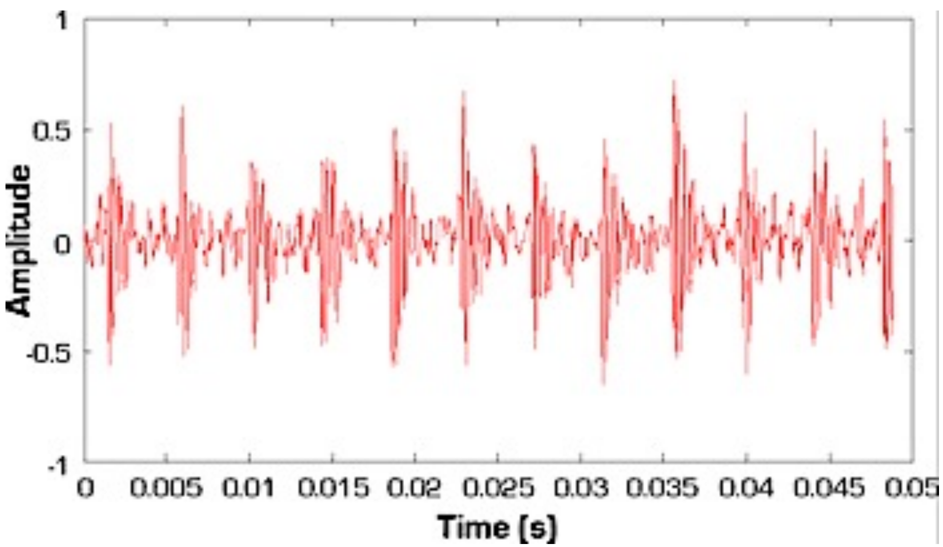
Electromechanical Systems
ASE 375

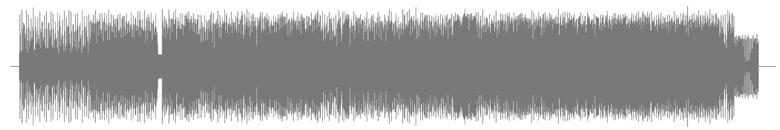
Lecture 14: Dynamic Measurements, Accelerometers - 1

Dynamic Measurements

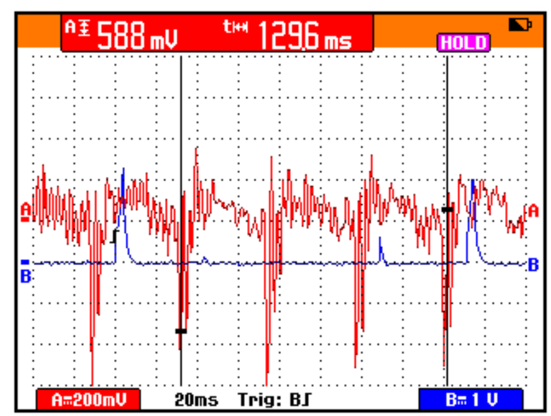
- Unsteady (or dynamic) phenomenon vary rapidly with time
- Involves acquisition and processing of a signal that varies with time.
  - Examples – vibration (acceleration), unsteady pressure (waves), turbulent velocity, audio, video, telecommunication signals etc.
- All components of a measurement system, i.e, the sensor, the data acquisition system and signal processing system need to have specific characteristics to accurately capture the physical phenomenon.



