Data Acquisition System

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CIVE 497 – CIVE 700: Smart Structure Technology

UNIVERSITY OF WATERLOO
FACULTY OF ENGINEERING

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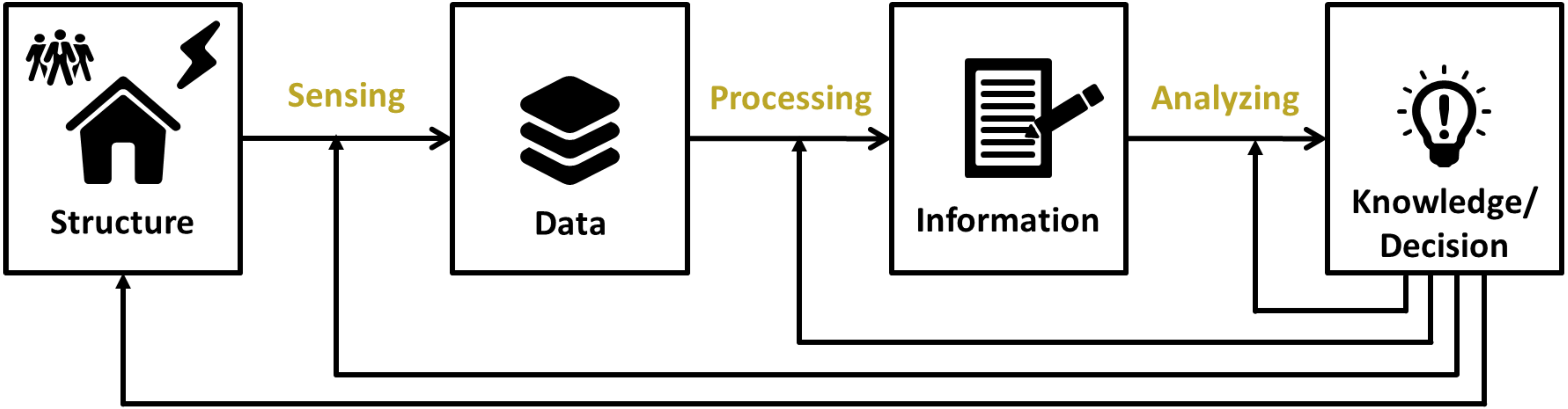
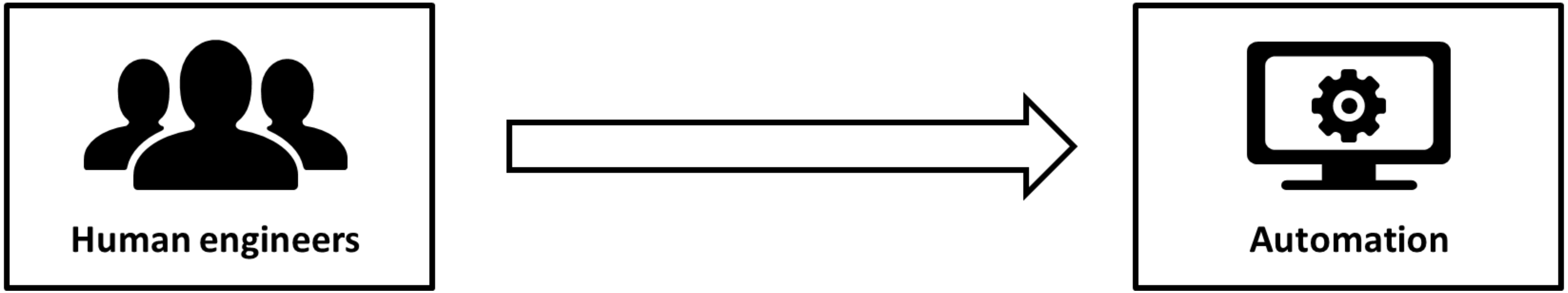
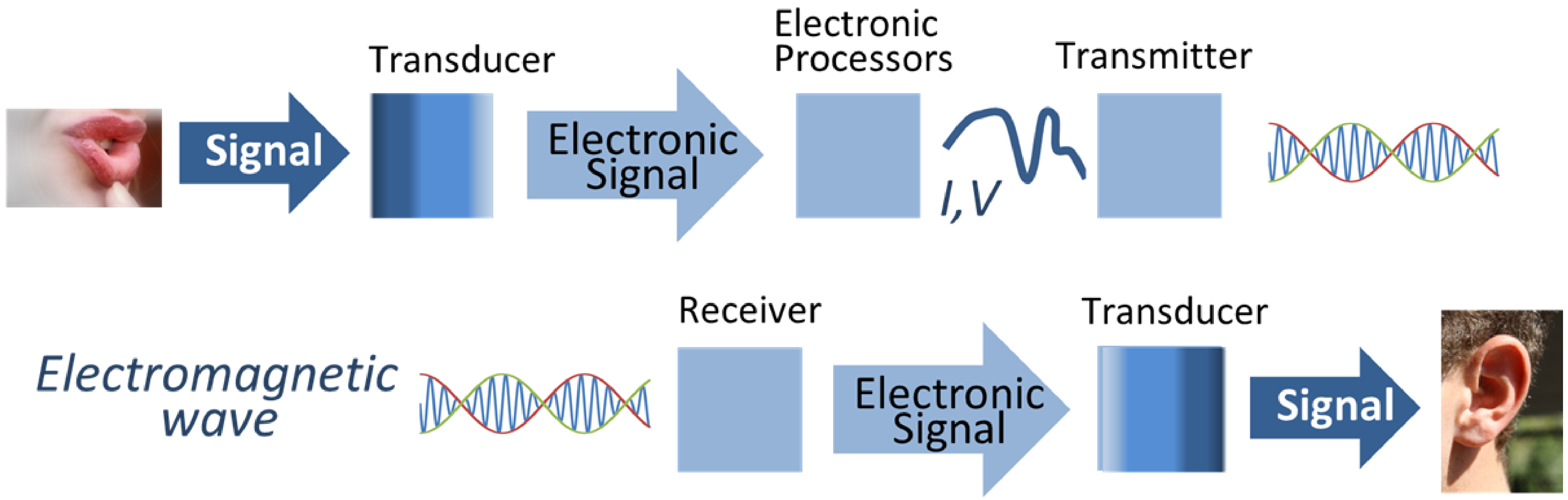
Structural Assessment





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.

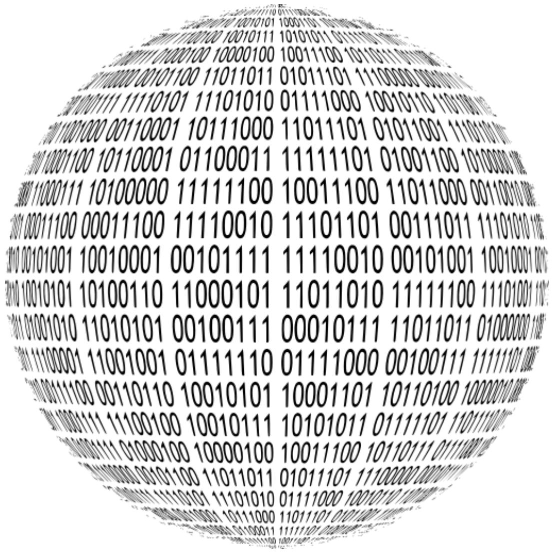


https://en.wikipedia.org/wiki/Signal_processing

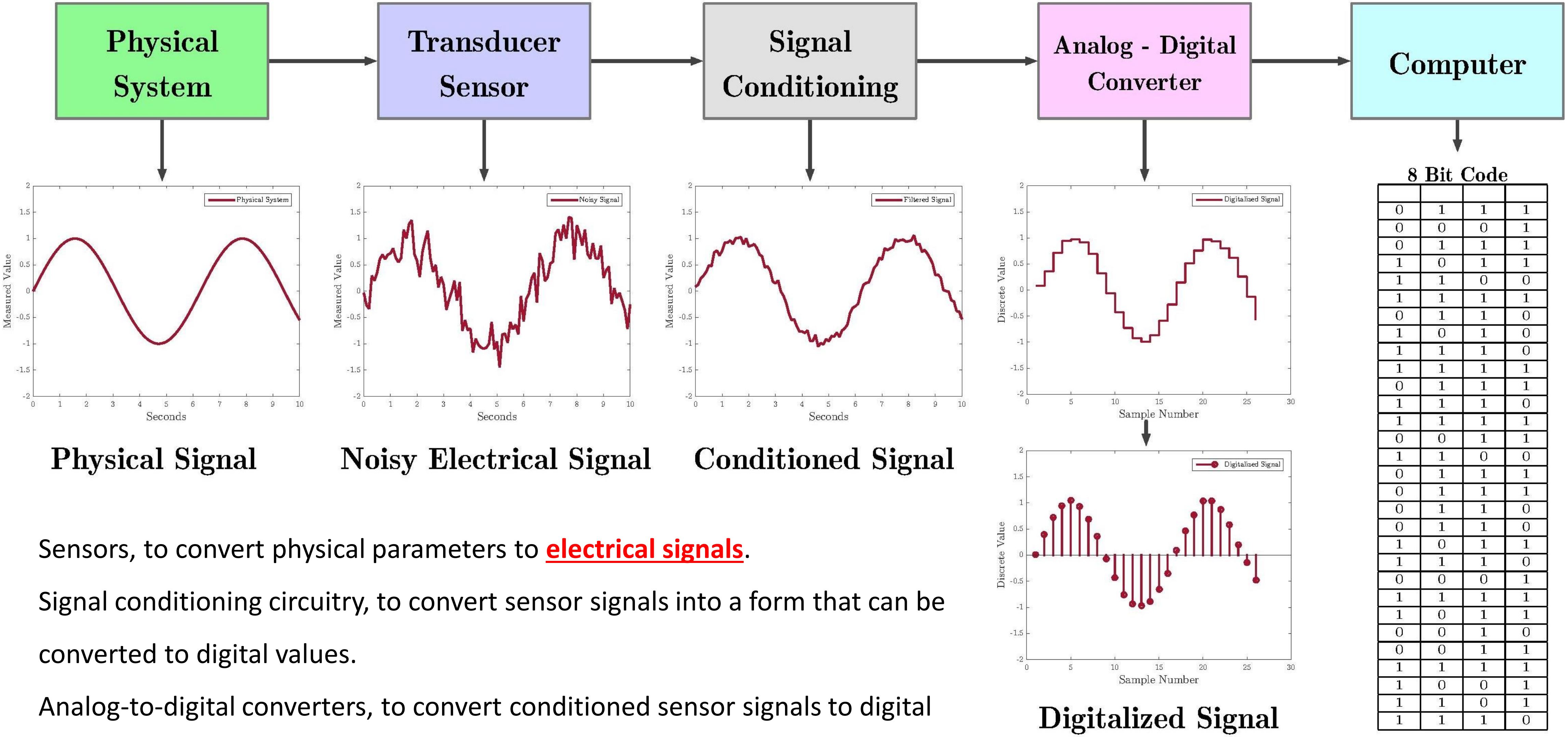
Data Acquisition

- Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into **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



