MODULE 2: Circuits, Signals and the Analog Discovery Board

BU SUMMER CHALLENGE

Electrical Engineering: Smart Lighting Project

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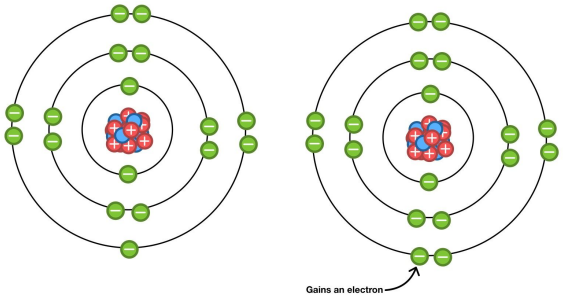
Overview

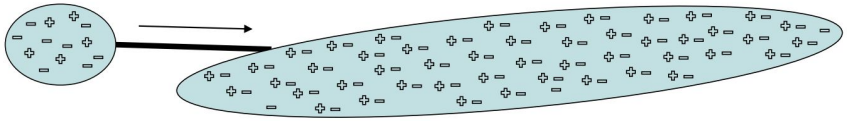
- Voltage and current
- Smart Lighting Kit
- What is a signal?
- Generating & observing signals
- Experiments
  - Using the Analog Discovery board & WaveForms
  - Time Domain Signals
  - Frequency Domain

Static Electricity

- Atoms vs Ions
  - Atoms consist of neutrons, protons, and electrons
  - Neutrons are neutral, protons are positive, electrons are negative
  - Ions are electrically charged atoms
    - (more or less electrons than protons)
- Charge
  - Measure of the difference in protons and electrons
  - Typically measured in Coulombs [C]
    - Coulomb: The electrical charge delivered by 1 Ampere of current in 1 second
  - Charge causes objects to experience an attractive or repulsive force

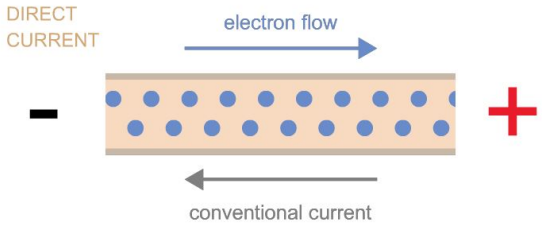


“Dynamic” Electricity



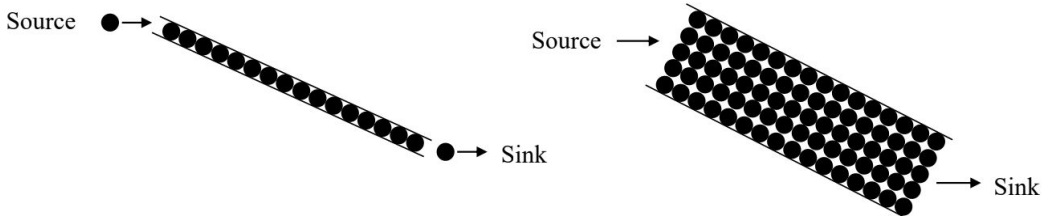
- Insulators and Conductors
  - Electrons in insulators have little freedom to move
    - Insulators: Rubber, Cotton, Wood, etc.
  - Electrons in conductors easily move from atom to atom
    - Conductors: Silver, Copper, aluminum, etc.

- Electric Current
  - Electric force tends to disperse charge if possible
  - Current is the rate of flow of charge
  - Current is measured in Amperes [A] or [C/s]
  - Current is opposite the flow of electrons!