Bearing Failure Onset



Small section of Moonlight Sonata

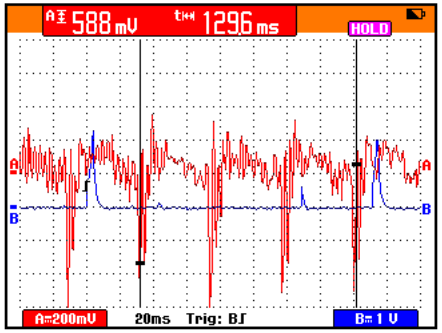


Pressure Waveform in Engine

Sensors for unsteady phenomenon

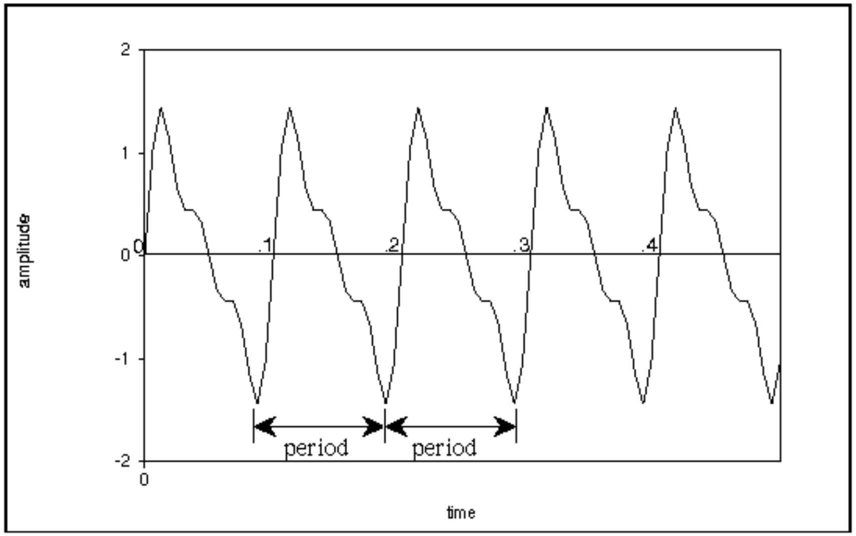
- The first element in the measurement chain is the sensor
- The following sensors can measure unsteady
  - Capacitive
  - Inductive
  - Piezoelectric
  - Strain-gauges
  - Optical

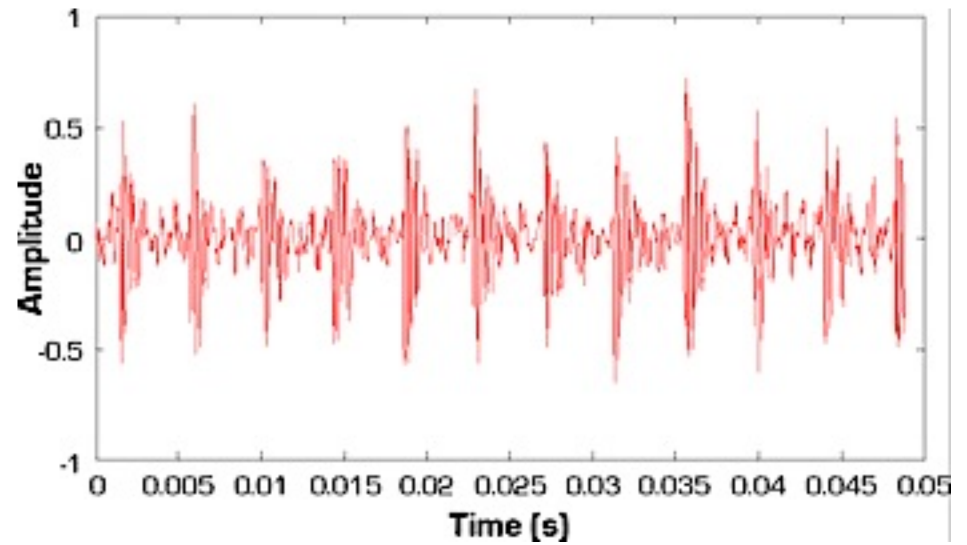
Pressure Waveform in Engine



- In most applications the output from the sensor circuit is a voltage or current
- The voltage varies with time, i.e., v= v(t), but most waveforms have some periodicity associated with them, i.e., a certain pattern repeats itself over time