8 Bit Code

0	1	1	1
0	0	0	1
0	1	1	1
1	0	1	1
1	1	0	0
1	1	1	1
0	1	1	0
1	0	1	0
1	1	1	0
1	1	1	1
0	1	1	1
1	1	1	0
1	1	1	1
0	0	1	1
1	1	0	0
0	1	1	1
0	1	1	1
0	1	1	0
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1	1	1	0
0	0	0	1
1	1	1	1
1	0	1	1
0	0	1	0
0	0	1	1
1	1	1	1
1	0	0	1
1	1	0	1
1	1	1	0

- Sensors, to convert physical parameters to **electrical signals**.
- Signal conditioning circuitry, to convert sensor signals into a form that can be converted to digital values.
- Analog-to-digital converters, to convert conditioned sensor signals to digital values.

https://en.wikipedia.org/wiki/Data_acquisition

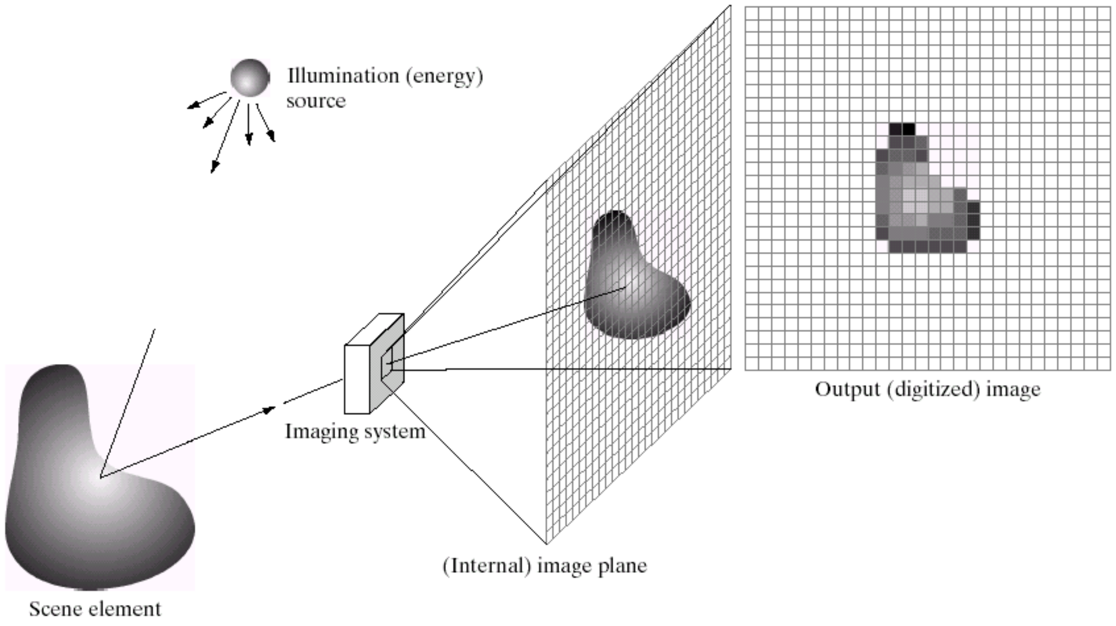
Analog vs Digital Signal

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).

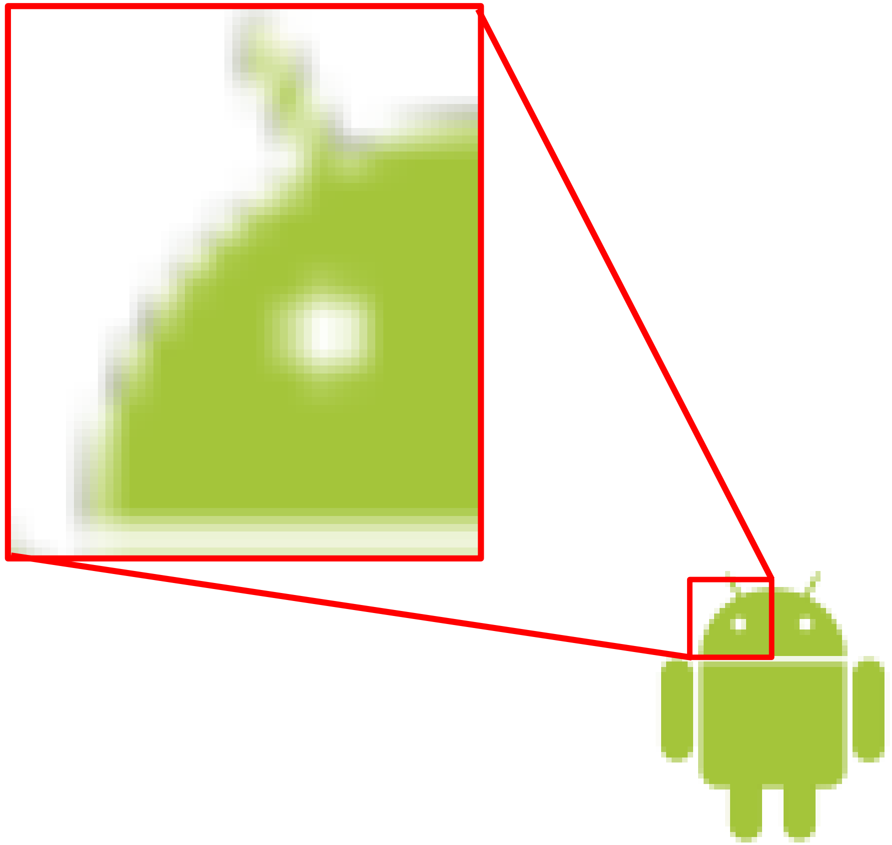
- Continuous-time vs Discrete-time signal
- Continuous-valued vs Discrete-valued signal
- Output range

Note that in certain physical situations, 'time' may not be the natural independent 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

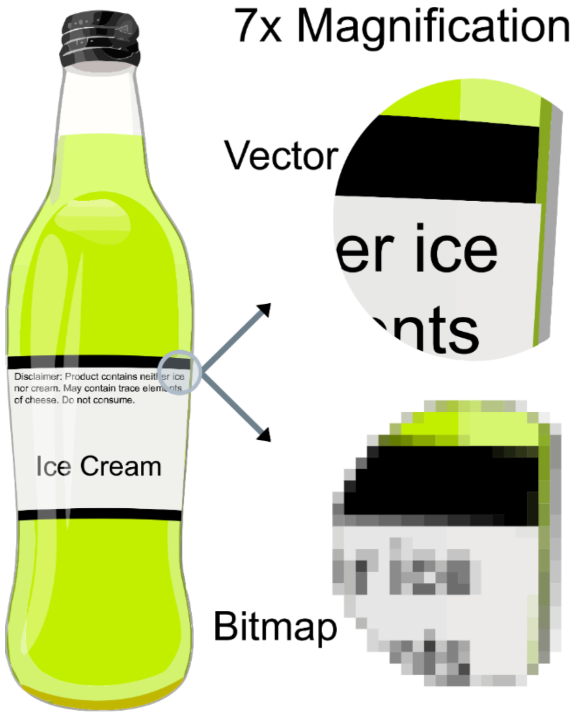


Digital Image Acquisition



Pixel

Example: Vector Graphics



Acrobat PDF

Vector graphics is the creation of digital images through <u>a sequence of commands or mathematical statements that place lines and shapes</u> 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

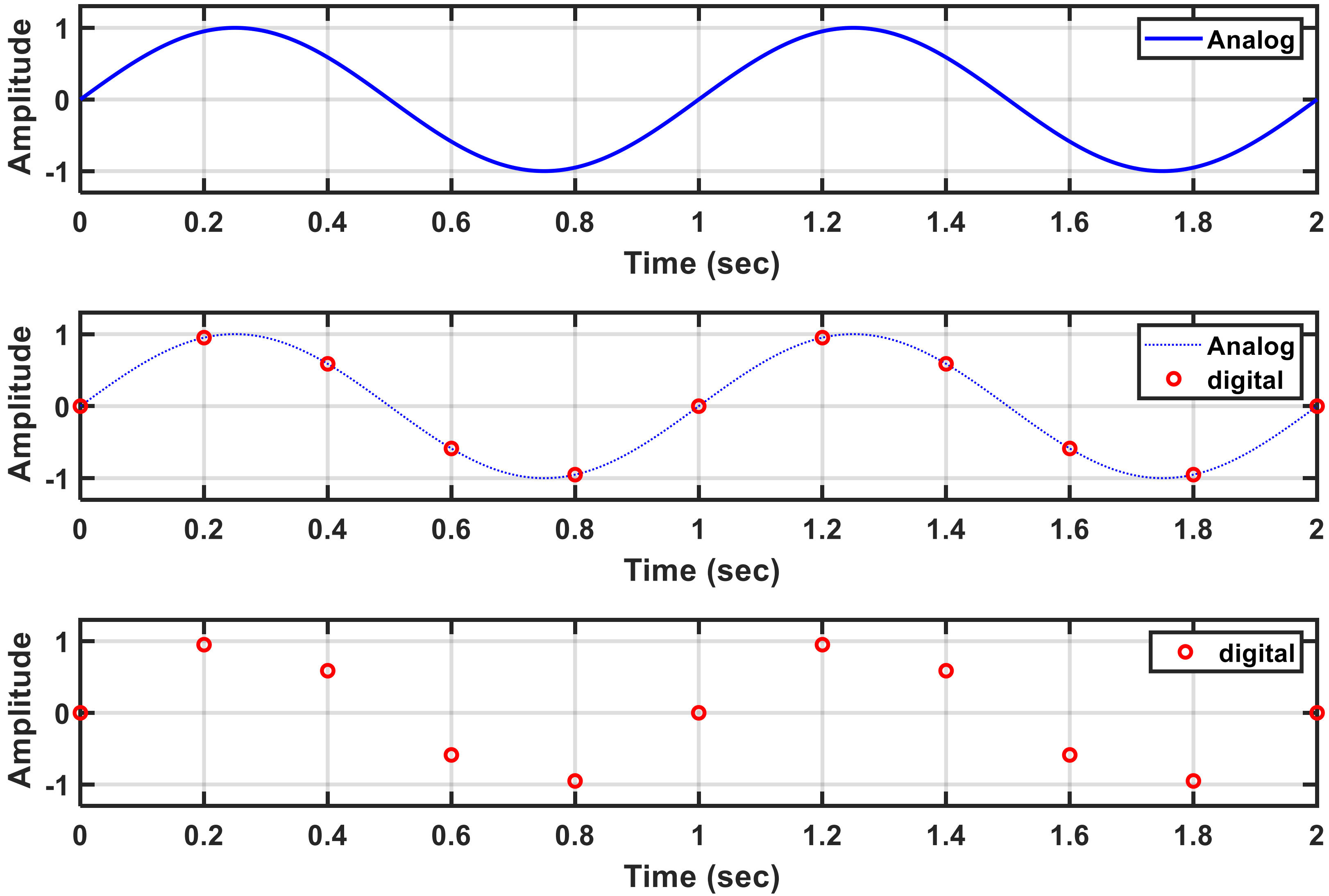
Sampling: How often the data is sampled in the time axis.