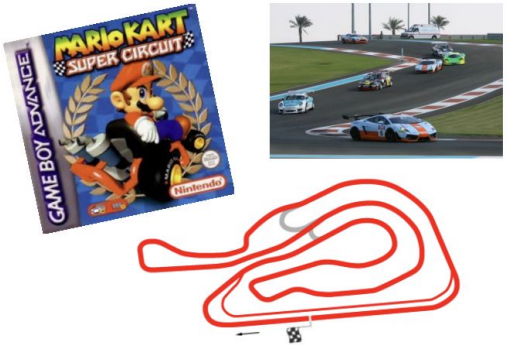


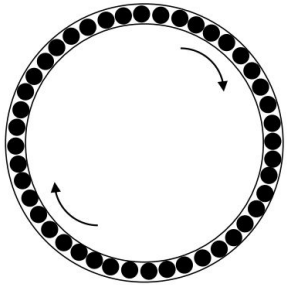
Circuits

- Continuous flow requires an “infinite” source of electrons



- What is another “circuit” you’ve heard of?



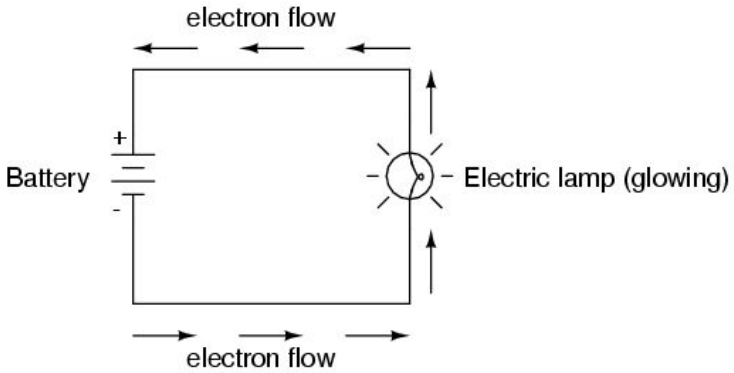


What is flow rate of marbles in this scenario?

What is missing?

Voltage

- Electric Potential, or Voltage [V], is the Electric PE per unit charge
- Batteries are a source of voltage
  - They act as the “pump” in an electric circuit

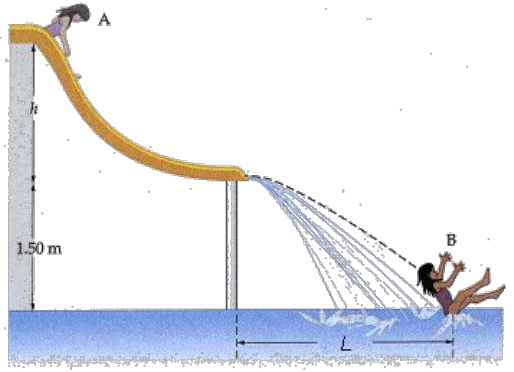


★ Buildup of charge at the battery terminal forces electrons to move through the circuit

★ Electrons flow from the negative terminal to the positive terminal

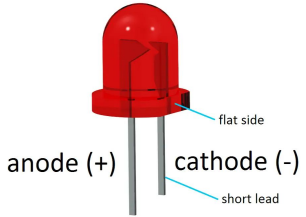
Voltage

- Another Analogy: Water Slide
  - Pump moves water back to the top
  - Pumping water to the top requires energy
  - This increases the Potential Energy of the water
  - As water flows down the slide, it releases stored energy
  - Water at the top of higher slides has more PE relative to ground



Voltage - Terminology

- Differential
  - Potential energy is related to the “drop” from one level to another
  - Voltage is the electric potential difference between two points
- Ground
  - In the water slide analogy, the ground can be a common reference
  - Similarly, electrical “ground” can be a common reference
  - Ground isn’t always exactly the same across devices!
- Polarity
  - Some devices, like diodes, only allow current to flow in one direction
  - LEDs are polarized components.