Periodic Waveforms

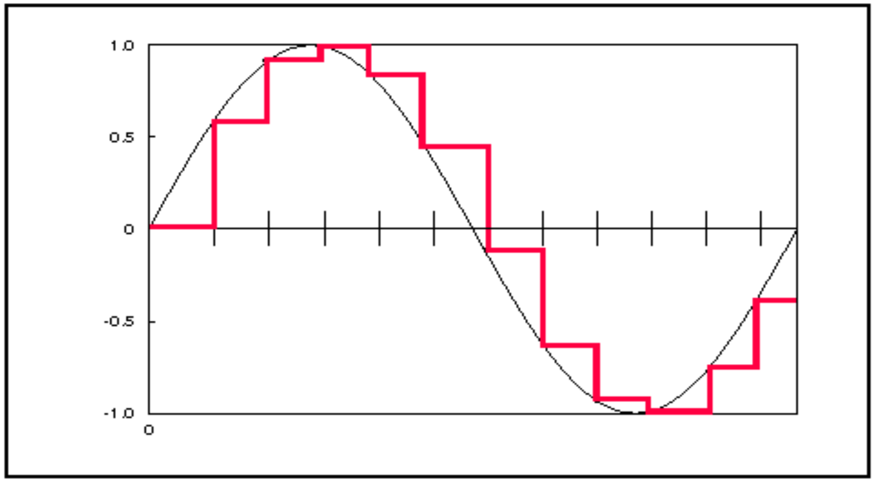




Bearing Failure Onset (200Hz)

- Many waveforms in engineering have some periodicity associated with them.
- For periodic waveforms, the duration of the waveform before it repeats is called the period of the waveform
- Frequency is the rate at which a regular vibration pattern repeats itself (frequency = 1/period)
- The next step in the measurement chain is sampling this voltage