$$y = \sin(2\pi f t)$$

Frequency (f): 1Hz

Sampling frequency

$$f_s = 1/5 \text{ Hz}$$



Determination of a Sampling Frequency (Rate)

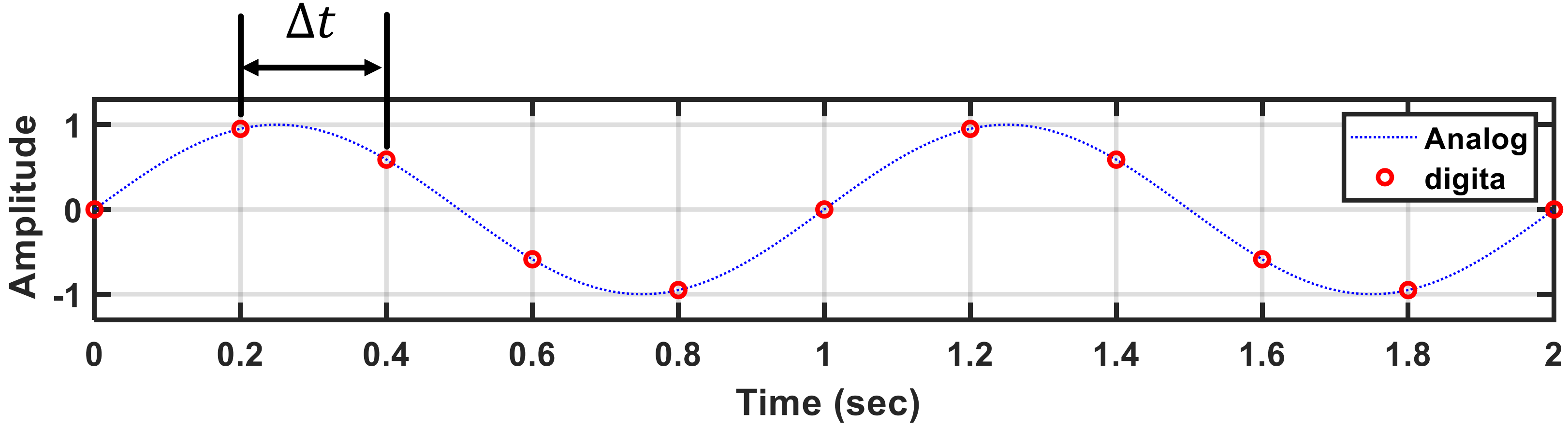
- Sampling frequency (Hz) is the inverse of the sampling interval

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

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

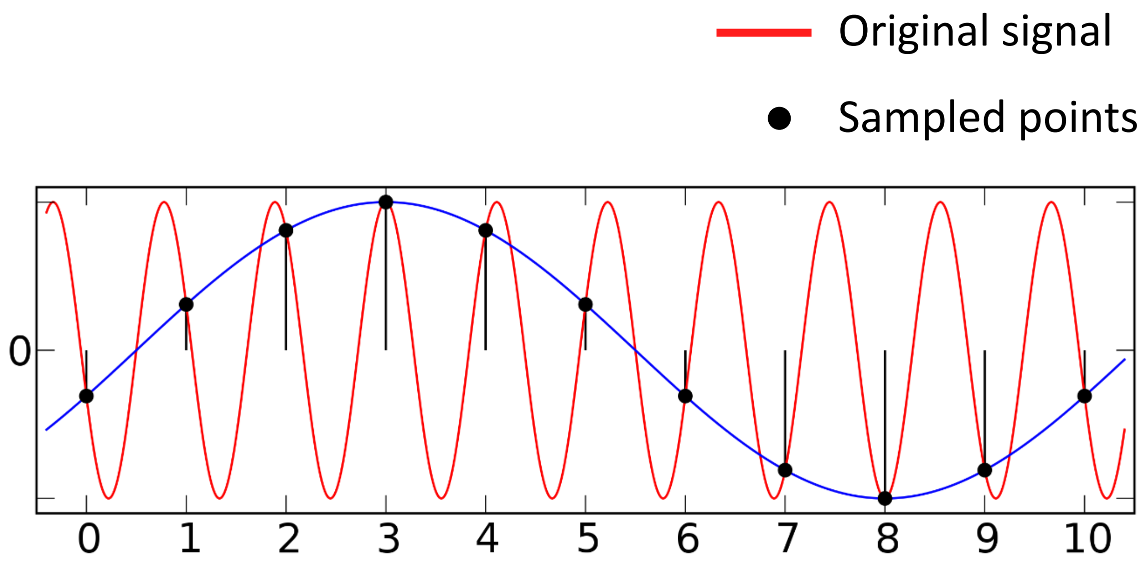
$$f_h < \frac{f_s}{2} = 1/(2\Delta t)$$

- 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.



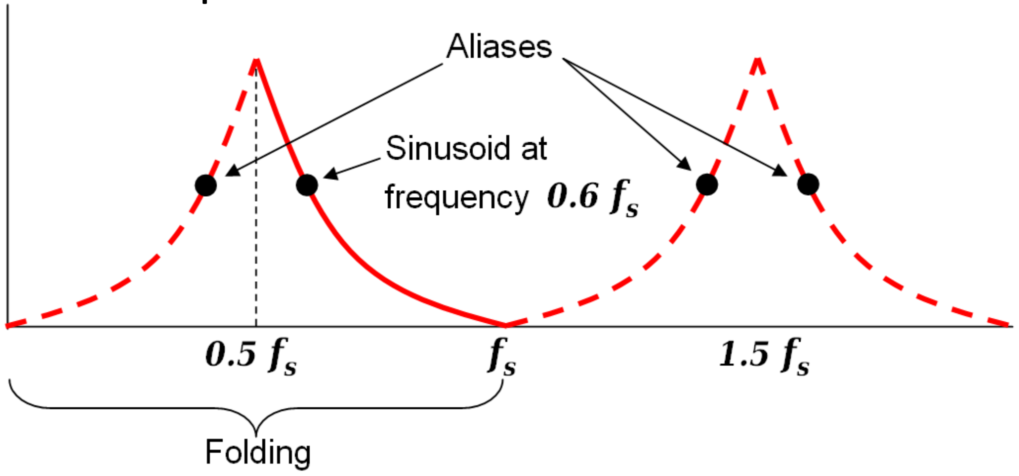
Aliasing

- 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

Wrap-around



This aliasing occurs along the half of the sampling frequency.