Team Formation

- Team 1:
- Team 2:
- Team 3:
- Team 4:
- Team 5:
- Team 6:
- Team 7:
- Team 8:

Smart Lighting Kit

Course webpage:
https://www.bu.edu/peaclab/BUSC19/
WaveForms Project:
www.digilentinc.com/WaveForms/

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Contents of the Smart Lighting Lab Kit

- 2 Analog Discovery Boards
- 2 Arduino Boards
- 2 USB to micro-B USB cables
- Headphones
- Magnifying Lens
- Flashlight
- Tape measure
- Protractor
- 2 Breadboards
- 2 Wiring kits
- Parts Kit
    - Resistors and capacitors
    - Red, green and white LEDs
    - Photodiode(PD)
    - Operational amplifier (Op-Amp)
    - Exclusive-OR (XOR) gate
    - Header Pins
- Transceiver printed circuit board (PCB)
    - Board Components
    - 2 USB to serial cables (FTDI)

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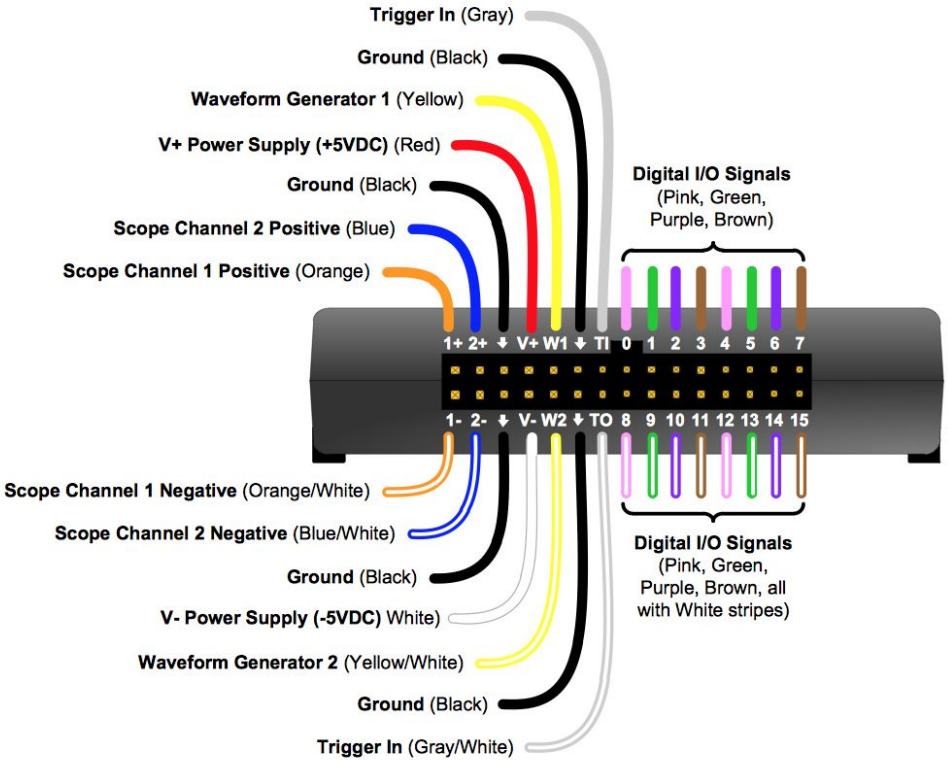
AD Board Pinout



1+/-	Analog Input 1 (Oscilloscope and Voltmeter)
2+/-	Analog Input 2 (Oscilloscope and Voltmeter)
↓	Ground
V+/-	5V DC Supply
W1	Analog Output 1 (Waveform Generator)
W2	Analog Output 2 (Waveform Generator)
T1	Trigger 1
T2	Trigger 2
0-15	Digital Input and Output

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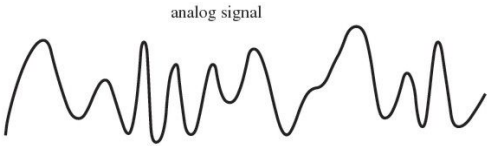
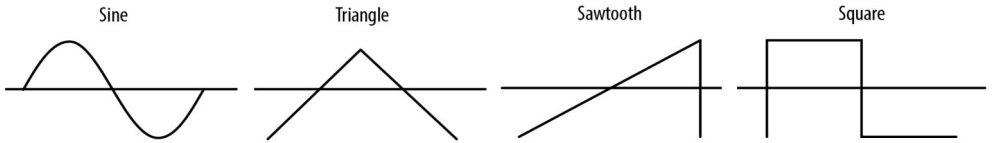
Experiment I