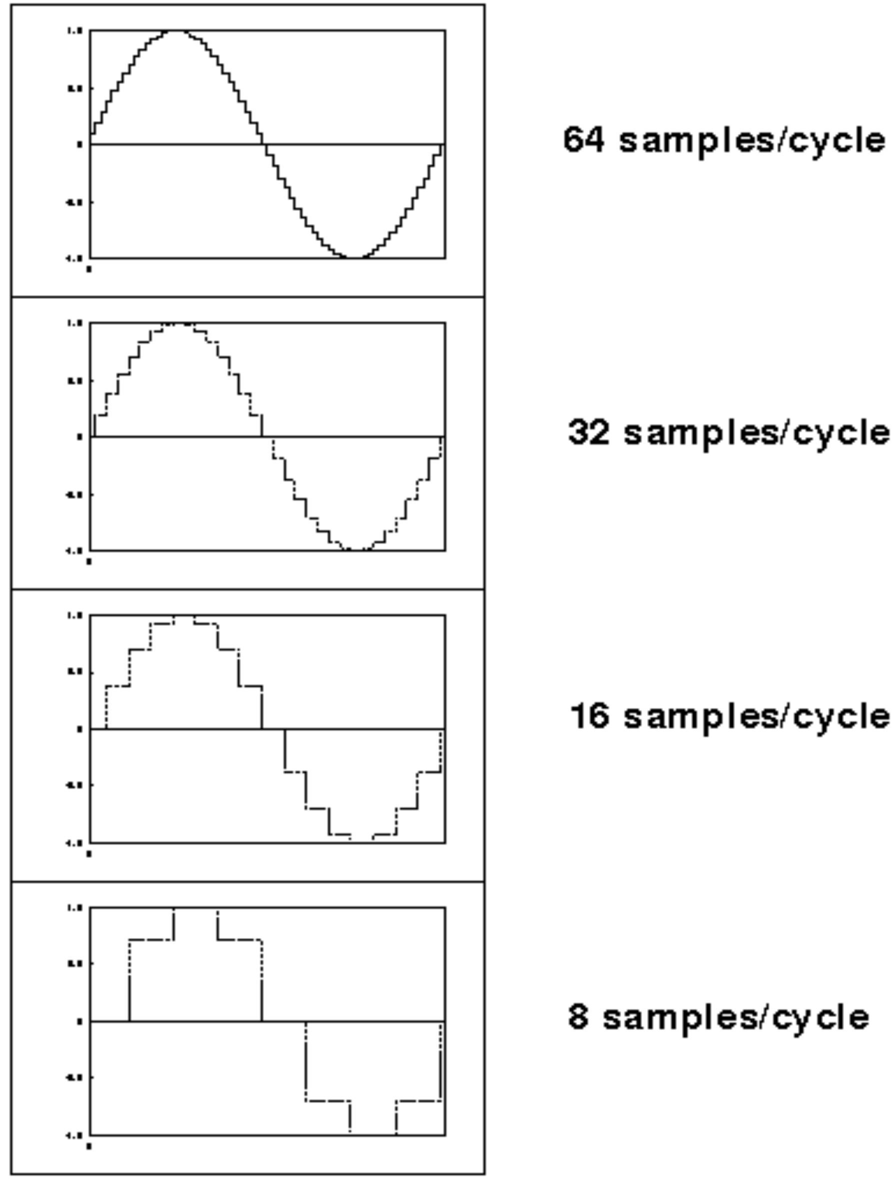
Waveform Sampling



- To analyze and represent waveforms on digital computers, we need to digitize or sample the waveform.
- This process is called an Analog-to-Digital or A/D conversion
- The digitization process discretizes the analog output from the sensor
- side effects of digitization:
  - introduces some noise
  - limits the maximum upper frequency range
  - potentially small shift in phase (depending on clock speeds)

Sampling Rate

- The sampling rate (SR) is the rate at which amplitude values are digitized from the original waveform.
  - Typical sampling rates vary from 30-300 K-samples/s
  - Higher speed boards can go from 300-1000 K-samples/sec
- Higher sampling rates allow the waveform to be more accurately represented
- Inadequate sampling will lead to aliasing and quantization errors



A/D resolution: Quantizing the data

- The output resolution of an A/D board depends on its bit resolution
- Example: An Analog voltage from 0-10V
- The number of possible states that the converter can output is: $N=2^n$
  – where n is the number of bits in the A/D converter
- Example:
  – For a 3 bit A/D converter, $N=2^3=8$.
  – More commonly, A/D converters are 8 bit or 16 bit
- Analog quantization size for 3 bit A/D:
  – $Q=(V_{max}-V_{min})/N = (10V – 0V)/8 = 1.25V$