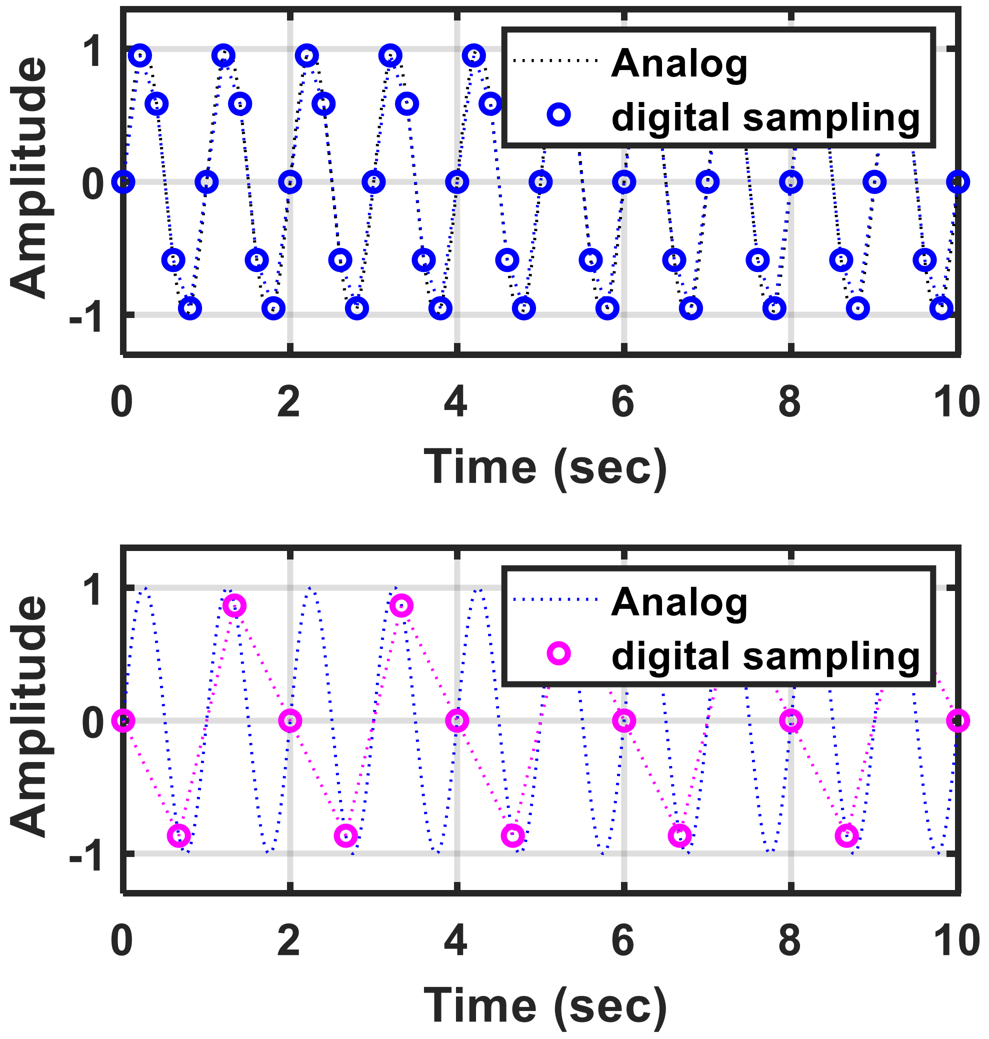
Example: Spinner

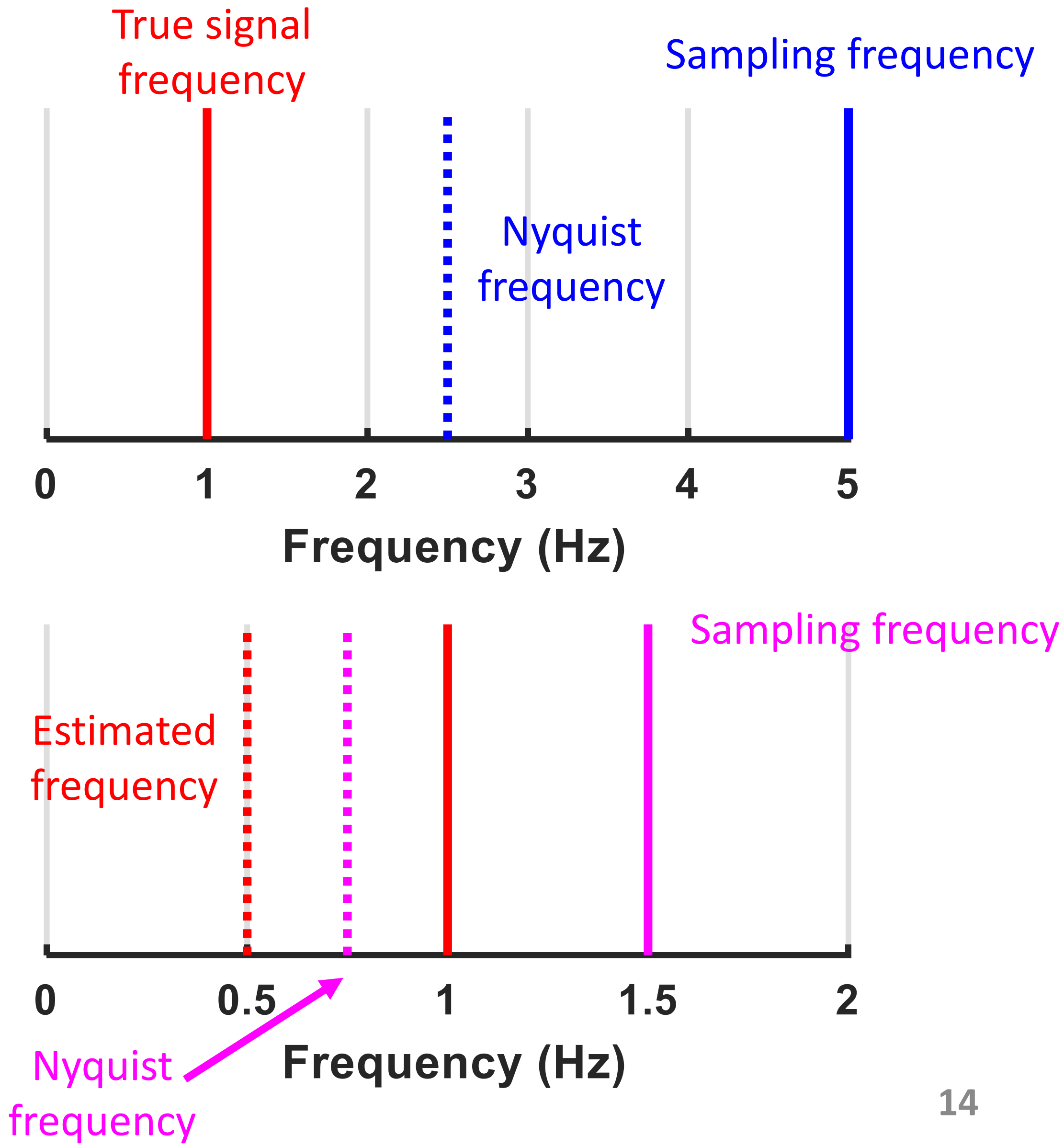
https://www.youtube.com/watch?v=cMZJZGtWFCA

Example: Helicopter Like Spaceship

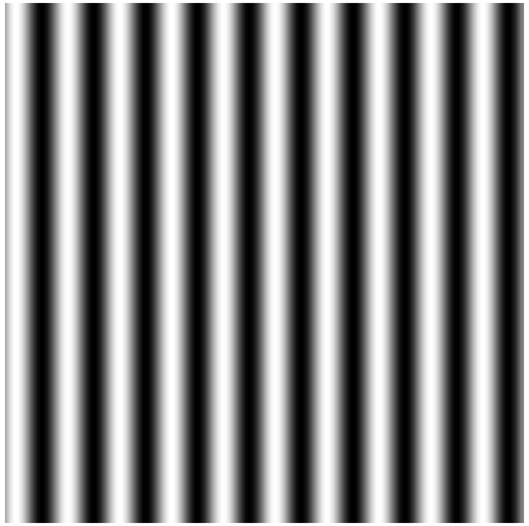
https://www.youtube.com/watch?v=yr3ngmRuGUc

Example: Effect of Aliasing

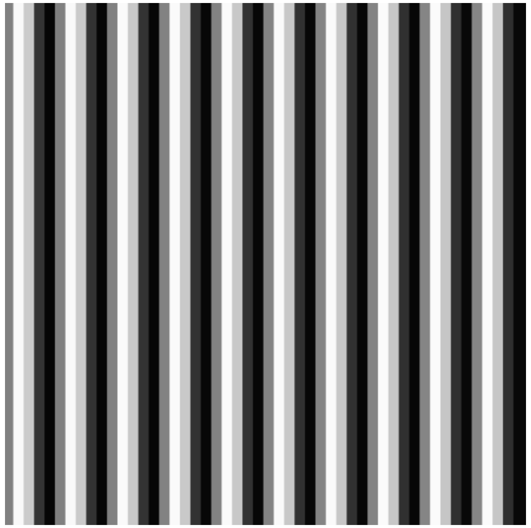




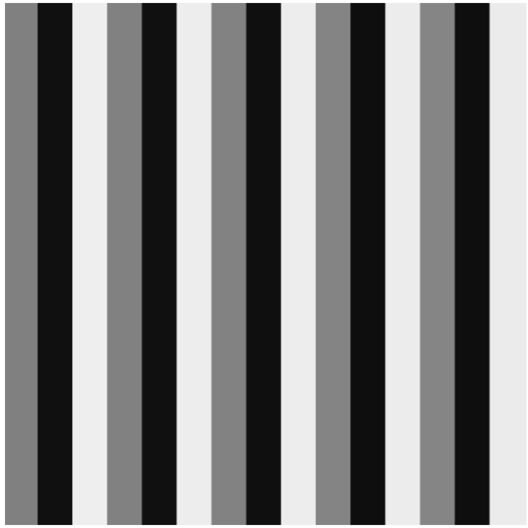
Example: Spatial Aliasing



Original image (1200 x 1200)



Resampling (50 X 50)



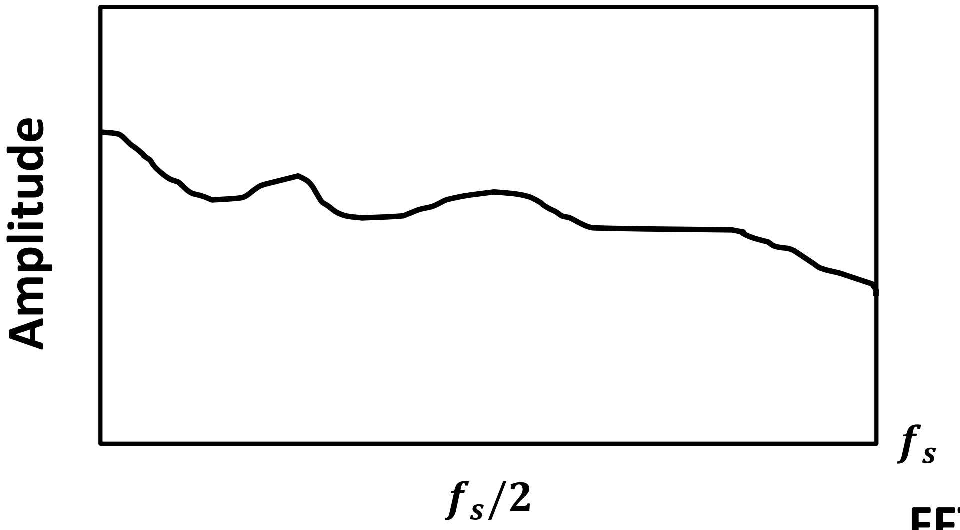
Resampling (15 X 15)

Example: Spatial Aliasing (Continue)

1:40 – 1:50

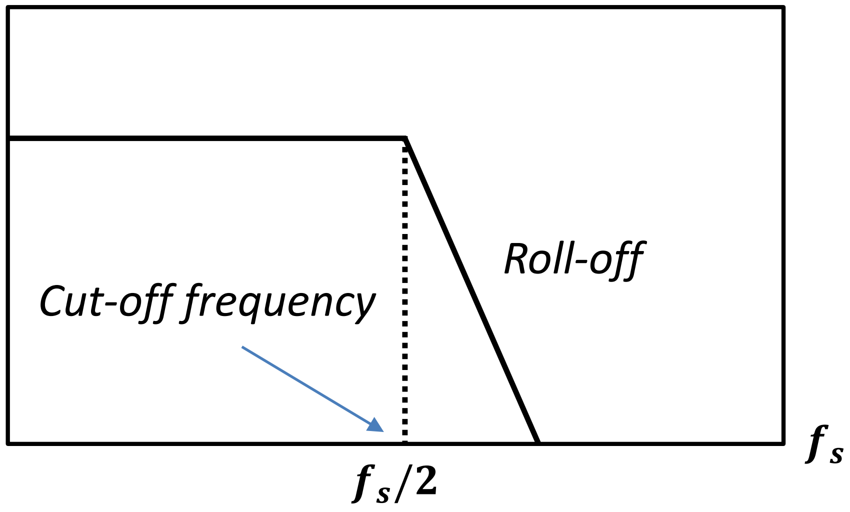
Anti-Aliasing Analog Filter

FFT of Analog Signal



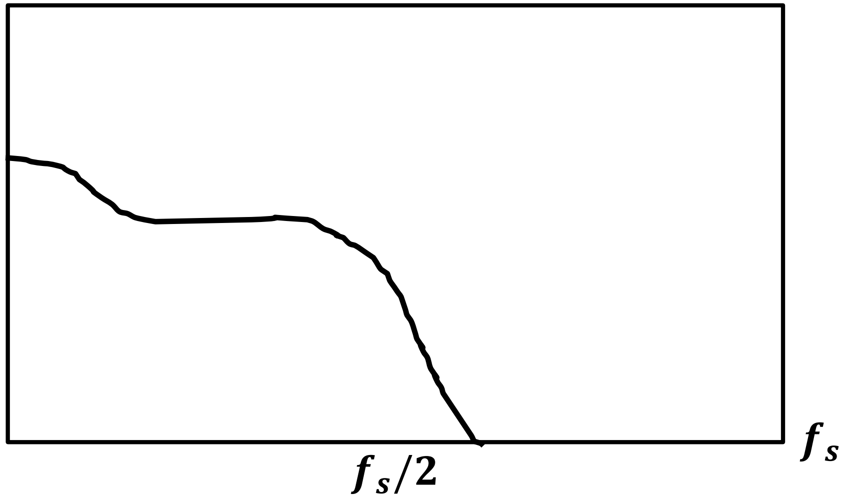
Frequency (Hz)