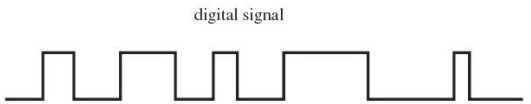
- Go to “Lab Module 2(b): Signal Generation and Observation “ in your experiment manual
- WaveForms Introduction
- Digital I/O

Signal Analysis

- What is “Time Domain”?
- Types of Signals
  - As EE’s, we want to convert to ELECTRICAL signals (voltage, current)!
- Digital vs Analog (Discrete vs Continuous)



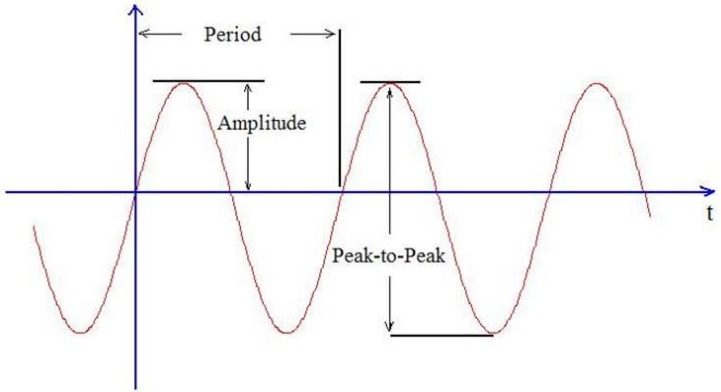


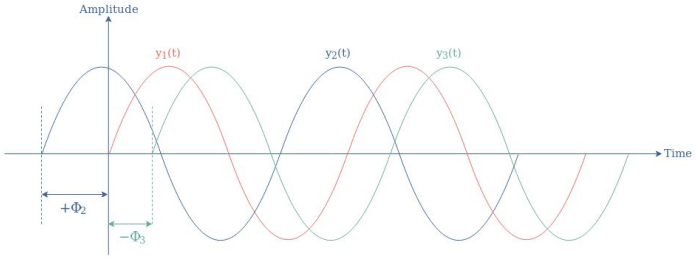


- Input vs Output

Signal Analysis - Terminology

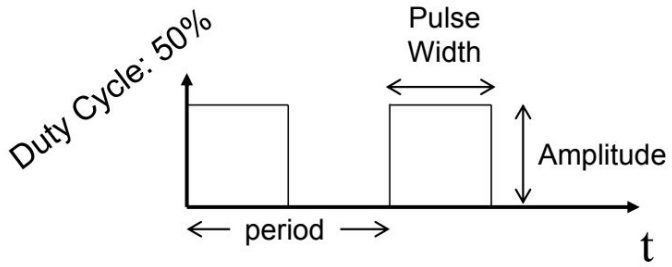
- Waveform
  - Representation of signals repeated indefinitely
- Amplitude
  - Peak-to-peak amplitude vs semi-amplitude
- Period and Frequency
  - Period: Duration of repeating component of the signa
  - Frequency: Number of repetitions per second [Hz]
- Phase
  - Ranges from 0 to 360 degrees
- Single Ended (SE) vs Differential (DIF)
  - SE: Voltage difference between a point and “ground”
  - DIF: Voltage difference between point A and point B
- AC vs DC coupling

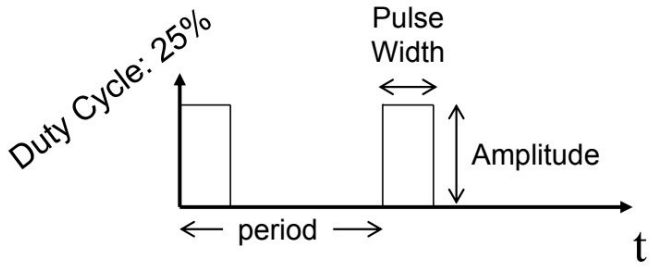




Digital Signal

- Discrete level signals
  - Consider 2-level (binary) signals that are “on” or “off”
  - How many states do a car’s tail lights have?
  - Variations in time send information!
- Pulse Width and Duty Cycle