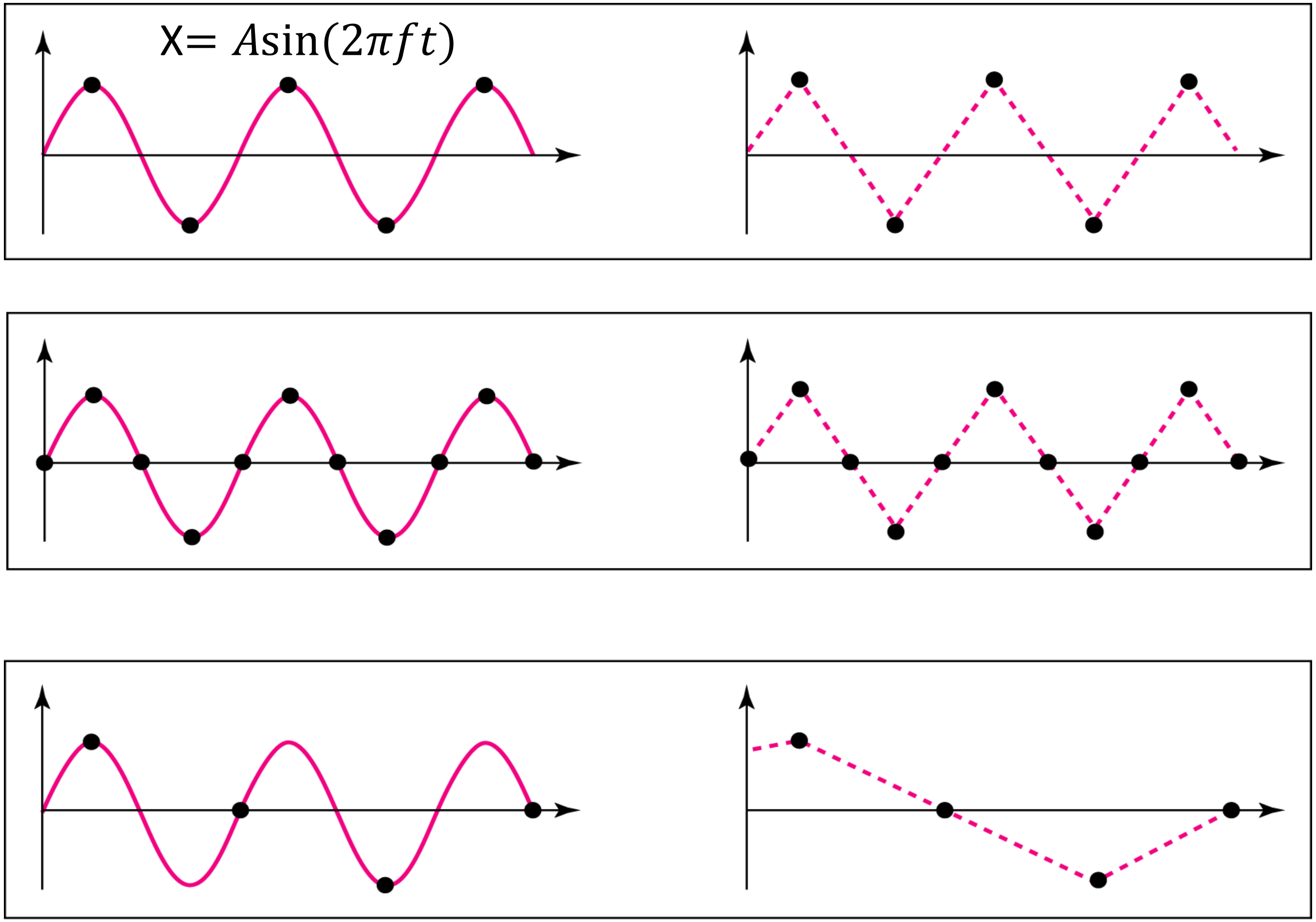
States for 3 bit device

Output States	Output Binary Equivalent
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111

Limits of Sampling Rate

- If higher sampling rate is better, why not just get the highest sampling rate device?
  - Cost
  - Data storage
  - Processing power
  - Additional noise may creep in
- Is there a minimum sampling rate?
  - This is determined by the Nyquist Frequency
  - According to the Nyquist theorem, the sampling rate must be at least 2 times the highest frequency contained in the signal.
  - In practice, sampling is done between 2-10 times Nyquist frequency