FFT of Analog Filter



Frequency (Hz)

FFT of Filtered Signal



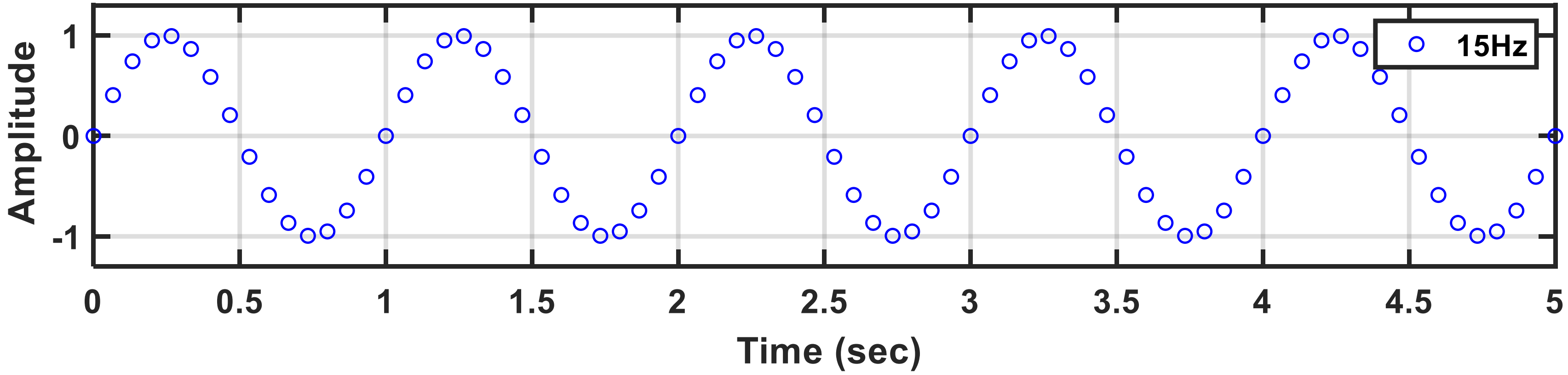
Frequency (Hz)

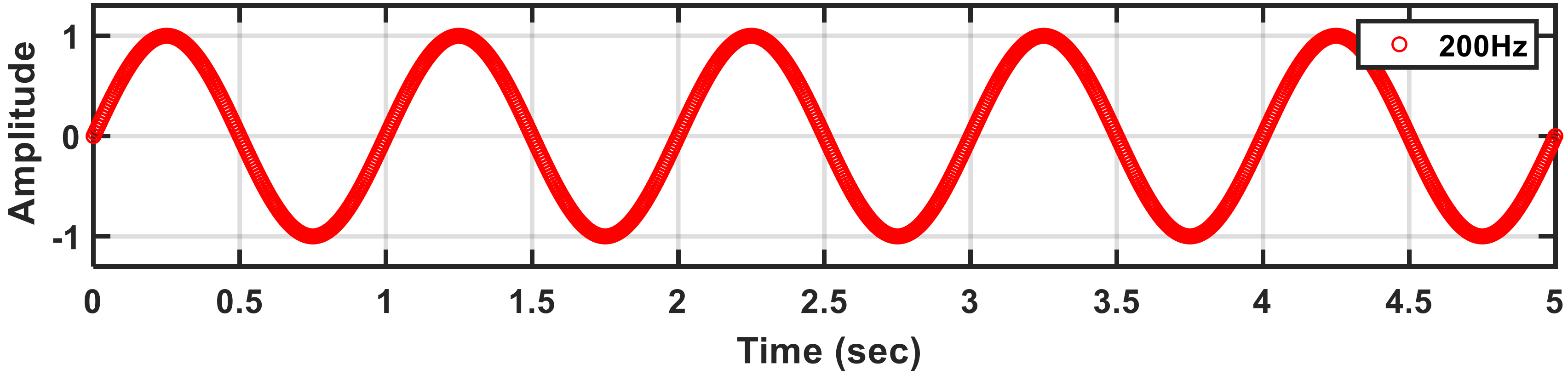
Anti-Aliasing is done before sampling.

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



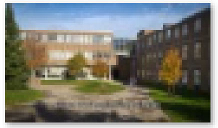


Do we really need 200Hz?

Example: Image Oversampling

maxresdefault.jpg

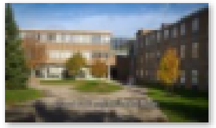
JPG File



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
Comments:	Add comments
Camera maker:	Add text
Camera model:	Add a name
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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Authors:	Add an author
Comments:	Add comments
Camera maker:	Add text
Camera model:	Add a name
Subject:	Specify the subject
Date created:	12/26/2018 2:01 PM
Date modified:	12/26/2018 2:01 PM

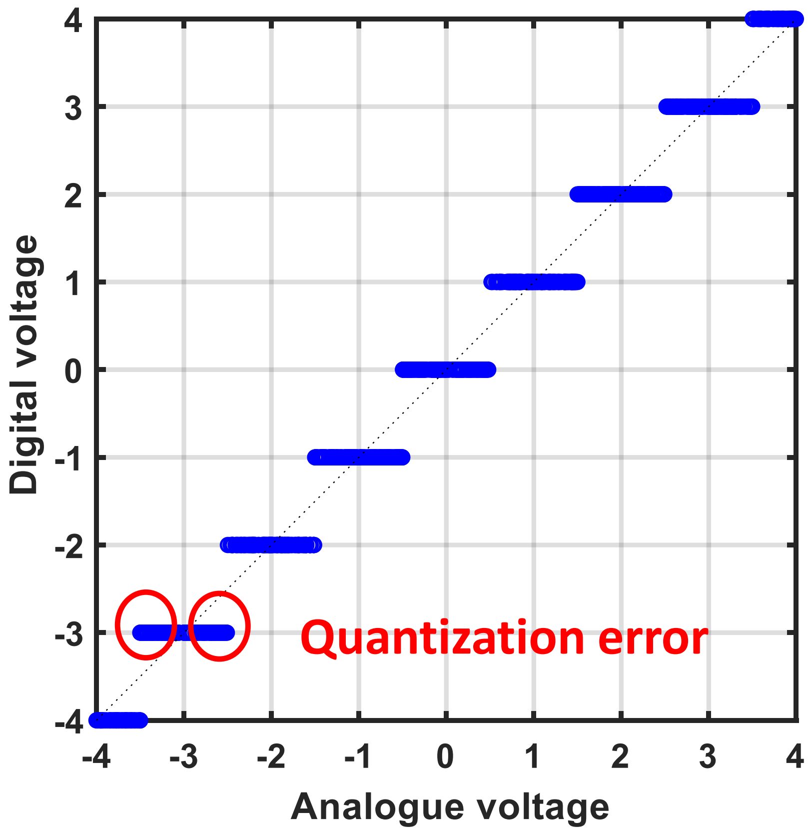
Quantization of Analog Signals

- **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.



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:

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

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

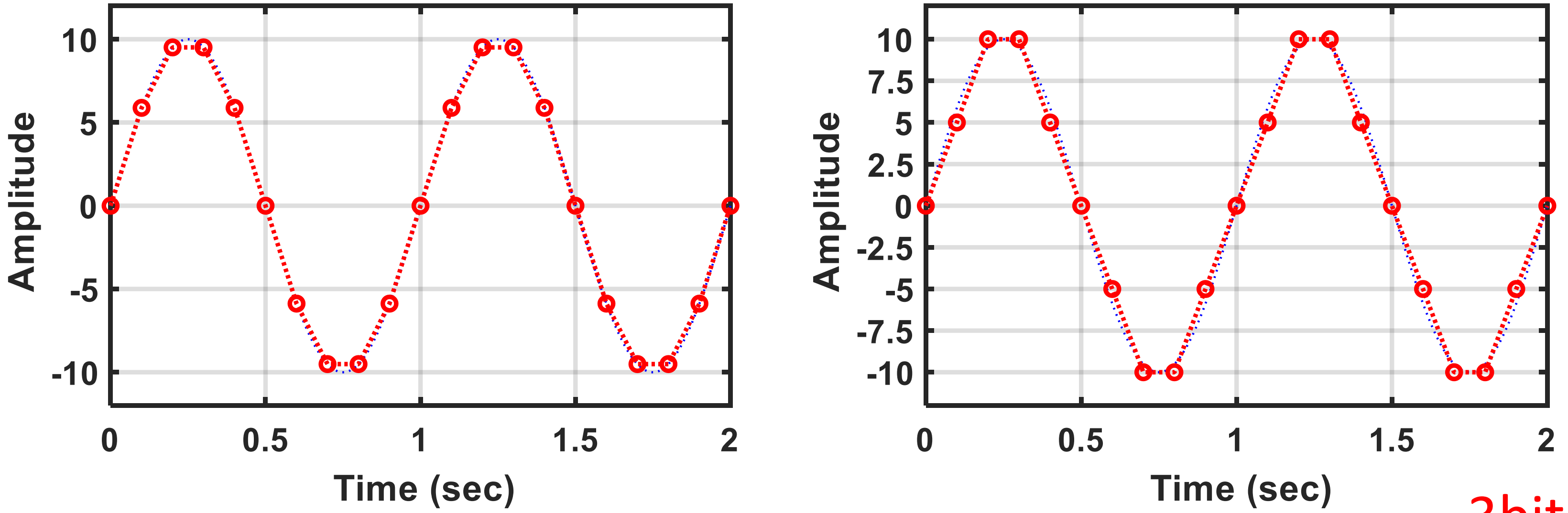
Other Considerations for Resolution

$y = 10 * \sin(2\pi f t)$

Frequency (f): 1

Sampling frequency

$f_s = 1/10$ Hz



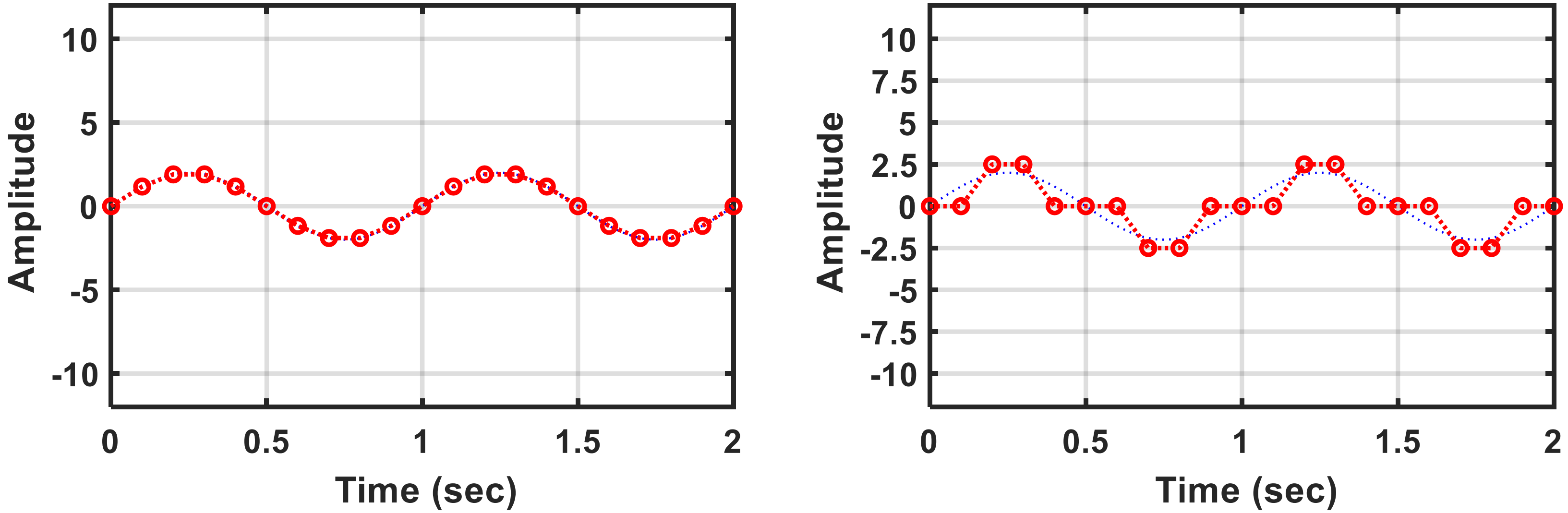
3bit ADC

$y = 2 * \sin(2\pi f t)$

Frequency (f): 1

Sampling frequency

$f_s = 1/10$ Hz



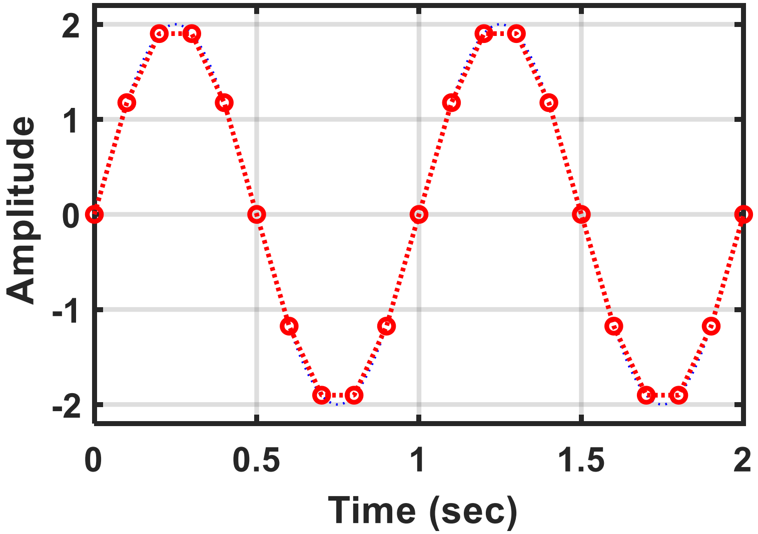
Clipping

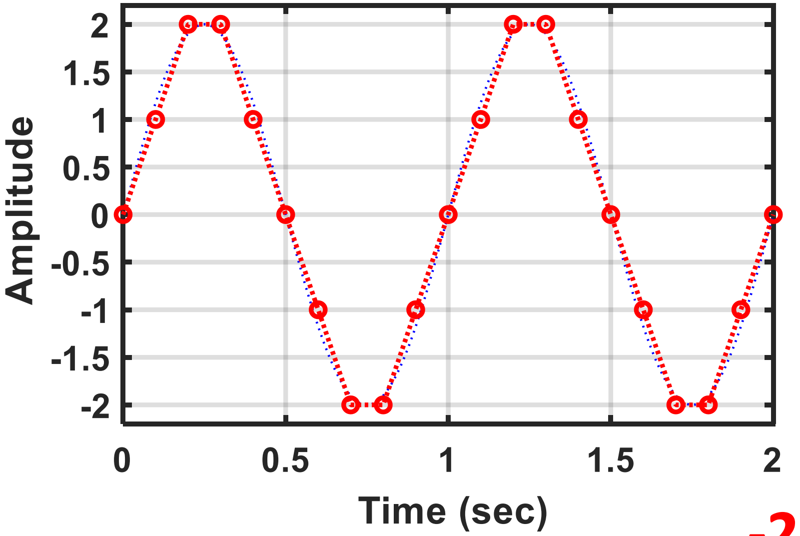
$y = 2 * \sin(2\pi f t)$

Frequency (f): 1

Sampling frequency

$f_s = 1/10$ Hz





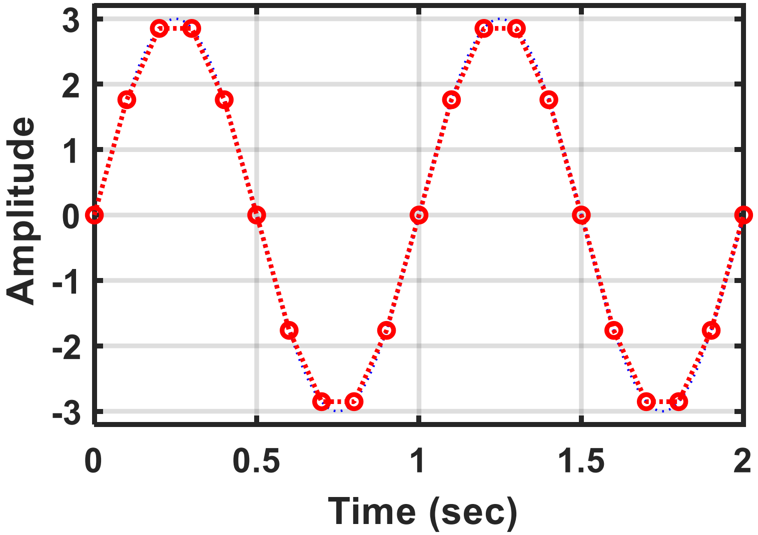
-2V - 2V

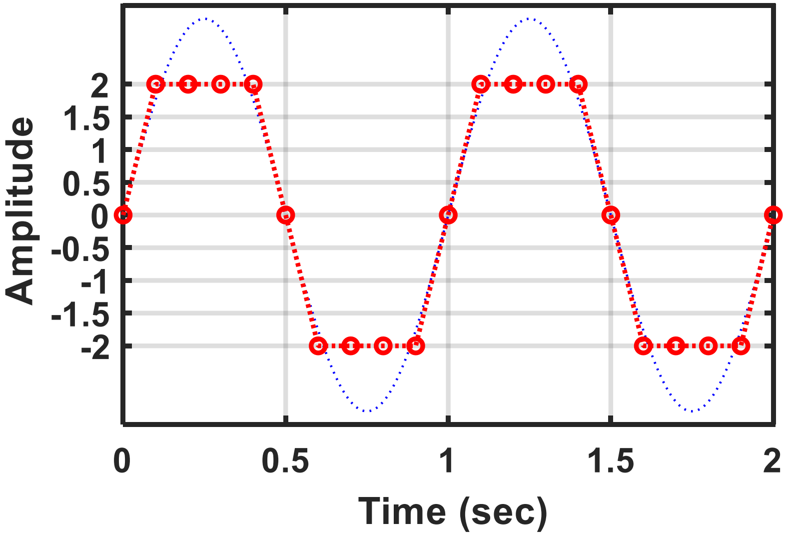
$y = 3 * \sin(2\pi f t)$

Frequency (f): 1

Sampling frequency

$f_s = 1/10$ 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): ± 2 g, ± 4 g, ± 8 g, ± 16 g (G): ± 125°/s, ± 250°/s, ± 500°/s, ± 1000°/s, ± 2000°/s
Sensitivity (calibrated)	(A): ±2g: 16384LSB/g ±4g: 8192LSB/g ±8g: 4096LSB/g ±16g: 2048LSB/g (G): ±125°/s: 262.4 LSB/°/s ±250°/s: 131.2 LSB/°/s ±500°/s: 65.6 LSB/°/s ±1000°/s: 32.8 LSB/°/s ±2000°/s: 16.4 LSB/°/s
Zero-g offset (typ., over life-time)	(A): ±40mg (G): ± 10°/s
Noise density (typ.)	(A): 180 µg/√Hz (G): 0.008 °/s/√Hz
Bandwidths (programmable)	1600 Hz ... 25/32 Hz

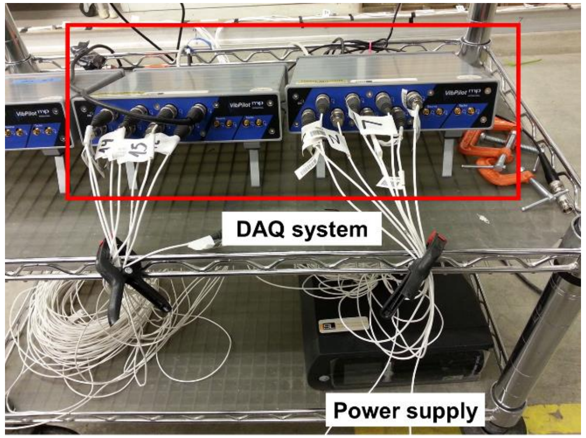
LSB: Least Square Bit

Digital inputs/outputs	SPI, I²C, 4x digital interrupts
Supply voltage (VDD)	1.71 ... 3.6 V
I/0 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 × 3.0 × 0.8 mm³
Shock resistance	10,000 g x 200 µs