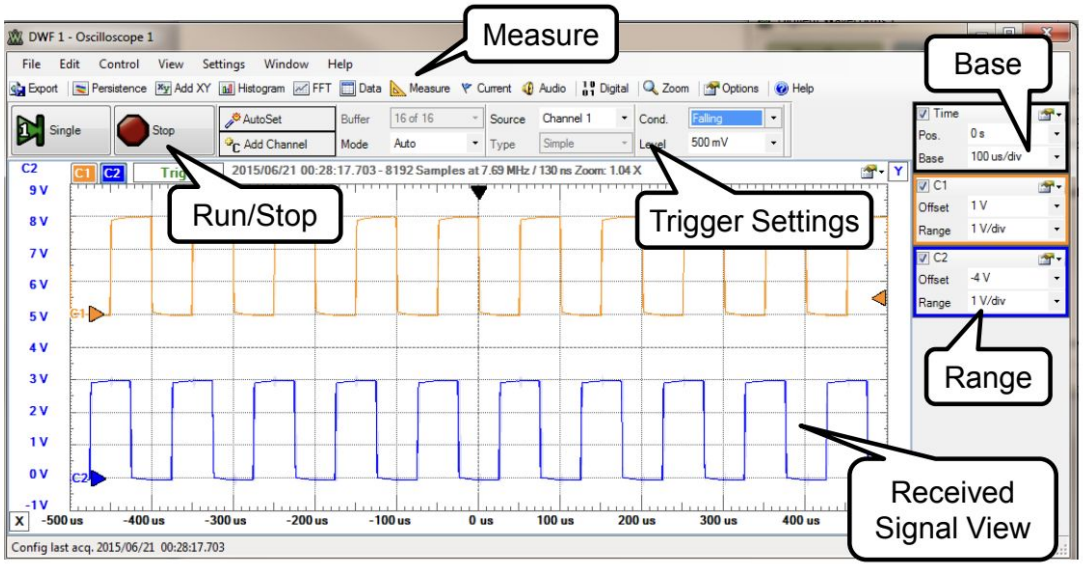


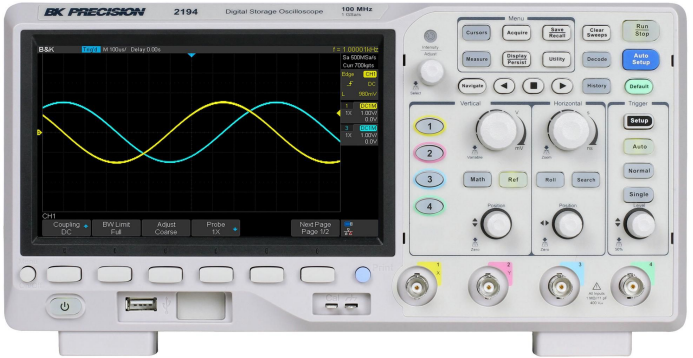


Signal Generation

Function Generator

Signal Observation





Oscilloscope

- ★ Reflect on what you learned so far!