Sampling Frequency and Aliasing



Nyquist Freq = f
Sampling Rate = 2f

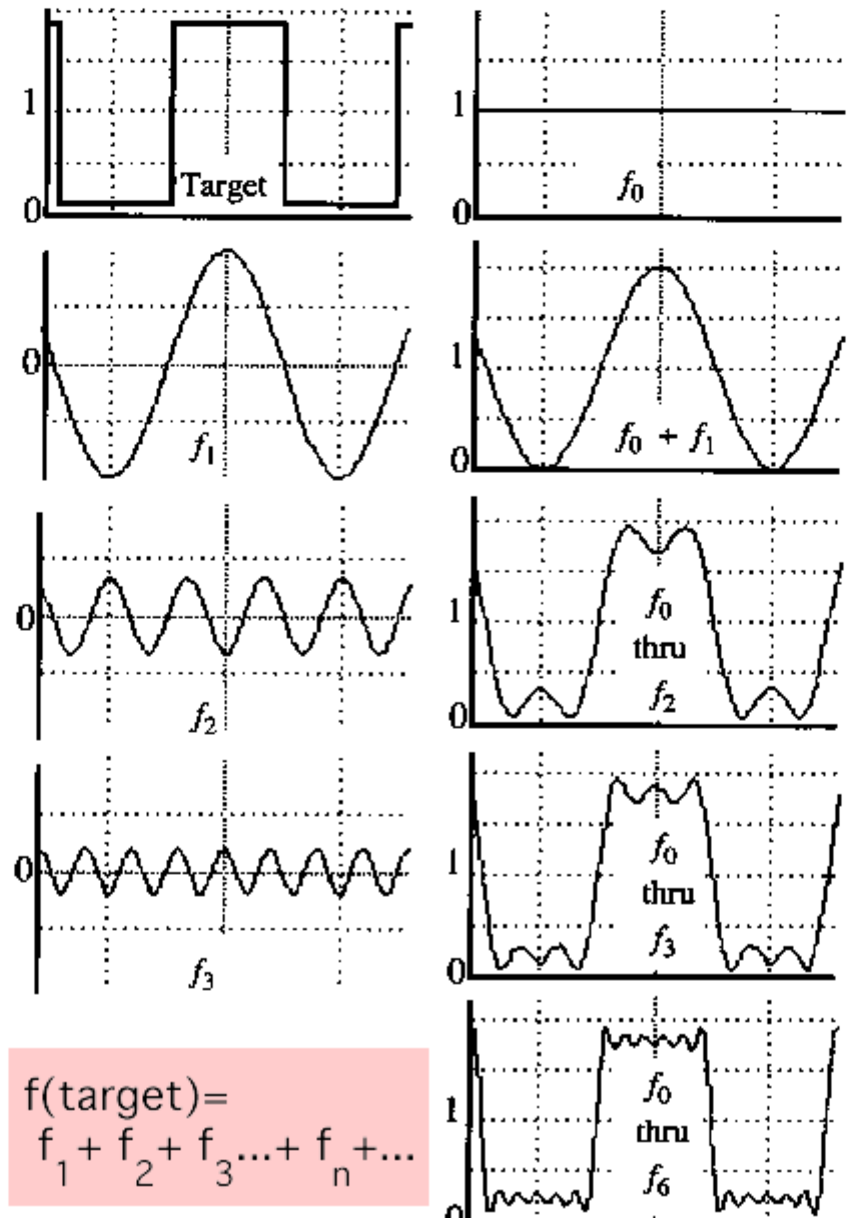
Nyquist Freq = f
Sampling Rate = 4f

Nyquist Freq = f
Sampling Rate = 3/2f

- Sampling less than 2 times the Nyquist Frequency results in a changed shape of the digitized waveform.
- This is called Aliasing

