUINO SCIENCE JOURNAL

A pocket-sized science lab that encourages students to explore how the world works, record data, document observations, and experiment like a real scientist.



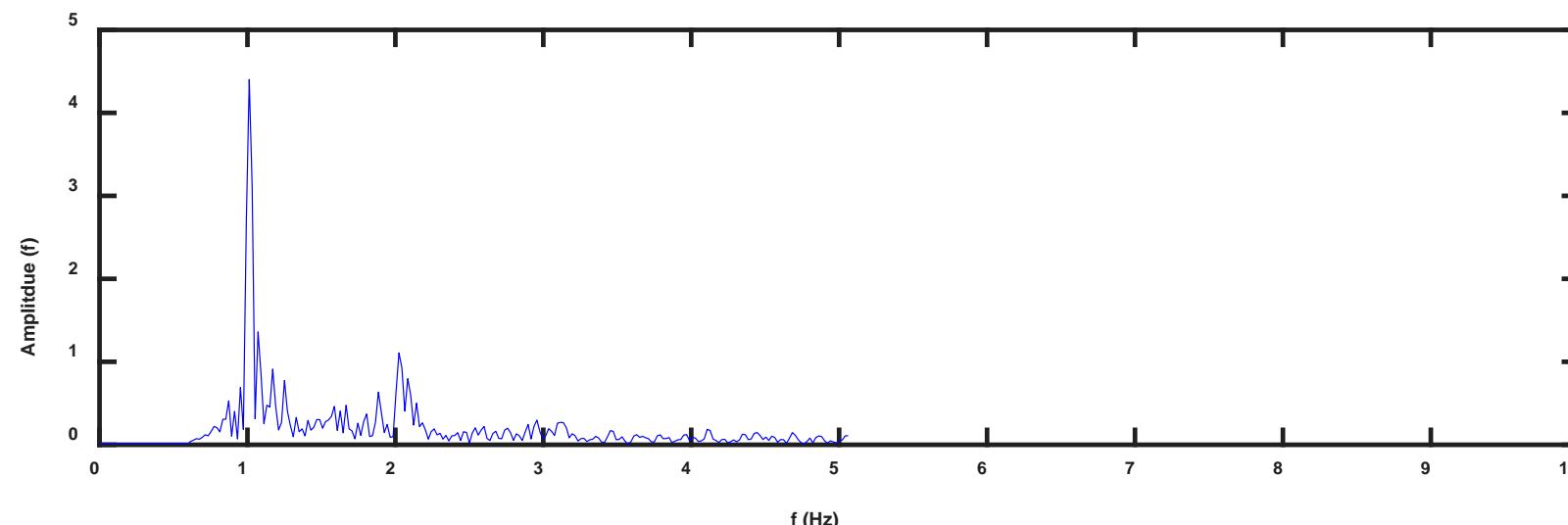
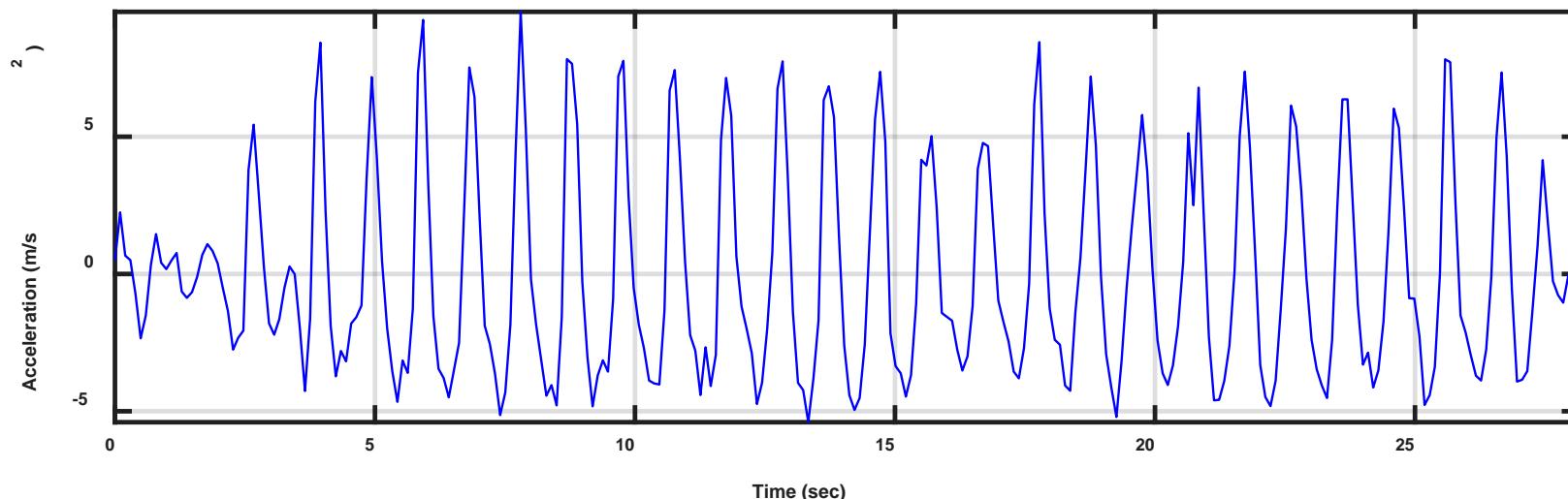
<https://www.arduino.cc/education/science-journal>

Demo: Acceleration Measurement using a Smart Phone – Vibration Analysis

Frequency (f): 1

Sampling frequency

$$f_s = 10 \text{ Hz}$$



Slide Credits and References

- Shin, K., & Hammond, J. K. (2008). Fundamentals of Signal Processing: for Sound and Vibration Engineers, 418.
- <http://www.now-instruments.com/get-help/5-vibsensor-user-guide>
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- <https://www.edaboard.com/showthread.php?250221-Accelerometer-Questions>
- [http://www2.hawaii.edu/~peterb/resources/equipment/analog devices accelermoter specifications.pdf](http://www2.hawaii.edu/~peterb/resources/equipment/analog_devices_accelermoter_specifications.pdf)
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