- References:
  - http://www.physicsclassroom.com/
  - http://www.allaboutcircuits.com/

Experiment II

- WaveForms Signal Generation (Digital)
  - Function Generator
  - Oscilloscope

NOTES

- Connect the output of one analog discovery to the input of another
- Take screenshots of your work! (PrtSc or win + shift + S, then paste in paint)

Teams

- Team 1:
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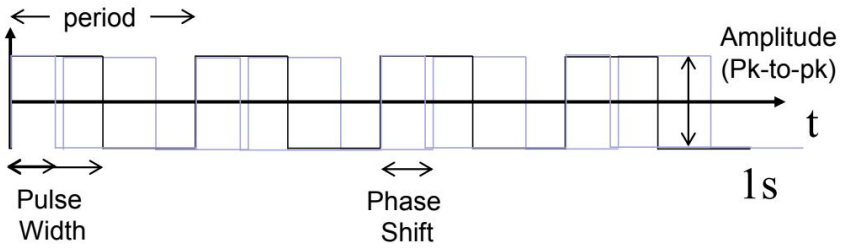
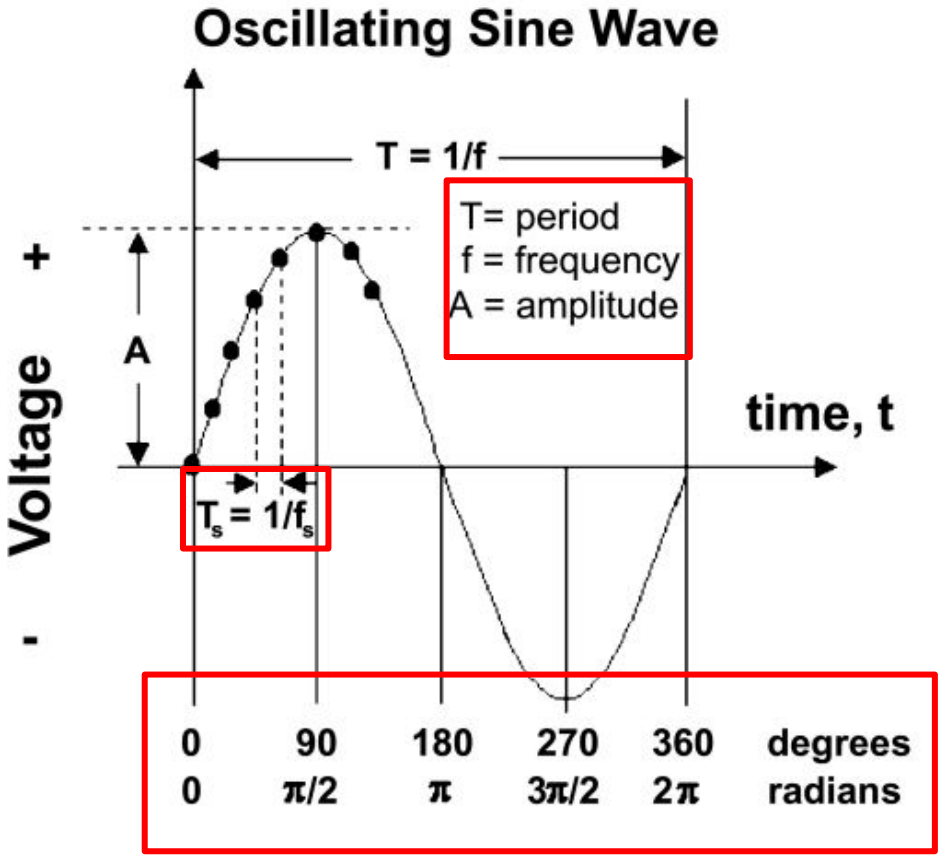
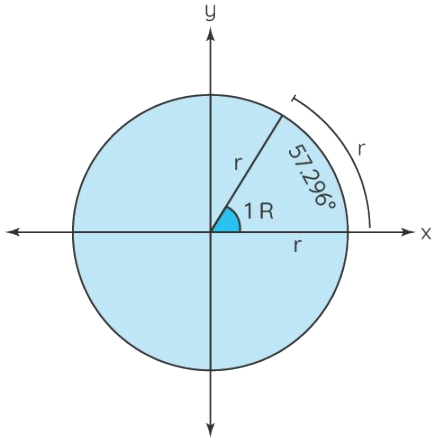
Signal Analysis - Recap