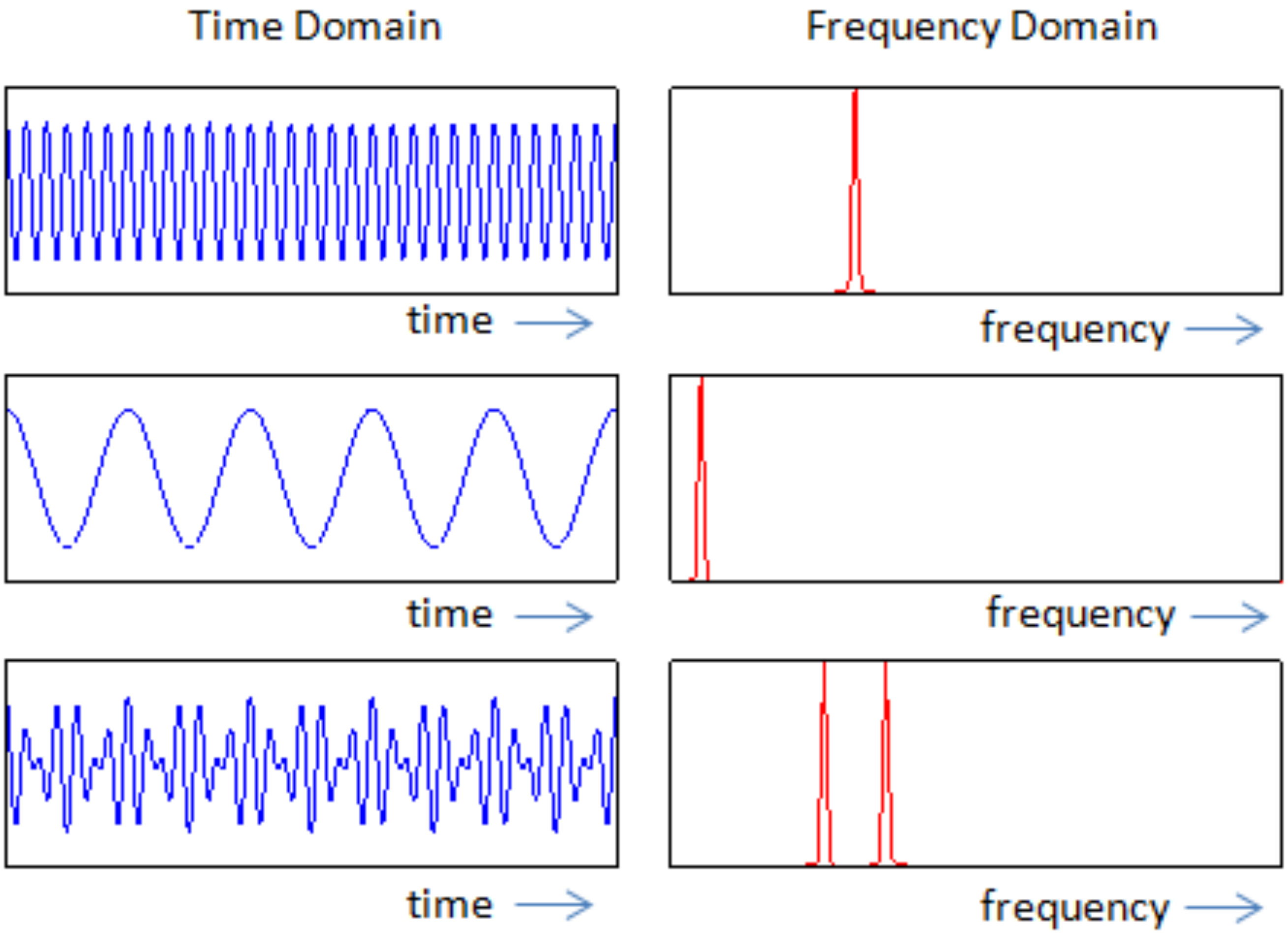
Analysis of Time Signals

- Any periodic function can be rewritten as a weighted sum of Sines and Cosines of different frequencies.
- Superposition of n-Sine Waves $A\sin(\omega x + \phi)$
- Enough sine waves of different frequencies and magnitudes can create any signal *f(x)*!



f(target)= $f_1 + f_2 + f_3 \ldots + f_n + \ldots$

Time vs Frequency Domain



- The frequency content of a signal is as important as its magnitude
- The frequency content of a physical phenomenon show the key features in that phenomenon
- Fourier transforms are used to convert from one domain to another

Fourier Transform

- We want to understand the frequency ω of our signal. So, let's reparametrize the signal by ω instead of x:

$$f(x) \longrightarrow \boxed{\text{Fourier Transform}} \longrightarrow F(\omega)$$

- For every ω from 0 to inf, $F(\omega)$ holds the amplitude A and phase ϕ of the corresponding sine $A\sin(\omega x + \phi)$

$$A = \pm\sqrt{R(\omega)^2 + I(\omega)^2} \qquad \phi = \tan^{-1}\frac{I(\omega)}{R(\omega)}$$

$$F(\omega) \longrightarrow \boxed{\text{Inverse Fourier Transform}} \longrightarrow f(x)$$