2^{16} = 65536 bins

https://www.bosch-sensortec.com/bst/products/all_products/bmi160

Example: Modal Testing



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 MΩ, 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)

Click to zoom

Model: 333B30

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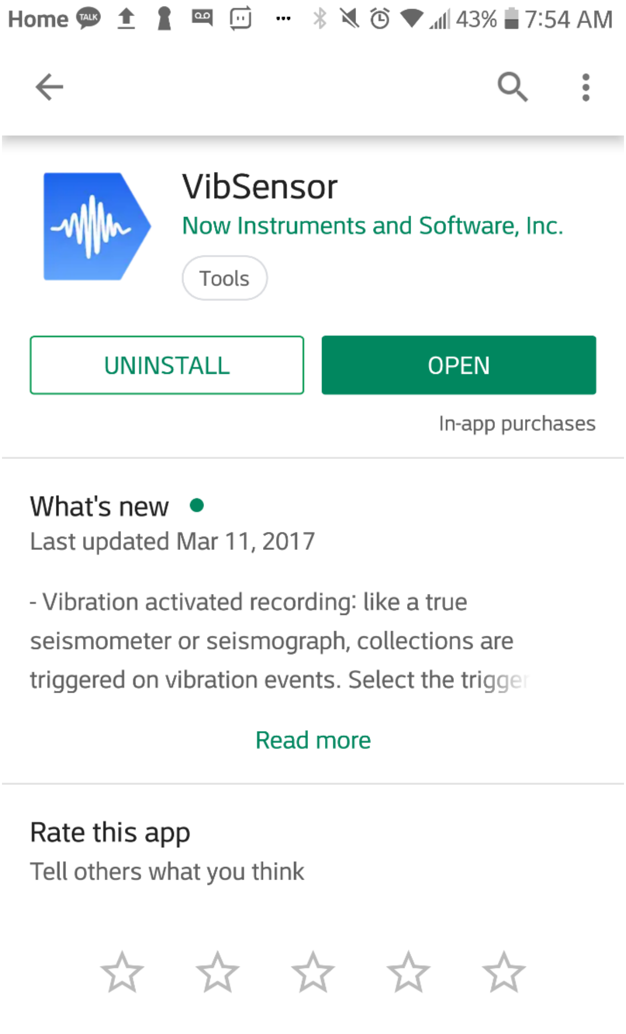
Product Summary | **Specifications** | Documents & Downloads

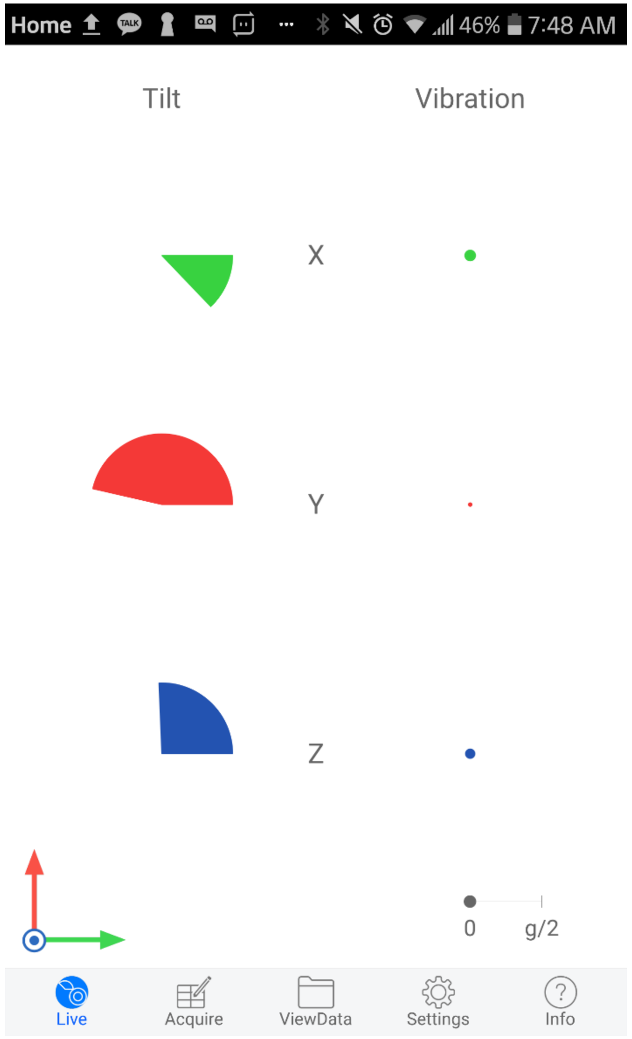
	English:	SI:	
PERFORMANCE			
Sensitivity (±10 %)	100 mV/g	10.2 mV/(m/s²)	
Measurement Range	±50 g pk	±490 m/s² pk	
Frequency Range (±5 %)	0.5 to 3000 Hz	0.5 to 3000 Hz	
Resonant Frequency	≥40 kHz	≥40 kHz	
Phase Response (±5 °) (at 70°F [21°C])	2 to 3000 Hz	2 to 3000 Hz	
Broadband Resolution (1 to 10000 Hz)	0.00015 g rms	0.0015 m/s² rms	[2]
Non-Linearity	≤1 %	≤1 %	[1]
Transverse Sensitivity	≤5 %	≤5 %	[3]
ENVIRONMENTAL			
Overload Limit (Shock)	±5000 g pk	±49000 m/s² 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 g/με	0.1 (m/s²)/με	[2]
ELECTRICAL			
Excitation Voltage	18 to 30 VDC	18 to 30 VDC	
Constant Current Excitation	2 to 20 mA	2 to 20 mA	
Output Impedance	≤300 Ohm	≤300 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 μg/√Hz	380 (μm/sec²)/√Hz	[2]
Spectral Noise (10 Hz)	11 μg/√Hz	110 (μm/sec²)/√Hz	[2]
Spectral Noise (100 Hz)	3.4 μg/√Hz	33 (μm/sec²)/√Hz	[2]
Spectral Noise (1 kHz)	1.4 μg/√Hz	14 (μm/sec²)/√Hz	[2]

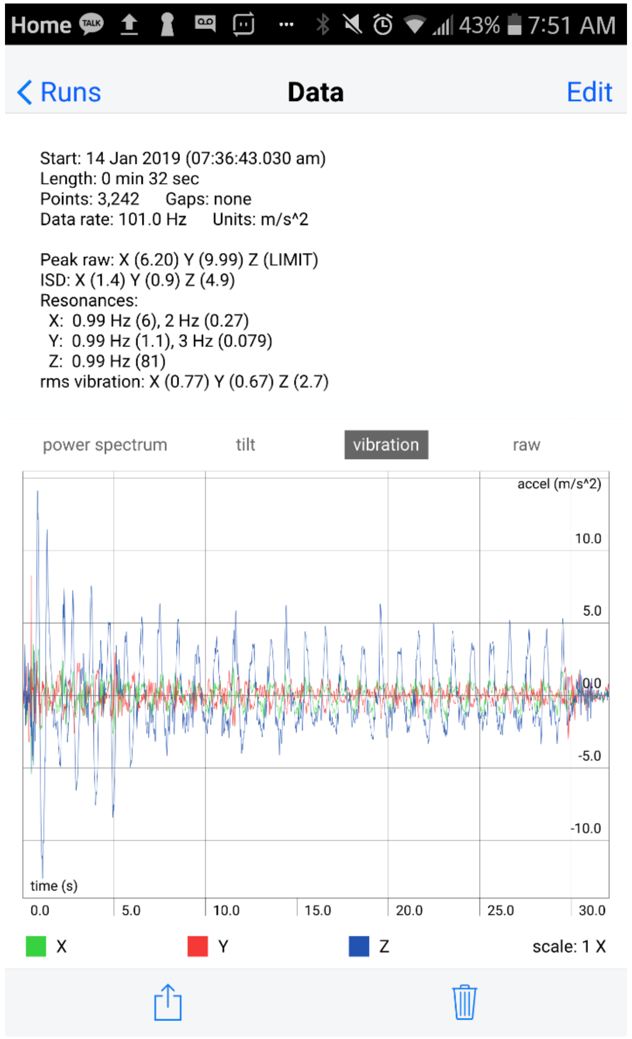
↑ Accelerometer

← Data acquisition system

Demo: Acceleration Measurement using a Smart Phone – VibSensor







http://www.now-instruments.com/get-help/5-vibsensor-user-guide

Demo: Acceleration Measurement using a Smart Phone – Vibration Measurement

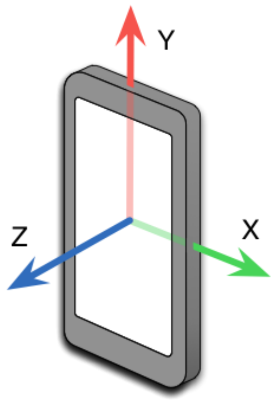
Plot: The plot allows interactive viewing of four types of data. The data type can be selected along the top of the plot. At the bottom of the plot is an interactive legend. Touch a legend entry to toggle that trace on or off. Also on the bottom is an x-axis scale factor. Touch to select the desired scale factor, then swipe to scroll through the data. The four types of data are:

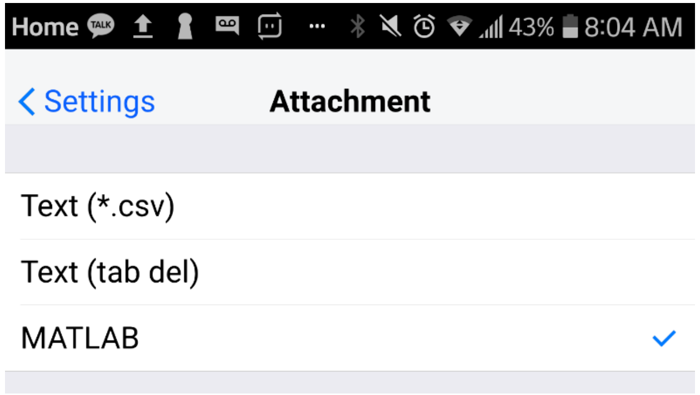
power spectrum: The power spectrum is calculated from 0 Hz to the Nyquist frequency. The units are acceleration squared divided by the frequency. To integrate over the power spectrum, sum all data and then multiply by the frequency step size. This returns the mean squared amplitude in acceleration units squared. Both x and y axes can be toggled between linear and log by selecting the desired label next to the axis.