- Draw 3 more periods of the square wave
  - What is the frequency of this waveform?
- Label the peak-to-peak amplitude
- Label the pulse width
  - What is the duty cycle of this square wave?
- Draw another signal with 25% duty cycle
- Draw another signal with a phase shift



Analog Signals





Degrees→ radians

× by $\frac{\pi}{180}$

Radians→ degrees

× by $\frac{180}{\pi}$

$$y(t) = A\sin(2\pi f t + \varphi)$$

$$\omega = 2\pi f$$

$$y[n] = A\sin(\omega n + \varphi)$$

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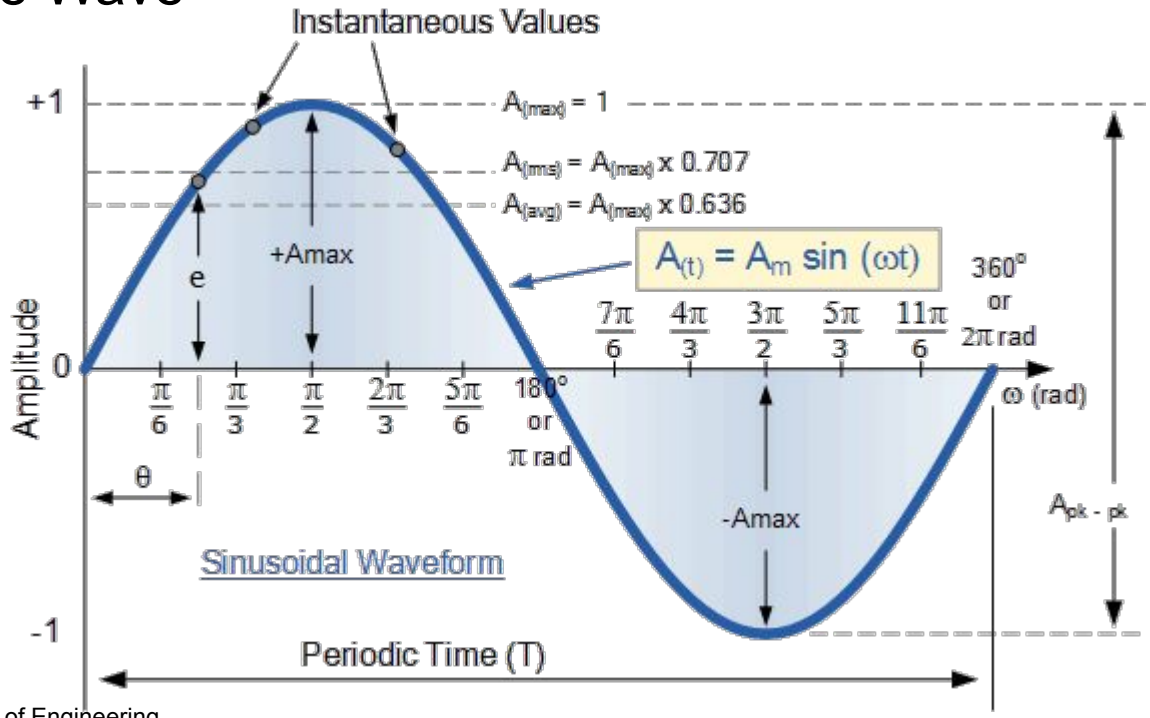
Analog Signals

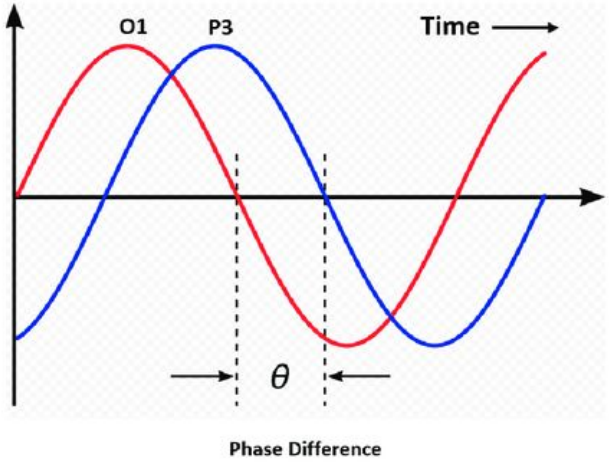
Example: Sine Wave

$$y(t) = A\sin(2\pi ft + \varphi)$$

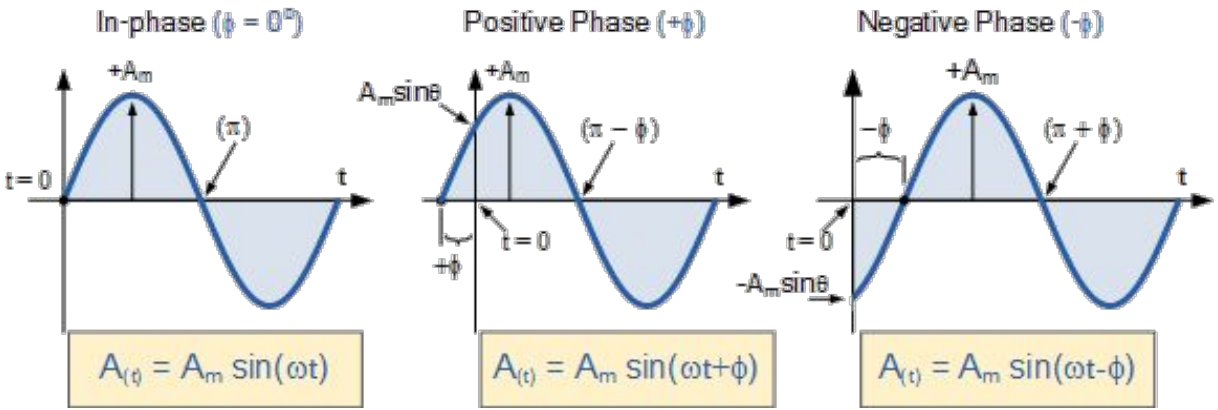


Analog Signals

Phase Shift Phenomenon



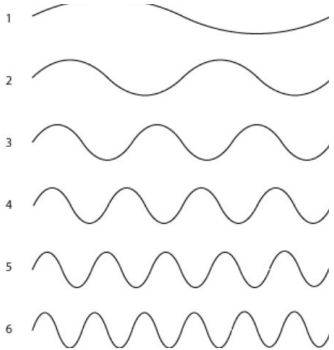
Phase Difference

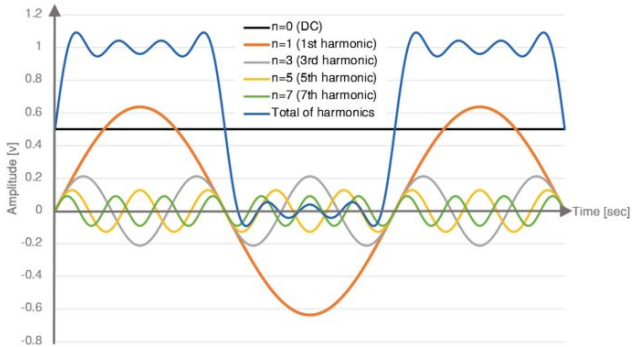


$$\text{Time Shift}\,(\Delta t) = \frac{\phi}{360 \times \text{freq}}$$

Frequency Domain Analysis

- Time domain signals have a frequency domain representation
- Sine waves generate a “pure” frequency
  - Every analog signal can be generated with a combination of sine waves
- Harmonics
  - A signal whose frequency is a positive integer multiple of a reference signal
  - First harmonic: reference signal(i.e., reference signal)





Experiment III

- Arbitrary Waveform Generator (AWG)
  - Standard signals are a subset of potential AWG signals!
- Spectrum Analyzer
  - Frequency domain analysis
  - Harmonics

NOTES

- When you connect the headphones, be careful! It might be very loud.
- Run the AWG BEFORE putting your headphones on.

Think – Pair – Share