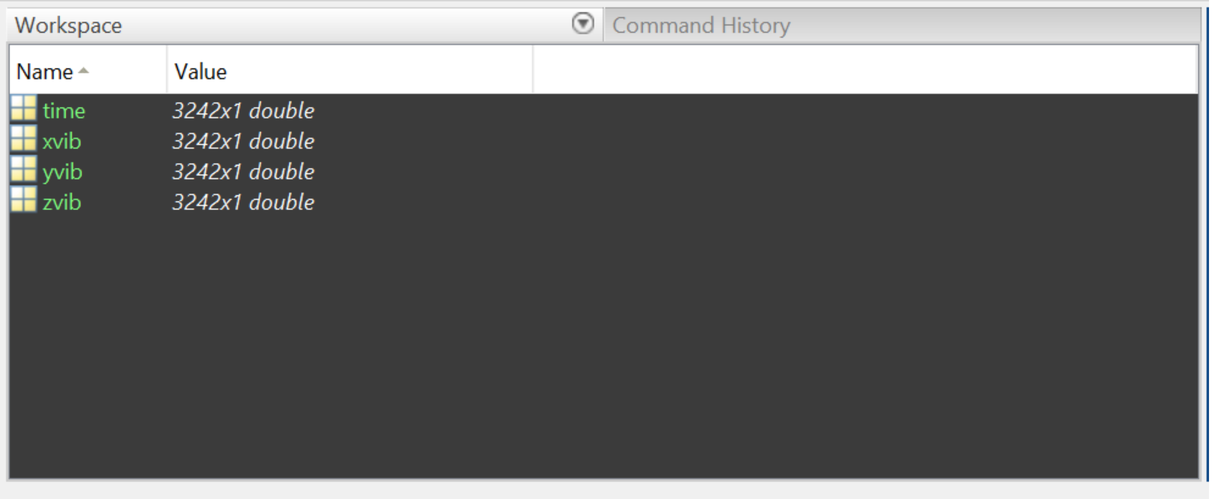
vibration: The raw accelerometer data high-pass filtered to emphasize vibration. The roll-off frequency is 1 Hz in high frequency mode, and 0.1 Hz in low frequency mode.

tilt: The raw accelerometer data low-pass filtered to emphasize tilt. The roll-off frequency is the same as for vibration.

raw: The unmodified accelerometer data from the device.







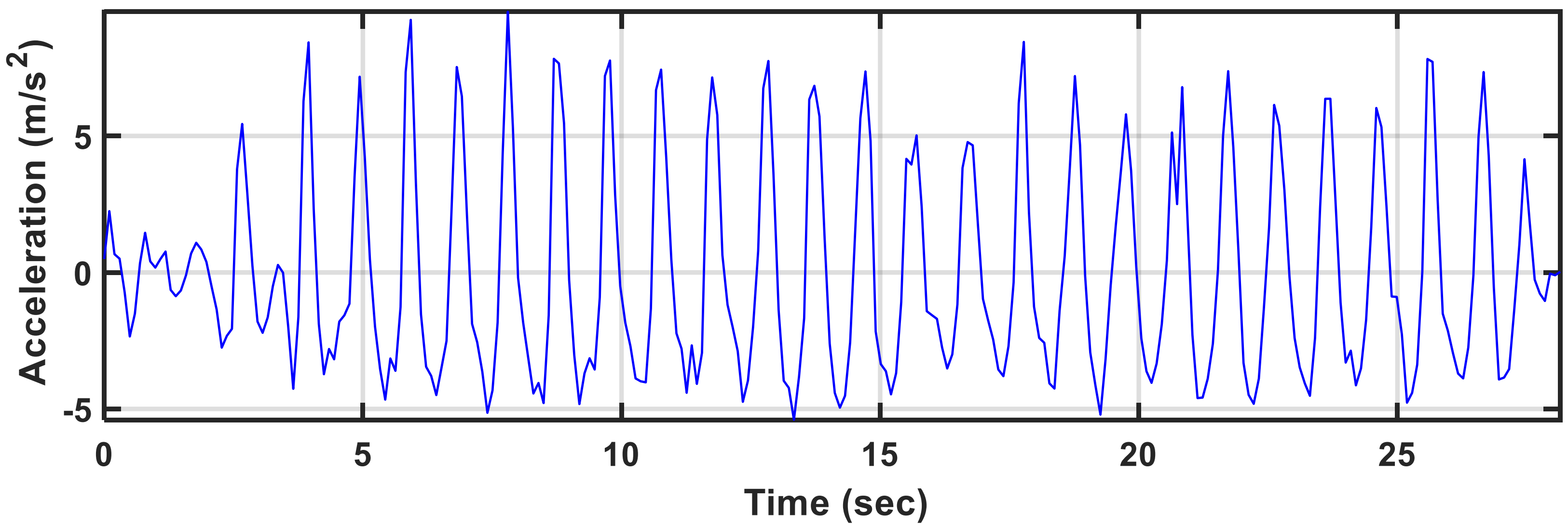
https://www.google.com/search?q=metronome

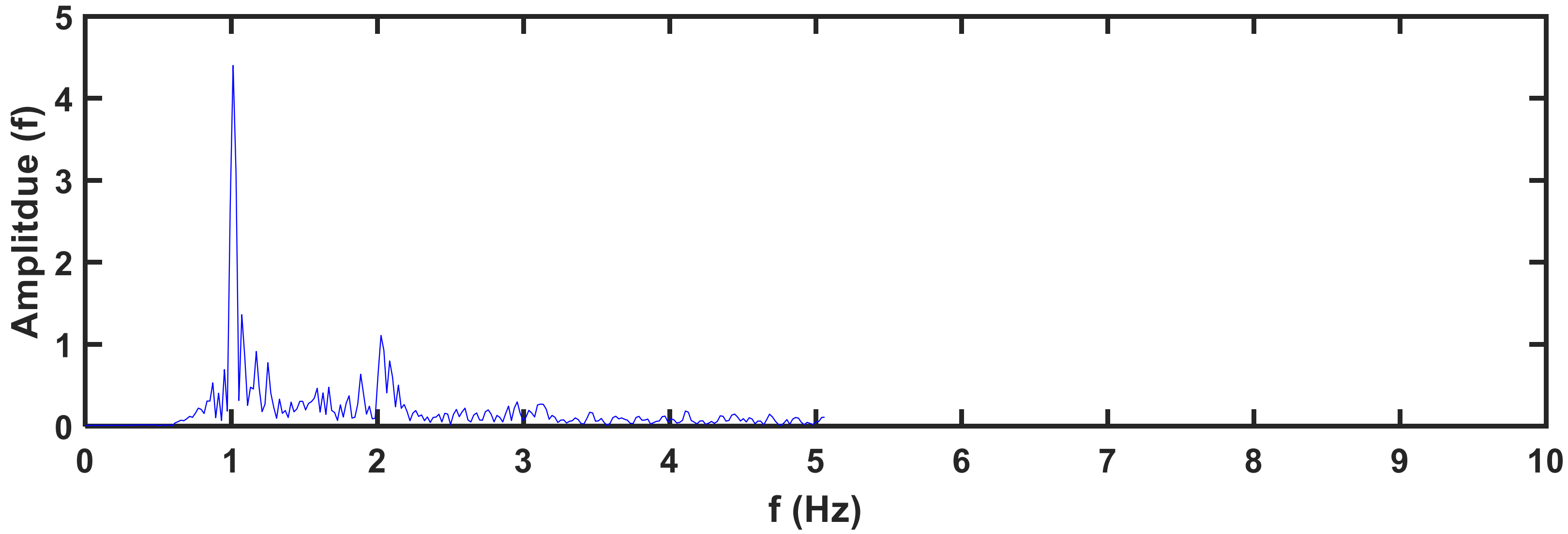
Demo: Acceleration Measurement using a Smart Phone – Vibration Analysis

Frequency (f): 1

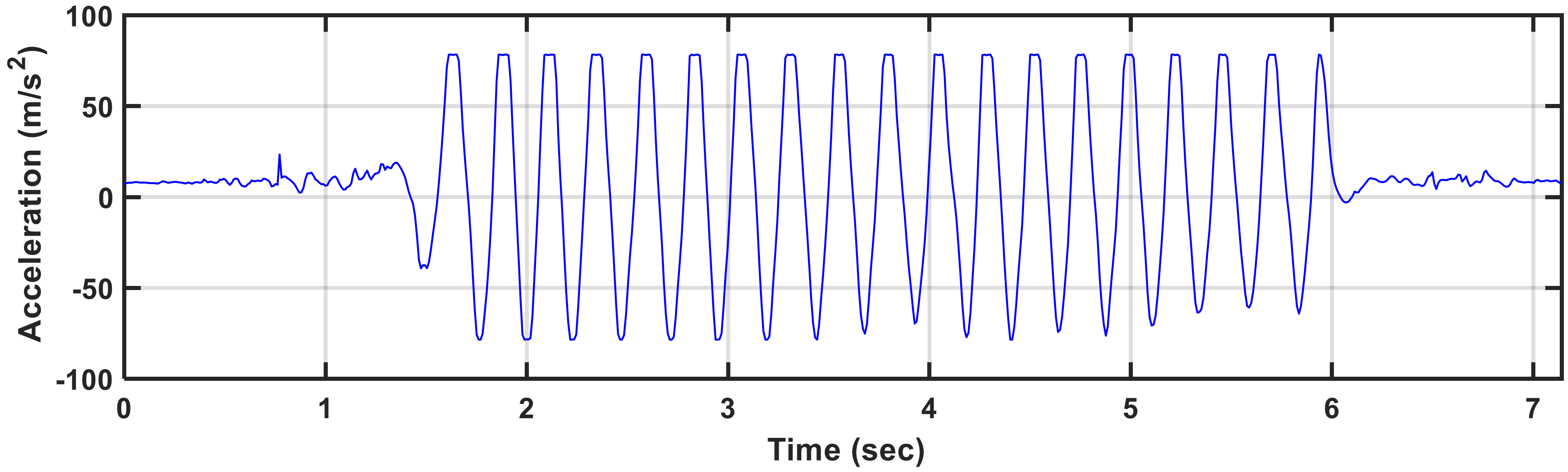
Sampling frequency

$f_s = 10$ Hz





Demo: Acceleration Measurement using a Smart Phone – Clipping



Slide Credits and References

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